HETEROSIS AND COMBINING ABILITY IN GREENGRAM (*Vigna radiata* (L.) Wilczek) FOR BIOLOGICAL NITROGEN FIXATION AND YIELD

By

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DECLARATION

I hereby declare that this thesis entitled **"Heterosis and combining ability in greengram (*Vigna radiata* (L.) Wilczek) for biological nitrogen fixation and yield"** 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 to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Heterosis and combining ability in greengram (*Vigna radiata* (L.) Wilczek) for biological nitrogen fixation and yield"** is a record of research work done independently by **Miss. Bhadra. K.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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INTRODUCTION

INTRODUCTION

Pulses are indispensable source of protein for the predominantly vegetarian population of our country. Pulses play an important role in enhancing soil fertility through their ability to fix atmospheric nitrogen. Greengram (*Vigna radiata* (L.) Wilczek.) one of the important grain legume of Kerala, is cultivated as a third season crop in rice fallows. The cultivation of legumes was reported to be beneficial to the suceeding cereal crop (Nambiar *et al.*, 1988). According to Herridge *et al.* (1994) nitrogen fixation and legume productivity are greatly influenced by interactions between the legume host Rhizobium above ground and below ground environments.

Response to use of N_2 - fertilizer as measured by increased crop yield is not always be large in tropical climates as in temperate climates due to the fact that the tropical soils are inherently low in organic matter and subjected rapid losses through leaching. This factor combined with high cost of nitrogenous fertilizers has created an interest in the exploitation of nitrogen fixing potential of leguminous crops through genetic manipulation. There is a possibility of breeding legumes for increased nitrogen fixing capacity by improving nitrogen fixing traits (Singh and Murthy, 1988). For developing greengram varieties having good nitrogen fixing capacity and reasonable yield, the information on combining ability of parents and the nature of gene action involved in the inheritance of biological nitrogen fixation traits and yield components is very essential. Combining abilities can be assessed in different ways and diallel analysis is one of the efficient methods used for the same.

The present study was undertaken with the objective of estimating the general and specific combining abilities and the gene action involved in the inheritance of biological nitrogen fixation traits and yield components in greengram for improving the yield potential along with high biological nitrogen fixing capacity.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1. Combining ability and gene action

The term "general combining ability" (gca) was coined by Sprague and Tatum (1942) to designate the average performance of a line in a number of hybrid combinations. They used "specific combining ability" (sca) to designate those cases in which certain hybrid combinations did relatively better or worse than would be expected on the basis of the average performance of the lines involved. Various methods have been used for testing of inbred lines. Davis (1927) tested the gca of inbred lines by means of inbred x variety cross (top cross). Hayes and Johnson (1939) studied the segregants from crosses of high and low combining lines and concluded that lines of good combining ability were obtained more frequently from crosses involving good combiners than from crosses involving lines having low combining ability. Griffing (1956b) demonstrated the method of working out gca and sca effect along with their variances.

The combining ability and gene action estimated in different pulse crops with regard to biological nitrogen fixation and yield components are reviewed in this chapter.

2.1.1. Biological nitrogen fixation traits

2.1.1.1. Root length

In a half diallel cross of eight mungbean genotypes and their twentyeight F_1s Islam *et al.* (1987) revealed significant additive and non-additive genetic variances for seedling root length and yield but additive gene action was important for root length.

Thomas (1996) in blackgram reported that non-additive gene action was predominant for length of primary root.

2.1.1.2. Number of secondary roots at maturity

Combining ability for biological nitrogen fixation traits and yield components in blackgram were studied by Thomas (1996) and reported that additive gene action was important for number of secondary roots.

2.1.1.3. Shoot/root ratio

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

In a line x tester analysis in blackgram, Thomas (1996) reported the significance of gca and sca variances indicating the importance of additive and non-additive gene action for shoot/root ratio. The ratio of additive to dominance variance was less than unity which implies the predominance of non-additive gene action.

Varghese (1997) reported predominance of non-additive gene action for root shoot ratio in blackgram.

2.1.1.4. Weight of nodules at 50% flowering

In *Trifolium ambiguum*, Hely (1972) observed that gca and sca effects were significant for nodule weight. Pinchbeck *et al.* (1980) found that additive gene effects were important for nodule fresh weight. In alfalfa Tan (1981) reported that gca and sca effects were significant for nodule fresh weight and nodule dry weight.

Combining ability studies in crimson clover revealed that both additive and non-additive gene effects were important for nodule fresh weight (Smith *et al.*, 1982).

A diallel analysis in cowpea by Miller *et al.* (1986) revealed the significance of sca variance for nodule fresh weight and nodule number. They also suggested the predominance additive gene action for nodule number and non-additive gene action for nodule weight.

In a diallel cross involving eight varieties of greengram Singh and Murthy (1988) observed the significance of gca and sca effects for nodule fresh weight indicating the importance of both additive and non-additive gene effects.

A line x tester analysis of cowpea varieties Sreekumar (1995) indicated the significance of both gca and sca variances and predominance of non-additive gene action for weight of nodules.

In a line x tester analysis in blackgram, Thomas (1996) studied combining ability for biological nitrogen fixation traits and yield components and reported that weight of nodules at 50% flowering was controlled by non-additive gene effects.

2.1.1.5. Dry weight of plants

Hely (1972) reported significance of gca and sca effects for dry weight of plants in *Trifolium ambiguum*. Pinchbeck *et al.* (1980) observed the importance additive gene effects alone for dry weight in spanish clover. In alfalfa Tan (1981) reported significance of both gca and sca effects for dry weight of plants indicating the importance of both additive and non-additive gene action.

A diallel analysis in cowpea showed the significance of sca variance indicating the importance of non-additive gene action (Miller *et al.*, 1986).

A line x tester analysis of cowpea by Sreekumar (1995) revealed the significance of both gca and sca variances and predominance of non-additive gene effects for dry weight of plants at 50% flowering.

In blackgram significant gca and sca variances were observed by Thomas (1996) for dry weight of the plants indicating that additive and non-additive genetic components were important for the expression of this trait. The ratio of additive to dominance genetic variance suggested the predominant role of additive gene action.

2.1.1.6. Nitrogen content in plants

In *Trifolium ambiguum* Hely (1972) reported the significance of both gca and sca effects for total nitrogen content. Pinchbeck *et al.* (1980) reported the importance of additive gene effects for nitrogen content per plants. Tan (1981) reported the significance of gca and sca effects for total nitrogen content in alfalfa.

Combining ability studies in crimson clover revealed that both additive and non-additive gene effects were important for total nitrogen content per plant (Smith *et al.*, 1982).

In a diallel cross involving eight varieties of greengram Singh and Murthy (1988) observed the significance of gca and sca effects for total nitrogen content per plant.

A line x tester analysis of cowpea varieties, Sreekumar (1995) indicated the significance of both gca and sca variances and predominance of non-additive gene action for nitrogen content in the plants at 50% flowering.

In a line x tester analysis of blackgram, Thomas (1996) studied combining ability and reported that nitrogen content at 50% flowering was controlled by non-additive gene effects but for nitrogen content at maturity gca and sca variances were significant indicating the influence of additive and non-additive gene effects, but the ratio of additive to dominance component was too small to be estimated.

2.1.2. Yield and Yield Components

2.1.2.1. Plant height

Sagar and Chandra (1977) and Pillai (1980) observed that the variance due to gca was much higher than sca variance indicating the predominance of additive gene action for plant height in blackgram.

The variance due to sca was of greater magnitude than gca suggesting non-additive gene action for plant height in blackgram (Rajarathinam and Rathnaswami, 1990).

Sood and Garten (1991) while estimating the combing ability in blackgram from nine diverse genotypes proposed the presence of additive gene effects for plant height.

Naidu and Satyanarayana (1993) in their combining ability studies of six genotypes reported the predominance of additive gene action for plant height in urdbean.

In a study of eight varieties of *Cicer arietinum* and their 28 F_1s revealed that both additive and non-additive gene effects were important for plant height (Jahagirdhar *et al.*, 1994).

Jayarani and Manju (1996) in cowpea reported that the character plant height was governed by both additive and non-additive gene effects. Thomas (1996) studied combining ability for biological nitrogen fixation traits and yield components in blackgram and reported that gca and sca variances were significant for this character indicating that additive and non-additive genetic components were important for the expression of plant height.

While studying the combining ability for drought tolerance and yield in blackgram, Varghese (1997) reported that for height of the plant, line x tester interaction was significant suggesting the importance of sca effect for the trait. The ratio of additive to dominance variance was also found to be less than unity, which also emphasised the importance of non-additive gene action for this character.

2.1.2.2. Number of clusters per plant

An analysis of diallel cross using five varieties of greengram by Wilson *et al.* (1985) reported the predominance of additive gene action for number of clusters per plant.

2.1.2.3. Number of pods per plant

Diallel analysis for yield components in bengalgram by Pande *et al.* (1979) reported that additive and non-additive effects were influencing this character but non-additive effects were more important.

In an eight parental diallel analysis in mungbean, Deshmukh and Manjare (1980) found highly significant variances due to sca indicating non-additive gene action for number of pods per plant. Chauhan and Joshi

(1981) in a diallel cross involving eight cowpea varieties observed the importance of general and specific combining ability variances for number of pods per plant. In a combining ability analysis of ten cultivars of pigeonpea, Venkiteswaralu and Singh (1982 a) indicated the importance of both gca and sca variances for number of pods per plant and gca variance was more than sca variance indicating the predominance of additive gene action.

Combining ability analysis of 10 x 10 diallel cross in pea, Dubey and Lal (1983) reported the significance of general and specific combining ability variances and additive genetic variance was found to be higher than non-additive.

Estimation of combining ability in a 8 x 3, line x tester cross in pigeonpea, Singh *et al.* (1983) observed that both additive and non-additive components were important with the predominance of additive component for number of pods per plant. Wilson *et al.* (1985) observed significant variances due to gca and sca in an analysis of diallel cross with five greengram varieties. The gca variance was found to be higher than sca variance for number of pods per plant indicating the predominance of additive gene action. In an eight parental half diallel cross Chowdhury (1986) reported significant gca and sca variances for number of pods per plant in mungbean.

Combining ability analysis of thirtynine hybrids between three lines and thirteen testers in pigeonpea conducted by Patel *et al.* (1987) revealed the significance of additive and non-additive gene action with predominance of additive gene action. Study of eight chickpea lines and their F_1s for combining ability revealed the predominance of non-additive gene action for number of pods per plant (Yadavendra and Sudhirkumar, 1987).

In a combining ability analysis of six chickpea genotypes and their F_1 hybrids Katiyar *et al.* (1988) reported that gca and sca variances were significant for number of pods per plant suggesting that both additive and non-additive gene effects were important.

In a combining ability analysis with ten soyabean lines and their F_1 hybrids by Sharma and Nishisharma (1988) observed that both additive and non-additive genetic variances were important.

Thiyagarajan *et al.* (1990) studied combining ability in a six parental diallel cross in cowpea and reported that both additive and non-additive gene effects were important for number of pods per plant. Components of variance analysis revealed that non-additive action was predominant.

Kaliya *et al.* (1991) while studying combining ability for seed yield and its components over environment in blackgram indicated significant sca for number of pods per plant. A line x tester analysis to estimate combining ability of cowpea varieties revealed the predominance of non-additive gene action for number of pods per plant (Anilkumar, 1993).

Mishra and Yadav (1994) in a line x tester analysis using 5 lines and 3 testers in bengalgram suggested additive gene action for number of pods per plant.

Thomas (1996) studied combining ability in blackgram and reported that gca and sca variances were significant indicating the importance of additive and non-additive gene effects for the trait. But the ratio of additive to dominance variance was less than unity suggesting that non-additive gene action was predominant.

Varghese (1997) in a line x tester analysis in blackgram observed significance of gca and sca variances indicating the influence of both additive and non-additive gene action for pods per plant. But non-additive gene action seems to be predominant since the ratio of additive to dominance variance was less than unity.

2.1.2.4. Number of seeds per pod

In a diallel analysis for yield and yield components in bengalgram Pande *et al.* (1979) reported highly significant variances due to gca and sca. Estimate of variance due to sca was much higher than gca indicating the predominance of non-additive gene action.

In a diallel cross involving eight varieties of mungbean for the estimation of combining ability Deshmukh and Manjare (1980) found highly significant variances due to gca and sca for number of seeds per pod. Non-additive gene action was reported to be more important for this character.

Chauhan and Joshi (1981) reported that both gca and sca variances were important for number of seeds per pod in cowpea. The magnitude of gca variance was higher than sca which indicated that the character is controlled predominantly by additive gene action.

Das and Dana (1981) studied the inheritance of seed yield components in rice bean using seven parents crossed in diallel manner excluding reciprocals and reported the importance of dominant components for the character. They also found that late maturing parents were good general combiners for number of seeds per pod.

A diallel analysis involving six parents in gardenpea indicated the predominance of non-additive gene action for number of seeds per pod (Dhillon and Chahal, 1981).

Combining ability analysis of ten cultivars of pigeonpea by Venkateswaralu and Singh (1982 a) reported the importance of both additive and non-additive gene effects with predominance of additive gene effects for number of seeds per pod.

Venkateswaralu and Singh (1982 b) studied a diallel cross involving ten diverse cultivars of pea and reported that additive gene action was important for number of seeds per pod.

In a study of combining ability by Dubey and Lal (1983) using a 10 x 10 diallel cross in pea revealed that gca and sca variances were significant for number of seeds per pod.

Malhotra (1983) observed significant gca variance for number of seeds per pod in blackgram indicating the importance of additive gene action.

In a diallel cross of five greengram varieties Wilson *et al.* (1985) reported that gca and sca variances were significant but gca variance was much higher than sca variance indicating the predominance of additive gene action for this character.

The predominance of non-additive gene action was reported by Yadavendra and Shudhirkumar (1987) for number of seeds per pod in their studies with eight chickpea varieties and their hybrids.

Six chickpea genotypes and their F_1 hybrids were evaluated for their combining ability by Katiyar *et al.* (1988) and reported significant differences for gca and sca variances for number of seeds per pod indicating additive as well as non-additive gene effects with the predominance of additive gene action.

A comparative analysis of combining ability in irradiated diallel population of chickpea Onkar Singh and Paroda (1989) suggested that number of seeds per pod was governed mainly by additive genes.

While estimating the combining ability using diallel analysis Saxena and Sharma (1989) reported that both gca and sca variance were significant in F_1 and F_2 for number of seeds per pod indicating the predominance of additive gene action in mungbean.

Saxena *et al.* (1989) reported the predominance of gca variance for number of seeds per pod in F_1 and F_2 generations in a diallel cross of seven short duration varieties of pigeonpea.

A 7x7 diallel cross in greengram revealed that both additive and non-additive gene actions were important (Natarajan *et al.* 1989).

Kaliya *et al.* (1991) studied combining ability for seed yield and its components over environments in blackgram and reported that mean squares due sca for number of seeds per pod was significant.

In a study of eight mungbean genotypes and their twenty eight F_1s by Saxena and Sharma (1992) reported importance of additive as well as non-additive variances and predominance of additive variance.

In a line x tester analysis of cowpea Thiyagarajan (1990) observed the preponderance of additive variance for number of seeds per pod.

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

In a line x tester analysis in cowpea, Anilkumar (1993) revealed the presence of additive gene action for number of seeds per pod.

In a line x tester analysis of blackgram, Thomas (1996) reported that both additive and non-additive gene action were important for the expression of number of seeds per pod but non-additive gene action was predominant.

In a combining ability analysis in blackgram, Varghese (1997) observed the significance of sca variance. The ratio of additive to dominance variance was less than unity indicating the predominance of of non-additive gene action for number of seeds per pod.

2.1.2.5 Hundred grain weight

Combining ability was studied in a 5x5 diallel set of crosses in gram, by Singh *et al.* (1975) and revealed that additive gene action was predominant for hundred grain weight.

In a diallel analysis for yield and yield components, in bengalgram Pande *et al.* (1979) reported highly significant variances due to gca and sca for hundred grain weight. Estimates of variance due to gca indicated predominance of additive gene effect.

Chauhan and Joshi (1981) studied a half diallel cross of eight cowpea cultivars and reported that both general and specific combining abilities were important. The magnitude of gca variance was found to be much higher than sca indicating the predominance of additive gene effects in the inheritance of hundred grain weight.

Combining ability was studied in a diallel cross involving ten cultivars in pea and indicated the importance of both gca and sca and predominant role of additive gene effects for hundred grain weight (Venkateswaralu and Singh, 1981b).

While analysing the combining ability of ten diverse cultivars of pigeonpea Venkateswaralu and Singh (1982 a) reported that both additive and non-additive gene effects were important with predominance of additive gene effects.

In a study to estimate the combining ability of cowpea varieties, Anilkumar (1993) reported the importance of additive gene action for hundred grain weight. Thiyagarajan (1990) also reported the predominance of additive variance for this character in cowpea.

A 10 x 10 diallel cross (excluding reciprocals) revealed that both gca and sca variances were highly significant for hundred grain weight in bengalgram (Sewant, 1995).

In a line x tester analysis in blackgram, Thomas (1996) reported the significance of gca and sca variances indicating the importance of both additive and non-additive gene action for hundred grain weight.

In blackgram, Varghese,(1997) reported the significance of sca variance for hundred grain weight indicating the importance of non-additive gene action.

2.1.2.6. Grain yield

Diallel analysis for yield and yield components in bengalgram revealed that variances due to general and specific combining ability were significant for yield per plant, indicating that genes having additive and dominant effects were influencing the character. Non-additive gene action was reported to be more important for grain yield per plant (Pande *et al.*, 1979).

While estimating the combining ability in a diallel cross Deshmukh and Manjare (1980) reported the significance of gca and sca effects for grain yield per plant in mungbean. The variance due to sca was reported to be comparatively much higher in magnitude suggesting non-additive gene action.

Durong (1980) studied combining ability using a 8 x 8 diallel cross of soyabean and reported the importance of both additive and non-additive gene action for grain yield per plant.

A half diallel cross of eight cowpea varieties studied by Chauhan and Joshi (1981) revealed that both gca and sca variances were significant for grain yield per plant. The variance due to gca was reported to be higher than sca indicating the predominance of additive gene action.

Dhillon and Chalal (1981) while analysing the combining ability of gardenpea hybrids derived from a diallel cross of six parents observed the predominance of non-additive gene action for grain yield per plant.

Venkateswaralu and Singh (1982 b) reported the importance of both gca and sca and predominance of additive gene action for grain yield per plant in pea.

Combining ability analysis of ten cultivars of pigeonpea indicated the importance of both additive and non-additive gene effects for the trait (Venkateswaralu and Singh, 1982a).

Combining ability studies using ten cultivars of pea crossed in all possible combinations indicated the importance of both sca and gca variances for grain yield per plant. The variance due to gca was reported to be much higher than sca in F_1 and F_2 generations (Venkateswaralu and Singh, 1982c).

Malhotra (1983) in urdbean reported the importance of additive and non-additive components, with a predominance of additive gene effects for grain yield per plant. .

While estimating the combining ability in a line x tester cross in pigeonpea, Singh *et al.* (1983) reported that both additive and non-additive gene actions were important with the predominance of non-additive gene action.

Zaveri *et al.* (1983) evaluated six cowpea genotypes and their fifteen crosses for yield and its components and reported that both gca and sca variances were significant with predominance of non-additive gene action.

An analysis of diallel cross using five varieties of greengram by Wilson *et al.* (1985) indicated the existence of both additive and non-additive gene actions for grain yield per plant. The variance due to gca was reported to be higher than due to sca indicating the predominance of additive gene action.

Combining ability analysis in mungbean using eight parental half diallel cross by Chowdhury (1986) revealed the significance of gca and sca variances for grain yield per plant.

Study of combining ability using six chickpea lines and their twenty eight F_1s revealed that non-additive gene action was predominant for grain yield (Yadavendra and Sudhirkumar, 1987).

In a line x tester analysis with six urdbean lines of diverse origin Haque *et al.* (1988) reported higher sca effect for yield in the cross PLV-652 and T_9.

Katiyar *et al.* (1988) while analysing the combining ability in six chickpea genotypes and their F_1 hybrids reported additive and non-additive gene action for grain yield and predominance of additive gene action.

Diallel analysis in mungbean revealed the significance of gca and sca variance for yield per plant (Patel *et al.*, 1988).

In a line x tester analysis Bahl and Kumar (1989) reported that sca variance was much greater than gca indicating the predominance of non-additive gene action for yield in chickpea.

In a comparative analysis of combining ability in irradiated and non-irradiated diallel population of chickpea, Onkar Singh and Paroda (1988) suggested importance of additive and non-additive genes for grain yield per plant.

While estimating the combining ability in mungbean, Saxena and Sharma (1989) reported that both gca and sca variances were significant for yield per plant. Variance due to gca was much higher than sca suggesting the predominance of additive gene action.

A six parental diallel cross in cowpea revealed that both additive and non-additive gene effects were important for yield per plant (Thiyagarajan, 1990).

In a 7 x 7 diallel cross in greengram combining ability was studied by Natarajan *et al.* (1989) and revealed the importance of both additive and non-additive gene action and predominance of additive gene action.

Combining ability analysis for yield and its components over environments in blackgram revealed significant mean sum of square due to sca for seed yield (Kaliya *et al.*, 1991).

Sood and Garten (1991) while estimating the combining ability from nine diverse genotypes proposed the presence of additive gene action for grain yield.

Study of yield and yield related characters in eight mungbean genotypes and their twenty eight F_1s revealed the importance of additive as well as non-additive variances and predominance of additive variance (Saxena and Sharma, 1992).

Three male and four female parents and twelve hybrids of cowpea varieties were evaluated for combining ability in two seasons for yield and yield components by Thiyagarajan (1990) and proposed the preponderance of additive variance.

In a line x tester analysis, Anilkumar (1993) reported the presence of both additive and non-additive gene action for grain yield in cowpea.

The variance due to sca was reported to be high indicating the preponderance of non-additive gene action for this character.

In a study of eight varieties of *Cicer arietinum* and their 28 F_1s revealed that both additive and non-additive gene effects were predominant for grain yield per plant (Jahagirdhar *et al.*, 1994).

Thomas (1996) studied combining ability for biological nitrogen fixation traits and yield components in blackgram and reported that gca and sca variances were significant indicating the involvement of additive and non-additive gene action but non-additive gene action was predominant.

In blackgram grain yield was found to be controlled by both additive and dominant gene actions. But the predominance of non-additive component was expected since the ratio of additive to dominance variance was less than unity (Varghese, 1997).

2.1.2.7. Harvest Index

Studies on combining ability in a 9 x 9 diallel cross for yield and yield components in bengalgram showed highly significant gca and sca variances for harvest index and additive gene action was predominant for this character (Pande *et al.*, 1979).

Katiyar *et al.* (1987) while studying combining ability for phenological and physiological traits in pea using F_1s of fourteen lines and three testers reported the predominance of non-additive gene action for harvest index.

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

Singh *et al.* (1987 b) analysed the general and specific combining abilities for yield and yield components from F_1 and F_2 generations of a diallel cross involving ten parents of pea showed significant additive and non-additive gene actions for harvest index in both generations.

Patel *et al.* (1988) studied the combining ability in a 7 x 7 diallel crosses excluding reciprocals in mungbean and reported that gca and sca variances were significant for harvest index, showing additive and non-additive gene effects.

Hazarika *et al.* (1988) estimated combining ability in a line x tester analysis of pigeon pea and reported significance of both gca and sca variances for harvest index.

The combining ability analysis in soyabean conducted by Sharma and Nishisharma (1988) revealed that harvest index was controlled by additive gene action.

A half diallel cross of seven short duration varieties of pigeon pea was evaluated in F_1 and F_2 generations and indicated the predominance of gca variance for harvest index (Saxena *et al.*, 1989). In soyabean, 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 indicated the predominance of non-additive gene action for harvest index.

In a line x tester analysis in greengram Sreekumar (1993) reported the influence of both additive and non-additive gene actions for harvest index. Additive to dominance variance ratio was less than unity indicating predominance of non-additive gene action.

Varghese (1997) in blackgram also reported the predominance non-additive gene action for harvest index.

Heterosis

Sagar and Chandra (1977) observed heterosis for number of pods per plant in blackgram.

In blackgram, Pillai (1980) found heterosis for yield components viz., pod number, 100 seed weight and plant height over mid parent, better parent and standard parent.

According to Dasgupta and Das (1981) the direction of heterosis varied greatly for different crosses in blackgram. Two crosses viz., Mash 1xLU 272 and Mash 1 x LU 241 exhibited significantly positive heterosis.

Ten characters were studied in an incomplete diallel cross among seven varieties of greengram. Heterosis over better parent was observed for plant height, pods per cluster, pods per plant, seeds per pod and seed yield but most hybrids showed negative heterosis for 100 seed weight (Thimmappa, 1987).

F_1 plants derived from diallel cross among five genotypes were grown along with their parents and evaluated for plant height, days to flowering, number of branches, pods per plant and yield per plant. All hybrids showed significant standard heterosis C_{11} being the standard with seven displaying heterosis for yield. Each parent in the cross ICP8863 x LRG 30 possessed high gca for yield, along with positive gca effects for plant height, branches and pods per plant and days to flowering (Cheralu *et al.*, 1989).

Five genetic stocks, three commercial varieties and 15 F_1 hybrids all of *Vigna radiata* were evaluated for seed yield, harvest index, total dry matter (TDM) and five DM components. Highest TDM and lowest harvest index was recorded for tester Co_4 while the reverse was noted for lines K851 and ML65. Four hybrids, all with Co_4 as one parent were shown to have highly significant heterosis over better parent for grain yield and pod weight but negative heterosis for TDM, harvest index (Natarajan, 1989).

A study of eleven characters in 90 F_1s of greengram revealed heterosis over the better parent for yield and many yield components (Singh and Pathak, 1992).

Study for heterosis for yield and its components in cowpea by Hazra *et al.* (1993) revealed that the frequency of level of heterosis was related more to specific combining ability than to the genetic divergence of the parents.

Twenty F_1s derived from four lines and five testers of greengram were grown under rice fallows. Average heterosis over mid and better parents was positive for seed yield per plant, shoot dry matter at harvest, pods per plant, branches per plant and clusters per plant and negative for days to 50% flowering and days to maturity. Additive genetic variance was important for days to 50% flowering days to maturity pods per plant and seed protein content. Non additive gene action was mainly responsible for plant height, seed weight, shoot dry matter and seed yield. Both additive and non-additive gene actions are important for branches per plant, cluster per plant, pod length, seeds per pod and shoot nitrogen (Naidu and Satyanarayana, 1993).

Nodulation and yield traits in greengram were studied from a diallel crossing programme with old reciprocals by Singh and Singh (1994) the highest heterosis over BP and MP was seen in the cross T_{44} x ML 80 for all nodulation traits HG19 x T44 for 100 seed weight and T44 x Black Neelalu for seed yield per plant.

Heterosis for days to first flowering 50% flowering, height and number of branches, pods, seeds per pod, pod length, 100 seed weight and seed yield was estimated in diallel cross of six *Phaseolus vulgaris* (L.) varieties. Maximum heterosis was observed for number of branches per plant followed by pods per plant and seed yield. Heterosis was least for seed weight and number of seeds per pod.

Sewant *et al.* (1994) in cowpea found that highest positive heterosis over mid parent was for seed yield per plant followed by inflorescence per plant, pods per plant, branches per plant and plant height. A similar trend over better parent was observed except for branches per plant and plant height. Average heterosis was maximum for seed yield per plant followed by pods per plant and inflorescence per plant.

In cowpea, significant and positive standard heterosis was observed for weight of nodules and nitrogen content at 50% flowering. For number of pods and grain yield per plant relative heterosis, heterobeltiosis and standard heterosis were significant and positive (Sreekumar, 1995).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation on greengram was carried out at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during the period from 1996 to 1998.

3.1. Materials

The experimental materials consisted of four varieties (Pusa 9333, KM-1285, IIPRM-3, MG-368) of greengram selected based on their grain yield and three varieties (NDM-88-14, COGG-902, LGG-444) selected based on their high nitrogen fixing capacity. The seven varieties were crossed in a diallel fashion excluding the reciprocals. The list of seven parents and 21 hybrids combinations are presented in table 1.

3.1.1. Collection of seed materials

Selfed seeds were collected from the selected varieties by covering the mature flower buds with butter paper cover on the previous day of its anthesis. The cover was removed only after the fruit set, and the selfed pods were labelled. The pods were harvested, dried seeds extracted, cleaned and stored in seperate packets.

Table 1. Parents and hybrids in a 7 x 7 diallel cross in greengram

Sl. No.	Treatment Number	Name of variety / cross
1	T1	P.9333
2	T2	KM-1285
3	T3	NDM-88-14
4	T4	MG-368
5	T5	IIPRM-3
6	T6	COGG-902
7	T7	LGG-444
8	T8	P1 x P2
9	T9	P1 x P3
10	T10	P1 x P4
11	T11	P1 x P5
12	T12	P1 x P6
13	T13	P1 x P7
14	T14	P2 x P3
15	T15	P2 x P4
16	T16	P2 x P5
17	T17	P2 x P6
18	T18	P2 x P7
19	T19	P3 x P4
20	T20	P3 x P5
21	T21	P3 x P6
22	T22	P3 x P7
23	T23	P4 x P5
24	T24	P4 x P6
25	T25	P4 x P7
26	T26	P5 x P6
27	T27	P5 x P7
28	T28	P6 x P7

3.1.2. F_1 seed production

The selfed seeds from the seven selected varieties were grown in pots for hybrid seed production during August 1997. Sowing of seeds were done in different dates to get synchronised flowering of different varieties. Selfed seeds were also collected from the parental varieties.

3.1.3. Techniques of crossing

The technique of hybridization in greengram outlined by Boiling *et al.* (1961) was followed for the production of hybrid seed from the female parents. Yellowish green buds which would likely to open the next morning were selected and emasculated in the evening hours between 4 and 6 pm. The emasculated flower buds were covered with butter paper cover.

The emasculated flower buds were pollinated on the next morning between 6 and 8 am with the pollen from the protected flowers of the male parent and again covered with the butter paper cover, and labelled properly. Hybrid seeds were produced in all possible combinations except reciprocals. The seeds from each cross were collected seperately and were used for the evaluation of hybrids and estimation of combining ability and gene action.

3.2. Experiment 1

3.2.1. Evaluation of F_1 hybrids

The seven parents and twenty one hybrids were evaluated in a randomised block design with three replications. The seeds were sown at a spacing of 25 x 15 cm in 3 m^2 plot so that 80 plants could be accommodated in each plot. The cultural and management practices were followed according to the package of practice recommendations (KAU, 1996). Data on yield and nitrogen fixing characters were recorded from 10 plants selected at random from each treatment in each replication.

3.2.2. Observations recorded

3.2.2.1. Length of primary root at 50% flowering

Ten sample plants were uprooted without injury to root at the time of 50 per cent flowering and the length of primary root was measured in cm.

3.2.2.2. Number of secondary roots at maturity

The number of secondary roots from uprooted ten sample plants were counted and mean value was recorded.

3.2.2.3. Shoot / Root ratio

The ratio of the shoot dry weight to root dry weight is expressed as shoot / root ratio. The root and shoot portion of the uprooted ten sample plants were cut and seperated. The root and shoot portions were sundried seperately for two days followed by oven drying at 60-70°C for one day. The dry weight of root and shoot were recorded seperately and the ratio was worked out.

3.2.2.4. Weight of nodules in the root at 50 per cent flowering

The nodules present in the roots of the ten samples were seperated and the fresh weight was recorded in mg.

3.2.2.5. Dry weight of the plants at maturity

Ten sample plants were sundried for 2 days followed by oven drying for one day at 60-70°C. The dry weight of each plant was taken seperately and mean was recorded.

3.2.2.6. Nitrogen content in plants at 50 per cent flowering

Ten sample plants were uprooted at 50 per cent flowering, sun dried for two days and then ovendried at 60-70°C for one day. Properly dried plants were powdered and from this 0.5 g was taken for the nitrogen estimation by Microkjeldahl method.

3.2.2.7. Nitrogen content at maturity

Nitrogen content in plants at maturity was also estimated using Microkjeldahl method as in the previous case.

3.2.2.8. Plant height (cm)

Height of the ten sample plants from ground to the tip of the main stem is measured at maturity and mean was recorded.

3.2.2.9. Number of clusters per plant

The number of pod bearing clusters in the randomly selected observational plants were counted and the average was worked out and recorded.

3.2.2.10. Number of pods per plant

Total number of pods from the observational plants were counted and mean was recorded.

3.2.2.11. Number of seeds per pod

The average number of seeds per pod was worked out from ten pods selected from each sample plant.

3.2.2.12. Hundred grain weight

Random sample of hundred seeds were selected from each plot at harvest and mean weight recorded in g.

3.2.2.13. Grain yield

Grain yield (economic yield) obtained from the obeservational plants was recorded and the mean expressed in g.

3.2.2.14. Harvest index

Harvest index was calculated by using the following formula and expressed in grams.

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

Biological yield - Total dry weight of all plant parts including grain yield was taken and expressed in g.

3.3 Experiment II

3.3.1 Pot culture experiment

All the F_1 hybrids along with the seven parents were raised in pots using sand as the medium, to study the nodulation efficiency of hybrids and parents. The experiment was laid out in completely randomised block design with seven replications. The seeds were inoculated with a known Rhizobium culture (PA-GG-I) for effective nodulation. The non inoculated seeds were used as control. The inoculated plants were irrigated with nitrogen free nutrient solution. A set of absolute control was also kept without inoculation and were irrigated with nitrogen free nutrient solution.

3.3.2 Observations recorded

3.3.2.1 Number of nodules at 50% flowering

Ten sample plants were uprooted at 50% flowering and nodules were seperated and counted.

3.3.2.2 Weight of nodules at 50% flowering

After counting, the weight of nodules were taken by using an analytical balance and expressed in mg.

3.3.2.3 Nitrogen content at 50% flowering

Nitrogen content of the ten sample plants were estimated by using Microkjeldahl method.

3.3.2.4 Dry weight of the plants at 50 per cent flowering

Ten sample plants were collected at 50 per cent flowering and sundried for two days and oven dried for one day at 60-70°C. The dry weight of each plant was taken seperately and mean expressed in grams.

3.4. Statistical analysis

Data recorded from the parents and hybrids were subjected to analysis of variance followed by combining ability analysis for all those characters for which the mean square due to genotypes was found to be significant. Diallel analysis by Griffing's approach under the situation parents and F_1's only. Preliminary analysis was carried out as in the case of RBD for experiment I and that of CRD for experiment II making use of P=7 parents and P(P-1)/2 = 7 x 6/2 = 21 F_1's. The combining ability analysis was performed by using the mean values of various characters. Additive and non-additive variances and heterosis over better parent were also studied.

ANOVA for combining ability analysis

Source	df	Ms	E(MS) Expectation of mean squares
Genotypes	$\frac{P+P(P-1)}{2} - 1$	M	$\sigma^2 e + \sigma^2 g$
gca	P−1	Mg	$\sigma^2 e + \sigma^2 sca + (P+2)\ \sigma^2 gca$
sca	$\frac{P\ (P-1)}{2}$	Ms	$\sigma^2 e + \sigma^2 sca$
Error	$\left[\frac{[P+P(P-1)-1]}{2}\right](r-1)$	Me	$\sigma^2 e$

where $Me = \frac{MSE}{r}$

MSE = Error Mean Square; r = number of replications

If significant differences among gca and among sca effects were obtained, their effects were estimated as follows.

Effect of i^{th} parent = gi

$$\text{General combining ability} = \frac{1}{P+2} \left[\Sigma (Y_{i.} + Y_{ii}) - \frac{2Y_{..}}{P} \right]$$

Specific combining ability effect of ixj^{th} cross = Sij

$$= Y_{ij} - \frac{1}{P+2}[Y_{i.} + Y_{ii} + Y_{.j} + Y_{jj}) + \frac{2Y_{..}}{(P+1)\ (P+2)}$$

where

Y_{ij} = Mean of character with respect to $(i \times j)^{th}$ cross

$Y_{i.}$ = Total of mean values corresponding to i^{th} parent over the other crosses involving i^{th} parent

$Y_{.j}$ = Total of mean values corresponding to j^{th} parent over the other crosses involving j^{th} parent

$Y_{..}$ = Total of all mean values

SE for the difference of gca and sca effects are :

$$SE\ (gi - gj) = \left[\frac{2}{(P+2)}\ Me \right]^{1/2}$$

$$SE\ (Sij - Sik) = \left[\frac{2\ (P+1)}{(P+2)}\ Me \right]^{1/2}$$

$$SE\ (Sij - Skl) = \left[\frac{2P}{(P+2)}\ Me\right]^{1/2}$$

CD = SE x t (table value at error of df)

The significance of gca effects implies that additive heritable variance is responsible for variation for the observed character. The significance of sca effect reveals the importance of non-additive variance for the inheritance of the character. The gca and sca components of variance were estimated as.

$$\sigma^2 gca = \frac{Mg - Ms}{(P + 2)}$$

$$\sigma^2 sca = Ms - Me$$

Further estimates of additive variance $\sigma^2 a = 2\sigma^2 gca$ and estimate dominant variance = $\sigma^2 d = \sigma^2 sca$

Additive to dominance ratio were estimated and if it is more than unity then there is predominance of additive gene action otherwise there is predominance of non-additive gene action.

Heterosis

The mean values of each parent and their hybrids were taken for the estimation of heterosis. Heterosis was calculated as the percent deviation of the mean performance of F_1s from its better parent.

1. Deviation of the hybrid mean from the better parental value (Heterobeltiosis)

$$\frac{\overline{F}_1 - \overline{B}_p}{\overline{B}_p} \times 100$$

superior between those of the parents in each cross was taken as better parental values (BP)

To test the significance over better parent

$$CD_{(0.05)} = t \times \sqrt{\frac{2MSE}{r}}$$

where

t = tabulated students t table value for 5 % level at the error degrees of freedom

MSE = Error mean square

r = Number of replications

RESULTS

4. RESULTS

The data on various characters in greengram recorded from the experiments were statistically analysed. The results showed significant differences among the parents and F_1s for all the characters studied.

The mean value of biological nitrogen fixation traits, yield and its components of the first experiment are presented in table 2 and 3.

4.1. Mean performance

The length of primary root at 50 per cent flowering ranged from 13.37 cm (KM-1285) to 16.06 cm (IIPRM-3) among the parents. MG-368 was on par with KM-1285 and P.9333 was on par with IIPRM-3. Among hybrids the minimum length of primary root was recorded by KM-1285 x COGG-902 (15.49 cm) and maximum was observed in P.9333 x IIPRM-3 (17.86 cm). Hybrids KM-1285 x MG-368, MG-368 x COGG-902, MG-368 x LGG 444 and COGG-902 x LGG 444 were on par with KM-1285 x COGG-902 and P.9333 x NDM-88-14 was on par with P.9333 x IIPRM-3.

Highest number of secondary roots at maturity was found in the parent NDM-88-14 (16.70 cm) and lowest number was recorded in MG-368 (5.13). Among hybrids highest number of secondary roots at

Table 2. Mean value of various nitrogen fixation traits in 7 x 7 diallel set of crosses without reciprocals

Treatments	Length of primary root at 50% flowering	Number of secondary root at maturity	Shoot / root ratio	Weight of nodules at 50% flowering	Dry weight plants at maturity	Nitrogen content at 50% flowering	Nitrogen content at maturity
P_1 (P.9333)	16.01	15.07	6.77	10.90	7.31	4.42	3.24
P_2 (KM-1285)	13.37	7.37	5.17	10.23	3.30	4.22	3.13
P_3 (NDM-88-14)	15.91	16.70	7.20	17.33	8.84	5.84	3.94
P_4 (MG-368)	13.44	5.13	3.80	9.57	4.68	5.74	2.66
P_5 (IIPRM-3)	16.06	14.73	5.57	11.60	5.23	4.27	3.06
P_6 (COGG-902)	14.86	11.37	4.67	12.63	4.08	4.91	3.65
P_7 (LGG-444)	14.63	10.10	4.90	13.60	4.44	4.71	3.52
$P_1 \times P_2$	16.71	14.67	9.87	12.23	10.77	7.15	4.02
$P_1 \times P_3$	17.77	17.30	12.27	17.70	9.16	11.34	4.75
$P_1 \times P_4$	16.79	13.50	8.77	10.43	11.03	4.97	3.28
$P_1 \times P_5$	17.86	18.13	10.50	14.47	11.00	5.12	3.41
$P_1 \times P_6$	16.72	13.80	8.23	18.07	10.30	6.09	3.51
$P_1 \times P_7$	16.84	13.30	10.7	16.73	10.13	5.93	3.44
$P_2 \times P_3$	16.58	13.03	9.17	14.50	10.20	5.17	3.44
$P_2 \times P_4$	15.74	9.87	7.87	10.97	7.63	5.92	3.22
$P_2 \times P_5$	16.83	15.83	10.23	13.63	10.75	5.70	3.44
$P_2 \times P_6$	15.49	11.80	8.40	13.43	8.01	4.78	3.32
$P_2 \times P_7$	16.30	11.17	6.53	12.60	5.92	4.70	3.41
$P_3 \times P_4$	16.94	12.93	10.23	15.17	8.07	5.84	3.58
$P_3 \times P_5$	16.83	18.10	8.40	17.47	10.17	5.37	3.49
$P_3 \times P_6$	16.52	14.67	6.30	17.47	10.05	5.98	3.46
$P_3 \times P_7$	16.79	14.73	9.57	18.47	10.96	5.93	3.55
$P_4 \times P_5$	16.42	11.70	7.50	11.80	11.17	5.47	3.62
$P_4 \times P_6$	15.77	9.83	9.13	11.33	8.76	6.02	3.48
$P_4 \times P_7$	15.77	11.43	10.77	16.77	8.30	6.07	3.55
$P_5 \times P_6$	16.68	12.47	9.13	17.20	9.91	5.93	3.46
$P_5 \times P_7$	16.66	16.33	5.67	11.17	10.66	5.93	3.46
$P_6 \times P_7$	15.82	11.00	8.7	17.57	4.80	5.88	3.47
MSE	0.064	0.900	0.192	0.961	3.88	2.24	0.124
CD	0.414	1.552	0.718	1.601	0.322	2.45	0.578

Table 3. Mean value of yield and yield components in a 7 x 7 diallel set of crosses without reciprocals

Treatments	Plant height	Number of clusters / plant	Number of pods / plant	Number of seeds / pod	Hundred grain weight	Grain yield	Harvest index
P_1 (P.9333)	34.83	9.50	24.33	8.47	4.93	7.60	0.59
P_2 (KM-1285)	29.27	6.67	24.33	10.90	4.67	5.63	0.50
P_3 (NDM-88-14)	31.60	6.60	23.87	10.37	3.37	5.47	0.56
P_4 (MG-368)	29.70	6.93	24.33	10.50	4.30	6.93	0.35
P_5 (IIPRM-3)	32.93	10.30	26.93	10.60	4.07	7.83	0.45
P_6 (COGG-902)	33.77	4.83	19.83	9.93	2.63	3.63	0.37
P_7 (LGG-444)	31.10	5.20	19.30	9.83	2.97	4.03	0.34
$P_1 \times P_2$	42.13	10.70	21.57	10.87	4.03	9.23	0.74
$P_1 \times P_3$	36.87	12.73	34.37	11.30	5.00	11.53	0.80
$P_1 \times P_4$	37.37	10.87	30.57	11.57	4.53	12.87	0.78
$P_1 \times P_5$	44.07	17.00	28.33	10.50	4.87	19.13	0.55
$P_1 \times P_6$	36.27	12.27	31.17	10.10	4.97	19.67	0.63
$P_1 \times P_7$	38.73	9.57	34.70	11.60	4.60	9.80	0.76
$P_2 \times P_3$	36.53	10.10	33.23	11.30	4.23	9.80	0.69
$P_2 \times P_4$	36.57	12.20	31.27	11.20	4.53	14.70	0.72
$P_2 \times P_5$	40.13	10.83	26.57	11.83	3.87	14.73	0.78
$P_2 \times P_6$	37.70	10.83	25.13	10.67	4.63	9.90	0.61
$P_2 \times P_7$	35.47	10.53	23.63	11.47	3.73	9.33	0.61
$P_3 \times P_4$	35.50	11.30	31.00	9.93	3.57	15.33	0.72
$P_3 \times P_5$	37.73	9.60	27.23	11.60	4.30	10.87	0.77
$P_3 \times P_6$	35.47	9.13	23.37	11.17	3.93	7.77	0.75
$P_3 \times P_7$	37.43	10.70	38.60	13.00	4.00	8.40	0.70
$P_4 \times P_5$	38.30	11.93	24.67	11.03	4.10	10.77	0.65
$P_4 \times P_6$	40.53	10.57	32.17	10.90	4.20	6.13	0.65
$P_4 \times P_7$	35.80	12.27	24.63	10.27	3.57	11.60	0.76
$P_5 \times P_6$	37.03	12.13	27.40	11.57	4.87	10.20	0.76
$P_5 \times P_7$	41.17	11.67	31.17	11.20	4.73	10.57	0.63
$P_6 \times P_7$	41.07	10.57	24.27	10.63	3.53	8.87	0.58
MSE	5.128	0.775	2.648	0.452	0.026	0.176	0.022
CD	3.71	1.44	2.66	1.10	0.23	0.68	0.24

maturity was recorded in P.9333 x IIPRM-3 (18.13) and lowest number in MG-368 x COGG-902 (9.83). P.9333 x NDM-88-14 was on par with P.9333 x IIPRM-3 and KM-1285 x MG-368 was on par with MG-368 x COGG-902.

For shoot/root ratio the mean values varied from MG-368 (3.80) to NDM-88-14 (7.20). P.9333 was on par with NDM-88-14 among parents. Among hybrids the mean values ranged from IIPRM-3 x LGG-444 (5.67) to P.9333 x NDM-88-14 (12.27). NDM-88-14 x COGG-902 was on par with IIPRM-3 x LGG-444.

Maximum weight of nodules at 50 per cent flowering was observed in NDM-88-14 (17.33 mg) and minimum value was observed in MG-368 (9.57 mg) among parents. P.9333 and KM-1285 were on par with MG-368. Among hybrids mean values ranged from 10.43 mg (P.9333 x MG-368) to 18.47 mg (NDM-88-14 x LGG-444). P.9333 x NDM-88-14, P.9333 x COGG-902, NDM-88-14 x IIPRM-3, NDM-88-14x COGG-902 were on par with NDM-88-14 x LGG-444. MG-368 x COGG-902 and IIPRM-3 x LGG-444 were on par with P.9333 x MG-368.

Mean values for dry weight of the plants varied from 3.30g (KM-1285) to 8.84 g (NDM-88-14) among parents. Among hybrids the values ranged from 4.80 g (COGG-902 x LGG-444) to 11.17 g (MG-368 x IIPRM-3) . P.9333x MG-368 and P.9333 x IIPRM-3 were on par with MG-368 x IIPRM-3.

In the case of nitrogen content at 50 per cent flowering KM-1285 (4.22) showed poor performance and best performance was shown by NDM-88-14 (5.84) among parents. IIPRM-3, P.9333, LGG 444 were on par with KM-1285. MG-368 was on par with NDM-88-14. Among hybrids KM-1285 x LGG-444 (4.70) was the poor performer and P.9333 x NDM-88-14 (11.34) showed the best performance. All the crosses except P.9333 x NDM-88-14 were on par with KM-1285 x LGG-444.

Nitrogen content at maturity was minimum for MG-368 (2.66) and maximum for NDM-88-14 (3.94) among parents. P.9333, KM-1285 and IIPRM-3 were on par with MG-368. COGG-902 and LGG-444 were on par with NDM-88-14. Among hybrids maximum value was observed in P.9333 x NDM-88-14 (4.75) and minimum value was observed in KM-1285 x MG-368 (3.22). All the hybrids except P.9333 x KM-1285 and P.9333 x NDM-88-14 were on par with KM-1285 x MG-368.

The plant height ranged from 29.27 cm (KM-1285) to 34.83cm (P.9333) among parents. Among hybrids the minimum plant height was recorded by KM-1285 x LGG-444 and NDM-88-14 x COGG-902 (35.47 cm) and maximum by P.9333 x IIPRM-3 (44.07 cm).

The lowest mean number of clusters per plant was observed in COGG-902 (4.83) and highest number was observed in IIPRM-3 (10.30). Among parents P.9333 was on par with IIPRM-3. LGG-444 was on par with COGG-902. Among hybrids the minimum and maximum number of clusters per plant was observed in NDM-88-14 x COGG-902 (9.13) and P.9333 x IIPRM-3(17.00) respectively. P.9333 x LGG-444, NDM-88-14 x

IIPRM-3, MG-368 x COGG-902 and COGG-902 x LGG-444 were on par with NDM-88-14 x COGG-902.

Number of pods per plant ranged from 19.30 (LGG-444) to 26.93 (IIPRM-3). COGG-902 was on par with LGG-444. P.9333, KM-1285 and MG-368 was on par with IIPRM-3. Among hybrids maximum number of pods per plant was observed in NDM-88-14 x LGG-444 (38.60) and minimum number was observed in P.9333 x KM-1285 (21.57). KM-1285 x LGG-444 and NDM-88-14 x COGG-902 were on par with P.9333 x KM-1285.

Lowest number of seeds per pod was found in P.9333 (8.47) and the highest in KM-1285 (10.90) among parents. NDM-88-14, MG-368, IIPRM-3 were on par with KM-1285. Among hybrids minimum value was recorded NDM-88-14 x MG-368 (9.93) and maximum in NDM-88-14 x LGG-444 (13.00).

For hundred grain weight minimum value was expressed by COGG-902 (2.63) and maximum value was for P.9333 (4.93) among parents. LGG-444 was on par with COGG-902. Among hybrids the minimum value was for COGG-902 x LGG-444 (3.53) and maximum value was for P.9333 x NDM-88-14 (5.00). P.9333 x IIPRM-3, P.9333 x COGG-902 and IIPRM-3 x COGG-902 was on par with P.9333 x NDM-88-14.

Grain yield per plant ranged from 3.63 (COGG-902) to 7.83 (IIPRM-3) among parents. LGG-444 was on par with COGG-902. P.9333 was on par with IIPRM-3. Among hybrids grain yield was minimum for

MG-368 x COGG-902 (6.13) and maximum in P.9333 x COGG-902 (19.67). P.9333 x IIPRM-3 was on par with P.9333 x COGG-902.

Lowest harvest index was found in LGG-444 (0.34) and highest in P.9333 (0.59), KM-1285, NDM-88-14, IIPRM-3 were on par with P.9333. Among the hybrids the value ranged from 0.55 (P.9333 x IIPRM-3) to 0.80 (P.9333 x NDM-88-14). COGG-902 x LGG-444 were on par with P.9333 x IIPRM-3.

4.2. Combining ability

The analysis of variance of various characters are presented in Table 4.

Significant differences were observed among treatments for all characters studied. Hence the data were subjected to combining ability analysis.

The general combining ability of parents for various characters are presented in Table 5. The specific combining ability of the hybrids are presented in Table 6 and 7.

4.2.1. Length of primary root at 50 per cent flowering

Combining ability analysis of length of primary root at 50 per cent flowering showed that variance due to parents and hybrids were significant. Significant positive gca effects were shown by parent P.9333 (0.61) and significant negative gca effects were shown by KM-1285 (-0.53) and

Table 4. Analysis of variance for combining ability for nitrogen fixation traits and yield components in greengram

Character	Mean squares		
	gca	sca	Error
1. Length of primary root at 50% flowering	0.23*	0.79*	0.21
2. Number of secondary root at maturity	34.65*	2.39*	0.30
3. Shoot / Root ratio	3.20*	5.90*	0.60
4. Weight of nodules in the root at 50 per cent flowering	21.57*	4.48*	0.06
5. Dry weight of plants at maturity	7.35*	5.91*	1.29
6. Nitrogen content in plants at 50 per cent flowering	1.39NS	1.76*	0.75
7. Nitrogen content in plants at maturity	0.20*	0.10*	0.04
8. Plant height	9.50*	14.06*	1.70
9. Number of clusters / plant	6.81*	6.13*	0.26
10. Number of pods / plant	13.44*	26.69*	0.88
11. Number of seeds / pod	0.68*	0.69*	0.15
12. Hundred grain weight	0.73*	0.261*	0.07
13. Grain yield	14.50*	16.09*	0.06
14. Harvest index	0.024NS	0.26*	0.008

* Significant at 5% level NS - not significant at 5% level

Table 5. Estimates of gca effects of seven parents for various characters

Character	P.9333 P_1	KM-1285 P_2	NDM-88-14 P_3	MG-368 P_4	IIPRM-3 P_5	COGG-902 P_6	LGG 444 P_7	SE (gi)	SE (gi-gj)	CD
Length of primary root at 50 per cent flowering	0.61*	-0.53*	0.45	-0.54*	0.47	-0.27*	-0.19	0.045	0.068	0.134
Number of secondary root at maturity	-1.80	-1.50	2.18*	-2.78*	1.94*	-0.92	-0.71	0.169	0.258	0.505
Shoot / root ratio	1.04*	-0.24	0.64	-0.30	-0.22	-0.60*	-0.31	0.247	0.119	0.239
Weight of nodules in the root at 50 per cent flowering	-0.16	-1.67*	2.51*	-1.92*	-0.44	0.83	0.85	0.1748	0.266	0.522
Dry weight of the plants at maturity	1.08*	-0.83*	0.99	-0.33*	0.76*	-0.81*	-0.85*	0.351	0.537	1.077
Nitrogen content in plants at 50% flowering	0.44	-0.40	0.62	0.03	-0.38	-0.11	-0.18	0.267	0.407	NS
Nitrogen content in plants at maturity	0.11*	-0.09	0.25*	-0.20*	-0.10*	0.01	0.01	0.629	0.096	0.192
Plant height	1.36*	-0.65*	-1.13*	-1.05*	1.27*	0.30	-0.11	0.403	0.616	1.23
Number of clusters / plant	1.11*	-0.40*	-0.60*	0.09	1.29*	-0.78*	-0.72*	0.1569	0.239	0.479
Number of pods / plant	1.01*	-1.13*	1.70*	0.30	0.22	-1.90*	-0.19	0.917	0.443	0.888
Number of seeds / pod	-0.48*	0.21*	0.20*	-0.04	0.19*	-0.26*	0.18*	0.119	0.83	0.359
Hundred grain weight	0.52*	0.01	-0.16	-0.01	0.19	-0.20	-0.34*	0.0256	0.039	0.078
Grain yield / plant	1.86*	-0.19	-0.67	0.51	1.25	-1.21	-1.56*	0.0747	0.114	0.229
Harvest index	0.07	-0.01	0.08	-0.02	-0.01	-0.05	-0.05	0.0268	0.041	NS

* Significant at 5% level   NS - not significant at 5% level

Table 6. Sca effects of hybrids with respect to nitrogen fixation traits

Hybrids	Length of primary root at 50% flowering	No. of secondary root at maturity	Shoot/ root ratio	Wt. of nodules in the root at 50 % flowering	Dry wt. of plants at maturity	Nitrogen content in the plant at 50% flowering	Nitrogen content in the plant at maturity
$P_1 \times P_2$	0.48	1.29*	1.00	-0.05	2.10*	1.43	0.51*
$P_1 \times P_3$	0.56*	0.25	2.52	1.24	-1.33*	4.60*	0.90*
$P_1 \times P_4$	0.57*	1.41*	-0.04	-1.60	1.87*	-1.18*	-0.11
$P_1 \times P_5$	0.63*	1.32*	1.61	0.95	0.76	-0.62*	-0.09
$P_1 \times P_6$	0.23	-0.16	-0.28	3.29*	1.63*	0.08	-0.10
$P_1 \times P_7$	0.27	-0.86*	1.96	1.94	1.49*	-0.01	-0.16*
$P_2 \times P_3$	0.51	-0.72*	0.70	-0.45	1.62*	-0.73*	-0.21*
$P_2 \times P_4$	0.67*	1.08*	0.34	0.45	0.38	0.61	-0.14
$P_2 \times P_5$	0.75*	2.32*	2.63*	1.63	2.41*	0.80	-0.09
$P_2 \times P_6$	0.14	1.51*	1.16	0.17	1.24*	-0.39	0.01
$P_2 \times P_7$	0.88*	0.31	-0.99	-0.69	-0.81*	-0.40	0.05
$P_3 \times P_4$	0.88*	0.47	1.82	0.47	-1.01*	-0.50	-0.15
$P_3 \times P_5$	-0.24	0.91*	-0.09	1.29	0.01	-0.55	-0.29
$P_3 \times P_6$	0.19	0.34	-1.82*	0.02	1.45*	-0.21	-0.19
$P_3 \times P_7$	0.38	0.20	1.16	1.00	2.40*	-0.19	0.44*
$P_4 \times P_5$	-0.34	-0.53	-0.05	0.05	2.33*	0.13	0.18
$P_4 \times P_6$	0.43	0.46	1.96	-1.69	1.5*	0.41	0.26
$P_4 \times P_7$	0.35	1.86*	3.31*	3.73*	1.07*	0.54	0.06
$P_5 \times P_6$	0.33	-1.62*	1.88	2.70*	1.55*	0.73	0.07
$P_5 \times P_7$	0.23	2.04*	-1.87*	-3.35*	2.34*	0.80	0.07
$P_6 \times P_7$	0.14	-0.44	1.53	1.78	-1.95*	0.49	-0.03
SE (sij-sik)	0.195	0.730	0.337	0.754	1.517	1.153	0.271
SE (sij-skl)	0.182	0.683	0.316	0.705	1.419	1.078	0.254
CD_1	0.391	1.465	0.677	1.514	3.07	3.0734	0.545
CD_2	0.365	1.370	0.633	1.416	2.84	2.16	0.510

* Significant at 5% level

Table 7. Sca effects of hybrids with respect to various yield and yield components

Hybrids	Plant height	No. of clusters / plant	No. of pods / plant	No. of seeds / pod	Hundred grain weight	Grain yield / plant	Harvest index
$P_1 \times P_2$	4.81*	-0.28	-5.84*	0.24	-0.63*	-2.52	0.03
$P_1 \times P_3$	0.03	1.95	4.13	0.68	0.49	0.26	0.34*
$P_1 \times P_4$	0.44	-0.61	1.72	1.18*	-0.13	0.41	0.09
$P_1 \times P_5$	4.82*	4.33*	-0.43	-0.11	0.01	5.94	-0.15*
$P_1 \times P_6$	-2.00*	1.66	4.52	-0.06	0.50	8.93*	-0.03*
$P_1 \times P_7$	0.88	-1.09*	6.34	1.00*	0.27	-0.59	0.10
$P_2 \times P_3$	1.70	0.83	5.14	-0.02	0.24	0.58	-0.03*
$P_2 \times P_4$	1.65	2.24	4.57	0.12	0.40	4.29	0.50
$P_2 \times P_5$	2.90	-0.32	-0.05	0.53	-0.47*	3.59	0.15
$P_2 \times P_6$	1.43	1.74	0.63	-0.19*	0.69*	1.21	0.02
$P_2 \times P_7$	-0.39	1.38	-2.58	0.17	-0.67	1.00	0.02
$P_3 \times P_4$	1.06	1.54	1.46	-1.13*	-0.41	5.41	0.02
$P_3 \times P_5$	0.98	-1.36*	-2.21	0.31	0.12	0.20	0.05
$P_3 \times P_6$	-0.32	0.24	-3.96*	0.32	0.14	-0.44	0.07
$P_3 \times P_7$	2.06	1.75	9.56*	1.72*	0.35	0.55	0.02
$P_4 \times P_5$	1.47	0.80	-3.38	-0.02	-0.23	-1.08	0.05
$P_4 \times P_6$	4.67*	0.98	6.23	0.29	-0.26	-3.25*	0.07
$P_4 \times P_7$	0.35	2.62	-3.01	0.22	-0.23	2.56	0.19*
$P_5 \times P_6$	-1.15*	1.35	1.55	0.73	0.73*	0.07	0.18*
$P_5 \times P_7$	3.40*	0.82	6.60	-0.07	0.9*	0.79	0.05
$P_6 \times P_7$	4.27*	1.79	-1.18	-0.19*	-0.07	1.55	0.03
SE (sij-sik)	1.81	0.677	1.25	0.517	0.111	0.322	0.115
SE (sij-skl)	1.63	0.634	1.17	0.484	0.103	0.302	0.108
CD_1	3.64	1.36	2.51	1.03	0.222	0.647	0.232
CD_2	3.27	1.27	2.35	0.972	0.207	0.606	0.216

* Significant at 5% level

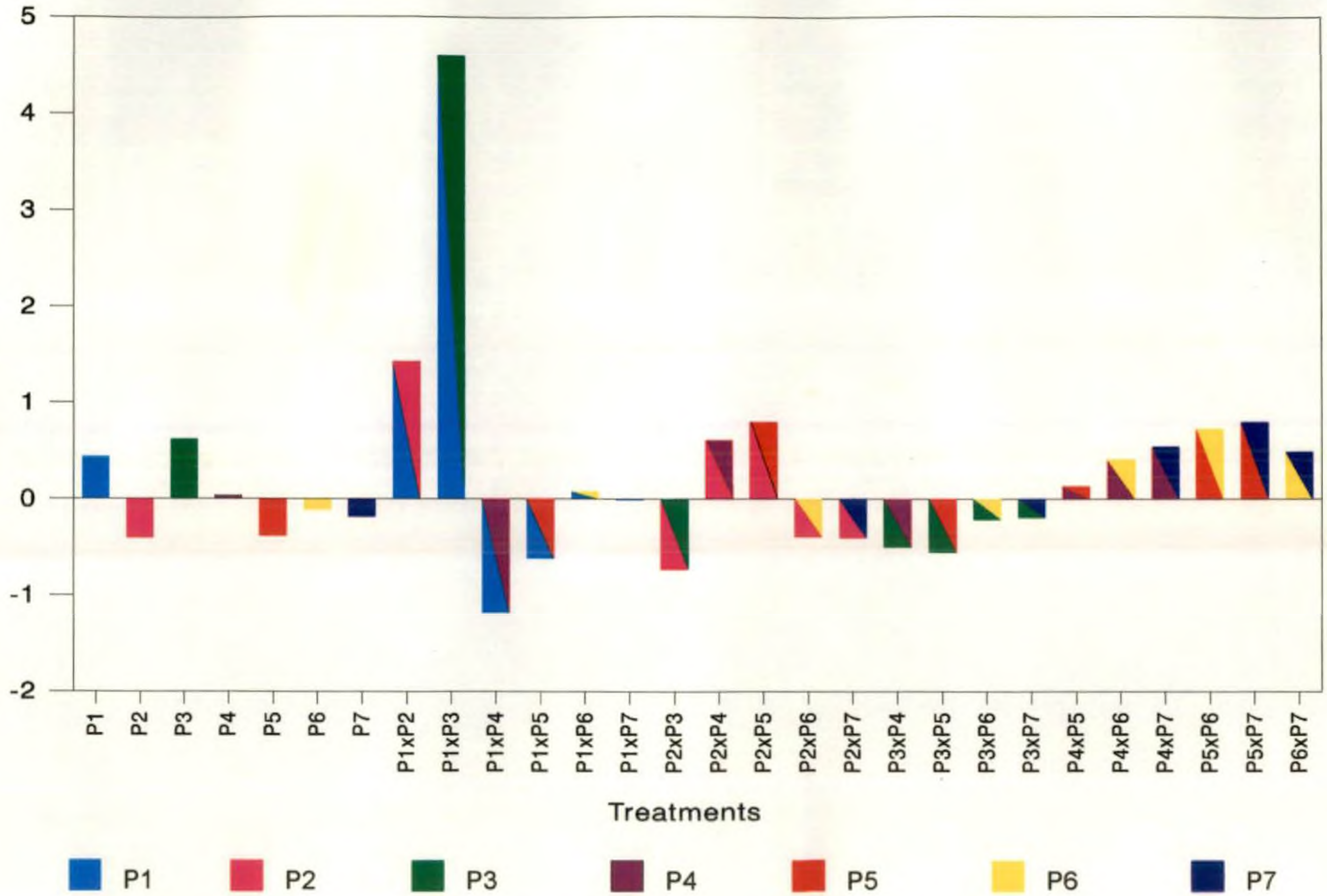

Fig. 1. G.C.A. and S.C.A. Nitrogen content at 50% flowering

MG-368 (-0.54). Significant positive sca effects were shown by the hybrids KM-1285 x LGG-444 (0.88), NDM-88-14 x MG-368 (0.88), KM-1285 x IIPRM-3 (0.75), KM-1285 x MG-368 (0.67), P.9333 x IIPRM-3 (0.63), P.9333 x MG-368 (0.57) and P.9333 x NDM-88-14 (0.56).

4.2.2. Number of secondary roots at maturity

Analysis of variance of number of secondary roots at maturity was significant for both parents and hybrids. Significant positive gca effects were shown by NDM-88-14 (2.18) and IIPRM-3 (1.94). Significant negative gca effects were shown by MG-368 (-2.78). Among hybrids significant positive sca effects were shown by KM-1285 x IIPRM-3 (2.32), IIPRM-3 x LGG-444 (2.04), MG-368 x LGG-444 (1.86), P.9333 x MG-368 (1.41), P.9333 x IIPRM-3 (1.32), P.9333 x KM-1285 (1.29), KM-1285 x COGG-902 (1.15), KM-1285 x MG-368 (1.08) and NDM-88-14 x IIPRM-3 (0.91). Significant negative sca effects were shown by hybrids IIPRM-3 x COGG-902 (-1.62), P.9333 x LGG-444 (-0.86) and KM-1285 x NDM-88-14 (-0.72).

4.2.3. Shoot / root ratio

Variance for shoot / root ratio was significant for both parents and hybrids. Significant positive gca effects were shown by P.9333 (1.04) and significant negative gca effect was shown by COGG-902 (-0.60). Among hybrids significant positive sca effects were shown by MG-368 x LGG-444 (3.31) and KM-1285 x IIPRM-3 (2.63). Significant negative sca effects were shown by the hybrids IIPRM-3 x LGG-444 (-1.87) and NDM-88-14 x COGG-902 (-1.82).

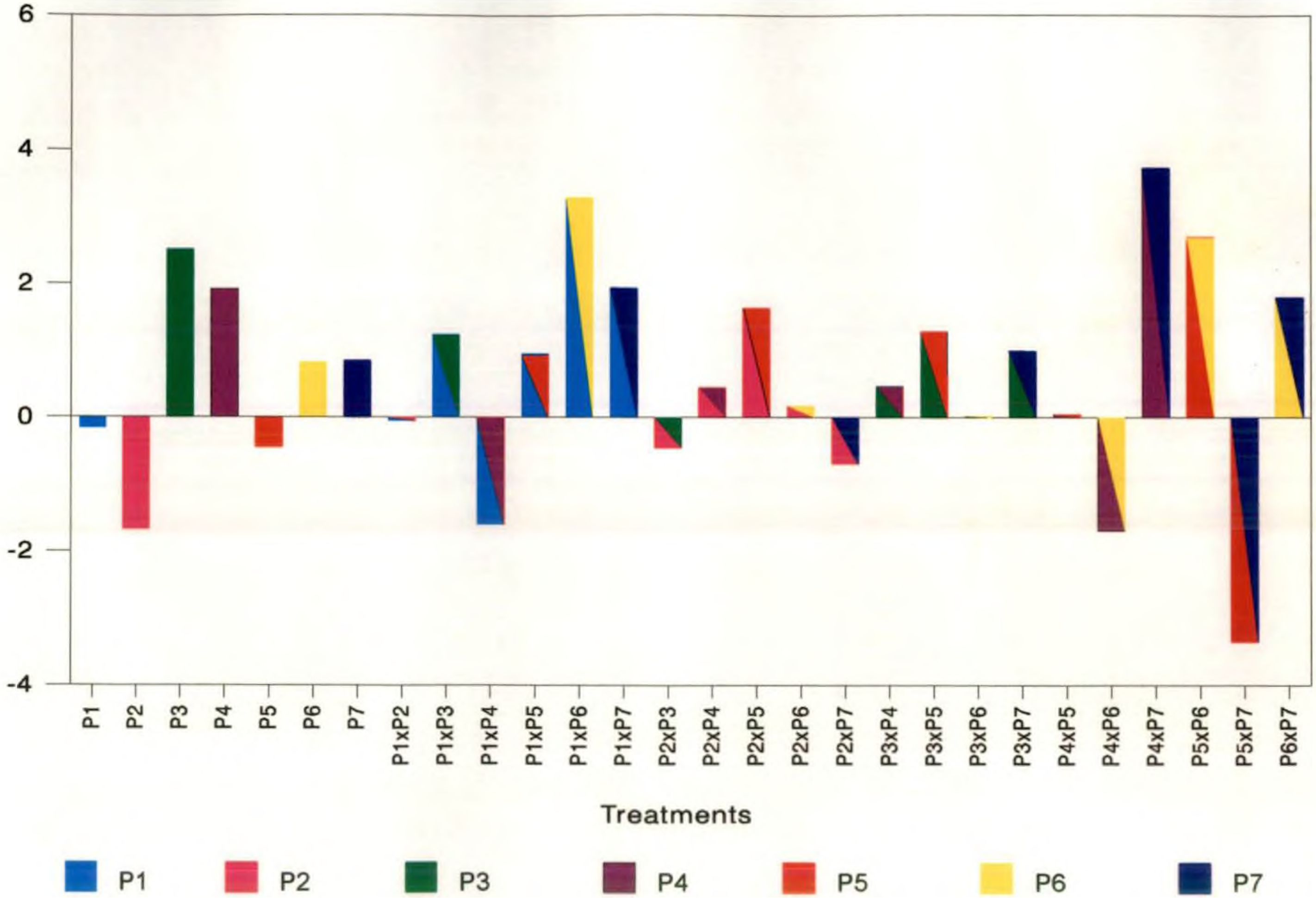

Fig. 2. G.C.A. and S.C.A. Weight of nodules at 50% flowering

4.2.4. Weight of nodules at 50 per cent flowering

Weight of nodules in the roots at 50% flowering varied significantly among parents and hybrids. Significant positive gca effects were shown by the parent NDM-88-14 (2.51). Significant positive sca effects were shown by hybrid MG-368 x LGG-444 (3.73), P.9333 x COGG-902 (3.29) and IIPRM-3 x COGG-902 (2.70). Significant negative sca effect was shown by IIPRM-3 x LGG-444 (-3.35).

4.2.5. Dry weight of plants at maturity

Analysis of variance for dry weight for plants at maturity showed that the variance due to parents and hybrids were significant. Significant positive gca effects were shown by P.9333 (1.08), NDM-88-14 (0.99) and IIPRM-3 (0.76). Significant negative sca effects were shown by LGG-444 (-0.85), KM-1285 (-0.83), COGG-902 (-0.81) and MG-368 (-0.33). Fourteen hybrids showed positive significant sca effects, among them the highest value was recorded by the hybrid KM-1285 x IIPRM-3 (2.41). Significant negative sca effects were shown by hybrids COGG-902 x LGG-444 (-1.95), P.9333 x NDM-88-14 (-1.33), NDM-88-14 x MG-368 (-1.01) and KM-1285 x LGG-444 (-0.81).

4.2.6. Nitrogen content in plants at 50 per cent flowering

Combining ability analysis revealed that gca effects were not significant for nitrogen content at 50 per cent flowering. Significant positive sca effects were shown by hybrids P.9333 x NDM-88-14 (4.60).

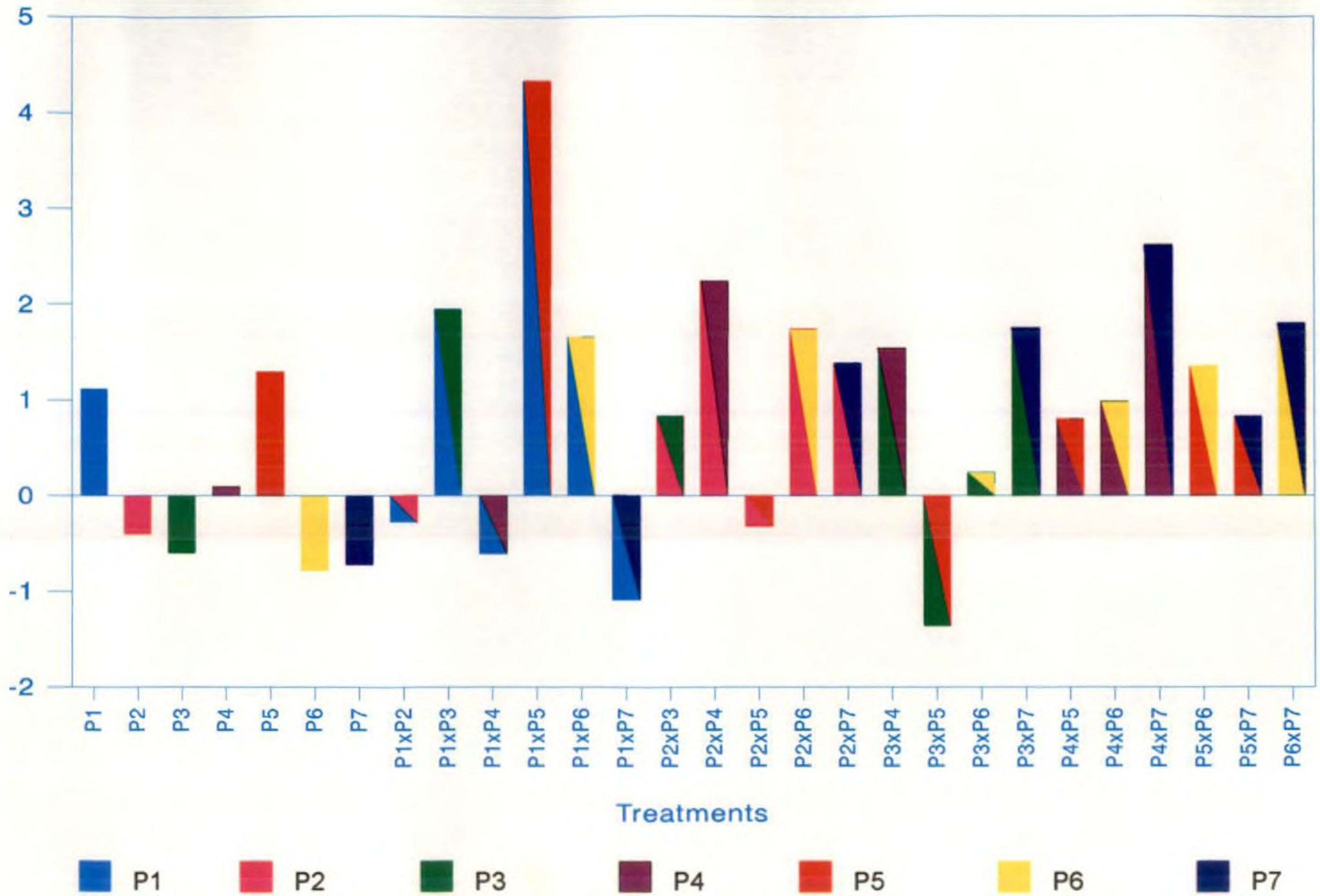

Fig. 3. G.C.A. and S.C.A. Number of clusters per plant

Significant negative sca effects were shown by hybrids P.9333 x MG-368 (-1.18), KM-1285 x NDM-88-14 (-0.73) and P.9333 x IIPRM-3 (-0.62).

4.2.7. Nitrogen content in plants at maturity

Combining ability analysis for nitrogen content in plants at maturity exhibited significant variances among the parents and hybrids. The parents NDM-88-14 (0.25) and P.9333 (0.11) showed significant positive gca effects. Significant negative gca effects were shown by MG-368 (-0.20) and IIPRM-3 (-0.10). Significant positive sca effects were shown by P.9333 x NDM-88-14 (0.90), P.9333 x KM-1285 (0.51) and MG-368 x IIPRM-3 (0.44). Significant negative sca effects were shown by P.9333 x LGG-444 (-0.16), KM-1285 x NDM-88-14 (-0.21), NDM-88-14 x LGG-444 (-0.19) and NDM-88-14 x COGG-902 (-0.29).

4.2.8. Plant height

Analysis of variance for plant height showed that variance due to parents and hybrids were significant. Among parents significant positive gca effects were shown by P.9333 (1.36) and IIPRM-3 (1.27) and significant negative gca effects were shown by NDM-88-14 (-1.13), MG-368 (-1.05) and KM-1285 (-0.65). Among hybrids significant positive sca effects were shown by hybrids P.9333 x IIPRM-3 (4.83), P.9333 x KM-1285 (4.81), MG-368 x COGG-902 (4.67), COGG-902 x LGG-444 (4.27) and IIPRM-3 x LGG-444 (3.40). Significant negative sca effects were shown by P.9333 x COGG-902 (-2.00) and IIPRM-3 x COGG-902 (-1.15).

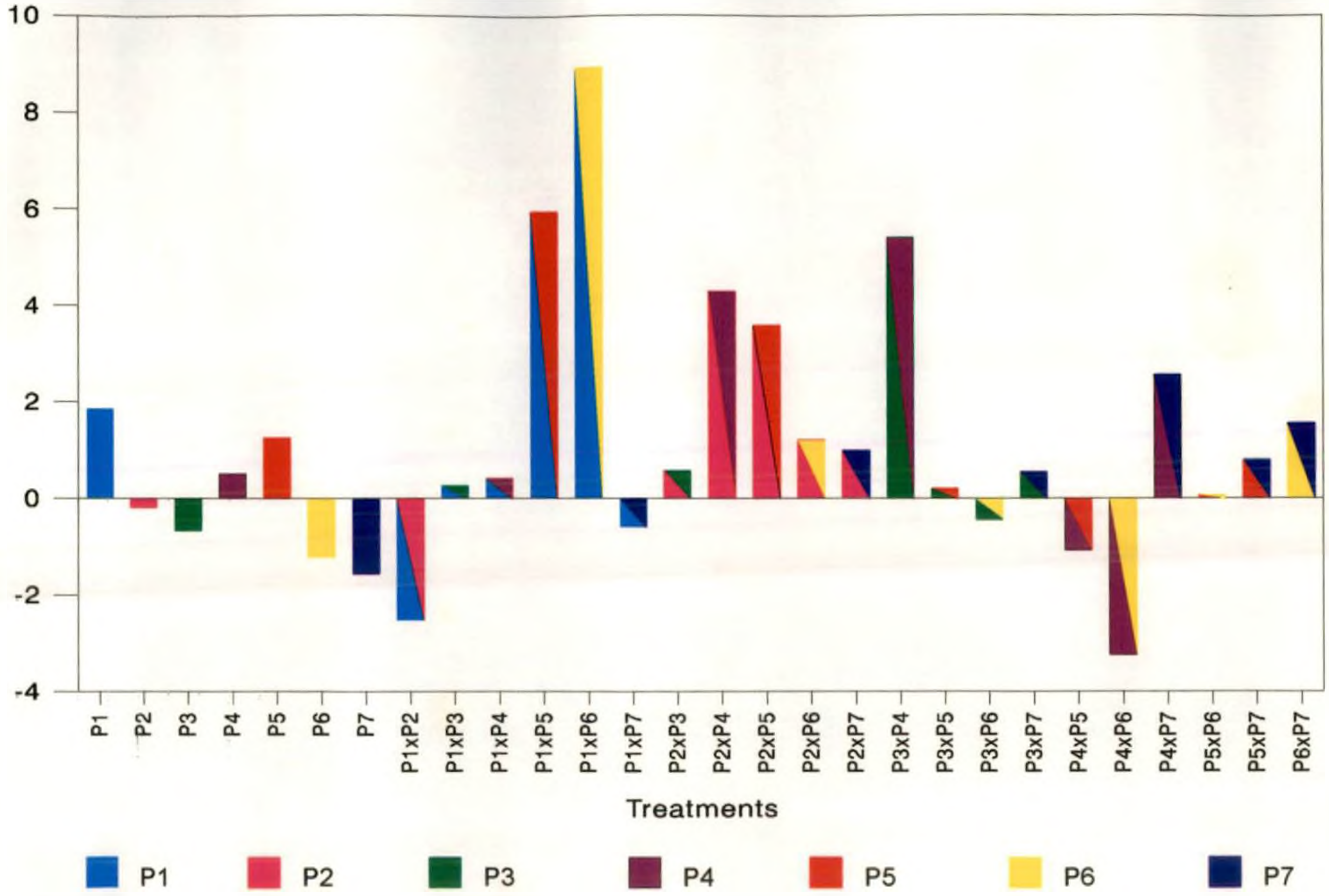

Fig. 4. G.C.A. and S.C.A. Grain yield per plant

4.2.9. Number of clusters per plant

Both parents and hybrids showed significant variance for number of clusters per plant. Significant positive gca effects were shown by parents IIPRM-3 (1.29) and P.9333 (1.11). Significant negative gca effects were shown by four parents COGG-902 (-0.78), LGG-444 (-0.72), NDM-88-14 (-0.60) and KM-1285 (-0.40). Among hybrids significant positive sca effect was shown by P.9333 x IIPRM-3 (4.33). Significant negative sca effects were shown by NDM-88-14 x IIPRM-3 (-1.36) and P.9333 x LGG-444 (-1.09).

4.2.10. Number of pods per plant

Analysis of variance for number of pods per plant showed that variance due to parents and hybrids differed significantly. Among parents significant positive gca effects were shown by NDM-88-14 (1.70) and P.9333 (1.01). Significant negative gca effects were shown by COGG-902 (-1.90) and KM-1285 (-1.13). Among hybrids significant sca effects were shown by NDM-88-14 x LGG-444 (9.56) and significant negative sca effects were shown by P.9333 x KM-1285 (-5.84) and NDM-88-14 x COGG-902 (-3.96).

4.2.11. Number of seeds per pod

Combining ability analysis for number of seeds per pod revealed that variance due to parents and hybrids were significant. Significant positive gca effects were shown by parents KM-1285 (0.21), NDM-88-14

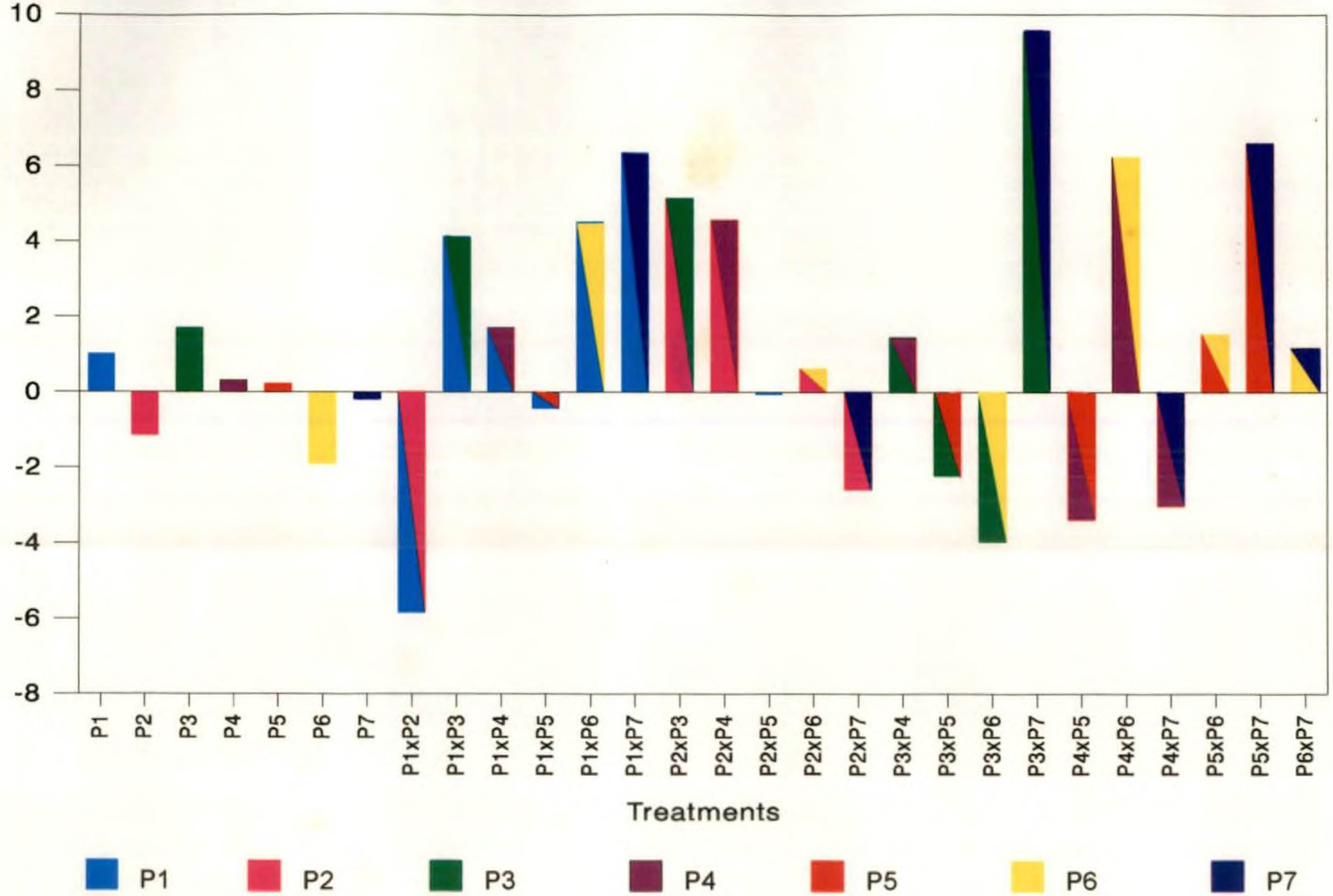

Fig. 5. G.C.A. and S.C.A. Number of pods per plant

(0.20), IIPRM-3 (0.19) and LGG-444 (0.18), significant negative gca effects were shown by P.9333 (-0.48) and COGG-902 (-0.26), significant positive sca effects were shown by the hybrids NDM-88-14 x LGG-444 (1.72), P.9333 x MG-368 (1.18) and P.9333 x LGG-444 (1.00). Significant negative sca effects were shown by hybrids NDM-88-14 x MG-368 (-1.13), COGG-902 x LGG-444 (-0.19) and KM-1285 x COGG-902 (-0.19).

4.2.12. Hundred grain weight

Hundred grain weight differed significantly among parents and hybrids. Among parents P.9333 (0.52) showed significant positive gca effects and LGG-444 (-0.34) showed significant negative gca effects. Among hybrids significant positive sca effects were shown by IIPRM-3 x LGG-444 (0.79), IIPRM-3 x COGG-902 (0.73) and KM-1285 x COGG-902 (0.69). Significant negative sca effects were shown by hybrids P.9333 x KM-1285 (-0.63) and KM-1285 x IIPRM-3 (-0.47).

4.2.13. Grain yield per plant

Analysis of variance for grain yield showed significant differences among parents and hybrids. Among parents P.9333 (1.86) showed significant positive gca effects and significant negative gca effects were shown by LGG-444 (-1.56). Among hybrids significant positive sca effects were shown by P.9333 x COGG-902 (8.93) and significant negative sca effects were shown by hybrids MG-368 x COGG-902 (-3.25).

4.2.14. Harvest index

The combining ability analysis for harvest index showed non-significance of gca effects. Significant positive sca effects were shown by P.9333 x KM-1285 (0.34), MG-368 x LGG-444 (0.19) and IIPRM-3 x COGG-902 (0.18) significant negative sca effects were shown by hybrids P.9333 x IIPRM-3 (-0.15), P.9333 x COGG-902 (-0.03) and KM-1285 x NDM-88-14 (-0.05).

4.3. Genetic components of variance

The genetic components of variance viz., additive variance (σ^2a) and dominance variance (σ^2d) are presented in Table 8.

For all characters except for number of secondary roots at maturity and weight of nodules at 50 per cent flowering, dominance variance was greater than additive variance. The ratio of additive to dominance variance was more than unity for number of secondary root at maturity (3.08) and weight of nodules at 50 per cent flowering (1.82). The ratio was less than unity for length of primary root at 50 per cent flowering (0.880), shoot / root ratio (-0.167), dry weight of plants at maturity (0.139), nitrogen content in plants at 50 per cent flowering (-0.159), nitrogen content at maturity (0.728), plant height (-0.164), number of cluster per plant (0.051), number of pods per plant (-0.230), number of seeds per pod (-0.0049), hundred grain weight (0.810), grain yield (-0.043) and harvest index (0.113).

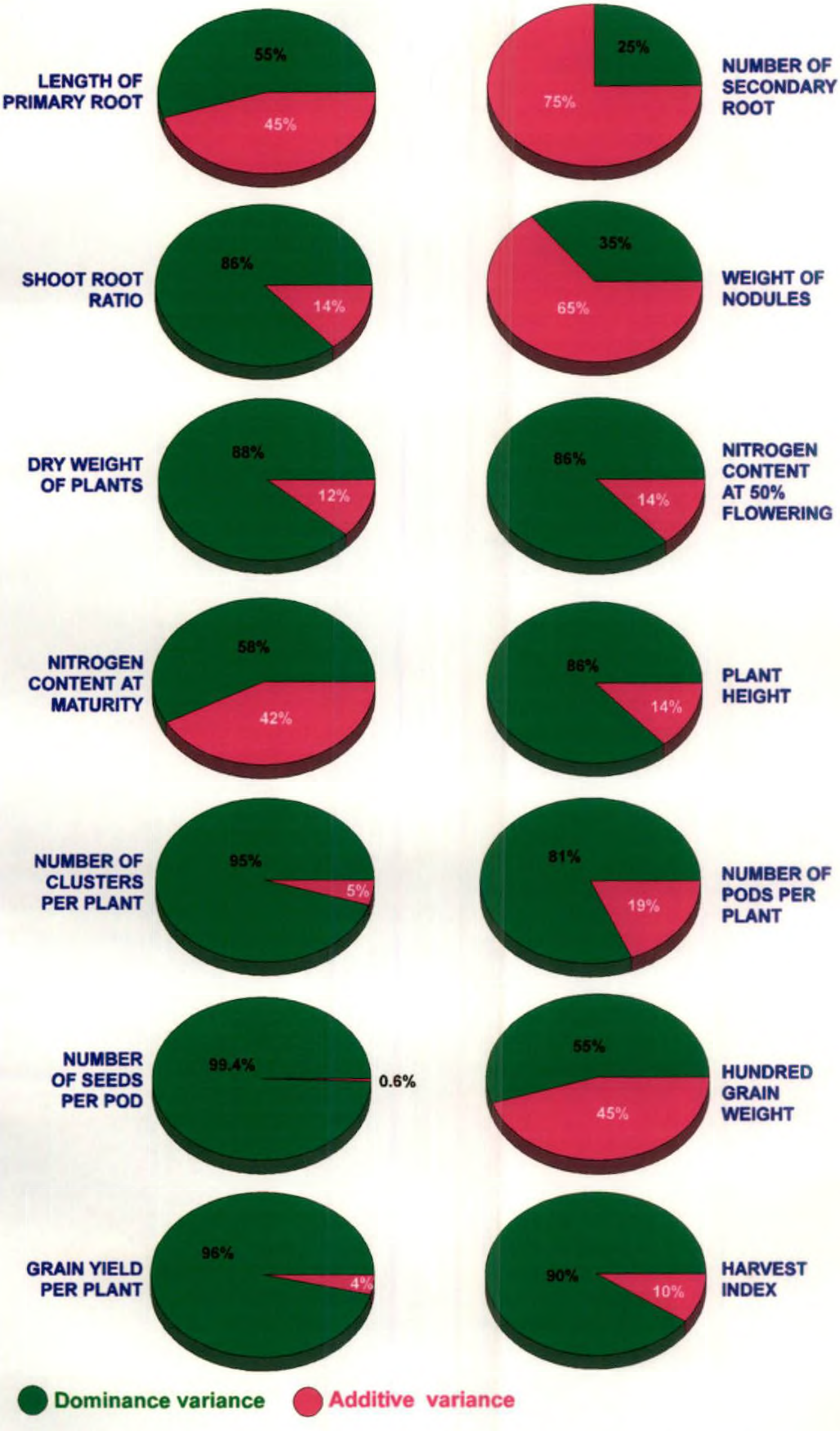

Fig. 6. Magnitude of additive to dominance variance

Table 8. Genetic components of variance for various nitrogen fixation traits and yield components in greengram

Sl. No.	Characters	Additive variance σ^2A	Dominance variance σ^2D	σ^2A/σ^2D
1.	Length of primary root at 50% flowering	0.638	0.774	0.88
2.	Number of secondary root at maturity	6.44	2.09	3.08
3.	Shoot / root ratio	-0.84	5.026	-0.167
4.	Weight of nodules in the root at 50% flowering	7.59	4.163	1.82
5.	Dry weight of plants at maturity	0.64	4.62	0.138
6.	Nitrogen content in plants at 50% flowering	-0.161	1.012	-0.159
7.	Nitrogen content in the plants at maturity	0.044	0.061	0.728
8.	Plant height	-2.02	12.35	-0.164
9.	Number of clusters / plant	0.302	5.87	0.051
10.	Number of pods / plant	-5.89	25.81	-0.23
11.	Number of seeds / pod	-0.002	0.538	-0.005
12.	Hundred grain weight	0.208	0.254	0.81
13.	Grain yield	-0.702	16.03	-0.045
14.	Harvest index	0.001	0.008	0.1129

4.4. Heterosis

The superiority of hybrids were estimated in comparison with the mean value of the better parent (heterobeltiosis) for various nitrogen fixation traits and yield components in greengram.

The magnitude of heterobeltiosis for various characters are presented in Table 9 and 10.

4.4.1. Length of primary root at 50% flowering

All hybrids exhibited positive heterobeltiosis for length of primary root at 50% flowering. Highest value was recorded in KM-1285 x MG-368 (17.11). No significant heterobeltiosis was shown by MG-368 x IIPRM-3 (2.24).

4.4.2. Number of secondary root at maturity

Significant positive heterobeltiosis was shown by hybrids P.9333 x IIPRM - 3 (20.30), KM-1285 x MG-368 (33.92) and IIPRM-3 x LGG 444 (10.86). Significant negative heterobeltiosis was exhibited by hybrids P.9333 x MG-368 (-10.41), P.9333 x LGG-444 (-11.74), NDM 88-14 x MG-368 (-22.57), NDM 88-14 x COGG 902 (-12.45), NDM 88-14 x LGG-444 (-11.79) and IIPRM-3 x COGG-902 (-15.34).

4.4.3. Shoot / root ratio

Nineteen hybrids showed significant positive heterosis for shoot / root ratio. One hybrid showed positive non-significant heterosis. One one

Table 9. Percentage heterosis over better parent for various nitrogen fixation traits in greengram

Parent hybrids	Length of primary roots 50% flowering		Number of secondary roots at maturity		Shoot root ratio		Weight of nodules in the root at 50% flowering		Dry weight of the plant at maturity		Nitrogen content in plant at 50% flowering		Nitrogen content in plant at maturity	
	Mean	HB%	Mean	HB%	Mean	HB%	Mean	HB%	Mean	HB%	Mean	HB%	Mean	HB%
P_1 (P.9333)	16.01		15.07		6.77		10.90		7.31		4.42		3.24	
P_2 (KM-1285)	13.37		7.37		5.17		10.23		3.30		4.22		3.13	
P_3 (NDM-88-44)	15.91		16.70		7.20		17.33		8.84		5.72		3.94	
P_4 (MG-368)	13.44		5.13		3.80		9.57		4.68		5.74		2.66	
P_5 (11 PRM-3)	16.06		14.73		5.57		11.60		5.23		4.27		3.06	
P_6 (COGG-902)	14.86		11.37		4.67		12.63		4.08		4.91		3.65	
P_7 (LGG-444)	14.63		10.10		4.90		13.60		4.44		4.71		3.52	
$P_1 \times P_2$	16.71	4.37*	14.67	-2.65	9.87	45.79*	12.23	12.20	10.77	47.33*	7.15	61.76*	4.02	24.07*
$P_1 \times P_3$	17.77	10.99*	17.30	3.59	12.27	70.41*	17.70	2.13	9.16	3.61*	11.34	98.25*	4.75	20.55*
$P_1 \times P_4$	16.79	4.87*	13.50	-10.41*	8.77	29.54*	10.43	4.31	11.03	50.88*	4.94	-13.41	3.28	1.23
$P_1 \times P_5$	17.86	11.20*	18.13	20.30*	10.50	55.09*	14.47	24.74*	11.00	50.47*	5.12	15.83	3.41	11.43
$P_1 \times P_6$	16.72	4.48*	13.80	-8.42	8.23	21.56*	18.07	43.23*	10.30	40.90*	6.09	24.03	3.51	-3.83
$P_1 \times P_7$	16.84	5.18*	13.30	-11.74*	10.77	59.08*	16.73	23.01*	10.13	38.57*	5.93	25.90	3.44	-2.27
$P_2 \times P_3$	16.58	4.21*	13.03	21.94	9.17	27.36*	14.50	-16.33*	10.20	15.38*	5.17	-9.61	3.44	-12.69
$P_2 \times P_4$	15.74	17.11*	9.87	33.92*	7.87	52.22*	10.97	7.23	7.63	63.03*	5.92	3.13	3.22	2.87
$P_2 \times P_5$	16.83	4.79*	15.83	7.46	10.23	83.66*	13.63	17.50*	10.75	105.32*	5.7	33.48	3.44	9.90
$P_2 \times P_6$	15.49	4.23*	11.80	3.78	8.40	62.47*	13.43	6.3	8.01	-96.32*	4.78	-2.64	3.32	-9.04
$P_2 \times P_7$	16.30	11.49*	11.17	10.59	6.53	26.30*	12.60	7.35	5.92	33.33*	4.70	-0.21	3.41	-3.12
$P_3 \times P_4$	16.94	6.47*	12.93	-22.57*	10.23	42.08*	15.17	-12.46*	8.07	-8.71*	5.84	1.74	3.58	-9.13
$P_3 \times P_5$	16.83	4.79*	18.10	8.38	8.40	16.66*	17.47	0.81	10.17	15.04*	5.37	-6.12	3.49	-11.42
$P_3 \times P_6$	16.52	3.83*	14.67	-12.15*	6.30	-12.50*	17.47	0.81	10.05	13.68*	5.95	4.54	3.46	-12.18
$P_3 \times P_7$	16.79	5.53*	14.73	-11.79*	9.57	32.91*	18.47	6.57	10.96	23.08*	5.93	3.67	3.55	-9.89
$P_4 \times P_5$	16.47	2.24	11.70	20.50	7.50	34.65*	11.80	1.72	11.17	113.57*	5.47	-4.70	3.62	18.30
$P_4 \times P_6$	15.77	6.12*	9.83	-13.54	9.13	95.50*	11.33	-11.17	8.76	87.18*	6.02	4.87	3.48	-4.65
$P_4 \times P_7$	15.77	7.79*	11.43	13.16	10.77	119.79*	16.77	22.86*	8.30	77.35*	6.07	5.75	3.55	0.85
$P_5 \times P_6$	16.68	3.86*	12.47	-15.34*	9.13	63.91*	17.20	36.18*	9.91	89.48*	6.93	20.77	3.46	-5.20
$P_5 \times P_7$	16.66	3.73*	16.33	10.86*	5.67	1.79	11.17	-17.86*	10.66	103.82*	5.93	27.28	3.46	-1.70
$P_6 \times P_7$	15.82	6.43*	11.00	-3.25	8.70	77.55*	17.57	29.19*	4.80	8.11*	5.80	19.75	3.47	-4.93
CD	0.414		1.55		0.72		1.61		0.32		2.45		0.58	

* Significant at 5% level   HB - Heterobeltiosis

Table 10. Percentage heterosis over better parent for yield and yield components in greengram

Parent hybrids	Plant height		Number of clusters per plant		Number of pods per plant		Number of seeds per plant		Hundred gram weight		Grain yield		Harvest index	
	Mean	HB%	Mean	HB%	Mean	HB%	Mean	HB%	Mean	HB%	Mean	HB%	Mean	HB%
P_1 (P.9333)	34.83		9.50		24.33		8.47		4.93		7.60		0.59	
P_2 (KM-1285)	29.27		6.67		24.33		10.90		4.07		5.63		0.50	
P_3 (NDM-88-44)	31.60		6.60		23.87		10.37		3.37		5.47		0.50	
P_4 (MG-368)	29.70		6.93		24.33		10.50		4.30		6.93		0.35	
P_5 (IIPRM-3)	32.93		0.30		26.93		10.60		4.07		7.83		0.45	
P_6 (COGG-902)	33.77		4.83		19.83		9.93		2.63		3.63		0.37	
P_7 (LGG-444)	31.10		5.20		19.30		9.83		2.97		4.03		0.34	
$P_1 \times P_2$	42.13	20.95*	10.70	12.63	21.57	-11.34*	10.87	-0.275	4.03	-18.25	9.23	21.44*	0.74	25.48
$P_1 \times P_3$	36.87	5.82	12.73	34.00*	34.37	41.26*	11.30	8.96*	5.00	1.42	11.53	51.71*	1.13	91.52*
$P_1 \times P_4$	37.37	7.29	10.87	41.47*	30.57	25.64*	11.57	10.19*	4.53	-8.11	12.87	69.34*	0.78	32.20
$P_1 \times P_5$	44.07	26.52*	17.00	65.04*	28.33	5.19	10.50	-0.94	4.87	-1.21	19.13	144.31*	0.55	-6.76
$P_1 \times P_6$	36.27	4.13	12.27	29.14*	31.17	28.11	10.10	1.71	4.97	0.81	19.67	158.81*	0.63	6.77
$P_1 \times P_7$	38.73	11.19*	9.57	0.73	34.70	42.62*	11.60	18.00*	4.60	-6.69	9.80	28.94*	0.76	28.81
$P_2 \times P_3$	36.53	15.60*	10.10	51.42*	33.23	36.58*	11.30	3.67	4.23	3.93	9.80	74.00	0.69	16.94
$P_2 \times P_4$	36.57	23.13*	12.20	76.04*	31.27	28.52*	11.20	2.75	4.53	5.34	14.70	112.12*	0.72	28.57*
$P_2 \times P_5$	40.13	21.77*	10.83	5.14	26.57	-1.336	11.83	8.53*	3.87	-4.91	14.73	88.12*	0.78	56.00*
$P_2 \times P_6$	37.70	11.63*	10.83	62.36*	25.13	3.288	10.67	-2.11	4.63	13.76	9.90	75.84*	0.61	22.00
$P_2 \times P_7$	35.47	14.01*	10.53	57.87*	23.63	-2.87	11.47	5.23	3.73	8.35	9.33	65.71*	0.61	22.00
$P_3 \times P_4$	35.50	12.34*	11.30	63.05*	31.00	27.41*	9.93	-5.42	3.57	-16.76	15.33	121.21*	0.72	28.57
$P_3 \times P_5$	37.73	14.57	9.60	6.79	27.23	1.11	11.60	9.43*	4.3	5.69	10.87	38.82*	0.77	37.50
$P_3 \times P_6$	35.47	5.03	9.10	38.33*	23.37	-2.09	11.17	7.71	3.93	16.61	7.77	42.04*	0.75	33.92
$P_3 \times P_7$	37.43	21.20*	10.70	62.12*	38.60	61.70*	13.00	25.36	4.00	18.69	8.40	53.56*	0.70	0.25
$P_4 \times P_5$	38.30	16.30*	11.93	15.82*	24.67	-8.39	11.03	4.05	4.10	-4.65	10.77	37.54*	0.66	46.66
$P_4 \times P_6$	40.53	20.01*	10.57	52.52*	32.17	32.22*	10.90	3.81	4.20	2.32	6.13	-11.54*	0.65	75.67*
$P_4 \times P_7$	35.80	15.11*	12.27	70.05*	24.63	12.33	11.27	-2.19	3.57	16.97	11.60	67.38*	0.76	117.14*
$P_5 \times P_6$	37.03	9.65	12.13	17.76*	27.40	1.74	11.57	9.15	3.87	19.65	10.20	30.26*	0.76	68.88*
$P_5 \times P_7$	41.17	25.02*	11.67	13.30	31.17	26.88*	11.20	5.66	4.73	16.21	10.57	34.99*	0.63	40.00
$P_6 \times P_7$	41.07	21.61*	10.57	103.26*	24.27	22.39*	10.63	0.285	3.53	18.85	8.87	120.09*	0.58	56.75
CD	3.71		1.44		2.67		0.64		1.102		0.219		0.25	

* Significant at 5% level HB - Heterobeltiosis

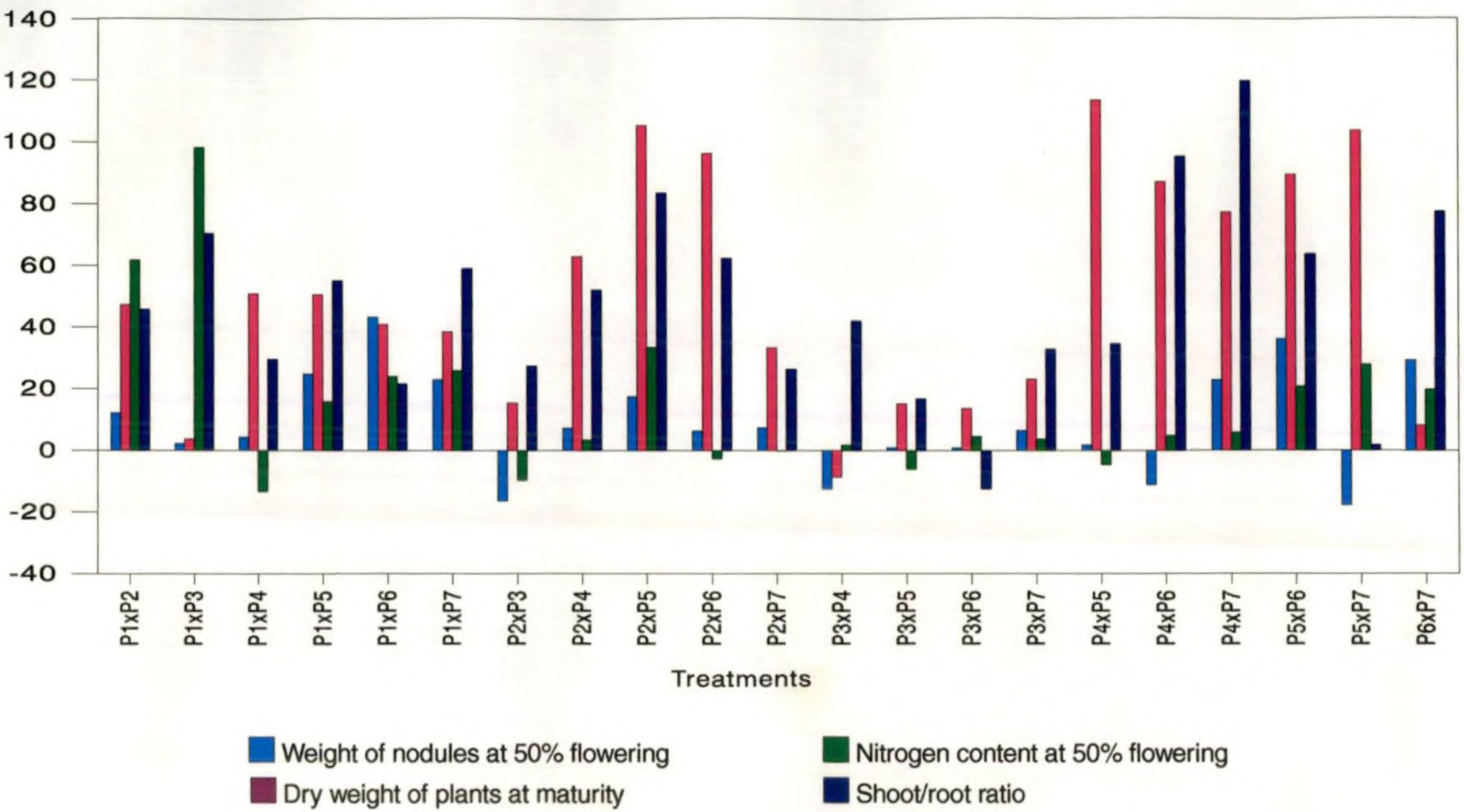

Fig. 7. Estimate of heterobeltiosis in greengram for important biological nitrogen fixation traits

hybrid, NDM-88-14 x COGG-902 (-12.50) showed significant negative heterosis.

4.4.4. Weight of nodules at 50% flowering

Significant positive heterobeltiosis was exhibited by hybrids P.9333 x IIPRM-3 (24.74), P.9333 x LGG-444 (23.01), KM-1285 x IIPRM-3 (17.50), P.9333 x COGG-902 (43.23), MG-368 x LGG-444, (22.86), IIPRM-3 x COGG-902 (36.18) and COGG-902 x LGG-444 (29.19). Significant negative heterobeltiosis was observed in KM-1285 x NDM-88-14 (-16.33), NDM-88-14 x MG-368 (12.46) and IIPRM-3 x LGG-444 (-17.86).

4.4.5. Dry weight of plants at maturity

All hybrids exhibited significant heterobeltiosis, among them KM-1285 x COGG-902 (-96.32) and NDM-88-14 x MG-368 (-8.71) showed negative heterobeltiosis for dry weight of plants at maturity.

4.4.6. Nitrogen content in plants at 50% flowering

Only two hybrids P.9333 x KM-1285 (61.76) and P.9333 x NDM-88-14 (98.25) showed significant heterobeltiosis. Hybrids P.9333 x MG-368 (-13.41), KM-1285 x NDM-88-14 (-9.61), KM-1285 x COGG-902 (-96.32) and NDM-88-14 x MG-368 (-8.71) showed negative heterobeltiosis for dry weight of plants at maturity.

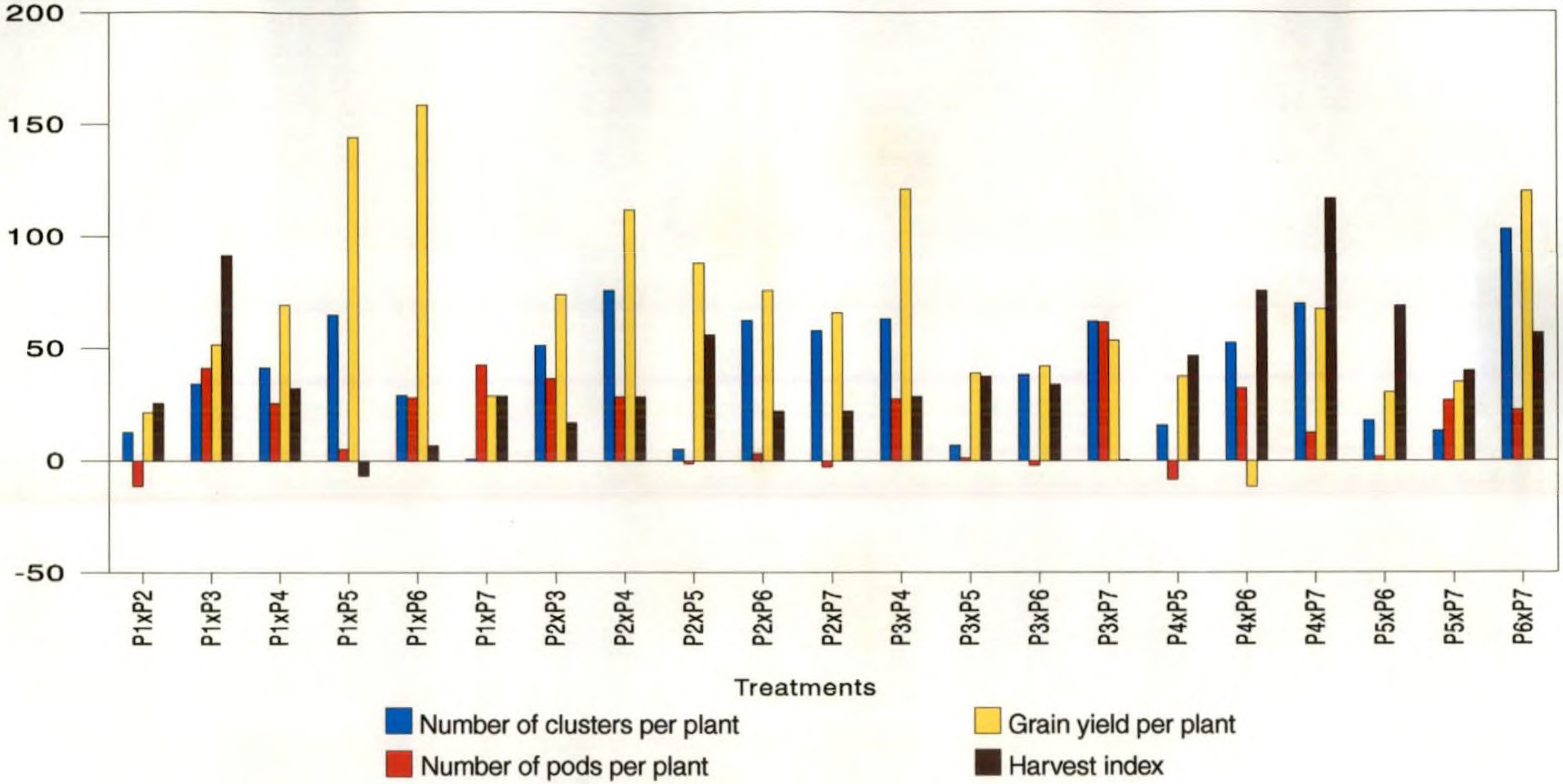

Fig. 8. Estimate of heterobeltiosis in greengram for yield and yield components

4.4.6. Nitrogen content in plants at 50% flowering

Only two hybrids P.9333 x KM-1285 (61.76) and P.9333 x NDM-88-14 (98.25) showed significant heterobeltiosis. Hybrids KM-1285 x COGG-902 (-2.64), KM-1285 x LGG-444 (-0.21), NDM-88-14 x IIPRM-3 (-6.12) and MG-368 x IIPRM-3 (-4.70) showed negative heterobeltiosis.

4.4.7. Nitrogen content at maturity

For nitrogen content at maturity significant positive heterobeltiosis was shown by hybrids P.9333 x KM-1285 (24.07) and P.9333 x NDM-88-14 (20.55). Twelve hybrids showed non-significant negative heterobeltiosis.

4.4.8. Plant height

All the hybrids showed positive heterobeltiosis for plant height, of which the heterosis manifested in five hybrids were not significant. The maximum heterobeltiosis for plant height was observed in hybrids P.9333 x IIPRM-3 (26.52)

4.4.9. Number of clusters per plant

All hybrids exhibited positive heterobeltiosis among them five hybrids showed non-significant heterobeltiosis for number of clusters per plant. Highest positive heterosis was shown by KM-1285 x MG-368 (76.04).

4.4.10. Number of pods per plant

Sixteen hybrids exhibited positive heterobeltiosis. Among them P.9333 x IIPRM-3 (5.19), KM-1285 x COGG-902 (3.28), NDM-88-14 x IIPRM-3 (1.11), MG-368 x LGG-444 (12.33) and IIPRM-3 x COGG-902 (1.74) exhibited non-significant heterobeltiosis. Among the five hybrids exhibited negative heterobeltiosis P.9333 x KM-1285 was significant.

4.4.11. Number of seeds per pod

Sixteen hybrids exhibited positive heterobeltiosis among them eight hybrids showed significant heterobeltiosis and highest value was recorded by P.9333 x LGG-444 (18.00). Non-significant negative heterobeltiosis was displayed by five hybrids.

4.4.12. Hundred grain weight

All hybrids exhibited non-significant heterobeltiosis, fourteen hybrids showed positive heterobeltiosis and seven hybrids showed negative heterobeltiosis. Highest value was observed in IIPRM-3 x COGG-902 (19.65).

4.4.13. Grain yield

All hybrids exhibited significant heterobeltiosis for grain yield among them MG-368 x COGG-902 (-11.54) exhibited negative heterosis. Highest positive heterobeltiosis was shown by the hybrid P.9333 x

COGG-902 (158.81) lowest positive heterobeltiosis was exhibited by the hybrid P.9333 x KM-1285 (21.44).

4.4.14. Harvest index

All the hybrids except P.9333 x IIPRM-3 (6.76) showed positive heterobeltiosis for harvest index, among them significant heterobeltiosis was recorded by P.9333 x NDM 88-14 (91.52), KM-1285 x MG-368 (28.57), KM-1285 x IIPRM-3 (56.00), MG-368 x COGG-902 (75.67), MG-368 x LGG-444 (117.14) and IIPRM-3 x COGG-902 (68.88).

4.5.1. Pot culture experiment

The results of the experiment conducted to study the nodulation efficiency and other nitrogen fixation traits of the seven parents and twenty one hybrids under inoculated, non-inoculated and absolute control condition are presented below.

Mean performance

The mean performance of parents and hybrids for different nitrogen fixation traits are given in Table 11.

4.5.1.1. Number of nodules at 50 per cent flowering

Among the inoculated population lowest mean number of nodules at 50 per cent flowering was recorded by MG-368 (33.71) and highest

Table 11. Mean value for various nitrogen fixation traits obtained from pot culture experiment in 7 x 7 diallel cross of greengram

Treatments	No. of nodules at 50 % flowering			Wt. of nodules at 50 % flowering			Nitrogen content in plants at 50 % flowering			Dry weight of plants at 50 % flowering		
	Inoculated	Non inoculated	Absolute control	Inoculated	Non inoculated	Absolute control	Inoculated	Non inoculated	Absolute control	Inoculated	Non inoculated	Absolute control
P_1 (P.9333)	50.80	5.18	5.75	118.51	1.61	1.64	4.85	4.2	2.45	7.64	7.10	5.24
P_2 (KM-1285)	46.92	4.16	4.84	112.78	1.54	1.54	4.51	4.14	2.15	4.41	3.13	1.94
P_3 (NDM-88-14)	74.41	10.14	12.80	272.85	3.70	3.43	5.97	5.64	3.84	9.13	8.11	6.83
P_4 (MG-368)	33.71	3.21	4.94	70.78	1.28	1.17	4.04	3.922	1.93	5.16	4.20	2.84
P_5 (11 PRM-3)	53.18	4.20	5.14	117.32	1.51	1.47	4.33	4.18	2.35	5.81	5.08	3.25
P_6 (COGG-902)	64.22	7.22	8.899	229.78	2.51	2.44	5.06	4.61	2.83	4.23	4.20	3.24
P_7 (LGG-444)	67.00	7.74	7.38	219.37	2.50	2.45	4.90	4.57	2.65	4.51	4.53	3.25
$P_1 \times P_2$	63.04	6.68	7.15	221.3	2.14	2.31	5.06	4.14	2.25	11.94	10.78	9.44
$P_1 \times P_3$	194.42	14.51	16.71	401.38	6.23	6.12	7.93	5.94	3.94	14.04	12.90	11.55
$P_1 \times P_4$	59.04	8.87	8.66	215.57	2.17	1.95	5.01	4.65	2.96	9.64	3.87	7.64
$P_1 \times P_5$	84.77	10.30	9.13	250.17	2.93	2.14	5.39	4.21	2.37	12.00	11.18	9.48
$P_1 \times P_6$	173.58	12.12	11.15	388.10	3.81	3.64	6.43	4.83	2.95	10.18	9.15	7.95
$P_1 \times P_7$	124.98	8.76	12.78	278.45	4.68	4.24	6.18	4.66	2.63	11.23	8.93	7.85
$P_2 \times P_3$	90.25	6.95	9.14	248.42	3.07	2.94	5.45	3.94	1.95	10.14	8.95	7.65
$P_2 \times P_4$	65.11	7.91	7.21	220.32	2.16	1.96	6.20	4.64	2.82	7.09	6.19	4.82
$P_2 \times P_5$	77.55	7.61	8.24	239.18	2.45	2.16	6.16	4.96	3.05	11.25	10.09	8.93
$P_2 \times P_6$	75.74	5.26	7.94	237.52	2.33	1.96	5.54	4.92	2.93	6.82	6.13	4.24
$P_2 \times P_7$	65.04	8.56	5.91	221.74	1.67	1.24	4.25	3.65	1.82	6.15	5.15	3.94
$P_3 \times P_4$	86.30	9.45	8.94	245.52	2.77	2.35	6.56	4.96	2.93	10.04	8.92	7.13
$P_3 \times P_5$	95.84	9.66	9.55	302.64	3.44	3.15	5.32	4.63	2.85	10.42	9.95	8.92
$P_3 \times P_6$	96.87	12.41	10.12	304.22	3.53	3.25	6.10	4.49	2.54	10.10	9.15	7.45
$P_3 \times P_7$	182.15	4.84	13.17	392.88	5.09	4.24	6.43	5.59	3.16	11.20	10.17	10.12
$P_4 \times P_5$	48.10	4.87	5.16	201.67	1.56	1.22	5.64	4.82	2.93	10.74	10.20	8.83
$P_4 \times P_6$	50.28	7.81	5.36	203.00	1.71	1.64	6.21	4.89	2.96	8.06	7.16	5.84
$P_4 \times P_7$	72.21	6.75	8.14	279.21	2.52	2.16	6.46	5.51	3.74	8.90	8.16	6.43
$P_5 \times P_6$	68.95	6.44	7.27	222.47	2.28	1.96	6.20	5.47	1.95	10.60	9.24	8.15
$P_5 \times P_7$	65.12	9.90	6.82	203.05	2.08	1.54	6.01	5.55	3.14	11.11	10.11	8.45
$P_6 \times P_7$	100.12	8.71	10.17	305.28	3.81	3.06	6.39	4.89	2.94	5.21	9.18	9.12
SE	0.478	0.105	0.068	0.184	0.418	0.0139	0.033	0.021	0.017	0.066	0.0344	0.025
CD	1.316	0.290	0.1801	0.5112	1.16	0.038	0.092	0.0577	0.049	0.183	0.095	0.069

number of nodules was observed in NDM-88-14 (74.41) in the case of parents. Among hybrids the minimum and maximum number of nodules were recorded by MG-368 x IIPRM-3 (48.10) and P.9333 x NDM-88-14 (194.42).

In the case of non-inoculated population mean value for number of nodules at 50 per cent flowering ranged from 3.21 (MG-368) to 10.14 (NDM-88-14) among parents. Among the hybrids the mean value varied from 4.84 (NDM-88-14 x LGG-444) to 14.51 (P.9333 x NDM-88-14). MG-368 x IIPRM-3 was on par with NDM-88-14 x LGG-444.

In the third situation (absolute control) lowest mean number of nodules at 50 per cent flowering was found in KM-1285 (4.84) and highest in NDM-88-14 (12.80) among parents. MG-368 was on par with KM-1285. In the case of hybrids minimum value was observed in MG-368 x IIPRM-3 (5.16) and maximum in P.9333 x NDM-88-14 (16.71).

4.5.1.2. Weight of nodules at 50 per cent flowering

In the case of inoculated population the mean weight of nodules at 50 per cent flowering was minimum in MG-368 (70.78 mg) and maximum in NDM-88-14 (272.85 mg) among parents. Among hybrids the minimum and maximum weight of nodules at 50 per cent flowering was observed in MG-368 x IIPRM-3 (201.67) and P.9333 x NDM-88-14 (401.38).

Among the non-inoculated population weight of nodules at 50 per cent flowering was minimum in MG-368 (1.28 mg) and maximum in NDM-

88-14 (3.70 mg). In the case of hybrids the value ranged from 1.56 mg (MG-368 x IIPRM-3) to 6.23 mg (P.9333 x NDM-88-14).

In the case of absolute control mean weight of nodules at 50 per cent flowering was lowest in MG-368 (1.17 mg) and highest in NDM-88-14 (3.43 mg) among parents. Among hybrids minimum value was observed in MG-368 x IIPRM-3 (1.22 mg) and maximum in P.9333 x NDM-88-14 (6.12 mg). KM-1285 x LGG-444 was on par with MG-368 x IIPRM-3.

4.5.1.3. Nitrogen content at 50 per cent flowering

In the inoculated population mean value for nitrogen content at 50 per cent flowering ranged from 4.04 (MG-368) to 5.97 (NDM-88-14) among parents. In the case of hybrids the value ranged from 4.23 (KM-1285 x LGG-44) to 7.93 (P.9333 x NDM-88-14).

Among the non-inoculated population nitrogen content at 50 per cent flowering was minimum in MG-368 (3.92) and was maximum in NDM-88-14 (5.64) in the case of parents. Among the hybrids the poor performance was shown by KM-1285 x LGG-444 (3.64) and P.9333 x NDM-88-14 (5.94) was the best performer.

In the case of absolute control nitrogen content at 50 per cent flowering varied from 1.93 (MG-368) to 3.84 (NDM-88-14) among parents. Among hybrids the mean value ranged from 1.82 (KM-1285 x LGG-444) to 3.94 (P.9333 x NDM-88-14).

4.5.1.4. Dry weight of plants at 50 per cent flowering

In the inoculated condition dry weight of plants at 50 per cent flowering ranged from 4.23 g (COGG-902) to 9.13 g (NDM-88-14) among parents. In the case of hybrids dry weight of plants varied from 6.15 g (KM-1285 x LGG-444) to 14.0 g (P.9333 x NDM-88-14).

Among the non-inoculated population dry weight of plants was maximum in NDM-88-14 (8.11 g) and minimum in KM-1285 (3.13) among parents. In the case of hybrids maximum value was observed in P.9333 x NDM-88-14 (12.90g) and minimum in KM-1285 x LGG-444 (5.15 g).

In the case of absolute control lowest value for dry weight of plants was recorded by KM-1285 (1.94 g) and highest in NDM-88-14 (6.83 g) among parents. Among hybrids average dry weight of plants was minimum in KM-1285 x LGG-444 (3.94 g) and maximum in P.9333 x NDM-88-14 (11.55 g).

4.5.2. Combining ability and gene action

Anova for combining ability and general combining ability effects of parents and specific combining effects of hybrids are presented in Tables 12, 13 and 14.

4.5.2.1. Number of nodules at 50 per cent flowering

Combining ability analysis for number of nodules at 50 per cent flowering in the inoculated condition exhibited significant variances among the parents and hybrids. Among the parents significant positive gca effects

Table 12. Analysis of variance for combining ability for nitrogen fixation traits in pot culture experiment

Characters	Mean squares		
	gca	sca	error
Inoculated			
Number of nodules at 50% flowering	2918.73*	1256.35*	0.23
Weight of nodules at 50% flowering	12803.48*	4405.18*	0.034
Nitrogen content at 50% flowering	0.057	0.788*	0.001
Dry weight of plants at 50% flowering	13.235*	5.643*	0.004
Non-inoculated			
Number of nodules at 50% flowering	11.601*	5.976*	0.011
Weight of nodules at 50% flowering	3.640*	0.765*	0.009
Nitrogen content at 50% flowering	0.433*	0.314*	0.001
Dry weight of plants at 50% flowering	9.673*	4.937*	0.001
Absolute control			
Number of nodules at 50% flowering	23.116*	4.055*	0.005
Weight of nodules at 50% flowering	3.294*	0.659*	0.001
Nitrogen content at 50% flowering	0.358*	0.286*	0.001
Dry weight of plants at 50% flowering	9.182*	5.673*	0.001

* Significant at 5% level

Table 13. GCA effects of seven parents for various biological nitrogen fixation traits in pot culture experiment

Treatments	No. of nodules at 50 % flowering			Wt. of nodules at 50 % flowering			Nitrogen content in plants at 50 % flowering			Dry weight of plants at 50 % flowering		
	Inoculated	Non inoculated	Absolute control	Inoculated	Non inoculated	Absolute control	Inoculated	Non inoculated	Absolute control	Inoculated	Non inoculated	Absolute control
P_1 (P.9333)	15.11	0.957	0.976	7.895	0.357	0.426	-0.03*	-0.12	-0.001	1.504	1.235	1.102
P_2 (KM-1285)	-15.05	-1.301*	-1.428	-34.106	-0.57	-0.461	-0.395*	-0.373*	-0.322*	-0.949	-1.250*	1.281*
P_3 (NDM-88-14)	25.464*	1.737*	2.814*	57.752*	1.055*	1.010*	0.501*	0.328*	0.34*	1.49*	1.271*	1.341*
P_4 (MG-368)	-24.113*	-1.231*	-1.661*	-46.017*	-0.731*	-0.689*	-0.12	-0.064	0.022	-0.66	0.767	-0.894
P_5 (11 PRM-3)	-13.26	-0.646	-1.252	-29.693	-0.475	-0.523	-0.205	0.012	-0.112	0.778	0.671	0.532
P_6 (COGG-902)	3.169	0.467	0.168	22.131	0.051	0.064	0.196	0.092	-0.008	-1.26*	-0.712	-0.578
P_7 (LGG-444)	8.683	-0.001	0.384	22.038	0.0131	0.173	0.051	0.124	0.081	-0.89	-0.449	-0.222
SE (Gi-Gj)	0.238	0.049	0.032	0.086	0.045	0.006	0.015	0.009	0.008	0.031	0.016	0.011
CD	0.443	0.097	0.063	0.172	0.090	0.011	0.031	0.012	0.016	0.062	0.021	0.020

* Significant at 5% level

Table 14. SCA effects of hybrids fo various nitrogen fixation trials in pot culture experiment

Treatments	No. of nodules at 50 % flowering			Wt. of nodules at 50 % flowering			Nitrogen content in plants at 50 % flowering			Dry weight of plants at 50 % flowering		
	Inoculated	Non inoculated	Absolute control	Inoculated	Non inoculated	Absolute control	Inoculated	Non inoculated	Absolute control	Inoculated	Non inoculated	Absolute control
$P_1 \times P_2$	-20.20*	-0.847	-0.937	7.81	-0.400	-0.131	-0.173	-0.120	-0.181	2.536*	2.697*	2.812
$P_1 \times P_3$	70.67	3.941	4.354*	95.607	2.064	2.203*	1.808*	0.993*	0.854*	2.197	2.291*	2.307
$P_1 \times P_4$	-15.14	1.254	0.805	13.563	-0.209	0.263	-0.491	0.092	0.184	-0.049	0.299	0.628
$P_1 \times P_5$	-0.263	2.11	0.871	31.839	-0.294	-0.24	-0.028	-0.442	-0.267	0.866	1.086	0.990
$P_1 \times P_6$	72.12	2.826	1.473*	118.029*	0.649	0.67	0.611	0.118	0.205	1.092	0.526	0.622
$P_1 \times P_7$	18.008	-0.073	2.884	8.394	1.256	1.134	0.501	-0.078	-0.197	1.794	0.046	0.168
$P_2 \times P_3$	-3.345	-1.361	-0.785	-15.348	-0.169	-0.081	-0.309	-0.755	-0.817*	0.75	0.826	0.785
$P_2 \times P_4$	21.089	2.546	1.763*	60.322	0.708	0.63	1.060	0.344	0.369	-0.138	0.106	0.189
$P_2 \times P_5$	22.122*	1.686	2.559	62.855	0.741	0.664	1.11	0.581	0.729	2.576*	2.574	2.873*
$P_2 \times P_6$	4.435	-1.783*	0.66	9.374	0.095	-0.121	0.086	0.465	0.512	0.212	-0.011	-0.699
$P_2 \times P_7$	-11.779	1.985	-1.587*	-6.32	-0.827*	-0.933	-1.061*	-0.84*	-0.688	-0.856	-1.252*	-1.359*
$P_3 \times P_4$	1.761	1.049	-0.753	-6.337	-0.308	-0.447	0.525	-0.038	-0.18	0.372	0.313	-0.118
$P_3 \times P_5$	0.449	0.691	-0.148	34.453*	0.105	0.187	-0.626	-0.443	-0.126	-0.692	-0.093	0.247
$P_3 \times P_6$	-14.95	2.331	-1.394	-15.785	-0.330	-0.303	-0.251	-0.662	-0.54	1.022	0.489	-0.119
$P_3 \times P_7$	64.82	4.769*	1.432	72.965	0.967	0.583*	0.225	0.403	-0.011	1.751	1.246*	2.203
$P_4 \times P_5$	2.28	-1.141	-0.446	37.252*	0.012	0.044	0.308	0.138	0.273	1.778	2.193	2.393
$P_4 \times P_6$	-11.96	0.686	-1.680*	-13.243	-0.364	-0.214	0.478	0.127	0.195	1.145	0.536	0.507
$P_4 \times P_7$	4.456	0.087	0.884	63.063	0.184	0.196	0.878	0.718	0.882*	1.609*	1.275	0.749
$P_5 \times P_6$	-4.14	-1.257	-0.182	-10.15	0.050	-0.059	0.555	0.625	-0.677	2.275	1.18	1.395*
$P_5 \times P_7$	-13.48	2.67	-0.849	-29.418*	0.513	-0.583*	0.508	0.674	0.42	2.376	1.789	1.35
$P_6 \times P_7$	5.088	0.371	1.079	20.986*	0.692	0.347	0.489	-0.059	0.118	-1.568*	2.24	3.114
SE (Sij-Sik)	0.63	0.14	0.09	0.25	0.13	0.19	0.08	0.28	0.02	0.63	0.06	0.04
CD	1.25	0.28	0.18	0.49	0.25	0.37	0.17	0.05	0.05	1.25	0.09	0.07
SE (Sij-Skl)	0.59	0.13	0.09	0.23	0.12	0.17	0.08	0.03	0.02	0.59	0.04	0.03
CD	1.55	0.26	0.17	0.46	0.24	0.34	0.16	0.05	0.04	1.17	0.85	0.06

* Significant at 5% level

were shown by NDM-88-14 (25.464) and P.9333 (15.11), COGG-902 (3.16) and LGG-444 (8.68). Negative gca effects were showed by KM-1285 (-15.05), MG-368 (-24.13) and IIPRM-3 (-13.26) of which only MG-368 was significant. Among hybrids P.9333 x COGG-902 (72.12) showed significant positive sca effects and P.9333 x KM-1285 (-20.20) showed significant negative sca effects.

In the non-inoculated condition combining ability analysis for number of nodules at 50 per cent flowering showed significant differences among parents and hybrids. NDM-88-14 (1.73) showed significant positive gca effects and KM-1285 (1.30), MG-368 (-1.21) showed significant negative gca effects. Among hybrids NDM-88-14 x LGG-444 (4.769) showed significant positive sca effects and significant negative sca effects were shown by hybrid KM-1285 x COGG-902 (-1.78).

In the case of absolute control combining ability analysis for number of nodules at 50 per cent flowering exhibited significant variances among the parents and hybrids. Significant positive sca effects were shown by NDM-88-14 (2.81) and significant negative gca effects were shown by MG-368 (-1.661) among parents. Hybrid P.9333 x NDM-88-14 (4.38) showed significant positive sca effects and MG-368 x COGG-902 (-1.68), KM-1285 x LGG-444 (-1.58) showed significant negative sca effects.

4.5.2.2. Weight of nodules at 50 per cent flowering

Combining ability analysis for weight of nodules at 50 per cent flowering in the inoculated condition showed significant differences among parents and hybrids. Significant positive gca effects were shown by NDM-88-14 (57.75) and significant negative gca effects were shown by MG-368 (-46.02) among parents. Among hybrids significant positive sca effects were shown by P.9333 x COGG-902 (118.03) and significant negative sca effects were shown by IIPRM-3 x LGG-444 (-29.42).

Among the non-inoculated population analysis of variance for weight of nodules at 50 per cent flowering exhibited significant differences among parents and hybrids. NDM-88-14 (1.06) showed significant positive gca effects and MG-368 (-0.73) showed significant negative gca effects among parents. Among hybrids significant positive sca effects were shown by hybrids P.9333 x NDM-88-14 (2.06) and significant negative sca effects were shown by KM-1285 x LGG-444 (-0.83).

Both parents and hybrids showed significant variances for weight of nodules at 50 per cent flowering in the absolute control. Among parents significant positive gca effects were shown by NDM-88-14 (1.01) and significant negative gca effects were shown by MG-368 (-0.69). Among hybrids significant positive sca effects were shown by P.9333 x NDM-88-14 (2.20) and significant negative sca effects were shown by KM-1285 x LGG-444 (-0.93).

4.5.2.3. Nitrogen content in plants at 50 per cent flowering

Analysis of variance of nitrogen content in plants at 50 per cent flowering exhibited significant differences among parents and hybrids in the inoculated condition. Significant positive gca effects were shown by NDM-88-14 (0.50) and significant negative gca effects were shown by

KM-1285 (-0.39) among parents. Among hybrids significant positive sca effects were shown by P.9333 x NDM-88-14 (1.81) and significant negative sca effects were shown by KM-1285 x LGG-444 (-1.06).

In the non-inoculated condition also nitrogen content at 50 per cent flowering varied significantly among parents and hybrids. Significant positive gca effects were shown by NDM-88-14 (0.33) and significant negative gca effects were shown by KM-1285 (-0.37) among parents. Among hybrids significant positive sca effects were shown by hybrids P.9333 x NDM-88-14 (0.99) and significant negative sca effects were shown by KM-1285 x LGG-444 (-0.84).

Combining ability analysis for nitrogen content at 50 per cent flowering exhibited significant variances among the parents and hybrids in the absolute control. Significant positive gca effects were shown by NDM-88-14 (0.34) and significant negative gca effects were shown by KM-1285 (-0.32) among parents. Among hybrids significant positive sca effects were shown by P.9333 x NDM-88-14 (0.85) and negative sca effects were shown by KM-1285 x NDM-88-14 (-0.82).

4.5.2.4. Dry weight of plants at 50 per cent flowering

Variance for dry weight of plants at 50 per cent flowering was significant for both parents and hybrids in the inoculated condition. Significant positive gca effects were shown by P.9333 (1.50) and NDM-88-14 (1.49) and significant negative gca effects were shown by COGG-

902 (-1.26) among parents. Significant positive sca effects were observed in KM-1285 x IIPRM-3 (2.58) and P.9333 x KM-1285 (2.54) and significant negative sca effects were recorded by COGG-902 x LGG-444 (-1.57).

In the non-inoculated condition analysis of variance for dry weight of plants at 50 per cent flowering showed that the variances due to parents and hybrids were significant. Among parents significant positive gca effects were shown by NDM-88-14 (1.27) and significant negative gca effects were shown by KM-1285 (-1.25). Among hybrids significant positive sca effects were observed in P.9333 x KM-1285 (2.697) and significant negative sca effects were recorded by KM-1285 x LGG-444 (-1.252).

Combining ability analysis for dry weight of plants at 50 per cent flowering exhibited significant variances among parents and hybrids in the absolute control. Among parents significant positive gca effects were observed in NDM-88-14 (1.34) and significant negative gca effects were shown by KM-1285 (-1.28). Among hybrids significant positive sca effects were recorded by P.9333 x KM-1285 (2.81) and KM-1285 x IIPRM-3 (2.87) and significant negative sca effects were shown by KM-1285 x LGG-444 (-1.35).

4.5.3. Genetic components of variance

The genetic components of variance (additive variance (σ^2A) and dominance variance (σ^2D) were estimated and presented in Table 15.

Table 15. Estimate of genetic components of variance for various nitrogen fixation traits in pot culture experiments

Sl. No.	Characters	Additive variance σ^2A	Dominance variance σ^2D	σ^2A/σ^2D
	Inoculated			
1.	Number of nodules at 50% flowering	738.83	1256.12	0.588
2.	Weight of nodules at 50% flowering	3732.56	4405.1551	0.847
3.	Nitrogen content at 50% flowering	-0.027	0.787	-0.017
4.	Dry weight of plants at 50% flowering	3.374	5.639	0.598
	Non inoculated			
1.	Number of nodules at 50% flowering	2.5	5.96	0.419
2.	Weight of nodules at 50% flowering	1.27	0.756	1.69
3.	Nitrogen content at 50% flowering	0.052	0.314	0.168
4.	Dry weight of plants at 50% flowering	2.10	4.93	0.425
	Absolute control			
1.	Number of nodules at 50% flowering	8.47	4.05	2.09
2.	Weight of nodules at 50% flowering	1.17	0.659	1.775
3.	Nitrogen content at 50% flowering	0.032	0.286	0.112
4.	Dry weight of plants at 50% flowering	1.55	5.67	0.27

4.5.3.1. Inoculated population

The dominance variance was greater than additive variance for all characters in inoculated population for different nitrogen fixation traits.

The additive to dominance ratio ranged from 0.84 for weight of nodules at 50 per cent flowering to 0.017 for nitrogen content at 50% flowering. The ratio for number of nodules at 50 per cent flowering was 0.588 and for dry weight of the plants it was 0.598.

4.5.3.2. Non-inoculated population

The additive to dominance ratio ranged from 1.69 for weight of nodules at 50 per cent flowering to 0.168 for nitrogen content at 50% flowering. The ratio estimated for number of nodules at 50 per cent flowering was 0.419 and for dry weight of the plants it was 0.425.

4.5.3.3. Absolute control

Additive to dominance ratio ranged from 2.09 for number of nodules at 50 per cent flowering to 0.1112 for nitrogen content at 50 per cent flowering. The ratio for weight of nodules at 50 per cent flowering was 1.77 and for dry weight of plants at 50 per cent flowering it was 0.27.

DISCUSSION

5. DISCUSSION

The research programme was carried out at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani as an initial step for developing high yielding greengram varieties with reasonably good biological nitrogen fixing capacity. Knowledge of combining ability of parents and crosses is essential for achieving this objective. Here, four high yielding varieties of greengram and three varieties having high nitrogen fixation capacity were selected and crossed in a diallel fashion excluding the reciprocals. Estimate of percentage of heterosis will give a reliable information on best performing hybrid combination that can be selected for further utilisation.

5.1. Mean performance

In earlier days, parents for hybridization were selected based on their mean performance. But now a days, selection of parents depends on combining ability estimates. However, based on mean performance also potential and desirable genotypes can be selected for crop improvement.

The parent IIPRM-3 was significantly superior for length of primary root at 50% flowering. Among the twenty one hybrids P.9333 x IIPRM-3 displayed better performance and was on par with P.9333 x NDM-88-14.

Highly significant and wide variation was observed for number of secondary roots at maturity. For this trait NDM-88-14 was significantly superior among parents. The hybrid P.9333 x IIPRM-3 had maximum number of secondary roots at maturity, which was on par with NDM-88-14 x IIPRM-3 and P.9333 x NDM-88-14.

In the case of shoot / root ratio NDM-88-14 displayed better performance among the parents. P.9333 x NDM-88-14 which was significantly superior for length of primary root and number of secondary roots was also found to be significantly superior for shoot/root ratio.

The parent NDM-88-14 was significantly superior to all other parents for weight of nodules at 50% flowering. The best hybrid combination was NDM-88-14 x LGG-444 which was on par with P.9333 x COGG-902, P.9333 x NDM-88-14 and COGG-902 x LGG-444.

For dry weight of plants also NDM-88-14 was significantly superior to all other parents. The hybrid MG-368 x IIPRM-3 recorded maximum dry weight of plants at maturity and was on par with two other hybrids P.9333 x MG-368 and P.9333 x IIPRM-3.

With respect to nitrogen content at 50% flowering NDM-88-14 displayed better performance among parents and P.9333 x NDM-88-14 was significantly superior to all other hybrids and parents taken for hybridization.

The hybrid P.9333 x NDM-88-14 which showed significant differences for length of primary root, shoot/root ratio, weight of nodules at 50 % flowering and nitrogen content at 50% flowering was also found to have the maximum nitrogen content at maturity. The parent NDM-88-14 was significantly superior to all other parents, but significantly inferior to the best hybrid combination P.9333 x NDM-88-14.

As far as plant height is concerned P.9333 was significantly superior to all other parents. Among hybrids P.9333 x IIPRM-3 displayed better performance.

Number of clusters per plant was highest in IIPRM-3. Out of the twenty one hybrid combinations P.9333 x IIPRM-3 was significantly superior for number of clusters per plant.

For number of pods per plant IIPRM-3 displayed best performance among parents. Among hybrids NDM-88-14 x LGG-444 was significantly superior for number of pods per plant.

The parent KM-1285 was significantly superior for number of seeds per pod. Among hybrids NDM-88-14 x LGG-444 displayed best performance.

Hundred grain weight was the highest in P.9333, among parents. Out of the twenty one hybrids P.9333 x NDM-88-14 was significantly superior for hundred grain weight.

Among the parents grain yield per plant was maximum in IIPRM-3. Among hybrids P.9333 x COGG-902 was significantly superior for grain yield per plant.

For harvest index P.9333 was significantly superior among parents. P.9333 x NDM-88-14 displayed the best performance among hybrids.

Considering the nitrogen fixation traits NDM-88-14 was the best performer for weight of nodules and nitrogen content and dry weight of the plants. P.9333 x NDM-88-14 displayed better performance for nitrogen content. Therefore these can be selected for biological nitrogen fixation traits and can be utilised for crop improvement. Main yield contributing traits like number of clusters per plant, number of pods per plant, grain yield per plant were highest for IIPRM-3. For hundred grain weight and harvest index P.9333 displayed better performance and among hybrids P.9333 x IIPRM-3 displayed better performance for grain yield. These can be utilised as potential genotypes for high yield and yield contributing traits.

5.2. Combining ability

Length of primary root at 50% flowering

For length of primary root at 50% flowering mean squares due to general and specific combining abilities were significant indicating the importance of both additive and non-additive genetic components for expression of this traits. However, the ratio σ^2A to σ^2D was less than unity indicating the predominance of non-additive gene action. This is in agreement with findings of Thomas (1996) in blackgram.

Among parents P.9333 showed significant positive gca effects and MG-368, KM-1285 and COGG-902 exhibited significant negative gca effects. Hybrid combinations KM-1285 x LGG-444, KM-1285 x IIPRM-

3, KM-1285 x MG-368, NDM-88-14 x MG-368, P.9333 x IIPRM-3 and P.9333 x MG-368 showed significant positive sca effects and NDM-88-14 x IIPRM-3 recorded negative gca effects. Both.the parents of MG-368 x LGG-444, KM-1285 x MG-368 were negative general combiners. Positive sca effects of KM-1285 x IIPRM-3, NDM-88-14 x MG-368, P.9333 x MG-368 were contributed by negative and positive general combiners. Both the parents of P.9333 x IIPRM-3 were positive general combiners. Since the character is predominantly under the control of non-additive gene action combination breeding is a viable preposition.

5.2.2. Number of secondary roots at maturity

Number of secondary roots at maturity had significant mean squares due to gca and sca suggesting the involvement of both additive and non additive gene action. The ratio of σ^2A to σ^2D was more than unity indicating the predominance of additive gene action. Similar results were also reported by Thomas (1996) in blackgram.

The estimate of combining ability revealed that the parents NDM-88-14 and IIPRM-3 had significant positive gca effects. On the other hand MG-368 had significant negative gca effect. Significantly high sca effects were observed in KM-1285 x IIPRM-3, IIPRM-3 x LGG-444, P.9333 x KM-1285, KM-1285 x COGG-902, KM-1285 x MG-368 and NDM-88-14 x IIPRM-3. Significant negative sca effects were observed in IIPRM-3 x COGG-902. NDM-88-14 x IIPRM-3 involved both negative general combiners. Positive sca effects of P.9333 x IIPRM-3 were contributed by positive general combiners. Positive sca effects of rest of the hybrids and negative sca effects of IIPRM-3 x COGG-902 is due to positive and negative general combiners. Since, this character is under the control of additive gene action, selection will be helpful for improvement.

5.2.3. Shoot / root ratio

A significant mean squares due to gca and sca effects were recorded for shoot root ratio suggesting the involvement of both additive and non additive gene action in the expression of this character. The ratio of additive to dominance variance was less than unity which implies the predominance of non-additive gene action. This is in agreement with results reported earlier by Sreekumar (1995) in greengram, Thomas (1996) in blackgram and Varghese (1997) in blackgram.

Among the parents P-9333 exhibited significant positive sca effects while COGG-902 showed significant negative gca effect. Out of all hybrids significant positive sca effects were shown by MG-368 x LGG-444 and KM-1285 x IIPRM-3. Significant negative sca effects were observed in IIPRM-3 x LGG-444 and COGG-902. MG-368 x LGG-444, KM-1285 x IIPRM-3 and IIPRM-3 x LGG-444 had parents with negative gca effects. Parents of NDM-88-14 x COGG-902 had positive and negative gca effects. Since shoot root ratio is under the control of non-additive gene action it can be utilized through combination breeding.

5.2.4. Weight of nodules at 50% flowering

Mean squares due to gca and sca effects were significant for weight of nodules at 50% flowering, suggesting the importance of additive and non-additive gene action for the expression of this trait. The ratio of σ^2A to σ^2D was more than unity indicating the predominance of additive gene action which is in agreement with Miller *et al.* (1986) in cowpea. Contrary to the present result Sreekumar (1995) and Thomas (1996) reported the predominance of non-additive gene action for weight of nodules. However, Singh and Murthy (1988) observed the significance of both gca and sca variance for nodule weight of greengram.

The parent NDM-88-14 exhibited significant positive gca effects while MG-368 and KM-1285 showed significant negative gca effects. Significant positive sca effects were recorded by MG-368 x LGG-444, IIPRM-3 x COGG-902, P.9333 x COGG-902. These three hybrids had parents with positive and negative gca effects. Significant negative sca effects were shown by IIPRM-3 x LGG-444 this hybrid also had parents with positive and negative gca effects. Since, this character is under the control of additive gene action, selection will be helpful for improvement.

5.2.5. Dry weight of plants at maturity

Dry weight of plants at maturity recorded significant mean squares due to gca and sca indicating that the additive and non-additive genetic components were important for the expression of this trait. This finding is in agreement with the results of Singh and Murthy (1988) in greengram. But the ratio of σ^2A to σ^2D was less than unity indicating the predominance of non-additive gene action. This result is in agreement with Miller *et al.* (1986) and Sreekumar (1995) in cowpea. Contrary to this result additive gene action was reported by Pinchbeck *et al.* (1980) in Spanish clover and Thomas (1996) in blackgram.

Significant positive gca effects were shown by the parents P.9333, NDM-88-14 and IIPRM-3. Significant negative gca effects were shown by KM-1285, MG-368, COGG-902 and LGG-444. Significant positive sca effects were shown by P.9333 x KM-1285, P.9333 x MG-368, P.9333 x COGG-902, P.9333 x LGG-444, KM-1285 x NDM-88-14, KM-1285 x IIPRM-3, KM-1285 x COGG-902, MG-368 x LGG-444, IIPRM-3 x COGG-902, IIPRM-3 x LGG-444, KM-1285 x COGG-902, MG-368 x COGG-902 and MG-368 x LGG-444 had parents with negative gca effects but all the other hybrids exhibiting significant positive sca effects had parents with negative and positive gca effects. Significant negative sca effects were shown by P.9333 x NDM-88-14, KM-1285 x LGG-444, NDM-88-14 x MG-368 and COGG-902 x LGG-444. P.9333 x NDM-88-14 had both parents with positive gca effects, NDM-88-14 x MG-368 involved positive x negative general combiners but, the other two had parents with negative and gca effects. Dry weight of the plants is under the control of non-additive gene action and therefore improvement is possible through combination breeding.

5.2.6. Nitrogen content at 50% flowering

For nitrogen content at 50% flowering sca effects were significant indicating the predominance and non-additive gene action. However, Sreekumar (1995) reported the significance of both gca and sca variance in cowpea. The ratio of σ^2A to σ^2D was less than unity indicating the predominance of non-additive gene action which is in agreement with the report of Sreekumar (1995) in cowpea and Thomas (1996) in blackgram. Hely (1972) in *Trifolium ambiguum*, Tan (1981) in alfafa, Smith *et al.*

(1982) in crimson clover and Singh and Murthy (1988) in greengram reported the role of additive and non-additive genetic components in the expression of nitrogen content. Contrary to this result additive gene action was reported by Pinchbeck *et al.* (1980) in spanish clover.

Among parents positive gca effects were shown by P.9333, NDM-88-14 and MG-368 while negative gca effects were observed in KM-1285, IIPRM-3, COGG-902 and LGG-444. Significant positive sca effects were recorded by the hybrid P.9333 x NDM-88-14 which had parents with positive gca effects. Significant negative sca effects were shown by the hybrids P.9333 x MG-368, P.9333 x IIPRM-3 and KM-1285 x NDM-88-14 these three hybrids involved positive and negative general combiners. Since this triat is under the control of non additive gene action improvement can be made by combination breeding.

5.2.7. Nitrogen content at maturity

Mean squares due to gca and sca were significant suggesting that both additive and non-additive gene action were important for expression of this trait. The ratio of σ^2A to σ^2D was less than unity indicating the predominance of non-additive gene action. Thomas (1996) reported the importance of both additive and non-additive gene action for nitrogen content at maturity in blackgram.

The parents P.9333 and NDM-88-14 exhibited significant positive gca effects while KM-1285, MG-368 and IIPRM-3 showed significant negative gca effects. The gca effects were same in COGG-902 and LGG-

444. Significant positive sca effects were shown by P.9333 x KM-1285, P.9333 x NDM-88-14, MG-368 x IIPRM-3 and significant negative sca effects were shown by hybrids KM-1285 x NDM-88-14, NDM-88-14 x COGG-902 and P.9333 x LGG-444. P.9333 x NDM-88-14 and P.9333 x LGG-444 had both parents with positive gca effects and P.9333 x KM-1285 and KM-1285 x NDM-88-14 involved negative and positive general combiners but MG-368 x IIPRM-3 had both parents with negative gca effects.

5.2.8. Plant height

Plant height had significant mean squares due to gca and sca effects indicating the predominance of both additive and non-additive gene action. But the ratio of σ^2A to σ^2D was less unity suggesting the predominance of non-additive gene action. Similar results were observed by Rathinaswami (1990) Thomas (1996), Varghese (1997) in blackgram and Jayarani (1996) in cowpea. On the other hand Sagar and Chandra (1977), Pillai (1980) and Sood and Garten (1991) in blackgram reported additive gene action for this character.

Significant positive gca effects were shown by P.9333 and IIPRM-3 while significant negative gca effects were observed in KM-1285, NDM-88-14 and MG-368. The hybrids P.9333 x KM-1285, P.9333 x IIPRM-3, MG-368 x COGG-902, IIPRM-3 x LGG-444 and COGG-902 x LGG-444 exhibited significant positive sca effects while significant negative sca effects were observed in P.9333 x COGG-902 and IIPRM-3 x COGG-902, P.9333 x IIPRM-3 had both parents with positive gca effects but all the other hybrids which showed significant positive sca effects had positive negative gca effects. But both the hybrids showed significant negative sca effects had positive general combiners. Since, non-additive gene action controls this character combination breeding can be adopted for improvement.

5.2.9. Number of clusters per plant

Significant mean squares due to gca and sca were observed for number of clusters per plant indicating the predominance of both additive and non-additive gene action. Naidu and Satyanarayana (1993) also reported the importance of both additive and non-additive gene action for this trait in greengram. The ratio of σ^2A to σ^2D was less than unity suggesting the predominant role of non-additive gene action for the expression of this trait. Contrary to this result Wilson *et al.* (1985) reported the predominance of additive gene action in greengram.

The parents P.9333 and IIPRM-3 exhibited significant positive gca effects while KM-1285, NDM-88-14, COGG-902, LGG-444 showed significant negative gca effects. The hybrid P.9333 x IIPRM-3 showed significant positive sca effects which had parents with positive gca effects. Significant negative sca effects were shown by P.9333 x LGG-444 and NDM-88-14 x IIPRM-3 both had parents with positive and negative gca effects. Number of clusters per plant is under the control of non-additive gene action and therefore improvement is possible through combination breeding.

5.2.10. Number of pods per plant

Number of pods per plant had significant mean squares due to gca and sca effects indicating that both additive and non-additive genetic components were important for the expression of this trait. However, the ratio of σ^2A to σ^2D was less than unity suggesting the predominance of non-additive gene action for the expression of this trait. This result is in agreement with Deshmukh and Manjare (1980) Chowdhury (1986) in mungbean, Chauhan and Joshi (1981) Thiyagarajan (1990) in cowpea, Kaliya *et al.* (1991), Thomas (1996), Varghese (1997) in blackgram, Patel *et al.* (1987) in pigeonpea. Contrary to this result additive gene action was reported by Dubey and Lal (1983) in pea, Venkateswaralu and Singh (1982a) and Singh *et al.* (1983) in pigeonpea and Wilson *et al.* (1985) in greengram. Significant sca variance for the trait was observed by Kaliya *et al.* (1991) in blackgram.

Significant positive gca effects were shown by P.9333 and NDM-88-14 while KM-1285, COGG-902 exhibited significant negative gca effects. The hybrid NDM-88-14 x LGG-444 showed significant positive sca effects, which had parents with positive and negative sca effects. Significantly negative sca effects were shown by P-9333 x KM-1285 and NDM-88-14 x COGG-902 both had parents with positive and negative gca effects. This character is found to be under the control of non-additive gene action and therefore improvement is possible through combination breeding.

5.2.11. Number of seeds per pod

Mean squares due to gca and sca were significant for number of seeds per pod indicating the importance of both additive and non-additive gene action for the trait. The ratio of σ^2A to σ^2D was very small suggesting the predominance of non-additive gene action for expression of the trait. This result is in agreement with Deshmukh and Manjare (1980) in mungbean. Thomas (1996) and Varghese (1997) in blackgram Pande *et al.* (1979) in bengalgram, Dhillon and Chahal (1980) in gardenpea, Yadavendra and Sudhirkumar (1987) in chickpea. Contrary to this result additive gene action was reported by Chauhan and Joshi (1981), Thiyagarajan (1992), Rajatha (1992) and Anilkumar (1993) in cowpea, Wilson *et al.* (1985), Saxena and Sharma (1989) and Sharma (1992) in greengram, Malhotra (1983) in blackgram, Venkateswaralu and Singh (1982b) in pea and Onkar Singh and Paroda (1989) in chickpea. Kaliya (1991) in blackgram found significant sca variance for number of seeds per pod.

Estimate of combining ability revealed that parents KM-1285, IIPRM-3, NDM-88-14 and LGG-444 showed significant positive gca effects while P.9333, COGG-902 exhibited significant negative gca effects. Significant positive sca effects were observed in hybrids P.9333 x MG-368, P.9333 x LGG-444 and NDM-88-14 x LGG-444 among them P.9333 x MG-368 had parents with negative gca effects while P.9333 x LGG-444 had parents with negative and positive gca effects. Both the parents of the cross NDM-88-14 x LGG-444 had positive gca effects. Significant negative sca effects were shown by KM-1285 x COGG-902, NDM-88-14 x MG-368 and COGG-902 x LGG-444. All the three had parents with positive and negative gca effects. Since number of seeds per pod is predominantly under the control of non-additive gene action further improvement can be done through combination breeding.

5.2.12. Hundred grain weight

The mean squares due to gca and sca were significant indicating the importance of both additive and non-additive gene action. The ratio of σ^2A to σ^2D was less than unity suggesting the predominant role of non-additive gene action. This result is in agreement with Thiyagarajan *et al.* (1990), Sreekumar (1995) and Jayarani (1996) in cowpea, Wilson *et al.* (1985) and Sharma (1992) in greengram, Malhotra (1983) and Varghese (1997) in blackgram. Significance of sca variance alone was reported by Sreekumar (1993) in greengram indicating non-additive gene action. Contrary to this result Singh *et al.* (1985), Pande *et al.* (1979) in bengalgram, Chauhan and Joshi (1981), Anilkumar (1993) and Thiyagarajan (1992) in cowpea, Venkateswaralu and Singh (1982a) in pigeonpea reported the predominance of additive gene action for hundred grain weight.

Significant positive gca effects were shown by the parent P.9333 and significant negative gca effect were observed in LGG-444. The hybrids KM-1285 x COGG-902, IIPRM-3 x COGG-902 and IIPRM-3 x LGG-444 exhibited positive sca effects and all of them had parents with positive and negative gca effects. Significant negative sca effects were shown by P.9333 x KM-1285 and KM-1285 x IIPRM-3 and both of them had parents with positive gca effects.

5.2.13. Grain yield per plant

Significant mean squares due to gca and sca were observed for grain yield per plant indicating the predominance of both additive and non-additive gene action. The ratio of σ^2A to σ^2D was less than unity suggesting the predominance of non-additive gene action. Similar observations were made by several plant breeders. Deshmukh and Manjare (1980) and Sreekumar (1993) in greengram, Sagar and Chandra (1977), Singh *et al.* (1987) and Rajarathinam and Rathnaswamy (1990) in blackgram, Thiyagarajan *et al.* (1990), Anilkumar (1992) and Sreekumar (1995) in cowpea. However, additive gene action contradicting the present result was reported by Malhotra (1983) in blackgram, Saxena and Sharma (1989) in greengram, Chauhan and Joshi (1981) in cowpea. Kaliya *et al.* (1991) observed significant sca variance for this trait in blackgram.

Combining ability analysis revealed significant positive gca effects in P.9333 and negative gca effect in LGG-444. Significant positive sca effects were shown by P.9333 x COGG-902 while significant negative sca effects were shown by the hybrid MG-368 x COGG-902 both of them had parents with positive and negative gca effects. For improvement of grain yield combination breeding can be suggested due to non-additive gene action.

5.2.14. Harvest index

The mean squares due to sca was significant indicating the importance of non-additive gene action for this trait. The ratio of σ^2A to σ^2D was also less than unity indicating the predominance of non-additive gene action. Non-additive gene action for harvest index was reported by Sreekumar (1993) in greengram, Singh *et al.* (1987) and Varghese (1997) in blackgram, Katiyar *et al.* (1987) in gardenpea and Salimath and Bahl (1989) in chickpea. Significance of gca and sca effects were observed by Singh *et al.* (1987b) in gardenpea, Patel *et al.* (1988) in mungbean, Hazarika *et al.* (1988) in pegionpea. Additive gene action was reported by Pande *et al.* (1979) in bengalgram, Sharma and Nishisharma (1988) in soyabean, Saxena *et al.* (1989) in pigeonpea.

Positive gca effects were shown by the parents P.9333 and NDM-88-14 while negative gca effects were shown by KM-1285, MG-368, IIPRM-3, COGG-902 and LGG-444. Significant positive sca effects were shown by P.9333 x NDM-88-14, MG-368 x LGG-444, IIPRM-3 x COGG-902 among them P.9333 x NDM-88-14 had parents with positive gca effects. Significant negative sca effects were shown by P.9333 x IIPRM-3, P.9333 x COGG-902, KM-1285 x NDM-88-14 all the three had parents with positive and negative gca effects, sca effects of P.9333 x COGG-902 and KM-1285 x NDM-88-14 were equal in magnitude. Since, the character is predominantly under the control of non-additive gene action combination breeding can be utilized for improvement of this trait.

For important nitrogen fixation traits like nodule weight and nitrogen content at maturity NDM-88-14 was the best general combiner. For nitrogen content best specific combiner was P.9333 x NDM-88-14. Considering the important yield components viz., number of clusters per plant, hundred grain weight and grain yield per plant P.9333 was the best general combiner. Best specific combiners were P.9333 x IIPRM-3, IIPRM-3 x LGG-444 and P.9333 x COGG-902. These genotypes were identified as potential ones for further utilization in crop improvement.

5.3. Heterosis

The percentage of heterosis estimated with respect to different characters showed wide difference among the hybrid combinations. Some of the hybrids showed significant positive heterobeltiosis whereas some of the hybrids expressed significant negative heterobeltiosis for different traits.

All the hybrid combinations were found to have better performance in comparison with better parent for length of primary root at 50% flowering. All the hybrids except one showed significant positive heterobeltiosis for this trait. The maximum positive heterobeltiosis was exhibited by the hybrid KM-1285 x MG-368. The same hybrid also recorded the highest heterobeltiosis for number of secondary roots.

All the hybrids had better shoot / root ratio than their better parents as expressed by significant positive heterobeltiosis in twenty hybrids. Only in one hybrid the heterobeltiosis was non-significant. The maximum shoot/ root ratio was expressed by the hybrid MG-368 x LGG-444.

Heterobeltiosis for weight of nodules at 50 per cent flowering was manifested in both directions. The highest positive heterobeltios was expressed in the hybrid P.9333 x COGG-902. Sreekumar (1995) reported positive heterosis for this trait in cowpea.

The hybrid MG-368 x IIPRM-3 displayed maximum positive heterobeltiosis. Positive heterosis for dry weight was also reported earlier by Sreekumar (1995) in cowpea and Thomas (1996) in blackgram.

For nitrogen content at 50 per cent flowering P.9333 x NDM-88-14 expressed highest positive heterobeltiosis. Sreekumar (1995) in cowpea and Thomas (1996) in blackgram also observed heterobeltiosis for this character.

The hybrids P.9333 x KM-1285 exhibited maximum heterobeltiosis for nitrogen content at maturity. For nitrogen content at 50% flowering and at maturity among the twenty one hybrids P.9333 x NDM-88-14 and P.9333 x KM-1285 showed significant positive heterobeltiosis.

In the case of plant height P.9333 x IIPRM-3 exhibited maximum positive heterobeltiosis. Sagar and Chadra (1977) and Pillai (1980) in blackgram, Singh and Jain (1970) in greengram were reported heterosis for plant height.

The hybrid COGG-902 x LGG-444 exhibited highest positive heterobeltiosis for number of clusters per plant.

For number of pods per plant highest positive heterobeltiosis was exhibited by P.9333 x LGG-444. Patel *et al.* (1992), Wilson *et al.* (1985) in greengram and Sagar and Chandra (1977) and Pillai (1980) in blackgram also observed heterosis over better parent for this trait.

Highest positive heterobeltiosis was recorded by NDM-88-14 x LGG-444 for number of seeds per pod Swindell and Poehlman (1976) in greengram and Singh and Jain (1972) in cowpea also reported heterosis for this trait.

The hybrid IIPRM-3 x COGG-902 exhibited highest positive heterobeltiosis for hundred grain weight. Singh and Singh (1993) observed heterosis over better parent for hundred grain weight in greengram. Pillai (1980) in blackgram found heterosis over better parent for hundred grain weight.

For grain yield per plant highest positive heterobeltiosis was displayed by the cross P.9333 x COGG-902. In greengram heterosis over better parent was observed by Natarajan (1989) and Patil (1992). Sagar and Chandra (1977) reported a high degree of heterosis over better parent for this character in blackgram. Sewant *et al.* (1995) and Sreekumar (1995) in cowpea also found heterosis for grain yield per plant.

In the case of harvest index highest positive heterobeltiosis was exhibited by MG-368 x LGG-444. Natarajan (1989) reported negative heterosis over better parent for harvest index in greengram.

5.4. Pot culture experiment

An analysis of the results of the pot culture experiment revealed significant differences among hybrids and parents for different nitrogen fixation traits.

5.4.1. Mean performance

The number of nodules at 50% flowering showed wide variation among the parents and hybrids. Compared to the non-inoculated and absolute control population Rhizobium inoculated plants recorded more number of nodules in all the parents and hybrid combinations. Among the seven parents used in the hybridization programme NDM-88-14 was the best parent to produce more number of nodules. The hybrid P.9333 x NDM-88-14 was significantly superior and produced maximum number of nodules in the inoculated population.

The same parent NDM-88-14 and same hybrid P.9333 x NDM-88-14 were also found to be the best parent and hybrid respectively in the non-inoculated and absolute control population for the number of nodules at 50% flowering.

In the case of weight of nodules at 50% flowering the same parent and hybrid was found to be best in inoculated, non-inoculated and absolute control population.

For nitrogen content at 50% flowering, also the same trend was observed, although there were differences in the mean values among inoculated, non-inoculated, absolute control population. In all the three situations the same parent (NDM-88-14) and hybrid (P.9333 x NDM-88-14) recorded superior performance.

For dry weight of plants at 50% flowering also the parent NDM-88-14 and hybrid P.9333 x NDM-88-14 were again found to be significantly superior to all other parents and hybrids respectively in the inoculated, non-inoculated and absolute control population.

The parent NDM-88-14 showed outstanding performance, for all biological nitrogen fixation traits studied in all the three situations. The hybrid P.9333 x NDM-88-14 was found to be the best hybrid combination. This hybrid showed stable performance under inoculated non-inoculated and absolute control conditions.

5.4.2. Combining ability and gene action

5.4.2.1. Number of nodules at 50 per cent flowering

Significant mean squares due to gca and sca under inoculated, non-inoculated and absolute control indicating the predominance of additive gene action while in the absolute control the σ^2A to σ^2D was greater than unity suggesting the predominant role of additive gene action.

The estimate of combining ability revealed that NDM-88-14, P.9333, COGG-902 and LGG-444 had significant positive gca effects while KM-1285, MG-368 and IIPRM-3 showed negative gca effects. Significant positive sca effects were shown by P.9333 x COGG-902 and significant negative sca effects were shown by P.9333 x KM-1285. Both the parents involved in the cross P.9333 x COGG-902 were good general combiners.

Among the non-inoculated population NDM-88-14 had significant positive gca effects and KM-1285 and MG-368 had significant negative gca effects. The hybrids NDM-88-14 x LGG-444 recorded significant positive sca effects while KM-1285 x COGG-902 had significant negative sca effects.

5.4.2.2. Weight of nodules at 50 per cent flowering

Significant mean squares due to gca and sca were recorded for weight of nodules at 50 per cent flowering under inoculated, non-inoculated and absolute control, suggesting the predominance of both additive and non-additive gene action. In the case of inoculated population the ratio of σ^2A to σ^2D found to be less than unity indicating the predominance of non-additive gene action. But in the other two situations the ratio of σ^2A to σ^2D was greater than unity suggesting the importance of additive gene action.

Under all the three combinations significant positive gca effects were shown by NDM-88-14 and significant negative sca effects were exhibited by MG-368. In the inoculated condition significant positive sca effects were recorded by P.9333 x COGG-902. Both the parents involved in the cross had good gca. But in the non-inoculated and absolute control P.9333 x NDM-88-14 showed significant positive sca effects. In this case also both the parents involved in the cross were good general combiners.

In the inoculated condition significant negative sca effects were shown by IIPRM-3 x LGG-444. In the other two cases significant negative sca effects were exhibited by KM-1285 x LGG-444.

5.4.2.3. Nitrogen content at 50 per cent flowering

Nitrogen content at 50 per cent flowering had significant mean squares due to gca and sca indicating the predominance of additive and non-additive gene action under all the three situations. The ratio of σ^2A to σ^2D was less than unity indicating the predominance of non-additive gene action.

Under all the three conditions NDM-88-14 had significant positive gca effects and KM-1285 had significant negative gca effects and the hybrid P.9333 x NDM-88-14 recorded significant positive sca effects. KM-1285 x LGG-444 exhibited significant negative sca effects under inoculated and non-inoculated conditions. But in the case of absolute control KM-1285 x NDM-88-14 recorded significant positive sca effects. KM-1285 x LGG-444 exhibited significant negative sca effects under inoculated and non-inoculated conditions. But in the case of absolute control KM-1285 x NDM-88-14 recorded significant negative sca effects.

5.4.2.4. Dry weight of plants at 50 per cent flowering

Mean squares due to gca and sca were significant for dry weight of plants at 50 per cent flowering under inoculated, non-inoculated and absolute control. The ratio of σ^2A to σ^2D was less than unity suggesting the predominance of non-additive gene action.

In the case of inoculated population significant positive gca effects were shown by P.9333 and NDM-88-14 and significant negative gca effects were shown by COGG-902. Significant positive sca effects were shown by hybrids KM-1285 x IIPRM-3 and P.9333 x KM-1285 and significant negative sca effects were recorded by COGG-902 x LGG-444.

In the other two conditions NDM-88-14 exhibited significant positive gca effects and KM-1285 exhibited significant negative gca effects. Among the non-inoculated population significant positive sca effects were observed in P.9333 x KM-1285 and significant negative sca effects were recorded by KM-1285 x LGG-444. Both the hybrids had parents with positive and negative gca effects. Under absolute control significant positive sca effects were shown by hybrids P.9333 x KM-1285 and KM-1285 x IIPRM-3 and significant negative sca effects were recorded by KM-1285 x LGG-444.

For important nitrogen fixation traits NDM-88-14 was the best general combiner among the seven parents studied and P.9333 x NDM-88-14 was the best specific combiner.

SUMMARY

6. SUMMARY

Pulses are the major source of dietary protein, Legume-Rhizobium symbiosis play a predominant role in agriculture because they can fix atmospheric nitrogen. The present study was carried out with the objective of assessing the general and specific combining abilities and gene action involved in biological nitrogen fixation traits and yield components in green gram as an initial step for evolving high yielding varieties with good nitrogen fixation capacity. The experiment was carried out in diallel manner at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani, Thiruvananthapuram during 1996-98, using seven varieties of greengram of which four were high yielding and other three with high nitrogen fixing capacity. The experimental material consisted of seven varieties of green gram and their twenty one hybrids. The first experiment was laid out in Randomised Block Design with three replications. The observations were recorded on length of primary roots, number of secondary roots, shoot / root ratio, weight of nodules, nitrogen content at 50% flowering and at maturity, plant height, dry weight of plants, number of pods per plant, number of seeds per pod, hundred grain weight, grain yield per plant and harvest index. Second experiment was laid out in a Completely Randomised Block Design with seven replications. Data on the following biological nitrogen fixation traits viz., number of nodules, weight of nodules, nitrogen content, dry weight of plants and all the observations

were recorded at 50% flowering under inoculated non-inoculated and absolute control.

Analysis of variance indicated highly significant differences among the treatments (genotypes) for all the characters and hence subjected to combining ability analysis. Both gca and sca variances were significant for all the characters except for nitrogen content at 50% flowering and harvest index for these two characters, gca effects were not significant. The ratio of additive to dominance variance indicated that among the fourteen characters number of secondary roots and weight of nodules at 50% flowering showed additive gene action while all the other characters showed predominance of non-additive gene action.

The combining ability analysis showed that NDM-88-14 was the good general combiner with respect to important nitrogen fixation traits like nodule weight and nitrogen content where as P-9333 was the best general combiner with respect to yield and other yield attributes.

Among the twenty one hybrids P-9333 x NDM-88-14 was the best specific combiner for nitrogen content. This hybrid also showed significant positive heterobeltiosis for important nitrogen fixation traits. P-9333 x IIPRM-3, IIPRM-3 x LGG-444 and P-9333 x COGG-902 were the best specific combiners for yield and yield attributes. For length of primary root at 50% flowering and number of secondary roots at maturity KM-1285 x MG-368 showed significant positive sca effects as well as highest value for heterobeltiosis. For shoot root ratio MG-368 x LGG-444 showed highest positive heterobeltiosis as well as high sca effects. For plant height hybrid P-9333 x IIPRM-3 exhibited significantly high sca as well as heterobeltiosis.

The above promising hybrids can be carried forward to evolve high yielding varieties with good nitrogen fixing capacity.

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HETEROSIS AND COMBINING ABILITY IN GREENGRAM (*Vigna radiata* (L.) Wilczek) FOR BIOLOGICAL NITROGEN FIXATION AND YIELD

By

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ABSTRACT OF A THESIS
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ABSTRACT

The research programme was carried out in diallel manner at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani, Thiruvananthapuram during 1996-98. The objective was to assess the general and specific combining abilities and gene action involved in the inheritance of biological nitrogen fixation traits and yield attributes in green gram. The study was conducted in a diallel model in a replicated field experiment using seven varieties of greengram, out of them four were high yielders and three with good nitrogen fixing capacity. Seven parents and twenty one hybrids were also raised in pots with seven replications to study the nodulation efficiency of hybrids and parents.

Analysis of variance revealed highly significant differences among the genotypes for all the characters. Except for nitrogen content at 50% flowering and harvest index, gca effects were not significant, for all the other characters both gca and sca effects were significant. The additive to dominance ratio indicated a preponderance of non-additive gene action for all characters except number of secondary roots and weight of nodules.

The combining ability analysis revealed that NDM-88-14 was the good general combiner with respect to important nitrogen fixation traits where as P-9333 was the best general combiner with respect to yield and

other yield attributes. P-9333 x NDM-88-14 was the best specific combiner for nitrogen content. P-9333 x IIPRM-3, IIPRM-3 x LGG-444 and P-9333 x COGG-902 were the best specific combiners for yield and yield attributes.

Combining the mean performance, sca effects and heterobeltiosis P-9333 x NDM-88-14 was identified as the good hybrid combination for nitrogen fixation traits. Regarding yield, the hybrids P-9333 x IIPRM-3, P-9333 x COGG-902 turned out to be outstanding. Therefore, these hybrids can be utilized for crop improvement programme.