GENETICS OF BRUCHID (*Callosobruchus* sp.) RESISTANCE AND YIELD IN COWPEA

By

JYOTHI. C.

THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Plant Breeding and Genetics
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA

2001

DECLARATION

I hereby declare that the thesis entitled **"Genetics of bruchid (*Callosobruchus* sp.) resistance and yield in Cowpea"** 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, fellowship or other similar title, of any other University or Society.

Vellanikkara
16.11.2001

JYOTHI. C.

CERTIFICATE

Certified that the thesis, entitled **"Genetics of bruchid (*Callosobruchus* sp.) resistance and yield in Cowpea"** is a record of research work done independently by **Miss. Jyothi, C.**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Dr. Kanakamany, M.T.
Chairman, Advisory Committee
Associate Professor (Plant Breeding and Genetics)
Agricultural Research Station
Mannuthy

Vellanikkara
16-11-2001

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Miss. Jyothi, C.**, a candidate for the degree of **Master of Science in Agriculture** with major in **Plant Breeding and Genetics**, agree that the thesis entitled **"Genetics of bruchid (*Callosobruchus* sp.) resistance and yield in Cowpea"** may be submitted by **Miss. Jyothi, C.**, in partial fulfilment of the requirement for the degree.

14/12/01

Dr. Kanakamany, M.T.
(Chairman, Advisory Committee)
Associate Professor (Plant Breeding and Genetics),
Agricultural Research Station
Mannuthy

14/12/01

Dr. K. Pushkaran
(Member, Advisory Committee)
Professor and Head
Department of Plant Breeding and Genetics
College of Horticulture
Kerala Agricultural University
Vellanikkara

14/12/01

Dr. A.M. Ranjith
(Member, Advisory Committee)
Associate Professor
Department of Entomology
College of Horticulture
Kerala Agricultural University
Vellanikkara

14/12/01

Dr. V.V. Radhakrishnan
(Member, Advisory Committee)
Associate Professor
Department of Plant Breeding and Genetics
College of Horticulture
Kerala Agricultural University
Vellanikkara

14/12/01

Dr.S.Jebaraj, Ph.D.,
Professor (PB&G)
Centre for Plant Breeding and Genetics
TNAU
Coimbatore
(EXTERNAL EXAMINER)

ACKNOWLEDGEMENTS

I wish to express my heartfelt thanks to Dr. M.T. Kanakamany, Associate Professor, ARS, Mannuthy and chairman of my advisory committee for her valuable guidance, unstinting support rendered at all stages of the work and keen interest shown during the course of my study and preparation of thesis.

My deep sense of gratitude are due to Dr. V. V. Radhakrishnan, Associate Professor, Department of Plant Breeding and Genetics and member of my advisory committee for his affectionate approach, cordial help and fruitful suggestions during the various stages of my investigations.

I sincerely thank Dr. A. M. Ranjith, Associate Professor, Department of Entomology and member of my advisory committee for offering all possible help during the course of my research work.

I am indebted to Dr. K. Pushkaran, Professor and Head, Department of Plant Breeding and Genetics and member of my advisory committee for the kind co-operation and help rendered during the course of my study.

I extend my thanks to Dr. Achamma Ommen, Dr. Sallykutty Joseph, Dr. Augustine Antony and Sri. S. Krishnan for their precious advice, technical help and whole hearted co-operation shown during the investigation period.

I would like to acknowledge the help extended by each of the farm labourers, especially Santha chechi and Shobana Chechi.

My sincere thanks are also due to my beloved juniors and seniors for their support and help rendered to me.

I am also deeply obliged to Mr.Roy for the various help and assistance.

More personaly I am thankful forever to all my loving friends Ani^2, Chitra, Zahi, Saifu, Sheron, Shylu, Deepa, C.V., Shanu, Veena, Prince, Lasi, Labi, Lini, Smitha, Renu, Deepthi, Filu, Deepa (K.K.), Jayasree, Saira, Swapna, Jayalakshmi and Sindhu for the joyous company and sincere love.

I express my gratitude to Mr.Joy, JMJ Computer Center, Thottapady for the neat typing of my manuscript.

The award of KAU Junior Fellowship is gratefully acknowledged.

I am in dearth of words to express my indebtedness and affection to my amma, achan, monu, shaji and thankachechi for their moral support, love and constant prayers. Above all I submit this small achievement before God Almighty - the power that had driven me all through out.

Jyothi, C.

Dedicated to my
Achan and Amma

CONTENTS

LIST OF TABLES

List of tables contd…

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

Introduction

1. INTRODUCTION

Legumes are an important source of human dietary protein and calories in all the parts of the world. Their high protein and lysine content make them a natural supplement to staple diets of cereals, roots, tubers and fruits.

The genus *Vigna* includes more than 100 species distributed in tropical and subtropical areas. Cowpea [*Vigna unguiculata* (L.) Walp.] originated in Africa, is a common vegetable grown throughout the country, a rich and inexpensive source of vegetable protein. Verdcourt (1970) considered *Vigna unguiculata* to comprise of five species - two wild (*V. dekindtiana* and *V. mensensis*) and three cultivated *V. unguiculata* (L.) Walp., *V. cylindrica* (L.) Verdc. and *V. sesquipedalis* (L.) Verdc.

In an agriculture based country like India, increasing crop productivity is the keystone for overall development. Among the major reasons that have sustained a huge population in our country, the development of varieties with high production potential and the science based agrotechnology that expresses this potential optimally are most significant. Genetic improvement for higher production and better quality of crop plants has been an effective tool, since the advent of scientific agriculture. Two components involved in crop improvement are creation of genetic variability and devising methodologies for combining characteristics of different individuals into a superior cultivar.

The per capita availability of pulses has been reduced from 64 g per day to 40 g against the FAO/WHO recommendation of 80 g per day. India will have to produce 27.8 mt of pulses against the present 13.36 mt per year to attain self sufficiency (Chaudary, 2001).

Efforts are being made to achieve a breakthrough in pulse production so as to overcome the problem of protein deficiency. However, growing more pulses alone is not enough but reducing losses both quantitatively and qualitatively from the attack of pests during storage is also essential. Despite insecticide treatment, pulses suffer a great deal of damage during storage due to insect pests and other microorganisms. Among insect pests, bruchids appear to be the most serious ones and a number of species belonging to genus *Callosobruchus* cause a considerable damage.

According to FAO reports, in India 8.5 per cent of pulses are lost during post harvest handling and storage. Grain losses in storage due to the bruchid beetle may be upto 100 per cent after five months of storage. In addition to causing direct weight loss of cowpea, bruchids also affect the aesthetic and food value of the seed, and reduces the viability of the seed (Booker, 1967). Each larva consumes an average of 10 per cent of one seed. Losses in seed germination due to bruchid attack may reach 100 per cent for grains with four holes per seed.

To reduce the dependence on chemicals and to assist farmers in reducing losses due to bruchids, it is most important to develop alternative control methods such as varietal resistance. Breeding for resistance using diverse resistance sources is the most effective strategy to prolong the life of newly evolved varieties.

A knowledge about the genetic basis of resistance to this insect would facilitate the use of such sources in breeding programmes. Therefore the present study was undertaken with the following objectives.

1. To study the genetic basis of pulse beetle resistance in association with yield attributes in cowpea.
2. To evolve suitable recombinants having both bruchid resistance and high yield attributes.

Review of Literature

2. REVIEW OF LITERATURE

A brief review of the literature on various aspects of crop improvement with special reference to resistance breeding in cowpea and related crops is presented under the following heads.

1. Genetic variability
2. Genotypic and phenotypic coefficients of variation
3. Heritability, genetic advance and genetic gain
4. Correlation
5. Combining ability

2.1 Genetic variability

An experiment conducted by Gupta and Mishra (1970) in bengal gram revealed that none of the varieties tested was resistant to the attack of the pulse beetle, although they differed widely in their susceptibility. The percentage of infested grains and loss of weight were the highest in the most susceptible varieties. Grain size did not seem to play an important role in the attack by pulse beetle. Physical factors of seed, particularly the seed surface and thickness of the seed coat appeared to be the important reasons for different preferences by the beetle.

Eighteen varieties in red gram were studied for their resistance to pulse beetle by Regupathy and Rathnaswamy (1970). The difference in the amount of food consumed between the varieties was significant. Pulse beetle resistance was linked with greater seed size. Seed colour, seed volume, hardness of seed and earliness had no association with the resistance or susceptibility to pulse beetle.

The oviposition response and development of *Callosobruchus maculatus* on seven varieties of cowpea was studied by Vir (1980). The beetle seemed to be guided in its oviposition preferences by colour, texture and volume of seed. Bright coloured smooth surfaces with greater seed volume were much preferred for oviposition. The development and percentage emergence of adults was not affected on the grains which were preferred for oviposition. The seed weight did not have any relation for ovipositional preference as the correlation coefficient between the eggs laid and seed weight was not significant.

Dabi *et al.* (1981) reported that no variety of pigeon pea was completely resistant to pulse beetle. In more susceptible varieties, the food consumption and the percentage of seed infestation were more.

According to Vir (1981) it is not the morphological characters of seed, viz. seed weight, seed volume and colour of seed but the nutritional value of seed which governs the mechanism of resistance in cowpea to the attack of *Callosobruchus maculatus*.

Vir (1982) also reported that ovipositional behaviour was not related to the suitability of seeds for the development of pulse beetle in moth bean. There was significant difference among the varieties in the amount of food consumed per grub and also the loss in 100 seed weight. The average food consumed per grub is a good criterion for the assessment of relative susceptibility of different varieties.

Four bruchid-susceptible and four bruchid-resistant cowpea cultivars were crossed to produce 16 F_1s and their reciprocals by Fatunla and Badaru (1983a). From each cross, six generations, P_1, P_2, F_1, F_2, BC_1 and BC_2 were obtained. Each cross was fitted to the additive dominance model. Estimates of additive and dominance variances were obtained from the half and full sib analyses of the F_1s and their reciprocals respectively. It was demonstrated that resistance to cowpea weevils has additive, dominance and maternal components.

The F_2 crosses were evaluated for oviposition, egg hatching and emergence scores of cowpea weevils by Fatunla and Badaru (1983b). Oviposition and number of eggs hatched were normally distributed whereas percentage of eggs hatched was not. Preferential oviposition was not observed among the parents and their F_2 progenies. Resistance was observed at the egg hatching and weevil emergence stages. Percentage of eggs hatched was significantly and positively associated with percentage weevil emergence.

Dharne *et al.* (1984) observed that there was no significant difference in egg laying in different varieties of pigeon pea. But the differences in the varieties towards the per cent loss in seed weight due to insect feeding were significant.

The fact that *Callosobruchus maculatus* resistance is controlled by two recessive genes (Adjadi *et al.*, 1985) indicated that the chemical and/or physical factors responsible for resistance should be present in all resistant lines and absent in all susceptible lines.

Sachdeva *et al.* (1986) observed that the texture of seed coat in cowpea seemed to be an important factor for inciting ovipositional response but for further growth and development of *Callosobruchus maculatus,* internal chemical composition of different cowpea varieties might have acted as a limiting factor.

Sandhu *et al.* (1986) observed that in no choice test, the pulse beetle exercised least preference for small sized and rough seeds. In multiple choice test, large and smooth seeds were preferred. Similarly red seed colour was preferred under no-choice test while it was not preferred in multiple choice test. In equal seed sizes, the smooth seed was preferred to rough seed for oviposition, but large seed characters overrode the smooth seed character in stimulating the females for oviposition.

Singal (1986) observed that after screening of fifteen genotypes of cowpea against pulse beetle, none of the genotypes was observed to be completely immune to the attack of *C. chinensis*. The ovipositional behaviour varied significantly among the varieties. Genotypes with smooth seed surface and bold size were most preferred as compared to genotypes having wrinkled seed surface and small and medium size seeds. The coefficient of correlation between average number of eggs and average number of adults emerged as well as between average number of eggs and per cent losses in weight of different genotypes were found positive. The adult emergence from different genotypes varied significantly. The correlation between number of adults emerged and per cent losses of weight in different cowpea genotypes was positive.

Khokhar and Singh (1987) revealed that the oviposition, adult emergence, grain infestation, weight loss and food consumed per grub differed significantly in different genotypes of pigeon pea. Seed characters such as size, volume, colour and texture were not related with the ovipositional preference of the beetle. Seed coat thickness did influence the adult emergence, as a negative and significant correlation existed between the two. The adult emergence and the per cent grain damage were positively correlated with the number of eggs laid. Seed size and volume were found to be negatively and significantly correlated with the amount of food consumed per grub.

Two seed-resistant land races of cowpea were crossed to a seed susceptible cultivar to produce F_1, F_2, BC_1 and BC_2 generations by Rusoke and Fatunla (1987). It was observed that seed resistance was conditioned by two unlinked recessive genes and cytoplasmic factors. Similarly, generations derived from a pod-resistant, seed susceptible cultivar with a seed-resistant, pod susceptible land race demonstrated that seed and pod resistance were independently inherited.

The thickness and hardness of seed testa had been reported as one of the major factors in providing resistance to the bruchid attack by Sachdeva and Seghal (1987).

Sandhu *et al.* (1987) observed that there was no difference in the number of penetrating holes produced by the bruchid larvae on different hosts. The different physical characteristics such as hardness, colour, seed coat texture and size of the seeds of different genotypes of cowpea did not affect the larval development and adult emergence. Also evaluated the growth and development of the bruchid *Callosobruchus maculatus* on rice bean and 16 genotypes of cowpea.. The seeds of the genotypes varied in size, colour, hardness and seed coat texture. It was observed that neither the seed coat nor the cotyledon was responsible for resistance to the bruchid, in rice bean.

Fifteen lines of cowpea were analyzed for physical and chemical characteristics to study their relationship with resistance to *Callosobruchus maculatus* by Baker *et al.* (1989). No significant differences were found when data for each characteristics like seed coat thickness, tannin content, trypsin inhibitory activity etc. were compared between susceptible or resistant lines of cowpea.

Chaves and Vendramin (1995) reported that variation in preference for oviposition by pulse beetle was exhibited only in choice tests.

Twenty varieties of cowpea were evaluated by Ofuya and Credland (1995) for susceptibility to attack by *Bruchidius atrolineatus*. The bruchid showed differential responses to the seeds in terms of developmental period, percentage adult emergence, seed weight loss due to feeding by one larva, adult weight at emergence and life time fecundity of females. In a no-choice oviposition experiment, *Bruchidius atolineatus* females laid eggs equally on all varieties. Percentage egg hatch on the different cowpea varieties did not differ significantly.

Dongre *et al.* (1996) reported that when a wild progenitor of *Vigna mungo* var. *silvestris*, which was resistant to infestation by pulse beetle, crossed with cultivated accession of black gram, in F_1 plants pollen fertility was normal and seeds were completely resistant to *Callosobruchus maculatus*. In the F_2

generation, a 15:1 ratio was observed indicating the presence of two dominant duplicate genes that are controlling resistance to pulse beetle.

2.2 Genotypic and phenotypic coefficients of variation (gcv and pcv)

Patil and Baviskar (1987) observed maximum variation for seed yield/plant followed by pods/plant, pod clusters/plant and days to maturity. The genotypic and phenotypic coefficients of variation were highest for pods/plant, pod clusters/plant, seed yield and 100 seed weight. Heritability was the highest for 100 seed weight, followed by days to maturity and pod length.

Sharma *et al.* (1988) reported maximum genotypic coefficient of variation for dry matter yield followed by plant height, green forage yield, pods/plant, seed weight and green pod yield. Heritability ranged from 46.9 per cent for grain pod yield to 98 per cent for days to 50 per cent maturity.

Gowda *et al.* (1991) reported that an F_2 population of cowpea showed high estimate of genotypic component of variation for pods/plant and seed yield/plant followed by 100 seed weight.

High genotypic coefficient of variation for all characters except seeds/pod, seed weight/plant, 100 seed weight and petiole length was recorded by Savithramma (1992). High heritability values were observed for plant height, pod length and 100 seed weight. High genetic advance was recorded in respect of plant height, seed weight/plant and 100 seed weight.

High gcv and pcv were observed for leaf area index, number of pods/plant, number of clusters/plant and 100 seed weight (Backiyarani and Nadarajan, 1996). Heritability and genetic advance estimates suggested the preponderance of additive gene effects for 100 seed weight, harvest index, leaf area index and single plant yield.

Sreekumar *et al.* (1996) observed high pcv, gcv, heritability and genetic advance for pod length, seeds per pod indicating additive gene action. The number of days to flowering and the days to harvest had high heritability with low genetic advance indicating non additive gene action.

2.3 Heritability, genetic advance and genetic gain

According to Apte *et al.* (1987) cowpea genotypes showed high heritability for 100 seed weight, seeds/pod and days to maturity. The percentage of genetic gain was maximum for 100 seed weight, plant height, number of branches/plant and seeds/pod. Estimates of heritability and genetic gain were higher for 100 seed weight and seeds/pod. Days to maturity had high heritability estimates but low genetic gain.

A study by Thiagarajan (1989) showed high heritability and genetic advance for plant height, seeds per pod and 100 seed weight.

In a variability study for yield and other traits Kandaswamy *et al.* (1989) obtained increased yield through selection for pods/plant, seeds/pod and 100 seed weight.

Roquib and Patnaik (1990) also reported high heritability for seeds per pod, 100 seed weight, plant height, primary branches, pod length and breadth, days to 50 per cent flowering, maturity and yield in cowpea. Most of these traits exhibited high estimates of genetic advance.

Evaluating sixteen strains of cowpea for six fodder characters, Gopalan and Balasubramanian (1993) reported that genetic variability was maximum for plant height followed by green fodder yield and number of leaves. The heritability estimates were also high for plant height, green fodder yield and number of leaves.

Information on genetic variance and heritability was derived from parental, F_1, F_2 and back cross generations of cowpea (Golasangi *et al*., 1995). The predominance of additive genetic variance coupled with relatively high heritability and genetic advance for the majority of the yield components indicated their probable usefulness in a selection scheme.

Rewale *et al*. (1995) observed that estimates of heritability and genetic gain were higher for 100 seed weight, plant height and harvest index in cowpea.

In cowpea pcv and gcv were similar for pod yield and its five components (Chattopadhyay *et al*., 1997). Broad sense heritabilities were high for all characters. Pods/plant, pod length and pod yield/plant exhibited high phenotypic and genotypic variation and heritability in combination with moderate to high genetic advance, suggesting the predominance of additive gene action.

According to Ram and Singh (1997) heritability estimates were high for pod and peduncle length, green pod yield/plant, days to 50 per cent flowering, days to maturity, plant height, seed/pod, branches/plant and 100 seed weight. High heritability estimates combined with high genetic advance were observed for pod length and green pod yield/plant.

Vardhan and Savithramma (1998a) observed high pcv and gcv, heritability and genetic advance for green pod yield, pods/plant, plant height and number of secondary branches in cowpea.

Vardhan and Savithramma (1998b) observed high gcv, pcv, heritability and genetic advance for plant height, number of primary branches, number of secondary branches, seed yield/plant and green pod yield. Correlation analysis revealed a significant, positive association of green pod yield/plant with pod length, pod width, fresh pods/plant, biomass and harvest index.

Almost all the yield related traits showed high heritability values (Sharma, 1999). Plant height showed high genetic advance coupled with high heritability and gcv indicating a preponderance of additive gene effects for this trait.

Kalaiyarasi and Palanisamy (2000) observed that seed yield per plant and number of pods per plant had high estimates of gcv followed by 100 seed weight, number of seeds per pod and plant height in F_4 population of cowpea. High heritability coupled with high genetic advance was observed for seed yield/plant, number of pods per plant, 100 seed weight and number of seeds per pod.

2.4 Correlation studies

Twenty genotypes of chickpea against pulse beetle were screened by Singal (1987) and no genotype was observed to be completely resistant to the attack of beetle. Correlation between per cent adult emergence and losses in weight of different genotypes were found to be positive. A negative correlation though significant was observed between per cent moisture content and per cent weight loss in different genotypes.

Senanayake and Wijarathne (1988) reported that yield was negatively correlated with the primary branches per plant and positively with 100 seed weight as well as pod length.

Sharma *et al.* (1988) found that seed yield was highly and significantly correlated with number of pods/plant, seeds/pod, days to first flower and days to 50 per cent maturity. Green forage yield was highly and positively correlated with pods/plant, days to first flower, seeds/pod and plant height.

Tyagi and Koranne (1988) observed that branches per plant and seeds/pod were positively and significantly correlated with yield.

Eighteen chickpea genotypes were evaluated for their susceptibility to pulse beetle by Ahmed *et al.* (1989) and observed that varieties with smooth, soft and thin seed coats were preferred and the varieties with rough, hard, wrinkled and spiny seed coats were least preferred for oviposition. No correlation was found between the number of eggs laid and the number of adults emerged. Genotypic as well as phenotypic variability and estimates of broad sense heritability of the resistance were lower than those of the number of eggs or the number of adults per 50 seed. The number of emergence holes was a better indicator of seed resistance than the number of eggs present on the seeds.

Filho *et al.* (1989) reported that there was no obvious relationship between the levels of lectins or tannins and the resistance or susceptibility of seeds to attack by *Callosobruchus maculatus*.

Highly significant positive correlation of seed yield with inflorescence/plant, pods/plant and grains/pod was observed by Apte *et al.* (1991). However 100 grain weight and harvest index indicated significant negative genotypic correlation.

Biradar *et al.* (1991) noted strong positive association of grain yield with pod weight, pods/plant, clusters per plant, seeds/pod and pod length.

Oseni *et al.* (1992) showed that pods/plant had significant positive correlation with yield whereas both days to flowering and 100 seed weight had negative correlation with grain yield.

Gopalan and Balasubramanian (1993) observed positive and significant genotypic correlation of green fodder yield with plant height, number of leaves and stem girth.

Samiullah *et al.* (1993) found that green pod yield/plant was significantly and positively correlated with pod number at the genotypic level only.

It was suggested that the fruiting branches and days to flowering were the reliable and effective selection criteria for the improvement of pod yield in cowpea.

Tamilselvam and Das (1994) observed that in cowpea, seed yield/plant was positively correlated with plant height, number of branches, clusters and pods/plant, pod length, number of seeds/pod and 100 seed weight. Plant height was positively correlated with days to 50 per cent flowering, number of clusters/plant, pod length and 100 seed weight. Pod length was positively correlated with number of seeds/pod and 100 seed weight. Number of seeds/pod was positively correlated with 100 seed weight. Number of clusters and pods per plant were negatively correlated with pod length and 100 seed weight.

In pigeon pea, plant height and days to maturity showed strong positive genotypic and phenotypic correlation with grain yield (Singh *et al.*, 1995). Days to flowering was positively correlated with days to maturity and plant height.

In cowpea seed yield was positively correlated with all the yield components with the exception of plant height (Biradar *et al.*, 1996). A strong correlation was observed between pod weight/plant and seed yield, pod length and number of seeds per pod, number of clusters and number of pods/plant, and number of pods/plant and pod weight/plant.

Gowda (1996) observed that seed yield was positively and significantly correlated with the number of pods per plant, number of seeds/pod and 100 seed weight in cowpea. Hundred seed weight was found to have significant and negative association with number of pods per plant and number of seeds per pod.

The association between some physical characteristics and the tannin content of cowpeas and their susceptibility to infestation by the bruchid *Callosobruchus maculatus* was investigated by Oigiangbe and Onigbinde (1996). The physical characteristics were coat colour and texture, seed height, length and width and the thickness of the seed coat. The dimensional parameters showed a significant correlation with the number of eggs laid with seed height accounting for about 70 per cent of the variance. The same parameter accounted for 77 per cent of the variance in the number of F_1 progeny. The tannic acid content, however, became increasingly significant with the growth of the larvae to adulthood. The tannic acid content accounted for 14.3 and 39.9 per cent of the variance in the number of F_1 progeny and percentage adult emergence, respectively.

Marconi *et al.* (1997) observed significant positive correlation between seed resistance to bruchids and trypsin inhibitor, tannin and starch contents.

Seed yield exhibited a significant and positive correlation with clusters, flowers and pods/plant, plant height, pod set, pod length, seeds/pod and 100 seed weight (Parihar *et al.*, 1997).

According to Singh *et al.* (1998) genotypic correlation coefficients were higher than their corresponding phenotypic correlation coefficients for morphological traits in cowpea. Grain yield per plant was positively and significantly associated with clusters per plant, pods per plant and total biomass per plant.

2.5 Combining ability

A half-diallel cross involving five parents of faba bean was evaluated by Waly *et al.* (1988) for infestation of the bruchid *Callosobruchus maculatus*. Infestation was either natural or simulated. F_1 hybrids were generally more resistant than the parents. There was a highly significant general combining ability component and a large specific combining ability effect for both types of infestation.

High gca variance for peduncle length, grain yield/plant and seeds/pod was observed by Hebbal (1988). Specific combining ability variance was significant for pods/plant and 100 grain weight while both sca and gca variances were important for pod weight and volume of 100 grains.

The sca variance estimates were greater than those for gca for yield and its components, except 100 seed weight, where contribution of gca was greater (Bahl and Kumar, 1989).

Thiagarajan *et al.* (1990) in a 6 x 6 diallel cross of cowpea for combining ability studies found that additive and non additive gene effects were important for plant height, branches/plant, clusters/plant, pods/plant, pod length, seeds/pod, 100 seed weight and yield per plant.

Rejatha (1992) observed that the variance due to general combining ability was significant and higher in magnitude than specific combining ability for the days to flowering, pod weight, mean pod length, seeds/pod, internode length and seed:pod ratio.

According to Thiagarajan *et al.* (1993) the variance due to gca and sca showed that gene action was predominantly non additive for days to 50 per cent flowering, days to maturity, plant height, pod length, seeds/pod, 100 grain weight and yield/plant and primarily additive for primary branches/plant, clusters/plant and pods/plant.

Analysis of variance revealed significant mean squares due to gca as well as sca for all the yield components in cowpea (Patel *et al.*, 1994). The highest magnitude of gca variance compared to sca variance signified the predominant role of additive type of gene action in the expression of all the characters.

Madhusudan *et al.* (1995) observed that a line x tester analysis involving 9 lines and 3 testers indicated the importance of both additive and non additive genetic variance in the inheritance of seven quantitative traits in cowpea, with a preponderance of non additive gene effects in most cases.

The gca:sca variance ratio for all the yield related traits in cowpea showed the predominance of sca variance over gca variance, suggesting the predominance of non additive gene action (Aravindhan and Das, 1996).

Jayarani and Manju (1996) observed that combining ability analysis involving two lines, six testers and twelve hybrids in cowpea revealed the importance of specific combining ability for all the characters except for length of pod and days to flowering.

The ratio of gca to sca for all the yield related traits in cowpea showed non additive gene effects except days to 50 per cent flowering (Bushana *et al.*, 1998).

Plate 1. Field view of parental lines

Materials and Methods

3. MATERIALS AND METHODS

The present investigation was carried out at the Department of Plant Breeding and Genetics, College of Horticulture, Vellanikkara during the period 1999-2001. Field experiments related to the investigation were laid out at Agricultural Research Station, Mannuthy, which is located at an altitude of 15 m above mean sea level, and is situated between 10° 32" N latitude and 76° 10" E longitude. The soil type is laterite loam with pH around 5.6.

3.1 Materials

Three bruchid resistant genotypes of cowpea viz., EC 367711, EC 390231 and IC 201092 screened from among the exotic and indigenous collections and four high yielding susceptible genotypes viz., Kanakamoni, V 240, C 152 and V 16 selected from among the varieties recommended in Package of Practices (KAU, 1996) constituted the materials for the study.

3.2 Methods

3.2.1 Experiment 1

Seven parental lines comprising three bruchid resistant genotypes viz., EC 367711, EC 390231 and IC 201092 and four high yielding susceptible genotypes viz., Kanakamoni, V 240, C 152 and V 16 were laid out in a randomised block design, replicated thrice (Plate 1). The soil was lateritic loam and the cultural, manurial and plant protection measures were done as per Package of Practices Recommendations (KAU, 1996). Irrigation was provided uniformly as and when required.

3.2.2 Experiment 2

Crosses were carried out in a Line x Tester model, so as to obtain twelve F_1 hybrids with the resistant genotypes as testers. The physical characteristics of parents and hybrids are given in Table 1. A part of the F_1 seeds thus obtained were kept for laboratory studies to ascertain resistance/tolerance and the remaining for next generation study.

3.2.3 Experiment 3

The seeds obtained from twelve different crosses of resistant and susceptible genotypes were laid out in randomised block design with three replications, along with parents. The seeds collected from F_1 hybrids along with parents were stored and analysed for bruchid resistance.

3.2.4 Experiment 4

The F_1 seeds, seeds obtained from F_1 plants and seeds of parental lines were screened by no choice test and free choice test for their resistance to bruchids in the laboratory employing the method of Gibson and Raina (1972).

3.2.5 Observations recorded

3.2.5.1 Field observations

Three plants were randomly selected from each replication. Observations were recorded on the following characters and the average worked out.

3.2.5.1.1 *Plant height*

Height of the plant was measured at the time of final harvest of the plant. Nine plants were selected at random and height was measured in cm from ground level to the tip of the plant.

3.2.5.1.2 *Number of branches per plant*

Number of branches produced per plant was studied when the plants were in their maximum reproductive phase. The branches produced per plant were

Table 1. Physical characteristics of parents and hybrids

Genotypes	Seed coat colour	Seed coat texture
EC390231	Yellow	Rough
IC201092	Dark brown	Smooth
EC367711	Black	Smooth
V16	Brick red	Medium
C152	Brown	Medium and slightly depressed
Kanakamoni	Brown	Smooth
V240	Reddish brown	Smooth
V16 x EC390231	Light brown	Partly smooth and partly rough
V16 x EC367711	Black with brown spots	Rough
V16 x IC201092	Reddish black	Smooth
C152 x EC390231	Brown	Rough and depressed
C152 x IC201092	Light brown	Smooth
C152 x EC367711	Black	Smooth
V240 x EC390231	Brownish yellow	Partly smooth and partly rough
V240 x IC201092	Light brown	Smooth
V240 x EC367711	Black	Smooth
Kanakamoni x EC390231	Reddish brown	Smooth
Kanakamoni x EC367711	Brown	Smooth
Kanakamoni x IC201092	Light brown	Rough

counted separately for nine plants, and the average number of branches produced per plant was determined.

3.2.5.1.3 *Leaf Area Index (LAI)*

Leaf area index was calculated separately for all the nine plants at 45 DAP and 90 DAP using the method suggested by Puttaswamy *et al.* (1976) and the average was worked out.

3.2.5.1.4 *Days to flowering*

Number of days taken from sowing to first flower was calculated separately for all plants. Average of three plants from each replication was observed.

3.2.5.1.5 *Number of flowers per plant*

The number of flowers opened per day per plant was counted from the date of opening of the first flower to the day after which no flowering was observed. Three plants from each replication were used for this study.

3.2.5.1.6 *Number of pods per plant*

Number of pods from each plant was recorded separately immediately after each harvest. Three plants from each replication were used for this study.

3.2.5.2 Post harvest observations

3.2.5.2.1 *Pod weight*

The weight of ten randomly selected pods from nine plants of each genotype was taken at the time of harvest in an electric balance and the average worked out in g.

3.2.5.2.2 *Pod yield per plant*

Weight of pods from nine plants of each genotype at each harvest was taken using a top loading balance and added to get the total and the average recorded in g.

3.2.5.2.3 *Seeds per pod*

The number of seeds in ten pods of nine plants of each genotype was counted and recorded the average number of seeds per pod.

3.2.5.2.4 *100 seed weight*

One hundred dried seeds from each genotype were weighed using an electric precision balance and the weight recorded in g. An average of three plants from each replication was observed.

3.2.5.2.5 *Seed size*

Length of twenty seeds from nine plants of each genotype was measured using an ordinary scale and the average worked out and recorded in cm. The breadth was taken using vernier calipers and weight was taken using an electric precision balance, and recorded in g.

3.2.5.2.6 *Seed coat colour and texture*

Colour of seed coat was observed using the colour chart. Twenty seeds from each genotype were taken for this purpose. The texture of seed coat was taken as

1. smooth
2. rough and
3. depressed.

3.2.5.2.7 *Thickness of seed coat*

The seed coat thickness of twenty seeds of nine plants was recorded using a micrometer with a 2.54 µm accuracy and the average was worked out.

3.2.5.2.8 *Biochemical observation*

Tannin content in the seed coat of each genotype was calculated by Folin-Denis method as per Schandert (1970).

3.2.5.2.9 *Moisture content of seed during harvest and storage*

Moisture content of seed during harvest and storage was determined by oven-drying method. Nine samples of each genotype were dried in hot air oven at 70±2°C till the samples attained constant weight. The moisture content was expressed in percentage (Ranganna, 1986).

3.2.5.3 Laboratory observations

3.2.5.3.1 *Number of eggs laid*

Total number of eggs laid on ten seeds of each genotype/replication were counted after one week of release of bruchids in both no choice and free choice tests and the average of three replications of each genotype was recorded.

3.2.5.3.2 *Number of adults emerged*

Number of adult beetles emerged from the seeds kept for no choice and free choice tests were noted after fifteen days of release of bruchids and the average was worked out, for each genotype.

3.2.5.3.3 *Number of bore holes*

Total number of bore holes appeared on the same ten seeds of each genotype/replication were counted after fifteen days of release of bruchids and the average of three replications of each genotype was observed.

3.2.5.3.4 *Loss of weight per seed per insect developed*

The difference in the weight, before and after the attack of bruchids was recorded for each of the ten seeds of all the genotypes used in storage study and the average of three replications was worked out. Loss of weight per seed per insect developed was recorded in g.

3.3 Statistical analysis

Data on different characters were subjected to statistical analysis at the computer centre, Department of Statistics, College of Horticulture, Vellanikkara. The analysis of variance technique suggested by Fisher (1954) was employed for the estimation of various genetic parameters. The extent of association among characters was measured by correlation coefficients. The analysis for combining ability also was done for the parents and hybrids.

3.3.1 Components of heritable variation

The variance components were estimated as per the procedure suggested by Burton (1952).

3.3.1(a) *Phenotypic variance*

Phenotypic variance (Vp) = Vg + Ve

where (Vg) = Genotypic variance

(Ve) = Environmental variance

3.3.1(b) *Genotypic variance*

$$\text{Genotypic variance (Vg)} = \frac{VT - VE}{N}$$

Where VT = Mean sum of squares due to treatments

VE = Mean sum of squares due to error

N = Number of replications

Environmental variance Ve = VE

Where VE = Mean sum of squares due to error

3.3.1(c) *Phenotypic and genotypic coefficients of variation*

The phenotypic and genotypic coefficients of variation were calculated by the formula suggested by Burton and Devane (1953).

$$\text{Phenotypic coefficient of variation (pcv)} = \frac{\sqrt{Vp}}{\bar{X}} \times 100$$

Where Vp = Phenotypic variance

$\bar{X}$ = Mean of the character under study

$$\text{Genotypic coefficient of variation (gcv)} = \frac{\sqrt{Vg}}{\bar{X}} \times 100$$

where Vg = Genotypic variance

$\bar{X}$ = Mean of the character under study

The estimates of pcv and gcv were classified as

< 10 per cent	- Low
10 - 20 per cent	- Moderate
> 20 per cent	- High

3.3.1(d) *Heritability*

Heritability in the broad sense was estimated by following the formula suggested by Burton and Devane (1953).

$$\text{Heritability (H)} = \frac{Vg}{Vp} \times 100$$

Where Vg = Genotypic variance

Vp = Phenotypic variance

The heritability was categorised as

60 - 100 per cent - High

30 - 60 per cent - Moderate

<30 per cent - Low

3.3.1(e) *Expected genetic advance*

The expected genetic advance of the available germplasm was measured by the formula suggested by Lush (1949) and Johnson *et al.* (1955a) at five per cent selection intensity using the constant K as 2.06 given by Allard (1960).

$$\text{Expected genetic advance GA} = \frac{Vg}{\sqrt{Vp}} \times K$$

where Vg = Genotypic variance

Vp = Phenotypic variance

K = Selection differential

Genetic gain (Genetic advance as percentage of mean)

Genetic advance (GA) calculated in the above method was used for estimation of genetic gain.

$$\text{Genetic gain (GG)} = \frac{GA}{\bar{X}} \times 100$$

Genetic gain was categorised as

>20 per cent	- High
10 - 20 per cent	- Moderate
<10 per cent	- Low

3.3.1(f) *Phenotypic and genotypic correlation coefficients*

The phenotypic and genotypic covariances were worked out in the same way as the variances were calculated. Mean product expectations of the covariance analyses are analogous to the mean square expectation of the analyses of variance. The different covariance estimates were calculated by the method suggested by Fisher (1954).

Phenotypic covariance between two characters 1 and 2 (CoVp12) = CoVg12 + CoVe12

CoVg12 = Genotypic covariance between characters 1 and 2

CoVe12 = Environmental covariance between 1 and 2

Genotypic covariance between two characters 1 and 2

$$\text{CoVg12} = \frac{\text{Mt12 - Me12}}{\text{N}}$$

where

Mt12 = Mean sum of product due to treatment between characters 1 and 2

Me12 = Mean sum of product due to error between characters 1 and 2

N = Number of replications

The phenotypic and genotypic correlation coefficients among the various characters were worked out in all possible combinations according to the formula suggested by Johnson *et al.* (1955b).

Phenotypic correlation coefficient between two characters 1 to 2

$$(rp12) = \frac{CoVp12}{\sqrt{Vp1\ Vp2}}$$

where

CoVp12 = Phenotypic covariance between characters 1 and 2

Vp1 = Phenotypic variance of character 1

Vp2 = Phenotypic variance of character 2

Genotypic correlation coefficient between two characters 1 and 2

$$(rg12) = \frac{CoVg12}{\sqrt{Vg1\ Vg2}}$$

where

CoVg12 = Genotypic covariance between characters 1 and 2

Vg1 = Genotypic variance of character 1

Vg2 = Genotypic variance of character 2

3.3.1(g) *Analysis for combining ability*

The mean values of F_1 hybrids and parents for all the characters were analysed for combining ability using the method suggested by Kempthorne (1957).

Results

4. RESULTS

Three bruchid resistant and four high yielding susceptible cowpea genotypes, the hybrids and F_2 population obtained were evaluated for various morphological, physiological and biochemical observations. Data were subjected to statistical analysis and the results are presented in this chapter.

4.1 Evaluation of parents

4.1.1 Evaluation of parents for yield attributes

4.1.1.1 Genetic variability

The extent of genetic variability with respect to different quantitative characters in seven cowpea genotypes was estimated. The abstract of analysis of variance of different yield characters is given in Table 2. Results from analysis of variance revealed highly significant difference among the parents for most of the characters studied except for days to flowering, leaf area index at 45 and 90 DAP and breadth of seed.

Estimates of genetic parameters like heritability, genetic advance, genetic gain and genotypic and phenotypic coefficients of variation for different yield components are presented in Table 3.

4.1.1.2 Heritability

High estimates of heritability (broad sense) were noticed for number of branches per plant (0.68), number of flowers per plant (0.97), number of pods per plant (0.97), pod yield per plant (0.97), pod weight (0.60), 100 seed weight (0.61) and weight of seed (0.67). The characters plant height (0.58), days to flowering (0.32), leaf area index (90 DAP) (0.50), seeds per pod (0.49) and length of seed (0.49) recorded moderate heritability values. Heritability was low for leaf area index (45 DAP) (0.17) and breadth of seed (0.03) (Table 3).

Table 2. Anova for different yield components (Parents)

Yield characters	Error df	Mean sum of squares
Plant height	12	0.24**
Number of branches per plant	12	$0.23x10^{1}$**
Number of flowers per plant	12	$0.78x10^{2}$**
Days to flowering	12	$0.10x10^{2}$
Leaf Area Index (45 DAP)	12	$0.65x10^{-1}$
Leaf Area Index (90 DAP)	12	0.12
Pod yield per plant	12	$0.24x10^{3}$**
Number of pods per plant	12	$0.39x10^{2}$**
Pod weight	12	$0.18x10^{-1}$**
Seeds per pod	12	0.89*
100 seed weight	12	$0.13x10^{1}$**
Length of seed	12	$0.13x10^{-1}$**
Breadth of seed	12	$0.26x10^{-1}$
Weight of seed	12	$0.78x10^{-4}$**

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

Table 3. Estimates of genetic parameters for different yield components (Parents)

Yield characters	Mean	Heritability	Genetic advance	Genetic gain (%)	gcv (%)	pcv (%)
Plant height (m)	1.85	0.58	0.91	49.18	31.35	41.08
No. of branches/plant	12.71	0.68	3.73	29.34	17.31	21.02
No. of flowers/plant	108.05	0.97	108.34	100.26	49.34	50.02
Days to flowering	46.38	0.32	2.55	5.49	4.74	8.43
Leaf Area Index (45 DAP)	1.08	0.17	0.10	9.25	10.68	26.04
Leaf Area Index (90 DAP)	1.20	0.50	0.04	3.33	6.60	29.61
Pod yield per plant (g)	142.48	0.97	174.58	122.52	60.47	61.48
No. of pods per plant	75.90	0.97	75.68	99.71	49.09	49.78
Pod weight (g)	1.82	0.60	0.26	14.28	9.00	11.60
Seeds per pod	13.24	0.49	1.32	9.96	6.93	9.94
100 seed weight (g)	9.05	0.61	2.31	25.52	15.88	20.34
Length of seed (cm)	0.88	0.49	0.16	18.18	12.63	17.98
Breadth of seed (cm)	0.64	0.03	0.01	1.56	4.96	25.61
Weight of seed (g)	0.11	0.67	0.02	18.18	12.03	14.68

4.1.1.3 Genetic advance and genetic gain

The genetic advance as per cent of mean (genetic gain) was high for plant height (49.18), number of branches per plant (29.34), number of flowers per plant (100.26), pod yield per plant (122.52), number of pods per plant (99.71) and 100 seed weight (25.52). The characters pod weight (14.28), seeds per pod (9.96), length of seed (18.18) and weight of seed (18.18) recorded moderate genetic gain. Low genetic gain was observed for characters like days to following (5.49), leaf area index at 45 DAP (9.25), leaf area index at 90 DAP (3.33) and breadth of seed (1.56) (Table 3).

4.1.1.4 Phenotypic and genotypic coefficients of variation

The estimates of pcv and gcv are given in Table 3. Plant height (41.08, 31.35), number of flowers per plant (50.02, 49.34), pod yield per plant (61.48, 60.47) and number of pods per plant (49.78, 49.09) recorded high magnitudes of pcv and gcv. The phenotypic coefficient of variation was high for number of branches (21.02), leaf area index at 45 DAP (26.04) and 90 DAP (29.61), 100 seed weight (20.34) and breadth of seed (25.61). But the gcv was low to moderate for these characters. Length of seed (17.98, 12.63) and weight of seed (14.68, 12.03) showed moderate values of pcv and gcv. Low pcv and gcv values were observed for days to flowering (8.43, 4.74). Seeds per pod recorded moderate value of pcv with low gcv (9.94, 6.93).

4.1.2 Evaluation of parents for bruchid resistance traits

4.1.2.1 Genetic variability

Analysis of variance for different bruchid resistance traits is presented in Table 4. The results indicated highly significant difference among the parents for all the characters studied except for moisture content of seed during harvest. Estimates of genetic parameters like heritability, genetic advance, genetic gain, gcv and pcv for different bruchid resistance traits are presented in Table 5.

Table 4. Anova for different bruchid resistance traits (Parents)

Bruchid resistance traits	Error df	Mean sum of squares
Number of eggs laid (No choice)	12	0.69×10^{2}**
Number of bore holes (No choice)	12	0.11×10^{1}**
Number of adults emerged (No choice)	12	0.17×10^{1}**
Number of eggs laid (free choice)	12	0.19×10^{2}**
Number of bore holes (free choice)	12	0.53×10^{1}**
Number of adults emerged (free choice)	12	0.44×10^{1}**
Loss of weight/seed	12	0.44×10^{-3}**
Moisture content (harvest)	12	0.18
Moisture content (storage)	12	0.17*
Seed coat thickness	12	0.81×10^{-3}*
Tannin content	12	0.23**

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

Table 5. Estimates of genetic parameters for different bruchid resistance traits (Parents)

Bruchid resistance traits	Mean	Heritability	Genetic advance	Genetic gain (%)	gcv (%)	pcv (%)
No. of eggs laid (No choice)	33.62	0.56	14.44	42.95	27.91	37.35
No. of bore holes (No choice)	6.00	0.89	5.80	96.66	49.87	52.96
No. of adults emerged (No choice)	5.86	0.83	5.27	89.93	48.05	52.86
No. of eggs laid (Free choice)	33.71	0.74	13.04	38.68	21.88	25.50
No. of bore holes (Free choice)	6.29	0.58	4.32	68.68	43.52	56.80
No. of adults emerged (Free choice)	6.00	0.65	4.76	79.33	47.72	59.17
Loss of weight/seed (g)	0.07	0.57	0.04	57.14	40.57	53.71
Moisture content (harvest) (%)	8.63	0.07	0.06	0.69	1.36	5.05
Moisture content (storage) (%)	6.92	0.41	0.47	6.79	5.06	7.82
Seed coat thickness (mm)	1.12	0.43	0.03	2.67	2.24	3.40
Tannin content (mg g^{-1})	4.11	0.93	3.67	89.29	44.78	46.29

4.1.2.2 Heritability

High estimates of heritability (broad sense) were noticed for number of bore holes produced during no choice test (0.89), number of adults emerged during no choice test (0.83), number of eggs laid (0.74) and adults emerged (0.65) during free choice test and tannin content (0.93). Moderate estimates of heritability were observed for number of eggs laid during no choice test (0.56), number of bore holes produced during free choice test (0.58), loss of weight per seed (0.57), moisture content during storage (0.41) and seed coat thickness (0.43). The character moisture content during harvest (0.07) recorded low heritability value (Table 5).

4.1.2.3 Genetic advance and genetic gain

High estimates of genetic gain were observed for number of eggs laid (42.95%), number of bore holes (96.66%) and number of adults emerged (89.93%) during no choice test, number of eggs laid (38.68%), number of bore holes (68.68%) and number of adults emerged (79.33%) during free choice test, loss of weight per seed (57.14%) and tannin content (89.29%). Low genetic gain was observed for moisture content of seeds at harvest (0.69%) and storage (6.79%) and seed coat thickness (2.67%) (Table 5).

4.1.2.4 Phenotypic and genotypic coefficients of variation

The estimates of pcv and gcv are given in Table 5. Number of eggs laid during no choice test (37.35, 27.91), number of bore holes produced during no choice test (52.96, 49.87), number of adults emerged during no choice test (52.86, 48.05), number of eggs laid during free choice test (25.50, 21.88), number of bore holes produced during free choice test (56.80, 43.52), number of adults emerged during free choice test (59.17, 47.72), loss of weight per seed (53.71, 40.57) and tannin content (46.29, 44.78) recorded high pcv and gcv. Low pcv and gcv values were observed for moisture content at harvest (5.05, 1.36) and storage (7.82, 5.06) and seed coat thickness (3.40, 2.24).

4.2 Evaluation of hybrids

4.2.1 Evaluation of hybrids for yield attributes

4.2.1.1 Genetic variability

The abstract of analysis of variance of different yield characters is given in Table 6. The results indicated highly significant difference among the hybrids for all the yield attributing characters except for days to flowering and leaf area index at 45 DAP.

4.2.1.2 Phenotypic and genotypic coefficients of variation

Estimates of genetic parameters for different yield components in hybrids are presented in Table 7. High estimates of pcv and gcv were observed for characters like plant height (33.64, 27.16), number of flowers per plant (25.85, 22.75), pod yield per plant (36.66, 32.49) and number of pods per plant (26.24, 23.20). Moderate estimates of pcv and gcv were recorded for length of seed (18.02, 13.40) and breadth of seed (19.16, 12.52). Low estimates of pcv and gcv were observed for days to flowering (8.95, 1.87). The phenotypic coefficient of variation was high for leaf area index at 45 DAP (23.30) and 90 DAP (22.00), number of branches per plant (23.65), pod weight (21.72), seeds per pod (21.20), 100 seed weight (20.89) and weight of seed (20.17). But the gcv was low to moderate for these characters (Table 7).

4.2.2 Evaluation of hybrids for bruchid resistance traits

4.2.2.1 Genetic variability

Analysis of variance for different traits related to bruchid resistance is presented in Table 8. The results indicated highly significant difference among the hybrids for all the characters studied.

Table 6. Anova for different yield components (F_1)

Yield characters	Error df	Mean sum of squares
Plant height	22	0.35**
Number of branches per plant	22	$0.79x10^{1}$**
Number of flowers per plant	22	$0.84x10^{3}$**
Days to flowering	22	$0.15x10^{2}$
Leaf Area Index (45 DAP)	22	0.11
Leaf Area Index (90 DAP)	22	$0.62x10^{-1}$**
Pod yield per plant	22	$0.46x10^{4}$**
Number of pods per plant	22	$0.41x10^{3}$**
Pod weight	22	$0.86x10^{-1}$*
Seeds per pod	22	$0.27x10^{1}$**
100 seed weight	22	$0.40x10^{1}$**
Length of seed	22	$0.14x10^{-1}$**
Breadth of seed	22	$0.10x10^{-1}$**
Weight of seed	22	$0.20x10^{-3}$**

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

Table 7. Estimates of genetic parameters for different yield components (F_1)

Yield characters	Mean	gcv (%)	pcv (%)
Plant height (m)	3.00	27.16	33.64
Number of branches per plant	18.42	18.01	23.65
Number of flowers per plant	236.78	22.75	25.85
Days to flowering	44.06	1.87	8.95
Leaf Area Index (45 DAP)	1.48	6.49	23.30
Leaf Area Index (90 DAP)	1.95	17.96	22.00
Pod yield per plant (g)	401.20	32.49	36.66
Number of pods per plant	165.89	23.20	26.24
Pod weight (g)	1.71	13.42	21.72
Seeds per pod	11.17	15.19	21.20
100 seed weight (g)	15.58	16.44	20.89
Length of seed (cm)	0.99	13.40	18.02
Breadth of seed (cm)	0.70	12.52	19.16
Weight of seed (g)	0.13	16.89	20.17

Table 8. Anova for different bruchid resistance traits (F_1)

Bruchid resistance traits	Error df	Mean sum of squares
Number of eggs laid (No choice)	22	$0.30x10^{2}$**
Number of bore holes (No choice)	22	$0.34x10^{1}$*
Number of adults emerged (No choice)	22	$0.34x10^{1}$*
Number of eggs laid (free choice)	22	$0.78x10^{1}$**
Number of bore holes (free choice)	22	0.43**
Number of adults emerged (free choice)	22	0.47**
Loss of weight/seed	22	$0.21x10^{-3}$**
Moisture content (harvest)	22	$0.49x10^{-1}$**
Moisture content (storage)	22	0.20**
Seed coat thickness	22	$0.32x10^{-3}$**
Tannin content	22	$0.12x10^{1}$**

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

4.2.2.2 Phenotypic and genotypic coefficients of variation

The estimates of pcv and gcv are given in Table 9. Number of eggs laid (32.74, 28.08), number of bore holes produced (81.59, 48.89) and number of adults emerged (81.59, 48.89) during no choice test, number of eggs laid (32.89, 29.47), number of bore holes produced (99.54, 82.07) and number of adults emerged (105.55, 78.22) during free choice test, loss of weight per seed (45.08, 38.49) and tannin content (36.71, 29.0) recorded high magnitudes of pcv and gcv. Low pcv and gcv values were observed for moisture content at harvest (5.9, 5.26) and storage (9.6, 6.47) and seed coat thickness (2.30, 1.74).

4.3 Evaluation of F_2 generation

4.3.1 Evaluation of F_2 generation for seed characters and bruchid resistance traits

4.3.1.1 Genetic variability

Analysis of variance for different seed characters and bruchid resistance traits is presented in Table 10. Results from analysis of variance revealed significant difference for most of the characters studied except for length of seed, breadth of seed, number of bore holes produced and adults emerged during no choice test, number of bore holes produced during free choice test and moisture content during harvest.

4.3.1.2 Phenotypic and genotypic coefficients of variation

The estimates of pcv and gcv are given in Table 11. Number of eggs laid (28.66, 22.78), number of bore holes produced (40.39, 20.15), number of adults emerged (108.30, 89.66) during free choice test, loss of weight per seed (37.71, 21.02) and tannin content (53.07, 47.23) recorded high magnitudes of pcv and gcv. The characters like pod weight (17.90, 11.44), 100 seed weight (17.99, 14.34), weight of seed (14.40, 11.24) and number of eggs laid during no choice test (21.69, 14.90) recorded moderate estimates of pcv and gcv. Low pcv and gcv

Table 9. Estimates of genetic parameters for different bruchid resistance traits (F_1)

Bruchid resistance traits	Mean	gcv (%)	pcv (%)
No. of eggs laid (No choice)	32.67	28.08	32.74
No. of bore holes (No choice)	2.83	48.89	81.59
No. of adults emerged (No choice)	2.83	48.89	81.59
No. of eggs laid (Free choice)	19.17	29.47	32.89
No. of bore holes (Free choice)	1.17	82.07	99.54
No. of adults emerged (Free choice)	0.97	78.22	105.55
Loss of weight/seed (g)	0.06	38.49	45.08
Moisture content (harvest) (%)	8.31	5.26	5.90
Moisture content (storage) (%)	6.39	6.47	9.60
Seed coat thickness (mm)	1.14	1.74	2.30
Tannin content (mg g^{-1})	4.86	29.00	36.71

Table 10. Anova for different seed characters and bruchid resistance traits (F_2)

Seed characters and bruchid resistance traits	Error df	Mean sum of squares
Pod weight	22	0.11**
Seeds/pod	22	$0.16x10^{1}$**
100 seed weight	22	$0.15x10^{1}$**
Length of seed	22	$0.25x10^{-1}$
Breadth of seed	22	$0.15x10^{-1}$
Weight of seed	22	$0.13x10^{-3}$**
Number of eggs laid (No choice)	22	$0.49x10^{2}$**
Number of bore holes (No choice)	22	$0.81x10^{1}$
Number of adults emerged (No choice)	22	$0.77x10^{1}$
Number of eggs laid (free choice)	22	$0.15x10^{2}$**
Number of bore holes (free choice)	22	$0.72x10^{1}$
Number of adults emerged (free choice)	22	$0.53x10^{1}$**
Loss of weight/seed	22	$0.31x10^{-3}$*
Moisture content (harvest)	22	0.18
Moisture content (storage)	22	0.16*
Seed coat thickness	22	0.59**
Tannin content	22	0.58**

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

Table 11. Estimates of genetic parameters for different seed characters and bruchid resistance traits (F_2)

Seed characters and bruchid resistance traits	Mean	gcv (%)	pcv (%)
Pod weight (g)	2.37	11.44	17.90
Seeds/pod	16.00	9.77	12.63
100 seed weight (g)	11.59	14.34	17.99
Length of seed (cm)	1.09	5.36	15.68
Breadth of seed (cm)	0.70	4.45	17.60
Weight of seed (g)	0.13	11.24	14.40
Number of eggs laid (No choice)	44.33	14.90	21.69
Number of bore holes (No choice)	9.00	0.35	31.89
Number of adults emerged (No choice)	8.00	0.38	33.68
Number of eggs laid (free choice)	22.00	22.78	28.66
Number of bore holes (free choice)	8.00	20.15	40.39
Number of adults emerged (free choice)	4.00	89.66	108.30
Loss of weight/seed (g)	0.055	21.02	37.71
Moisture content (harvest) (%)	8.50	1.36	5.22
Moisture content (storage) (%)	6.57	4.95	7.89
Seed coat thickness (mm)	1.14	2.56	3.33
Tannin content (mg g^{-1})	3.10	47.23	53.07

values were observed for moisture content at harvest (5.22, 1.36) and at storage (7.82, 4.95) and seed coat thickness (3.33, 2.56). The characters seed per pod (12.63, 9.77), length of seed (15.68, 5.36) and breadth of seed (17.60, 4.45) showed moderate estimates of pcv and low gcv values. The phenotypic coefficient of variation was high for number of bore holes produced (31.89, 0.35) and adults emerged (33.68, 0.38) during no choice test. But the gcv was low for these characters.

4.4 Correlation studies

The genotypic and phenotypic correlations among yield and its component traits in parents have been worked out and presented in Table 12. The characters plant height (rg = 0.97, rp = 0.84), number of branches per plant (rg = 0.86, rp = 0.74), number of flowers per plant (rg = 0.98, rp = 0.98), number of pods per plant (rg = 0.98, rp = 0.98), pod weight (rg = 0.91, rp = 0.79), seeds per pod (rg = 1.01, rp = 0.64), 100 seed weight (rg = 1.02, rp = 0.87), length of seed (rg = 0.74, rp = 0.52) and weight of seed (rg = 0.97, rp = 0.82) showed significant positive association with yield at both genotypic and phenotypic levels. Hundred seed weight (rg = 1.02, rp = 0.87) recorded the highest significant positive value followed by seeds per pod (rg = 1.01, rp = 0.64).

The interrelationship among the yield components also exhibited significant positive association for all the component characters (Table 12). In parents, plant height showed significant association with yield through number of branches per plant, number of flowers per plant, number of pods per plant, pod weight, seeds per pod, 100 seed weight, length and weight of seed. Number of branches per plant had significant positive association with all other yield components except length of seed. Number of flowers per plant, number of pods per plant, 100 seed weight, pod weight, seeds per pod and weight of seed showed significant positive association with all other yield related traits. Length of seed

Table 12. Genotypic and phenotypic (lower and upper diagonal) correlation coefficients for 10 characters in parents

	Plant height	Number of branches/ plant	Number of flowers/ plant	Pod yield per plant	Number of pods per plant	Pod weight	Seeds per pod	100 seed weight	Length of seed	Weight of seed
Plant height		0.52	0.83*	0.84*	0.83*	0.67*	0.53	0.76*	0.64*	0.63*
Number of branches/plant	0.93**		0.74*	0.74*	0.74*	0.75*	0.46	0.68*	0.12	0.80*
Number of flowers/plant	0.96**	0.89**		0.98*	0.99*	0.76*	0.66*	0.88*	0.43	0.72*
Pod yield/ plant	0.97**	0.86**	0.98**		0.98*	0.79*	0.64*	0.87*	0.52	0.82*
Number of pods/plant	0.96**	0.89**	0.99**	0.98**		0.75*	0.67*	0.88*	0.43	0.78*
Pod weight	1.05**	0.79**	0.91**	0.91**	0.91**		0.41	0.74*	0.30	0.85*
Seeds per pod	1.19**	0.80**	0.98**	1.01**	0.98**	1.18**		0.42	0.54	0.63*
100 seed weight	0.93**	1.10**	1.02**	1.02**	1.01**	0.97**	1.11**		0.19	0.71*
Length of seed	0.88**	0.37	0.65*	0.74**	0.66*	0.81**	0.94**	0.69*		0.38
Weight of seed	1.07**	0.88**	0.92**	0.97**	0.91**	0.97**	1.03**	1.09**	0.84**	

* Significant at 5% level

** Significant at 1% level

had significant positive association with all other yield components except number of branches per plant.

The genotypic and phenotypic correlation coefficients among yield traits in hybrids have been worked out and presented in Table 13.

The association of pod yield with plant height (rg = 0.88, rp = 0.63), number of branches per plant (rg = 0.95, rp = 0.70), number of flowers per plant (rg = 0.99, rp = 0.89, leaf area index (90 DAP) (rg = 0.91, rp = 0.70), number of pods per plant (rg = 0.99, rp = 0.88), 100 seed weight (rg = 0.85, rp = 0.75) and weight of seed (rg = .88, rp = 0.58) were positive and significant in the case of hybrids at both phenotypic and genotypic levels. Number of flowers per plant exhibited the highest positive and significant association with pod yield (rg = 0.99, rp = 0.89) followed by number of pods per plant (rg = 0.99 and rp = 0.88).

Inter correlation studies revealed that in hybrid population, plant height, number of branches per plant, number of flowers per plant, leaf area index (90 DAP), number of pods per plant, pod weight, 100 seed weight and weight of seed showed significant positive association with all other yield components except length and breadth of seed. Seeds per pod had significant positive association with all other yield components except breadth of seed. Length of seed showed significant positive association only with seeds per pod. Breadth of seed did not have any significant association with other components.

The genotypic and phenotypic association among the traits related to bruchid resistance have been studied in parents, hybrids and F_2 population and the results are presented in Tables 14, 15 and 16.

In the case of parents, number of eggs laid by the pulse beetle during no choice test had significant positive association with number of bore holes (no choice test) (rg = 0.63), number of eggs laid during free choice test (rg = 0.99), number of adults emerged (free choice test) (rg = 0.83), number of bore holes (free

Table 13. Genotypic and phenotypic (lower and upper diagonal) correlation coefficients for 12 characters in F_1

	Plant height	Number of branches/ plant	Number of flowers/ plant	Leaf Area Index 90 DAP	Pod yield per plant	No. of pods per plant	Pod weight	Seeds per pod	100 seed weight	Length of seed	Breadth of seed	Weight of seed
Plant height		0.71*	0.57*	0.59*	0.63*	0.58*	0.73*	0.78*	0.50*	0.20	0.04	0.70*
Number of branches/ plant	0.96**		0.76*	0.48	0.70*	0.76*	0.36	0.48	0.56*	-0.08	0.08	0.60*
Number of flowers/ plant	0.75**	0.94**		0.64*	0.89*	0.99*	0.28	0.47	0.71*	0.01	0.13	0.42
Leaf Area Index (90 DAP)	0.81**	0.89**	0.97**		0.70*	0.64*	0.49*	0.48	0.48	0.32	0.03	0.49
Pod yield/plant	0.88**	0.95**	0.99**	0.91**		0.88*	0.34	0.48	0.75*	0.06	-0.09	0.58*
Number of pods/plant	0.76**	0.94**	1.00**	0.98**	0.99**		0.29	0.48	0.72*	0.02	0.12	0.43
Pod weight	1.04**	0.90**	0.67*	0.76**	0.90**	0.68*		0.80*	0.25	0.21	-0.10	0.60*
Seeds/pod	0.80**	0.87**	0.77**	0.74**	0.97**	0.77**	0.81**		0.36	0.34	0.09	0.62*
100 seed weight	0.82**	0.60**	0.73**	1.06**	0.85**	0.74**	0.80**	0.85**		0.24	-0.04	0.55*
Length of seed	0.20	-0.04	0.06	0.44	0.19	0.08	0.61	0.57*	0.44		0.01	0.18
Breadth of seed	-0.25	0.29	0.10	0.12	0.02	0.08	-0.66	-0.35	0.07	-0.07		0.03
Weight of seed	1.08**	0.98**	0.78**	0.82**	0.88**	0.78**	0.98**	0.98**	0.92**	0.32	0.13	

* Significant at 5% level

** Significant at 1% level

Table 14. Genotypic and phenotypic (lower and upper diagonal) correlation coefficients for bruchid resistance traits in parents

	Number of eggs laid (No choice)	Number of bore holes (No choice)	Number of adults emerged (No choice)	Number of eggs laid (Free choice	Number of bore holes (Free choice)	Number of adults emerged (Free choice)	Loss of weight per seed	Moisture content (harvest)	Seed coat thickness	Tannin
Number of eggs laid (No choice)		0.51	0.46	0.81*	0.57	0.62*	0.14	0.12	-0.38	-0.38
Number of bore holes (No choice)	0.63*		0.98*	0.62*	0.68*	0.67*	0.78*	0.03	-0.38	0.06
Number of adults emerged (No choice)	0.53	0.99**		0.57	0.68*	0.66*	0.75*	0.02	-0.33	0.12
Number of eggs laid (Free choice)	0.99**	0.82**	0.78**		0.58	0.64*	0.27	0.04	-0.76*	-0.14
Number of bore holes (Free choice)	0.79**	0.80**	0.78**	0.97**		0.98*	0.57	-0.29	-0.52	0.07
Number of adults emerged (Free choice)	0.83**	0.75**	0.72**	0.99**	0.98**		0.54	-0.32	-0.59*	-0.02
Loss of weight/seed	0.63*	1.02**	1.04**	0.77**	0.75**	0.70**		0.07	-0.31	0.06
Moisture content (harvest)	0.02	0.50	0.45	0.003	-0.35	-0.49	0.02		0.19	0.15
Seed coat thickness	-1.20**	-0.74*	-0.71*	-1.06**	-1.20**	-1.20**	-0.56	0.47		-0.04
Tannin	-0.37	0.08	0.16	-0.12	0.13	0.0004	-0.05	0.30	0.06	

* Significant at 5% level

** Significant at 1% level

choice test (rg = 0.79) and loss of weight per seed (rg = 0.63). Significant negative association was observed with seed coat thickness (rg = 1.2) (Table 14).

Number of adults emerged (no choice test) had significant positive association with number of bore holes (no choice test) (rg = 0.99), number of eggs laid (rg = 0.78), adults emerged (rg = 0.72) and bore holes (rg = 0.78) during free choice test and loss of weight per seed (rg = 1.04). Significant negative association was observed with seed coat thickness (rg = -0.71) (Table 14).

Number of bore holes (no choice test) showed significant positive association with number of eggs laid (no choice test) (rg = 0.63), number of adults emerged (no choice test) (rg = 0.99), number of eggs laid (rg = 0.82), adults emerged (rg = 0.75) and number of bore holes (rg = 0.80) during free choice test and loss of weight per seed (rg = 1.02). It had a significant negative association with seed coat thickness (rg = -0.74) (Table 14).

Number of eggs laid (free choice test) had significant positive association with number of eggs laid (rg = 0.99), adults emerged (rg = 0.78) and bore holes (rg = 0.82) during no choice test, adults emerged (rg = 0.99) and number of bore holes (rg = 0.97) during free choice test and loss of weight per seed (rg = 0.77). Significant negative association was observed with seed coat thickness (rg = -1.06) (Table 14).

Number of adults emerged (free choice test) had significant positive association with number of eggs laid (rg = 0.83), adults emerged (eg = 0.72) and bore holes (rg = 0.75) during no choice test, number of eggs laid (rg = 0.99) and bore holes (rg = 0.98) during free choice test and loss of weight per seed (rg = 0.70). It had a significant negative association with seed coat thickness (rg = -1.20) (Table 14).

Number of bore holes (free choice test) showed significant positive association with number of eggs laid (rg = 0.79), adults emerged (eg = 0.78) and bore holes (rg = 0.80) during no choice test, number of eggs laid (rg = 0.97) and adults emerged (rg = 0.98) during free choice test and loss of weight per seed (rg = 0.75). It had a significant negative association with seed coat thickness (rg = -1.20) (Table 14).

Loss of weight per seed showed significant positive association with number of eggs laid (rg = 0.63), adults emerged (rg = 1.04) and bore holes (rg = 1.02) during no choice test and number of eggs laid (rg = 0.77), adults emerged (rg = 0.70) and bore holes (rg = 0.75) during free choice test (Table 14).

Moisture content during harvest did not have any significant association with other characters. Seed coat thickness showed significant negative association with number of eggs laid (rg = -1.20) adults emerged (rg = -0.71) and bore holes (rg = -0.74) during no choice test and number of eggs laid (rg = -1.06), bore holes (rg = -1.20) and adults emerged (rg = -1.20) during free choice test. Tannin content showed no significant association with any other character (Table 14).

In the case of hybrids number of eggs laid (no choice test) showed significant positive association with number of eggs laid (rg = 1.01) during free choice test (Table 15).

Number of adults emerged (no choice test) showed significant positive association with number of bore holes (no choice test) (rg = 1.00) and adults emerged (rg = 0.85) and number of bore holes (rg = 0.69) during free choice test. It showed significant negative association with seed coat thickness (rg = -0.84) (Table 15).

Number of bore holes (no choice test) had significant positive association with number of adults emerged (no choice test) (rg = 1.00) and adults emerged (rg = 0.85) and number of bore holes (rg = 0.69) during free choice test. It

Table 15. Genotypic and phenotypic (lower and upper diagonal) correlation coefficients for bruchid resistance traits in F_1

	Number of eggs laid (No choice)	Number of bore holes (No choice)	Number of adults emerged (No choice)	Number of eggs laid (Free choice	Number of bore holes (Free choice)	Number of adults emerged (Free choice)	Loss of weight per seed	Moisture content (harvest)	Moisture content (storage)	Seed coat thickness	Tannin
Number of eggs laid (No choice)		0.21	0.21	0.82*	-0.34	-0.26	-0.27	0.03	-0.13	-0.06	-0.29
Number of bore holes (No choice)	0.23		1.00*	0.05	0.45	0.56*	-0.03	-0.07	-0.02	-0.38	0.06
Number of adults emerged (No choice)	0.23	1.00**		0.05	0.45	0.56*	-0.03	-0.07	-0.02	-0.38	0.06
Number of eggs laid (Free choice)	1.01**	0.25	0.25		-0.34	-0.27	-0.36	0.08	-0.04	-0.19	-0.29
Number of bore holes (Free choice)	-0.35	0.69**	0.69**	-0.37		0.91*	0.45	-0.30	-0.0007	-0.12	0.21
Number of adults emerged (Free choice)	-0.28	0.85**	0.85**	-0.24	0.94**		0.43	-0.16	0.08	-0.21	0.16
Loss of weight/seed	-0.39	0.38	0.38	-0.50	0.70**	0.74**		-0.13	0.19	0.05	0.36
Moisture content (harvest)	0.08	-0.31	-0.31	0.06	-0.54*	-0.41	0.02		0.57*	-0.06	0.007
Moisture content (storage)	-0.03	0.05	0.05	-0.02	-0.07	0.02	0.13	1.06**		-0.13	0.25
Seed coat thickness	-0.32	-0.84**	-0.84**	-0.07	-0.16	-0.42	0.07	-0.06	-0.02		-0.008
Tannin	-0.51	0.24	0.24	-0.30	0.58*	0.62*	0.44	0.17	0.40	-0.12	

* Significant at 5% level

** Significant at 1% level

had significant negative association with seed coat thickness (rg = -0.84) (Table 15).

Number of eggs laid (free choice test) showed significant positive association with number of eggs laid (rg = 1.01) during no choice test.

Number of adults emerged (free choice test) showed significant positive association with adults emerged (rg = 0.85) and number of bore holes (rg = 0.85) during no choice test, number of bore holes during free choice test (rg = 0.94), loss of weight per seed (rg = 0.74) and tannin content (rg = 0.62) (Table 15).

Number of bore holes (free choice test) showed significant positive association with adults emerged (rg = 0.69) and number of bore holes (rg = 0.69) during no choice test, number of adults emerged (free choice test) (rg = 0.94), loss of weight per seed (rg = 0.70) and tannin content (rg = 0.58). It showed significant negative association with moisture content during harvest (rg = -0.54) (Table 15).

Loss of weight per seed showed significant positive association with adults emerged (rg = 0.74) and number of bore holes (rg = 0.70) during free choice test (Table 15).

Moisture content during harvest had significant positive association with moisture content during storage (rg = 1.06) and had a significant negative association with number of bore holes during free choice test (rg = -0.54) (Table 15).

Moisture content during storage had significant positive association with moisture content during harvest (rg = 1.06). Seed coat thickness showed significant negative association with adults emerged (rg = -0.84) and number of bore holes (rg = -0.84) during no choice test (Table 15).

Tannin content showed significant positive association with adults emerged (rg = 0.62) and number of bore holes (rg = 0.58) during free choice test (Table 15).

In the case of F_2 population pod weight showed significant positive association with seeds/pod (rg = 1.08), 100 seed weight (rg = 0.98) and weight of seed (rg = 0.93) (Table 16).

Seeds per pod had significant positive association with pod weight (rg = 1.08), 100 seed weight (rg = 0.85) and weight of seed (rg = 0.90) (Table 16). Hundred seed weight showed significant positive association with pod weight (rg = 0.98), seeds per pod (rg = 0.85) and weight of seed (rg = 1.10). Weight of seed had significant positive association with pod weight (rg = 0.93), seeds per pod (rg = 0.90) and 100 seed weight (rg = 1.10) (Table 16).

Number of adults emerged during no choice test had no significant association with any other bruchid resistance trait. Number of eggs laid during free choice test showed significant positive association with moisture content during storage (rg = 0.70) and tannin content (rg = 0.54) (Table 16).

Number of adults emerged during free choice test had significant negative association with moisture content during storage (rg = -0.73). Loss of weight per seed had no significant positive association with any other character (Table 16).

Moisture content during storage had significant positive association with number of eggs laid during free choice test (rg = 0.70) and had significant negative association with number of adults emerged during free choice test (rg = -0.73). Seed coat thickness had no significant association with any other character (Table 16).

Table 16. Genotypic and phenotypic (lower and upper diagonal) correlation coefficients for seed characters and bruchid resistance traits in F_2

	Pod weight	Seeds per pod	100 seed weight	Weight of seed	No. of adults emerged (No choice)	No. of eggs laid (Free choice)	No. of adults emerged (Free choice)	Loss of weight per seed	Moisture content (storage)	Seed coat thickness	Tannin
Pod weight		0.66*	0.44	0.66*	0.04	0.18	-0.18	0.03	0.02	-0.26	0.35
Seeds per pod	1.08**		0.66*	0.55*	-0.02	0.18	-0.42	0.08	0.06	-0.26	0.21
100 seed weight	0.98**	0.85**		0.75	0.20	0.30	-0.17	0.07	0.15	-0.33	0.34
Weight of seed	0.93**	0.90**	1.10**		0.04	0.14	-0.08	0.11	0.20	-0.20	0.27
No. of adults emerged (No choice)	0.55	0.42	0.50	0.77		0.13	0.23	-0.31	-0.11	-0.49*	0.12
No. of eggs laid (Free choice)	0.33	0.15	0.23	0.21	0.66		0.05	-0.27	-0.18	-0.22	0.51
No. of adults emerged (Free choice)	-0.13	-0.39	-0.23	-0.13	0.33	0.19		-0.07	-0.22	-0.22	0.08
Loss of weight/seed	0.34	0.22	0.18	0.24	0.84	-0.37	-0.39		0.31	0.17	-0.005
Moisture content (storage)	0.56	0.55	0.41	0.27	-0.07	0.70*	-0.73**	0.29		0.36	0.34
Seed coat thickness	-0.37	-0.39	-0.34	-0.49	-0.34	-0.24	-0.20	0.04	0.15		0.03
Tannin	0.32	0.39	0.42	0.28	0.02	0.54*	0.10	0.31	0.72**	0.19	

* Significant at 5% level

** Significant at 1% level

Tannin content showed significant positive association with number of eggs laid during free choice test (rg = 0.54) and moisture content during storage (rg = 0.72) (Table 16).

Inercorrelation among seed coat thickness and yield and yield components in parents have been worked out and presented in Table 17. It was revealed that seed coat thickness had no significant positive association with yield and yield attributes except with number of branches per plant.

4.5 Combining ability analysis

Analysis of variance for combining ability for various yield attributes and bruchid resistance traits is presented in Tables 18 and 19 respectively.

There was significant difference between the lines for most of the yield attributes except for days to flowering, leaf area index (45 DAP) and pod weight. Between the testers also there was significant difference for all the observations taken except for days to flowering, leaf area index (45 DAP), pod weight and breadth of seed. For line x tester interaction there was significant difference for majority of the yield characters with the exception of number of branches per plant, number of flowers per plant, days to flowering, leaf area index (45 DAP), number of pods per plant and 100 seed weight (Table 18).

In the case of bruchid resistance traits the combining ability analysis revealed that there was significant difference between the lines for all the characters except for number of adults emerged during free choice test and seed coat thickness. Significant difference between the testers for all the characters under study except for number of eggs laid (no choice test), moisture content during harvest and storage and tannin content was observed. For line x tester interaction also there was significant difference for most of the characters with the

Table 17. Correlation coefficients between yield components and seed coat thickness

	Plant height	No. of branches/ plant	No. of flowers/ plant	Pod yield/plant	No. of pods/plant	Pod weight	Seeds/pod	100 seed weight	Length of seed	Weight of seed	Seed coat thickness
Plant height											
No. of branches/ plant	0.93**										
No. of flowers/ plant	0.97**	0.90**									
Pod yield/plant	0.98**	0.86**	0.99**								
No. of pods/Plant	0.97**	0.89**	1.00**	0.99**							
Pod weight	1.06**	0.80**	0.92**	0.92**	0.91**						
Seeds/pod	1.19**	0.81**	0.98**	1.02**	0.99**	1.19**					
100 seed weight	0.93**	1.10**	1.02**	1.03**	1.02**	0.98**	1.12**				
Length of seed	0.88**	0.37	0.66*	0.75**	0.66*	0.82**	0.94**	0.69			
Weight of seed	1.07**	0.88**	0.92**	0.97**	0.92**	0.98**	1.04**	1.09**	0.85**		
Seed coat thickness`	0.41	0.76**	0.61	0.48	0.61	0.56	-0.06	0.69	0.44	0.24	

Table 18. Anova for combining ability for yield characters

Source of variation	df	Plant height	No. of branches per plant	No. of flowers per plant	Days to flower-ing	LAI (45 DAP)	LAI (90 DAP)	Pod yield per plant	No. of pods per plant	Pod weight	Seeds per pod	100 seed weight	Length of seed	Breadth of seed	Weight of seed
Gca (lines)	3	2.90**	69.00**	16000**	17.00	0.23	0.69**	110000**	8100**	0.26	9.0*	50**	0.075**	0.048*	0.0022**
gca (testers)	2	3.40**	99.00**	23000**	2.50	0.30	0.76**	92000**	12000**	0.21	27*	25**	0.072*	0.0033	0.0019**
sca (line x tester)	6	1.70**	7.90	1800	21.00	0.034	0.19*	16000**	890	0.24*	7.3*	10	0.061**	0.035*	0.0013**
Error	22	0.35	8.00	840	14.00	0.11	0.062	4600	410	0.086	2.7	4.0	0.014	0.01	0.0002
σ^2 gca		0.13	7.20	1688	-1.10	0.02	0.05	8097	868	-0.0005	1.0	2.5	0.001	-0.0008	0.00007
σ^2 sca		0.46	0	319	2.20	-0.03	0.04	3852	158	0.051	2.5	67	0.008	0.0076	0.00036

* Significant at 5% level

** Significant at 1% level

Table 19. Anova for combining ability for bruchid resistance traits

Source of variation	df	No. of eggs laid (No choice)	No. of bore holes (No choice)	No. of adults emerged (No choice)	No. of eggs laid (Free choice)	No. of bore holes (Free choice)	No. of adults emerged (Free choice)	Loss of weight per seed	Moisture content (harvest)	Moisture content (storage)	Seed coat thickness	Tannin
gca (lines)	3	540**	14*	14*	200**	1.7*	1.1	0.0031**	0.39**	0.81*	0.00082	19**
gca (testers)	2	53	19*	19*	61**	7.0**	5.5**	0.00093*	0.14	0.21	0.0038*	0.41
sca (Line x tester)	6	230**	3.7	3.6	72**	2.7**	1.6*	0.0017**	0.90	0.84**	0.0011*	3.3*
Error	22	30	3.4	3.4	7.8	0.43	0.47	0.00021	0.049**	0.21	0.00032	1.2
σ^2 gca		6.3	1.2	1.2	5.3	0.15	0.16	0.00002	-0.06	-0.03	0.0001	0.62
σ^2 sca		66.4	0	0	21.4	0.7	0.39	0.00046	0.28	0.2	0.0002	0.66

* Significant at 5% level

** Significant at 1% level

exception of number of bore holes and adults emerged during no choice test (Table 19).

4.6 General combining ability for yield characters (Parents)

Results of estimates of general combining ability effects for yield characters of parental lines are presented in Table 20.

4.6.1 *Plant height*

The gca of lines ranged between -0.43 (V 240) and 0.82 (Kanakamoni) and that of testers between -0.44 (EC 367711) and 0.59 (EC 390231). The line Kanakamoni (0.82) and the tester EC 390231 (0.59) recorded positive significant gca. The line V 16 (-0.43) and the tester EC 367711 (-0.44) recorded negative significant gca.

4.6.2 *Number of branches per plant*

In the parental lines the gca ranged from -2.53 (V 16) to 3.81 (Kanakamoni). In the case of testers the range was between -2.58 (EC 367711) and 3.08 (EC 390231). The line Kanakamoni (3.81) and the tester EC 390231 (3.08) showed significant positive gca and the lines V 16 (-2.53) and C 152 (-1.42) and the testers EC 367711 (-2.58) and IC 201092 (-0.50) showed significant negative gca.

4.6.3 *Number of flowers per plant*

The gca of lines ranged from -22.00 (V 240 and C 152) to 63.56 (Kanakamoni) and testers from -41.94 (EC 367711) to 45.22 (EC 390231). The lines Kanakamoni (63.56) and the tester EC 390231 (45.22) showed significant positive gca and the lines V 240 (-22.00), V 16 (-19.56) and C 152 (-22.00) and the testers EC 367711 (-41.94) and IC 201092 (-3.28) had significant negative gca.

Table 20. Estimate of gca for yield characters (Parents)

Genotypes	Plant height	No. of branches per plant	No. of flowers per plant	Days to flower-ing	LAI (45 DAP)	LAI (90 DAP)	Pod yield per plant	No. of pods per plant	Pod weight	Seed per pod	100 seed weight	Length of seed	Breadth of seed	Weight of seed
V240	-0.10	0.14	-22.00*	1.28*	-0.08	-0.18	-81.06*	-16.11*	-0.13	-0.50*	-0.99*	-0.09	0.08	0.00
V16	-0.43*	-2.53*	-19.56*	0.94*	0.01	-0.02	-31.14*	-13.67*	-0.12	-0.50*	1.27*	0.12	0.01	0.00
Kanakamoni	0.82*	3.81*	63.56*	-0.50*	0.22	0.40*	162.68*	44.89*	0.24	1.50*	2.51*	0.01	0.01	0.02
C152	-0.29	-1.42*	-22.00*	-1.72*	-0.15	-0.20	-50.48*	-15.11*	0.02	-0.50*	-2.79*	-0.04	-0.10	-0.02
EC390231	0.59*	3.08*	45.22*	0.03	0.17	0.24	94.55*	32.44*	0.15	1.58*	1.38*	0.05	0.00	0.01
EC367711	-0.44*	-2.58*	-41.94*	-0.47*	-0.15	-0.27	-79.32*	-30.56*	-0.07	-0.17	-1.49*	0.04	-0.02	-0.01
IC201092	-0.15	-0.50*	-3.28*	0.44*	-0.01	0.03	-15.23*	-1.89*	-0.08	-1.42*	0.11	-0.09	0.02	-0.01

* Significant at 5% level

4.6.4 *Days to flowering*

The gca of lines ranged from -1.72 (C 152) to 1.28 (V 240) and testers from -0.47 (EC 367711) to 0.44 (IC 201092). V 240 (1.28) and V 16 (0.94) among the lines and IC 201092 (0.44) among the testers recorded positive significant gca. Lines Kanakamoni (-0.50) and C 152 (-1.72) and the tester EC 367711 (-0.47) recorded negative significant gca.

4.6.5 *Leaf area index (45 DAP)*

The gca of lines and testers ranged from -0.15 (C 152) to 0.22 (Kanakamoni) and from -0.15 (EC 367711) to 0.17 (EC 390231) respectively. None of the lines and testers showed significant gca.

4.6.6 *Leaf area index (90 DAP)*

The gca range of lines was -0.20 (C 152) to 0.40 (Kanakamoni) and that of testers from -0.27 (EC 367711) to 0.24 (EC 390231). The line Kanakamoni (0.40) showed significant positive gca.

4.6.7 *Pod yield per plant*

The gca ranged from -81.06 (V 240) to 162.68 (Kanakamoni) for lines and from -79.32 (EC 367711) to 94.55 (EC 390231) for testers. The line Kanakamoni (162.68) and the tester EC 390231 (94.55) had significant positive gca and the lines V 240 (-81.06), V 16 (-31.14) and C 152 (-50.48) and the testers EC 367711 (-79.32) and IC 201092 (-15.23) with negatively significant values.

4.6.8 *Number of pods per plant*

The gca for lines and testers ranged from -16.11 (V 240) to 44.89 (Kanakamoni) and from -30.56 (EC 367711) to 32.44 (EC 390231) respectively. The line Kanakamoni (44.89) and the tester EC 390231 (32.44) had significant positive gca and the lines V 240 (-16.11) V 16 (-13.67) and C 152 (-15.11) and the testers EC 367711 (-30.56) and IC 201092 (-1.89) recorded significant negative gca.

4.6.9 *Pod weight*

The gca of lines ranged from -0.13 (V 240) to 0.24 (Kanakamoni) and that of testers from -0.08 (IC 201092) to 0.15 (EC 390231). None of the lines and testers showed significant gca values.

4.6.10 *Seeds per pod*

The gca of lines and testers ranged from -0.50 (V 240, V 16 and C 152) to 1.50 (Kanakamoni) and from -1.42 (IC 201092) to 1.58 (EC 390231). Kanakamoni (1.50) among the lines and EC 390231 (1.58) among the testers recorded significant positive gca and the lines V 240, V 16 and C 152 (-0.50) and the tester IC 201092 (-1.42) recorded significant negative gca.

4.6.11 *100 seed weight*

The range of gca of lines was between -2.79 (C 152) and 2.51 (Kanakamoni) and that of testers from -1.49 (EC 367711) to 1.38 (EC 390231). The lines V 16 (1.27) and Kanakamoni (2.51) and the tester EC 390231 (1.38) recorded positive significant gca. The lines V 240 (-0.99) and C 152 (-2.79) and the tester EC 367711 (-1.49) recorded negative significant gca.

4.6.12 *Length of seed*

The range of gca of lines was between -0.09 (V 240) and 0.12 (V 16) and of testers between -0.09 (IC 201092) and 0.05 (EC 390231). None of the lines and testers showed significant gca values.

4.6.13 *Breadth of seed*

The gca of lines ranged from -0.10 (C 152) to 0.08 (V 240) and for testers from -0.02 (EC 367711) to 0.02 (IC 201092).

4.6.14 *Weight of seed*

The gca of lines ranged from -0.02 (C 152) to 0.02 (Kanakamoni) and testers from -0.01 (EC 367711 and IC 201092) to 0.01 (EC 390231).

4.7 General combining ability for bruchid resistance traits (Parents)

The general combining ability effect of traits related to bruchid resistance in parents are given in Table 21.

4.7.1 *Number of eggs laid (No choice test)*

The gca of lines and testers ranged from -8.00 (V 16) to 10.00 (Kanakamoni) and from -2.42 (EC 390231) to 1.33 (EC 367711) respectively. The lines V 240 (1.67) and Kanakamoni (10.00) and testers EC 367711 (1.33) and IC 201092 (1.08) recorded significant positive gca and the lines V 16 (-8.00) and C 152 (-3.67) and tester EC 390231 (-2.42) recorded significant negative gca.

4.7.2 *Number of bore holes (No choice test)*

The gca of lines ranged from -1.83 (C 152) to 0.83 (Kanakamoni) and testers from -1.33 (IC 201092) to 1.17 (EC 390231). V 240 (0.50), V 16 (0.50) and Kanakamoni (0.83) among the lines and EC 390231 (1.17) among the testers showed significant positive gca. The line C 152 (-1.83) and the tester IC 201092 (-1.33) recorded significant negative gca.

4.7.3 *Number of adults emerged (No choice test)*

The gca of lines and testers ranged from -1.83 (C 152) to 0.83 (Kanakamoni) and from -1.33 (IC 201092) to 1.17 (EC 390231) respectively. The

Table 21. Estimate of gca for bruchid resistance traits (Parents)

Genotypes	No. of eggs laid (No choice)	No. of bore holes (No choice)	No. of adults emerged (No choice)	No. of eggs laid (Free choice)	No. of bore holes (Free choice)	No. of adults emerged (Free choice)	Loss of weight per seed	Moisture content (harvest)	Moisture content (storage)	Seed coat thickness	Tannin content
V240	1.67*	0.50*	0.50*	2.17*	0.50*	0.25	-0.01	-0.20	-0.03	-0.01	1.21*
V16	-8.00*	0.50*	0.50*	-4.50*	0.17	0.36*	0.02	0.26	0.42*	0.00	1.26*
Kanakamoni	10.00*	0.83*	0.83*	5.50*	-0.50*	-0.31	-0.02	-0.13	-0.29	0.00	-1.64*
C152	-3.67*	-1.83*	-1.83*	-3.17*	-0.17	-0.31	0.01	0.08	-0.09	0.01	-0.83*
EC390231	-2.42*	1.17*	1.17*	-2.17*	0.83*	0.78*	0.01	-0.06	0.03	-0.02	0.17
EC367711	1.33*	0.17	0.17	-0.17	-0.17	-0.31	0.00	0.12	0.11	0.01	-0.20
IC201092	1.08*	-1.33*	-1.33*	2.33*	-0.67*	-0.47*	-0.01	-0.06	-0.14	0.01	0.03

* Significant at 5% level

lines V 240 (0.50), V 16 (0.50) and Kanakamoni (0.83) and the tester EC 390231 (1.17) showed significant positive gca. The line C 152 (-1.83) and the tester IC 201092 (-1.33) showed significant negative gca.

4.7.4 *Number of eggs laid (Free choice test)*

The gca of lines ranged from -4.50 (V 16) to 5.50 (Kanakamoni) and that of testers from -2.17 (EC 390231) to 2.33 (IC 201092). The lines V 240 (2.17) and Kanakamoni (5.50) and the tester IC 201092 (2.33) recorded positive significant gca. V 16 (-4.50) and C 152 (-3.17) among the lines and EC 390231 (-2.17) among the testers recorded significant negative gca.

4.7.5 *Number of bore holes (Free choice test)*

The range of gca of lines was between -0.50 (Kanakamoni) and to 0.50 (V 240) and of testers between -0.67 (IC 201092) and 0.83 (EC 390231). The line V 240 (0.5) and the tester EC 390231 (0.83) recorded significant positive gca and the line Kanakamoni (-0.50) and the tester IC 201092 (-0.67) showed significant negative gca.

4.7.6 *Number of adults emerged (Free choice test)*

The gca of lines ranged from -0.31 (Kanakamoni and C 152) to 0.36 (V 16) and testers from -0.47 (IC 201092) to 0.78 (EC 390231). The line V 16 (0.36) and tester EC 390231 (0.78) showed significant positive gca and tester IC 201092 (-0.47) showed significant negative gca.

4.7.7 *Loss of weight per seed*

The gca of lines and testers ranged from -0.02 (Kankamoni) to 0.02 (V 16) and from -0.01 (IC 201092) to 0.01 (EC 390231) respectively. None of the lines and testers showed significant gca.

4.7.8 *Moisture content (harvest)*

The gca of lines ranged from -0.20 (V 240) to 0.26 (V 16) and of testers from -0.06 (EC 390231 and IC 201092) to 0.12 (EC 367711). None of the lines and testers recorded significant gca values.

4.7.9 *Moisture content (storage)*

The gca ranged from -0.29 (Kanakamoni) to 0.42 (V 16) for lines and from -0.14 (IC 201092) to 0.11 (EC 367711) for testers. The line V 16 (0.42) had significant positive gca.

4.7.10 *Seed coat thickness*

The gca of lines ranged from -0.01 (V 240) to 0.01 (C 152) and for testers from -0.02 (EC 390231) to 0.01 (EC 367711 and IC 201092). None of the lines and testers recorded significant gca.

4.7.11 *Tannin content*

The gca of lines ranged from -1.64 (Kanakamoni) to 1.26 (V 16) and of testers from -0.20 (EC 367711) to 0.17 (EC 390231). The lines V 240 (1.21) and V 16 (1.26) recorded significant positive gca and the lines Kanakamoni (-1.64) and C 152 (-0.83) recorded significant negative gca.

4.8 Specific combining ability for yield characters (Hybrids)

Estimates of specific combining ability effects for yield attributes in twelve hybrid combinations were studied and the results are presented in Table 22.

4.8.1 *Plant height*

The sca of hybrids studied ranged between -0.91 (Kanakamoni/ EC 390231) and 1.05 (Kanakamoni/EC 367711). Out of twelve hybrids studied

Table 22. Estimate of sca for yield characters (Hybrids)

Genotypes	Plant height	No. of branches per plant	No. of flowers per plant	Days to flower-ing	LAI (45 DAP)	LAI (90 DAP)	Pod yield per plant	No. of pods per plant	Pod weight	Seeds per pod	100 seed weight	Length of seed	Breadth of seed	Weight of seed
V240xEC390231	0.07	0.69	12.00*	0.64	0.05	0.28	32.94*	8.78*	0.03	0.75*	0.60	0.05	0.02	0.01
V240xEC367711	-0.67	-0.97*	5.50*	1.14*	-0.07	-0.29	2.68*	3.11*	-0.19	-0.50	-0.50	-0.14	-0.03	-0.01
V240xIC201092	0.61	0.28	-17.50*	-1.78*	0.02	0.01	-35.63*	-11.89*	0.16	-0.25	-0.10	0.09	0.01	0.01
V16xEC390231	0.24	-1.64*	-8.78*	0.31	0.00	0.14	-12.27*	-4.67*	0.23	0.75*	1.39*	0.14	-0.11	0.00
V16xEC367711	-0.23	0.03	9.72*	0.47	-0.08	-0.02	-8.23*	5.67*	-0.26	-1.50*	-0.44	-0.11	0.01	-0.01
V16xIC 201092	-0.01	1.61*	-0.94*	-0.78*	0.08	-0.11	20.50*	-1.00*	0.03	0.75*	-0.95*	-0.02	0.11	0.01
Kanakamoni x EC390231	-0.91*	-0.97*	-16.56*	-0.25	-0.06	-0.23	-99.54*	-12.89*	-0.31	-2.25*	-3.11*	-0.05	0.12	-0.02
Kanakamoni x EC367711	1.05*	1.36*	-22.39*	1.92*	0.02	0.08	11.41*	-14.89*	0.43	1.50*	1.22*	0.06	-0.09	0.03
Kanakamoni x IC 201092	-0.14	-0.39	38.94*	-1.67*	0.04	0.15	88.13*	27.78*	-0.12	0.75*	1.90*	-0.01	-0.03	0.00
C152xEC390231	0.60	1.92*	13.33*	-0.69	0.00	-0.19	78.87*	8.78*	0.06	0.75*	1.13*	-0.13	-0.03	0.02
C152xEC367711	-0.14	-0.42	7.17*	-3.53*	0.14	0.23	-5.86*	6.11*	0.01	0.50	-0.28	0.19	0.12	0.00
C152xIC201092	-0.46	-1.50*	20.50*	4.22*	-0.14	-0.05	-73.01*	-14.89*	-0.07	-1.25*	-0.85*	-0.06	-0.08	-0.01

* Significant at 5% level

Kanakamoni/EC 367711 (1.05) recorded significant positive sca and Kanakamoni/EC 390231 (-0.91) recorded significant negative sca.

4.8.2 *Number of branches per plant*

The sca ranged from -1.64 (V 16/EC 390231) to 1.92 (C 152/ EC 390231). The hybrids V 16/IC 201092 (1.61), Kanakamoni/EC 367711 (1.36) and C 152/EC 390231 (1.92) recorded significant positive sca and the hybrids V 240/EC 367711 (-0.97), V 16/EC 390231 (-1.64), Kanakamoni/EC 390231 (-0.97) and C 152/IC 201092 (-1.50) recorded significant negative sca.

4.8.3 *Number of flowers per plant*

The sca of hybrids ranged from -22.39 (Kanakamoni/ EC367711) to 38.94 (Kanakamoni/IC 201092). The hybrids V 240/EC 390231 (12.00), V 240/ EC 367711 (5.50), V 16/EC 367711 (9.72), Kanakamoni /IC 201092 (38.94), C 152/EC 390231 (13.33), C 152/EC 367711 (7.17) and C 152/IC 201092 (20.50) recorded significant positive sca. The hybrids V 240/IC 201092 (-17.50), V 16/ EC 390231 (-8.78), V 16/IC 201092 (-0.94), Kanakamoni/EC 390231 (-16.56) and Kanakamoni/EC 367711 (-22.39) recorded significant negative sca.

4.8.4 *Days to flowering*

The sca ranged from -3.53 (C 152/EC 367711) to 4.22 (C 152/ IC 201092). The hybrids V 240/EC 367711 (1.14), Kanakamoni/EC 367711 (1.92) and C 152/IC 201092 (4.22) recorded significant positive sca and the hybrids V 240/IC 201092 (-1.78), V 16/IC 201092 (-0.78), Kanakamoni/IC 291092 (-1.67) and C 152/EC 367711 (-3.53) recorded significant negative sca.

4.8.5 *Leaf area index (45 DAP)*

The sca of hybrids ranged from -0.14 (C 152/IC 201092) to 0.14 (C 152/EC 367711). None of the hybrids showed significant sca.

4.8.6 *Leaf area index (90 DAP)*

The sca of hybrids ranged from -0.29 (V 240/EC 367711) to 0.28 (V 240/EC 390231). None of the hybrids showed significant sca.

4.8.7 *Pod yield per plant*

The sca of hybrids ranged from -99.54 (Kanakamoni/EC 390231) to 88.13 (Kanakamoni/IC 201092). The hybrids V 240/EC 390231 (32.94), V 240/EC 367711 (2.68), V 16/IC 201092 (20.50), Kanakamoni/EC 367711 (11.41), Kanakamoni/IC 201092 (88.13) and C 152/EC 390231 (78.87) recorded significant positive sca. The hybrids V 240/IC 201092 (-35.63), V 16/390231 (-12.27), V 16/EC 367711 (-8.23), Kanakamoni/EC 390231 (-99.54), C 152/EC 367711 (-5.86) and C 152/IC 201092 (-73.01) recorded significant negative sca.

4.8.8 *Number of pods per plant*

The sca of hybrids ranged from -14.89 (C 152/IC 201092 and Kanakamoni/EC 367711) to 27.78 (Kanakamoni/IC 201092).

The hybrids V 240/EC 390231 (8.78), V 240/EC 367711 (3.11), V 16/EC 367711 (5.67), Kanakamoni/IC 201092 (27.78), C 152/EC 390231 (8.78) and C 152/EC 367711 (6.11) recorded significant positive sca and the hybrids V 240/IC 201092 (-11.89), V 16/EC 390231 (-4.67), V 16/IC 201092 (-1.00), Kanakamoni/EC 390231 (-12.89), Kanakamoni/EC 367711 (-14.89) and C 152/IC 201092 (-14.89) recorded significant negative sca.

4.8.9 *Pod weight*

The sca of hybrids ranged from -0.31 (Kanakamoni/EC 390231) to 0.43 (Kanakamoni/EC 367711). None of the hybrids showed significant sca.

4.8.10 *Seeds per pod*

The sca of hybrids ranged from -2.25 (Kanakamoni/ EC 390231) to 1.50 (Kanakamoni/EC 367711). The hybrids V 16/EC 390231 (0.75), V 16/IC 201092 (0.75), Kanakamoni/EC 367711 (1.50), Kanakamoni/IC 201092 (0.75), C 152/ EC 390231 (0.75) and V 240/EC 390231 (0.75) recorded significant positive sca and the hybrids V 16/EC 367711 (-1.50), Kanakamoni/EC 390231 (-2.25) and C 152/IC 201092 (-1.25) recorded significant negative sca.

4.8.11 *100 seed weight*

The sca of hybrids ranged from -3.11 (Kanakamoni/EC 390231) to 1.90 (Kanakamoni/IC 201092). The hybrids V 16/EC 390231 (1.39), Kanakamoni/ EC 367711 (1.22), Kanakamoni/IC 201092 (1.90) and C 152/EC 390231 (1.13) recorded significant positive sca and the hybrids V 16/IC 201092 (-0.95), Kanakamoni/EC 390231 (-3.11) and C 152/IC 201092 (-0.85) recorded significant negative sca.

4.8.12 *Length of seed*

The sca of hybrids ranged between -0.14 (V 240/EC 367711) and 0.19 (C 152/EC 367711). None of the hybrids showed significant sca.

4.8.13 *Breadth of seed*

The sca ranged from -0.11 (V 16/EC 390231) to 0.12 (Kanakamoni/ EC 390231). None of the hybrids had significant sca.

4.8.14 *Weight of seed*

The sca of hybrids ranged from -0.02 (Kanakamoni/EC 390231) to 0.03 (Kanakamoni/EC 367711). None of the hybrids recorded significant sca.

4.9 Specific combining ability for bruchid resistance traits (Hybrids)

The specific combining ability effects of various bruchid resistance traits studied in twelve hybrid combinations are presented in Table 23.

4.9.1 *Number of eggs laid (No choice test)*

The sca of hybrids ranged from -8.33 (C 152/EC 367711) to 12.33 (V 240/EC 367711). The hybrids V 240/EC 367711 (12.33), V 16/IC 201092 (6.25), Kanakamoni/EC 390231 (5.75), C 152/EC 390231 (3.42) and C 152/ IC 201092 (4.92) recorded significant positive sca and the hybrids V 240/ EC 390231 (-6.92), V 240/IC 201092 (-5.42), V 16/EC 390231 (-2.25), V 16/ EC 367711 (-4.00), Kanakamoni/IC 201092 (-5.75) and C 152/EC 367711 (-8.33) showed significant negative sca.

4.9.2 *Number of bore holes (No choice test)*

The sca of hybrids ranged from -1.17 (C 152/EC 367711) to 1.33 (C 152/IC 201092). The hybrids Kanakamoni/EC 367711 (1.17) and C 152/ IC 201092 (1.33) recorded significant positive sca. The hybrids V 240/IC 201092 (-1.00), Kanakamoni/EC 390231 (-0.83) and C 152/EC 367711 (-1.17) recorded significant negative sca.

4.9.3 *Number of adults emerged (No choice test)*

The sca of hybrids ranged from -1.17 (C 152/EC 367711) to 1.33 (C 152/IC 201092). The hybrids Kanakamoni/EC 367711 (1.17) and C 152/ IC 201092 (1.33) recorded significant positive sca and the hybrids V 240/ IC 201092 (-1.00), Kanakamoni/EC 390231 (-0.83) and C 152/EC 367711 (-1.17) recorded significant negative sca.

Table 23. Estimate of sca for bruchid resistance traits (Hybrids)

Genotypes	No. of eggs laid (No choice)	No. of bore holes (No choice)	No. of adults emerged (No choice)	No. of eggs laid (Free choice)	No. of bore holes (Free choice)	No. of adults emerged (Free choice)	Loss of weight per seed	Moisture content (harvest)	Moisture content (storage)	Seed coat thickness	Tannin content
V240xEC390231	-6.92*	0.50	0.50	-3.17*	1.50*	1.00*	0.02	-0.65	-0.30	0.03	0.17
V240xEC367711	12.33*	0.50	0.50	4.83*	-0.50	-0.25	0.01	0.17	0.02	-0.02	-0.17
V240xIC201092	-5.42*	-1.00*	-1.00*	-1.67*	-1.00*	-0.75*	-0.03	0.48	0.28	0.00	0.01
V16xEC390231	-2.25*	0.50	0.50	-2.50*	-0.17	-0.11	0.00	-0.31	-0.54	-0.01	0.41
V16xEC367711	-4.00*	-0.50	-0.50	-0.50	-0.17	-0.03	-0.02	0.31	0.51	0.00	-0.04
V16xIC 201092	6.25*	0.00	0.00	3.00*	0.33	0.14	0.02	0.00	0.03	0.01	-0.36
Kanakamoni x EC390231	5.75*	-0.83*	-0.83*	3.50*	-0.50	-0.44	0.00	0.68	0.77*	0.00	1.12
Kanakamoni x EC367711	0.00	1.17*	1.17*	1.50*	0.50	0.64	0.00	-0.17	-0.31	0.00	-0.45
Kanakamoni x IC 201092	-5.75*	-0.33	-0.33	-5.00*	0.00	-0.19	0.00	-0.52	-0.46	-0.01	-0.68
C152xEC390231	3.42*	-0.17	-0.17	2.17*	-0.83*	-0.44	-0.02	0.27	0.07	-0.01	-1.70
C152xEC367711	-8.33*	-1.17*	-1.17*	-5.83*	0.17	-0.36	0.00	-0.31	-0.21	0.02	0.66
C152xIC201092	4.92*	1.33*	1.33*	3.67*	0.67	0.81*	0.02	0.04	0.14	0.00	1.04*

* Significant at 5% level

4.9.4 *Number of eggs laid (Free choice test)*

The sca of hybrids ranged from -5.83 (C 152/EC 367711) to 4.83 (V 240/EC 367711). The hybrids V 240/EC 367711 (4.83), V 16/IC 201092 (3.00), Kanakamoni/EC 390231 (3.50), Kanakamoni/EC 367711 (1.50), C 152/EC 390231 (2.17) and C 152/IC 201092 (3.67) recorded significant positive sca. The hybrids V 240/EC 390231 (-3.17), V 240/IC 201092 (-1.67), V 16/EC 390231 (-2.50), V 16/EC 367711 (-0.50), Kanakamoni/IC 201092 (-5.00) and C 152/EC 367711 (-5.83) recorded significant negative sca.

4.9.5 *Number of bore holes (Free choice test)*

The sca of hybrids ranged from -1.00 (V 240/IC 201092) to 1.50 (V 240/EC 390231). The hybrid V 240/EC 390231 (1.50) recorded significant positive sca and the hybrids V 240/IC 201092 (-1.00) and C 152/EC 390231 (-0.83) recorded significant negative sca.

4.9.6 *Number of adults emerged (Free choice test)*

The sca of hybrids ranged from -0.75 (V 240/IC 201092) to 1.00 (V 240/EC 390231). V 240/EC 390231 (1.00) and C 152/IC 201092 (0.81) recorded significant positive sca and the hybrid V 240/IC 201092 (-0.75) showed significant negative sca.

4.9.7 *Loss of weight per seed*

The sca of hybrids ranged from -0.03 (V 240/IC 201092) to 0.02 (C 152/IC 201092, V 16/IC 201092 and V 240/EC 390231). None of the hybrids had significant sca.

4.9.8 *Moisture content during harvest*

The sca of hybrids ranged from -0.65 (V 240/EC 390231) to 0.68 (Kanakamoni/EC 390231). None of the hybrids recorded significant sca.

4.9.9 *Moisture content during storage*

The sca of hybrids ranged from -0.54 (V 16/EC 390231) to 0.77 (Kanakamoni/EC 390231). The hybrid Kanakamoni/EC 390231 (0.77) had significant positive sca.

4.9.10 *Seed coat thickness*

The sca of hybrids ranged from -0.02 (V 240/EC 367711) to 0.03 (V 240/EC 390231). None of the hybrids had significant sca.

4.9.11 *Tannin content*

The sca of hybrids ranged from -1.70 (C 152/EC 390231) to 1.12 (Kanakamoni/EC 390231). The hybrid C 152/IC 201092 (1.04) recorded significant positive sca.

Discussion

5. DISCUSSION

Pulse beetle (*Callosobruchus* sp.) is one of the most destructive storage pests of cowpea that causes considerable losses, both in yield and quality. Most of the high yielding cultivated varieties are highly susceptible to this storage pest and the control of this pest poses a serious problem in cowpea production. The only effective, cheap and convenient way to control this pest is growing resistant varieties through genetic manipulation.

Information on the nature of inheritance of yield and its component characters and identification of parents showing genetic prepotency for yield are the prerequisites in any successful breeding programme. So the present experiment was conducted to study the genetic parameters such as genetic variability, heritability, genetic advance and genetic gain for yield and bruchid resistance traits in parental lines, F_1 and F_2 generations in cowpea. The association of various characters with respect to yield and their inter correlations and the combining ability of parental lines and hybrid combinations to transmit the desirable traits to offspring were also studied. The results from the present study are discussed in the following sections.

5.1 Genetic variability

The development of an effective plant breeding programme is dependant upon the existence of genetic variability. The efficiency of selection largely depends upon the magnitude of genetic variability present in the plant population. An insight into the magnitude of variability present in the gene pool of a crop species is of utmost importance for starting a judicious plant breeding programme.

Many workers have reported the existence of very high variability in respect of several vegetative, reproductive and qualitative characters in cowpea.

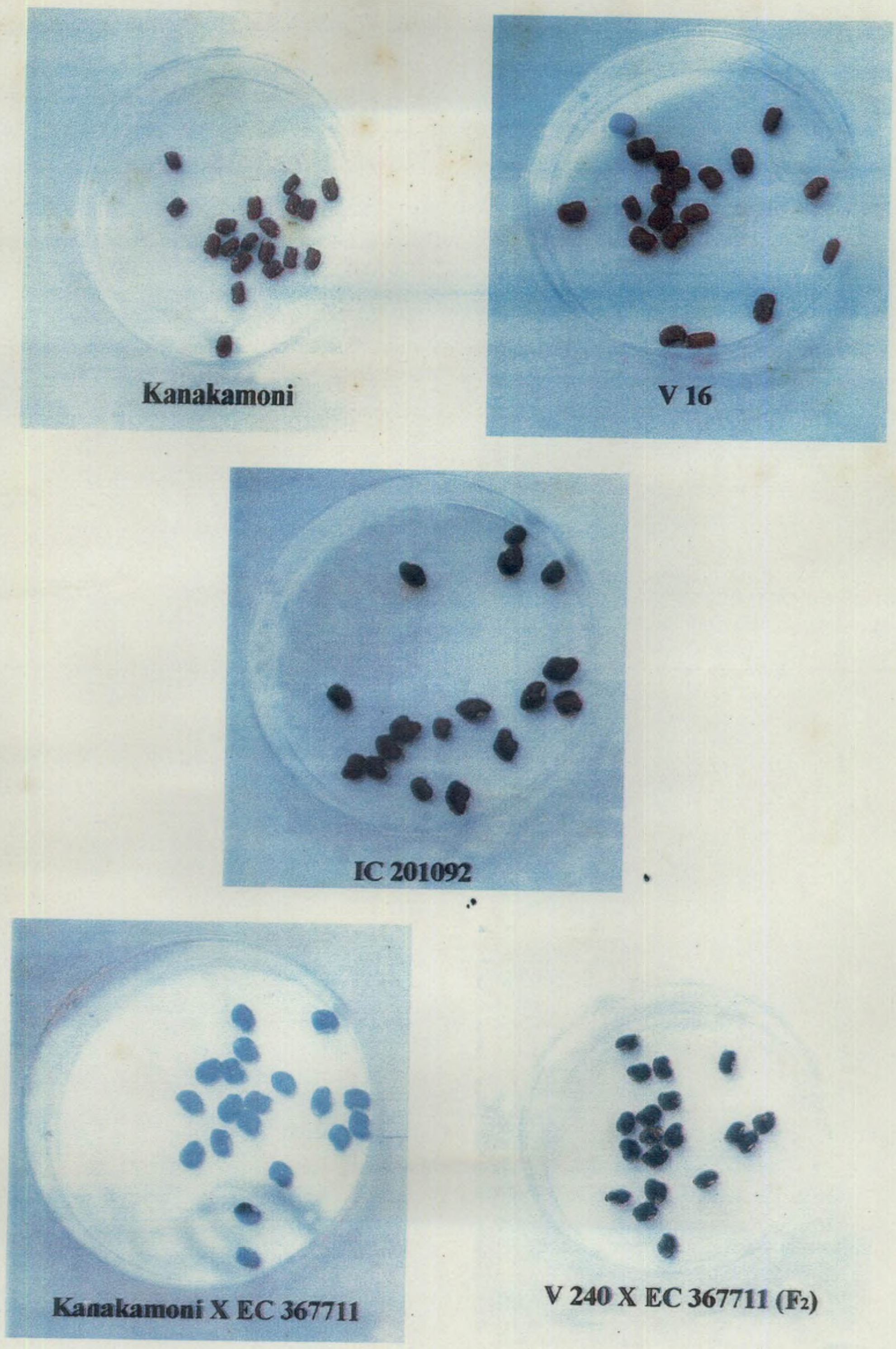
Also, genetic variability with respect to bruchid resistance has been reported in different genotypes of cowpea. The components of variation due to phenotype and genotype were studied in the present investigation.

The characters namely plant height, number of branches per plant, number of flowers per plant, pod yield per plant, number of pods per plant, pod weight, seeds per pod, 100 seed weight, length and weight of seed differed significantly in parents and hybrids. A field view of the hybrids are shown in Plate 2. The investigations by Lakshmi and Goud (1977), Chandrika (1979), Ramachandran *et al.* (1980), Jalajakumari (1981), Savithramma (1992) and Golasangi *et al.* (1995) have reported a wide range of variability for most of the characters in cowpea.

Genetic variability among genotypes for characters with respect to bruchid resistance was observed. The characters namely number of eggs laid, number of adults emerged, and number of bore holes produced in both no choice and free choice tests differed significantly in parents and hybrids (Plate 3). Loss of weight per seed, moisture content during storage, seed coat thickness and tannin content also expressed significant difference in parents and hybrids. In the case of F_2, pod weight, seeds/pod, 100 seed weight, weight of seed, number of eggs laid during no choice and free choice tests, number of adults emerged during free choice test, loss of weight per seed, moisture content during storage, seed coat thickness and tannin content showed significant difference. Khokhar and Singh (1987) also reported that the oviposition, adult emergence, grain infestation, weight loss and food consumed per grub differed significantly in different genotypes of pigeon pea. Ofuga and Credland (1995) have observed that percentage egg hatch on the different cowpea varieties did not differ significantly in no choice test. Gupta and Mishra (1970) have shown that thickness of the seed coat appeared to be an important reason for different preferences by the pulse beetle and cowpea genotypes show significant difference in seed coat thickness. Marconi *et al.*

Plate 2. Field view of hybrids

Plate 3. No choice test



(1997) observed significant difference among cowpea genotypes for tannin content.

5.2 Genotypic and phenotypic coefficients of variation

High gcv and pcv for plant height, number of flowers per plant, pod yield per plant and number of pods per plant in parents and hybrids indicate these characters have greater scope for genetic improvement through selection. Vardhan and Savithramma (1998a) reported high pcv and gcv for plant height, green pod yield and pods/plant in cowpea. Similar results were also reported by Vaid and Singh (1983) for yield per plant and Lakshmi and Goud (1977) for plant height. Jalajakumari (1981) have also reported high gcv with heritability for all the characters studied in cowpea. Moderate level of variability was observed for number of branches, 100 seed weight and length and weight of seed in parents and hybrids. Hence these characters are also useful in the genetic improvement programme. The scope of improvement through selection is less for days to flowering, as it was observed to have low gcv and pcv. Genotypic and phenotypic coefficients of variation of yield characters in parents and F_1 are presented in Fig.1 and 2.

From the results it is observed that almost all the characters are influenced by environmental factors, as the pcv for all the characters were higher than gcv. Leaf area index was the character, most influenced by the environment. Any genotype possessing stability in different environments with considerably good yield is of practical importance in plant breeding programme. Closeness in gcv and pcv values in the characters number of flowers per plant, pod yield per plant and number of pods per plant shows that these characters are less influenced by environment. Similar findings were reported by Chattopadhyay *et al.* (1997).

In the case of bruchid resistance traits high pcv and gcv were observed for number of eggs laid, number of adults emerged and number of bore holes

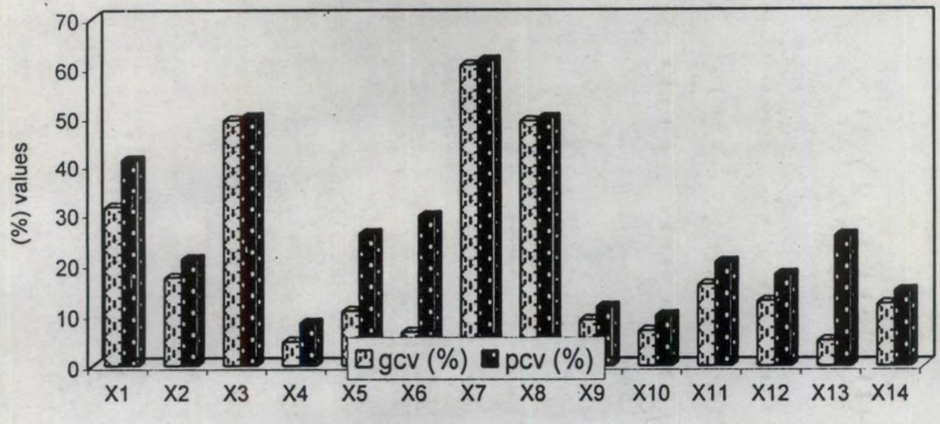


Fig. 1. Genotypic and phenotypic coefficients of variation of yield characters in parents

X1 - Plant height (m)
X2 - No. of branches/plant
X3 - No. of flowers/plant
X4 - Days to flowering
X5 - Leaf Area Index (45 DAP)
X6 - Leaf Area Index (90 DAP)
X7 - Pod yield per plant (g)
X8 - No. of pods per plant
X9 - Pod weight (g)
X10 - Seeds per pod
X11 - 100 seed weight (g)
X12 - Length of seed (cm)
X13 - Breadth of seed (cm)
X14 - Weight of seed (g)

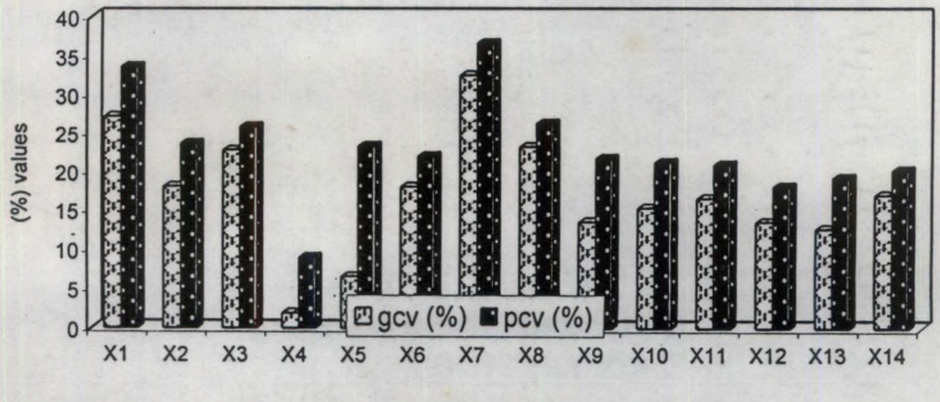


Fig. 2. Genotypic and phenotypic coefficients of variation of yield characters in F_1

X1 - Plant height (m)
X2 - Number of branches per plant
X3 - Number of flowers per plant
X4 - Days to flowering
X5 - Leaf Area Index (45 DAP)
X6 - Leaf Area Index (90 DAP)
X7 - Pod yield per plant (g)
X8 - Number of pods per plant
X9 - Pod weight (g)
X10 - Seeds per pod
X11 - 100 seed weight (g)
X12 - Length of seed (cm)
X13 - Breadth of seed (cm)
X14 - Weight of seed (g)

produced in no choice and free choice tests in parents and hybrids. The same result was observed for F_2 in free choice test. Ahmed *et al*. (1989) also reported high phenotypic and genotypic variability for number of eggs laid by bruchids and for number of adults per fifty seed. High gcv and pcv for loss of weight per seed and tannin content was observed in parents, F_1 and F_2. Moisture content during storage and harvest and seed coat thickness showed low pcv and gcv in parents, F_1 and F_2 populations. This shows that the scope for improvement through selection is less for these characters. Genotypic and phenotypic coefficients of variation of bruchid resistance traits in parents, F_1 and F_2 are presented in Fig. 3, 4 and 5.

5.3 Heritability

The progress in breeding programme depends on the extent to which desirable traits are heritable. All the characters except leaf area index and breadth of seed exhibited moderate to high heritability. The characters namely number of branches per plant, number of flowers per plant, pod yield per plant, number of pods per plant, pod weight, 100 seed weight and weight of seed expressed high values of heritability in broad sense. Hence these characters have more reliable phenotypic performance and there could be more correspondence between phenotypic and breeding values. Similar findings were also reported by Vaid and Singh (1983), Roquib and Patnaik (1990), Ram and Singh (1997) and Vardhan and Savithramma (1998a) for number of branches per plant. High heritability of number of flowers per plant was also reported by Sharma (1999). Pod yield per plant showed high heritability which was supported by Singh *et al*. (1977), Vaid and Singh (1983), Roquib and Patnaik (1990) and Vardhan and Savithramma (1998b). Reports of Sharma (1999) supported the high heritability of number of pods per plant. Apte *et al*. (1987) and Patil and Baviskar (1987) reported high heritability for 100 seed weight. Leaf area index was noted to have low heritability. Deviating from this result, high heritability of leaf area index was reported by Backiyarani and Nadarajan (1996). From the results observed, all the characters seem to be useful in cowpea breeding programme. In the case of bruchid

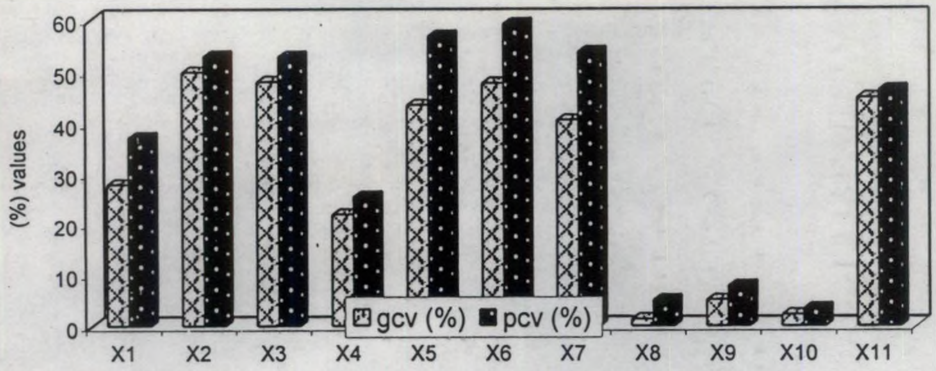


Fig. 3. Genotypic and phenotypic coefficients of variation of bruchid resistance traits in parents

X1 - No. of eggs laid (No choice)
X2 - No. of bore holes (No choice)
X3 - No. of adults emerged (No choice)
X4 - No. of eggs laid (Free choice)
X5 - No. of bore holes (Free choice)
X6 - No. of adults emerged (Free choice)
X7 - Loss of weight/seed (g)
X8 - Moisture content (harvest) (%)
X9 - Moisture content (storage) (%)
X10 - Seed coat thickness (mm)
X11 - Tannin content (mg g-1)

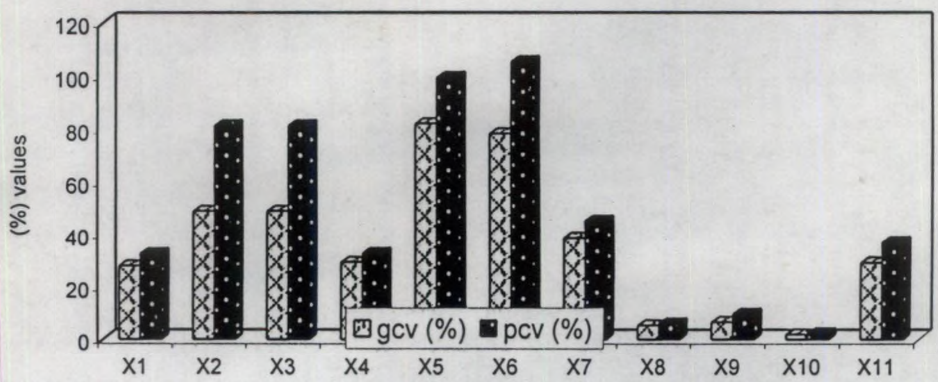


Fig. 4. Genotypic and phenotypic coefficients of variation of bruchid resistance traits in F_1

X1 - No. of eggs laid (No choice)
X2 - No. of bore holes (No choice)
X3 - No. of adults emerged (No choice)
X4 - No. of eggs laid (Free choice)
X5 - No. of bore holes (Free choice)
X6 - No. of adults emerged (Free choice)
X7 - Loss of weight/seed (g)
X8 - Moisture content (harvest) (%)
X9 - Moisture content (storage) (%)
X10 - Seed coat thickness (mm)
X11 - Tannin content (mg g-1)

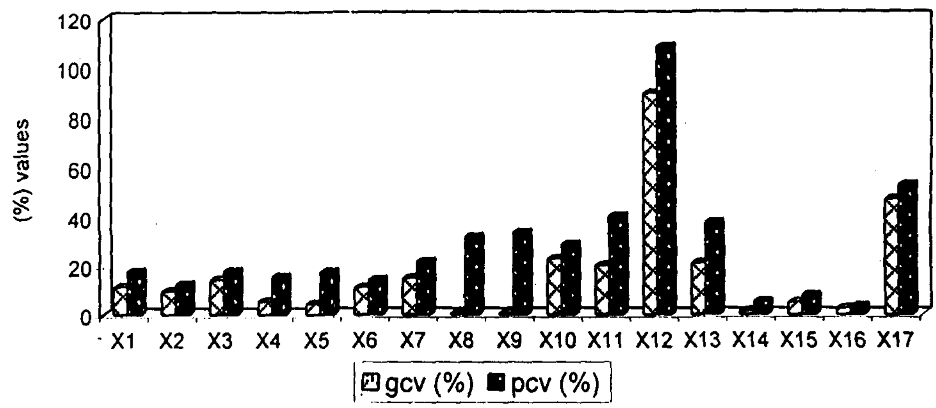


Fig. 5. Genotypic and phenotypic coefficients of variation of seed characters and bruchid resistance traits in F_2

X1 - Pod weight (g)
X2 - Seeds/pod
X3 - 100 seed weight (g)
X4 - Length of seed (cm)
X5 - Breadth of seed (cm)
X6 - Weight of seed (g)
X7 - Number of eggs laid (No choice)
X8 - Number of boreholes (No choice)
X9 - Number of adults emerged (No choice)
X10 - Number of eggs laid (free choice)
X11 - Number of boreholes (free choice)
X12 - Number of adults emerged (free choice)
X13 - Loss of weight/seed (g)
X14 - Moisture content (harvest) (%)
X15 - Moisture content (storage) (%)
X16 - Seed coat thickness (mm)
X17 - Tannin content (mg g-1)

resistance traits, moderate to high heritability was observed for number of eggs laid, number of adult beetles emerged and number of bore holes produced in no choice and free choice tests, loss of weight per seed, moisture content during storage, seed coat thickness and tannin content. Ahmed *et al.* (1989) reported high estimate of broad sense heritability for the number of eggs laid and number of adults emerged per fifty seed.

5.4 Genetic Advance and Genetic Gain

Heritability only denotes the percentage of effectiveness with which the selection can be based on the phenotypic performance. In order to assess the genetic progress, genetic gain should be measured along with heritability. It is found that the characters like plant height, number of branches per plant, number of flowers per plant, pod yield per plant, number of pods per plant and 100 seed weight showed high genetic advance (GA). The character pod yield per plant showed the highest GA. Similar findings were also reported for number of pods and pod yield by Borida *et al.* (1973). Veeraswamy *et al.* (1973) reported high genetic advance for number of pods and grain yield. High genetic advance of plant height, 100 seed weight, number of pods per plant and grain yield per plant was reported by Lakshmi and Goud (1977). Pod yield per plant showed higher genetic advance which was supported by Pandita *et al.* (1982). Roquib and Patnaik (1990) recorded high genetic advance for 100 seed weight, plant height, number of branches and pod yield. High genetic advance of plant height and 100 seed weight was supported by Savithramma (1992). Chattopadhyay *et al.* (1997) reported high genetic advance of number of pods/plant and pod yield per plant. Green pod yield, number of pods per plant and plant height showed higher genetic advance which was supported by Vardhan and Savithramma (1998a). Report of Sharma (1999) supported the high genetic advance of plant height. High genetic advance of number of flowers per plant was recorded by Golasangi *et al.* (1995). High expected genetic advance of these characters suggest that these characters are governed by additive genes and selection will be rewarding for improvement of these traits. Moderate expected genetic advance was recorded for seeds per pod, length of seed and weight of seed. Hence these characters will have a moderate level of improvement on selection. Moderate to high genetic advance of seeds per pod was supported by Apte *et al.* (1987), Thiagarajan (1989) and Roquib and Patnaik (1990). Savithramma (1992) reported high genetic advance for weight of seed. Relatively high genetic advance for seeds per pod, length and weight of seed was suggested by Golasangi *et al.* (1995). High genetic advance of seeds per pod was supported by Kalaiyarasi and Palanisamy (2000). Deviating from this result, low genetic advance of seeds per pod was reported by Tikka *et al.* (1977).

For more reliable conclusion, estimates of heritability and genetic advance should be considered together, which is more useful than heritability alone (Singh and Narayanan, 1993). Expected genetic advance would be high, if the heritability is due to additive gene effects. When non additive gene effect govern heritability, the expected GA would be low. The characters under present investigation which have high broad sense heritability, high expected genetic advance and high gcv include number of flowers per plant, pod yield per plant and number of pods per plant. High heritability and high expected genetic advance coupled with moderate gcv was exhibited by number of branches per plant and 100 seed weight. These results suggested that these characters are under additive gene effect. These findings were supported by Vaid and Singh (1983) with respect to yield per plant. Similar results were also reported by Backiyarani and Nadarajan (1996) for 100 seed weight and pod yield per plant, Chattopadhyay *et al.* (1997) for number of pods per plant and pod yield per plant, Vardhan and Savithramma (1998a) for green pod yield per plant, number of pods per plant and number of branches and Kalaiyarasi and Palanisamy (2000) for 100 seed weight.

High heritability accompanied with high genetic advance indicate that most likely the heritability is due to additive gene effects and selection may be effective (Singh and Narayanan, 1993). High heritability coupled with moderate to high expected genetic advance and moderate to low gcv were observed for the characters pod weight and weight of seed, which suggests that these characters are mostly controlled by additive gene action and are important components of yield. High heritability accompanied with high genetic advance was reported by Veeraswamy *et al.* (1973) for pods per plant, Lakshmi and Goud (1977) for 100 seed weight, Sreekumar *et al.* (1978) for 100 grain weight and grain yield, Pandita *et al.* (1982) for yield per plant, Apte *et al.* (1987) for 100 seed weight, Thiagarajan (1989) for 100 seed weight, Roquib and Patnaik (1990) for 100 seed weight, number of branches and pod yield and Ram and Singh (1997) for green pod yield per plant.

In general, the present investigation revealed that the characters namely, number of flowers per plant, pod yield per plant, number of pods per plant, number of branches per plant and 100 seed weight provide great help in direct selection from phenotypic performance.

In the case of bruchid resistance traits, the characters which showed high genetic advance (GA) include number of eggs laid, number of adults emerged and number of bore holes produced during no choice and free choice tests, loss of weight per seed and tannin content. Number of bore holes produced during no choice test showed highest GA. High expected genetic advance of number of eggs laid, number of adults emerged, number of bore holes produced and loss of weight per seed shows that the resistance of cowpea genotypes to pulse beetle can be improved by operating selection against those characters. High expected genetic advance of tannin content suggests that this character can be improved genetically by selection from a segregating population. These characters also showed high broad sense heritability, accompanied with high genetic advance and high gcv. These results suggested that these characters are under additive gene effect. Fatunla and Badaru (1983a) reported additive gene effect for percentage weevil emergence in cowpea crosses.

5.5 Correlation

Study of the association of characters is a must to understand the genetics of the crop. Correlation study helps the plant breeder to understand genetic architecture of the crop as the correlation occur due to genetic reasons namely, linkage or pleiotropy. From the knowledge of association of various characters with yield and among themselves, breeders can assess the complexity of the character and can practice selection based on appropriate selection criteria. Besides this, an attempt to find out the association among characters related to pulse beetle resistance also has been done here. The results of the correlation studies are discussed below.

Among the correlation coefficients of characters with yield, plant height, number of branches per plant, number of flowers per plant, number of pods per plant, pod weight, seeds per pod, 100 seed weight and length and weight of seed recorded highly significant positive association with yield at both genotypic and phenotypic levels in parents.

In the case of hybrids, plant height, number of branches per plant, number of flowers per plant, leaf area index (90 DAP), number of pods per plant, 100 seed weight and weight of seed showed highly significant positive association with yield at both genotypic and phenotypic levels.

All these characters in parents and hybrids showed higher genotypic correlation than phenotypic correlation, which indicate less influence of environment on these characters.

The characters, number of flowers per plant as well as number of pods per plant exhibited highest significant positive association with pod yield in both parents and hybrids. These were followed by plant height and weight of seed in parents and by seeds per pod in hybrids. It is indicated that higher pod yield could be achieved by increased selection on all the above characters. The above results were in agreement with the reports of Karthikeyan (1963) for number of pods and number of branches, Bapna *et al.* (1972) for number of pods, seed number per pod and seed size, Kumar *et al.* (1976) for branches per plant and pods per plant, Jana *et al.* (1982) for number of pods per plant, Jindal and Gupta (1984) for plant height, inflorescence per plant and seeds per pod, Sharma *et al.* (1988) for pods/plant and seeds/pod, Tyagi and Koranne (1988) for number of branches/plant and seeds/pod, Apte *et al.* (1991) for inflorescence/plant, pods/plant and grains/pod, Singh *et al.* (1995) for plant height, Tamilselvan and Das (1994) for plant height, number of branches, pods/plant, number of seeds per pod and 100 seed weight, Parihar *et al.* (1997) for flowers per plant, pods per plant, plant height, seeds per pod and 100 seed weight. Slightly deviating from present results Senanayake and Wijarathne (1988) suggested that seed yield was negatively correlated with number of branches per plant and Oseni *et al.* (1992) reported that 100 seed weight had negative correlation with grain yield. Biradar *et al.* (1996) reported negative association of plant height with seed yield.

From the inter correlation studies, it was evident that plant height, number of branches per plant, number of flowers per plant, number of pods per plant, pod weight, seeds per pod, 100 seed weight and weight of seed had significant positive association with each other and all these characters exhibited significant positive association with pod yield. This result reveals that heavy selection pressure on any of these characters will result in the correlated response for other desirable characters, which ultimately result in higher yield. In hybrids also plant height, number of branches per plant, number of flowers per plant, leaf area index (90 DAP), number of pods per plant, pod weight, 100 seed weight, seeds per pod and weight of seed showed significant positive association with each other and with yield. This shows the correlated response of desirable characters on the selection of any of these traits, along with yield. Genotypic correlation among different yield components in parents and F_1 are shown in Fig. 6 and 7. In the case of bruchid resistance traits, from the inter correlation studies among parents it was

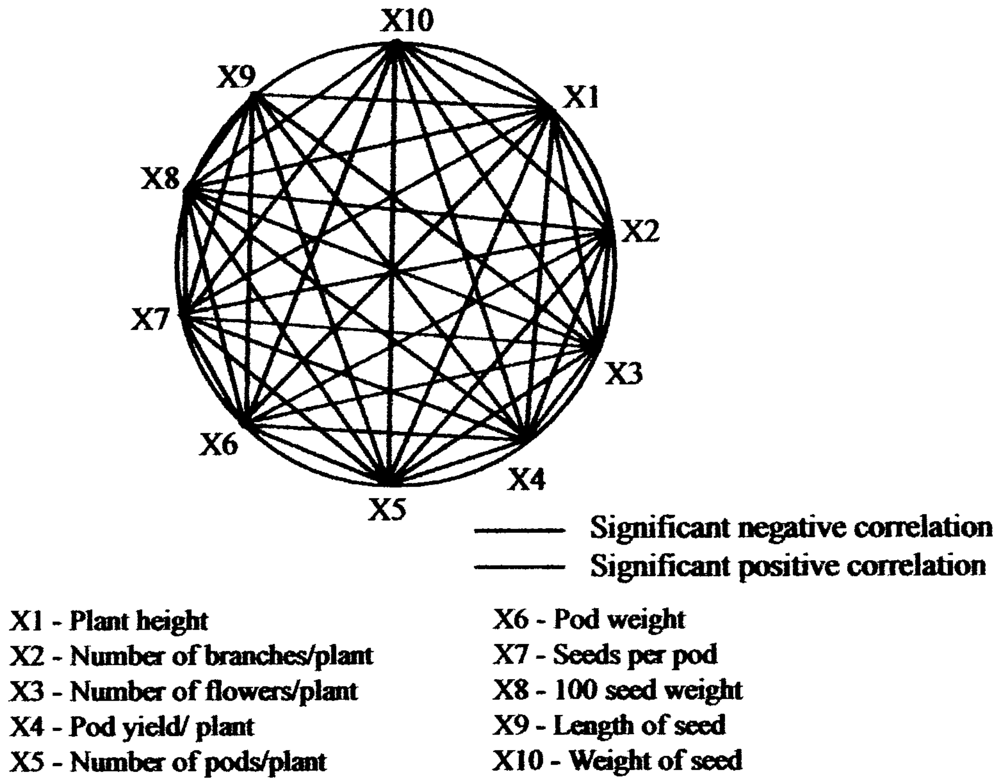


Fig. 6. Genotypic correlation among yield characters in parents

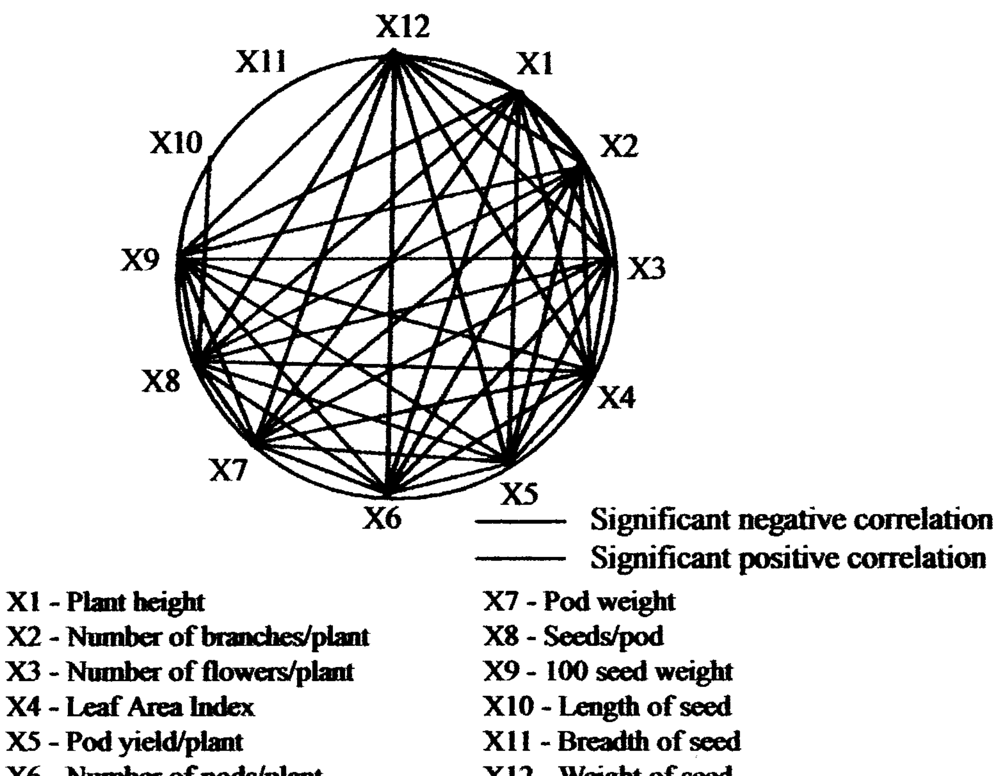
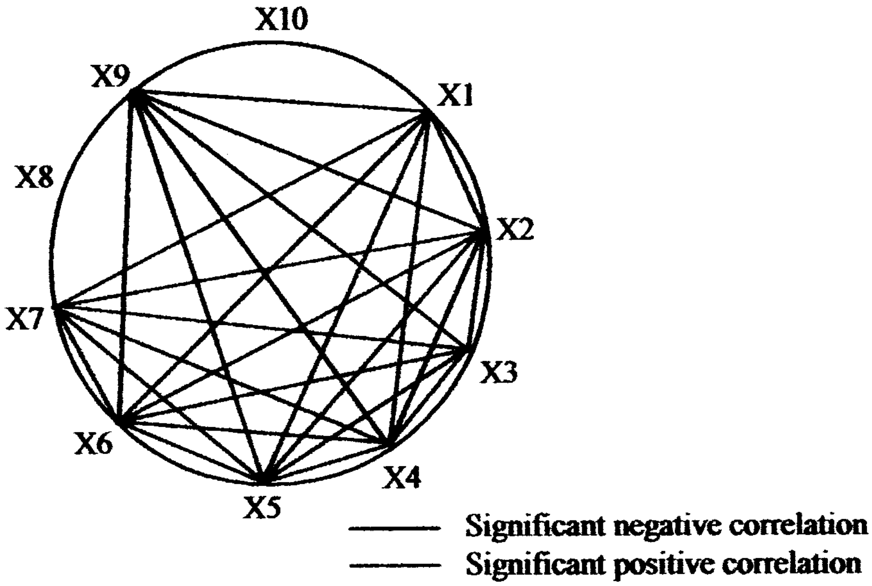


Fig. 7. Genotypic correlation among yield characters in F_1

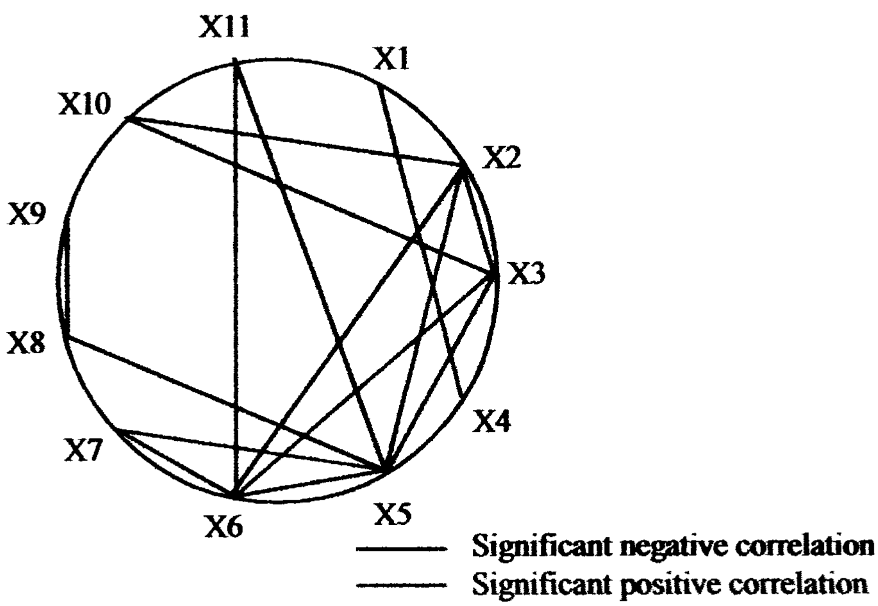
evident that number of eggs laid, number of adults emerged, number of bore holes produced (during no choice and free choice tests) and loss of weight per seed showed significant positive association with each other and all these characters except loss of weight/seed exhibited significant negative association with seed coat thickness. For all these characters genotypic correlation was higher than phenotypic correlation, which indicate less influence of environment on these characters. Genotypic correlation among different bruchid resistance traits in parents are shown in Fig. 8.

From the inter correlation studies among the hybrids it was observed that number of adults emerged and number of bore holes produced during no choice test and number of adults emerged and number of bore holes produced during free choice test showed significant positive association with each other and had significant negative association with seed coat thickness. This result reveals that when the number of adults emerged increases, the number of bore holes produced will also increase, and this is true for both no choice and free choice tests. Also shows that, when the seed coat thickness increases, the number of adults emerged and bore holes produced will decrease. Loss of weight per seed showed significant positive association with number of adults emerged and bore holes produced during free choice test. The significant positive association of loss of weight per seed with these characters suggested that increase in number of adults emerged and bore holes produced will result in increase in loss of weight per seed. Correlation of tannin content with number of adults emerged and bore holes produced during free choice test revealed that when tannin content increases, number of adults emerged and bore holes produced will also increase. Genotypic correlation among different bruchid resistance traits in F_1 are shown in Fig. 9. From the intercorrelation studies among the F_2 population it was observed that number of eggs laid during free choice test showed significant positive association with moisture content during storage and tannin content. It was also observed that, number of adults emerged during free choice test had significant negative



X1 - Number of eggs laid (No choice)
X2 - Number of bore holes (No choice)
X3 - Number of adults emerged (No choice)
X4 - Number of eggs laid (Free choice)
X5 - Number of bore holes (Free choice)
X6 - Number of adults emerged (Free choice)
X7 - Loss of weight/seed
X8 - Moisture content (harvest)
X9 - Seed coat thickness
X10 - Tannin content

Fig. 8. Genotypic correlation among bruchid resistance traits in parents



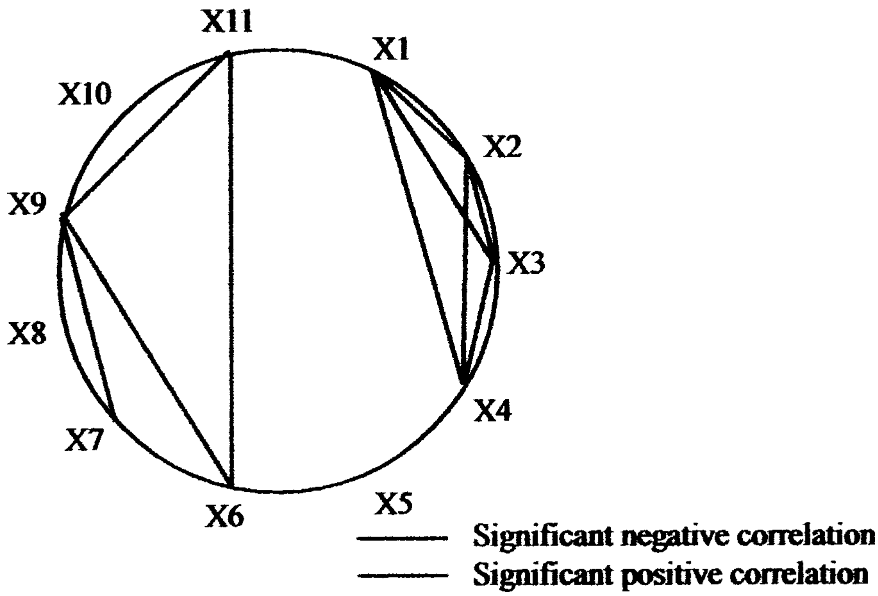
X1 - Number of eggs laid (No choice)
X2 - Number of bore holes (No choice)
X3 - Number of adults emerged (No choice)
X4 - Number of eggs laid (Free choice)
X5 - Number of bore holes (Free choice)
X6 - Number of adults emerged (Free choice)
X7 - Loss of weight/seed
X8 - Moisture content (harvest)
X9 - Moisture content (storage)
X10 - Seed coat thickness
X11 - Tannin content

Fig. 9. Genotypic correlation among bruchid resistance traits in F_1

association with moisture content during storage. Genotypic correlation among different bruchid resistance traits in F_2 are shown in Fig. 10.

Singal (1986) reported positive correlation between average number of eggs and average number of adults emerged as well as between average number of eggs and per cent losses in weight. Also reported that correlation between adults emerged and per cent loss in weight was positive. Deviating from this result Ahmed *et al.* (1989) reported no correlation between number of eggs laid and number of adults emerged. Significant negative correlation between the adult emergence and seed coat thickness was supported by Khokhar and Singh (1987). Correlation between per cent adult emergence and loss in seed weight was found to be positive by Singal (1987). He also suggested that a negative and significant correlation existed between per cent moisture contents and per cent weight losses. Khokhar and Singh (1987) also suggested that the adult emergence and the per cent grain damage were positively correlated with the number of eggs laid. Filho *et al.* (1989) reported no obvious relationship between the level of tannins and the resistance or susceptibility of seeds to attack by pulse beetle. Deviating from this result, a significant positive correlation between seed resistance to bruchids and tannin content was reported by Marconi *et al.* (1997).

From the results obtained it is observed that in free choice and no choice tests, when seed coat thickness increases, number of eggs laid by the pulse beetle, number of adults emerged and number of bore holes produced decreases. The thickness of seed testa had been reported as one of the major factors in providing resistance to bruchid attack by Sachdeva and Seghal (1987). Similar findings were also reported by Gupta and Mishra (1970) and by Khokhar and Singh (1987). In the present study, seed coat thickness showed no significant positive association with yield and yield associated characters except with number of branches per plant. Hence this result reveals that seed coat thickness is an independent trait which can be incorporated to high productivity characters.



X1 - Pod weight
X2 - Seeds per pod
X3 - 100 seed weight
X4 - Weight of seed
X5 - Number of adults emerged (No choice)
X6 - Number of eggs laid (Free choice)
X7 - Number of adults emerged (Free choice)
X8 - Loss of weight/seed
X9 - Moisture content (storage)
X10 - Seed coat thickness
X11 - Tannin content

Fig. 10. Genotypic correlation among seed characters and bruchid resistance traits in F_2

5.6 Combining ability

Combining ability effects of parents have been used for evaluating the ability of parents to transmit desirable traits to their offspring. In the present study combining ability of seven parents and twelve hybrid combinations were analysed through line x tester analysis. The analysis of variance for combining ability revealed that variance due to lines, testers and line x tester interaction were significant for most of the characters studied, indicating the presence of adequate variability in the experimental material. Magnitude of gca variance was more than sca variance for number of branches per plant, number of flowers per plant, leaf area index, pod yield per plant and number of pods per plant. This result reveals the preponderance of genes governing these attributes in additive fashion. The predominant role of additive gene effect was reported by Vijayakumar (1989) for number of branches, Patel (1990) for number of pods per plant and Hebbal (1988) for grain yield per plant. The characters like plant height, days to flowering, pod weight, seeds per pod, 100 seed weight, and size of seed were observed to have higher magnitude of sca variance suggesting predominance of non additive genetic variance for these traits which could be exploited through heterosis breeding. Similar results were reported by Sanghi and Kandalkar (1991) for plant height, Thiagarajan *et al.* (1993) for days to 50 per cent flowering, plant height, seeds per pod and 100 seed weight and Aravindhan and Das (1996) for all the yield related traits.

In the case of bruchid resistance traits, from the analysis of variance for combining ability it was observed that variance due to lines, testers and line x tester interaction were significant for most of the characters. This indicates that both additive and non additive gene actions are involved in the inheritance of these characters. Waly *et al.* (1987) have reported that there was a highly significant general combining ability component and a large specific combining ability effect for natural and simulated types of infestation by pulse beetle. Magnitude of gca variance was more than sca variance for number of adults emerged and bore holes produced during no choice test and seed coat thickness suggesting the preponderance of genes governing these attributes in additive fashion. Number of eggs laid during no choice test, number of eggs laid, number of adults emerged and number of bore holes during free choice test, loss of weight per seed, moisture content during harvest and storage and tannin content were observed to have higher magnitude of sca variance suggesting the preponderance of non additive (dominance and epistasis) gene action. Fatunla and Badaru (1983a) reported the importance of additive component for percentage weevil emergence for cowpea crosses.

In the present study, among the female parents, variety Kanakamoni recorded high positive gca for most of the characters studied viz., plant height, number of branches per plant, number of flowers per plant, leaf area index, pod yield per plant, number of pods per plant, pod weight, seeds per pod, 100 seed weight, breadth and weight of seed. Among the testers high gca for different characters was expressed by EC 390231 which recorded high positive gca for plant height, number of branches per plant, number of flowers per plant, leaf area index, pod yield per plant, number of pods per plant, pod weight, seeds per pod, 100 seed weight, length and weight of seed. These results indicate that Kanakamoni and EC 390231 can be effectively utilised in the recombination breeding programme aimed at production of superior hybrid derivatives. It could be expected that when parents possessing high gca are combined by hybridization, a large proportion of progenies would have high value for that trait.

Specific combining ability effect is the index to determine the usefulness of a particular cross combination in the exploitation of heterosis. The high estimate of sca might be due to the combinations of favourable genes from the diverse lines or might be due to the presence of linkage in repulsion phase (Jagtap, 1986). Kanakamoni x IC 201092 recorded highest sca for pod yield per plant and one of the parents (Kanakamoni) of this particular cross combination had highest positive gca and other (IC 201092) had significant negative gca (Plate 4). High sca

Plate 4. Superior cross for pod yield

for pod yield was also recorded by cross C 152 x EC 390231 in which also one parent (EC 390231) with positive gca and other (C 152) with significant negative gca. V 240 x EC 390231 recorded significant positive sca, EC 390231 with significant positive and V 240 with significant negative gca. V 16 x IC 201092 and V 240 x EC 367711 recorded significant positive sca for pod yield eventhough both the parents had significant negative gca in both the crosses. Kanakamoni x EC 367711 recorded significant positive sca, Kanakamoni with positive gca and EC 367711 with negative gca. All these reveal that the sca of a particular cross combination may not depend much on gca of parents. Besides for pod yield, the hybrid Kanakamoni x IC 201092 excelled others by registering high sca for number of flowers per plant, number of pods per plant and 100 seed weight. Kanakamoni x EC 367711 which recorded significant positive sca for pod yield also recorded highest positive sca for plant height and seeds per pod. Besides for pod yield, the hybrid C 152 x EC 390231 recorded highest positive sca for number of branches per plant. For days to flowering C 152 x IC 201092 recorded significant positive sca. In the present study for all the traits except for 100 seed weight hybrids with positive and significant sca were produced by two type of parental combinations, called high x low and low x low general combiners. For 100 seed weight hybrids with positive and significant sca were produced by high x high and high x low general combiners. The high sca in cross combinations (high x low) can be attributed to interaction between positive alleles from good combiner and negative alleles from poor combiner while heterosis involved in high x high combiners involve interaction between positive x positive alleles. In the present study low x low combinations also produced hybrids with high sca and this can be attributed to overdominance or epistasis. All these results reveal that there is no direct relation between gca of parents and sca of hybrid combinations. This can be explained from the point of gene action, since gca is more due to additive gene action whereas, sca is due to dominance and epistasis.

In the case of bruchid resistance traits, among the female parents C 152 and Kanakamoni recorded high negative gca for the characters viz., number of eggs laid by the pulse beetle, number of adults emerged, number of bore holes produced and loss in weight per seed per insect developed. The resistance to pulse beetle can be expressed by these characters (Fatunla and Badaru, 1983b). Among the testers high negative gca for these characters were expressed by EC 390231 and IC 201092. These results indicate that C 152, Kanakamoni, EC 390231 and IC 201092 can be effectively utilised for combination breeding programme aimed at production of superior genotypes having high yield and tolerance to pulse beetle. V 16 recorded high positive gca for moisture content among the lines and EC 367711 among the testers. Seed coat thickness is a major factor in providing resistance to bruchid attack and C 152 among the lines and EC 367711 and IC 201092 among the testers showed high positive gca for this character. V 16 among the lines and EC 390231 among the testers recorded high positive gca for tannin content.

C 152 x EC 367711 recorded highest negative sca for the characters number of eggs laid during no choice and free choice tests, number of adult beetles emerged and bore holes produced during no choice test and the hybrid V 240 x IC 201092 recorded highest negative sca for number of adult beetles emerged and bore holes produced during free choice test (Plate 5). None of the hybrids produced recorded significant sca for seed coat thickness which is a major factor in providing resistance to bruchid attack. Magnitude of gca variance was more than sca variance for seed coat thickness which indicate the preponderance of gene governing this trait in additive fashion. This result reveals that the genotypes having bruchid resistance can be effectively utilized in recombination breeding programme for producing hybrid derivatives possessing both the bruchid resistance and high yield characters.

Plate 5. Crosses rated supreme for bruchid resistance

Summary

6. SUMMARY

A systematic genetic study was undertaken in the Department of Plant Breeding and Genetics, College of Horticulture, Vellanikkara during 1999 to 2001 to elucidate the inheritance of pulse beetle resistance and yield in cowpea.

Three bruchid resistant genotypes of cowpea viz., EC 367711, EC 390231 and IC 201092 and four high yielding susceptible genotypes viz., Kanakamoni, V 240, C 152 and V 16 were used for the study. Crosses were carried out in a Line x Tester model, so as to obtain twelve F_1 hybrids with the resistant genotypes as testers. The seven parental lines, the hybrids and F_2 population were evaluated for yield characters and were screened by no choice and free choice tests for their resistance to bruchids in the laboratory.

The results are summarised as below:

1. There is ample scope of improvement through selection for most of the yield and storage characters under study, in both the parents and hybrids, as evidenced by their high genetic variability.

2. Phenotypic coefficient of variation (pcv) was higher than genotypic coefficient of variation (gcv) for all the characters studied in both parents, F_1 and F_2 generations.

3. Number of flowers per plant, pod yield per plant and number of pods per plant exhibited higher values of heritability, genetic advance and genotypic coefficient of variation and hence provide great help in direct selection.

4. Number of eggs laid, number of adult beetles emerged, number of bore holes produced, loss of weight per seed and tannin content exhibited higher values of heritability, genetic advance and genotypic coefficient of variation, indicating the preponderence of additive gene effects.

5. In parents and hybrids, the characters namely plant height, number of branches per plant, number of flowers per plant, number of pods per plant, pod weight, 100 seed weight, seeds per pod and weight of seed showed significant positive association with each other and with yield at genotypic level.

6. All the traits related to bruchid resistance except loss of weight per seed showed a decreasing trend with increase in seed coat thickness in parents.

7. Genotypic correlation studies among hybrids revealed that when the number of adult beetles emerged increases, the number of bore holes produced will also increase.

8. Inter correlation studies for bruchid resistance traits revealed that there is negative association between seed coat thickness and number of eggs laid, number of adults emerged and number of bore holes produced. Seed coat thickness showed no significant positive association with yield and yield associated characters except with number of branches per plant. It was evident that seed coat thickness is an independent trait which can be incorporated to high productivity characters.

9. Among the lines, Kanakamoni was identified as the best combiner for most of the yield associated traits and among the testers EC 390231 recorded high positive gca for most of the yield attributing characters.

10. Hybrid combinations Kanakamoni x IC 201092 followed by C 152 x EC 390231 were the best specific combiners for pod yield per plant.

11. Kanakamoni and C 152 among the lines and EC 390231 and IC 201092 among the testers recorded high negative gca for number of eggs laid, number of adult beetles emerged, number of bore holes produced and loss of weight per seed per insect developed. Inter crosses among these parents can produce superior genotypes having high yield and tolerance to pulse beetle.

12. C 152 among the lines and EC 367711 and IC 201092 among the testers showed high positive gca for seed coat thickness which is a major factor in providing resistance to bruchid attack.

13. The hybrids viz., C 152 x EC 367711 and V 240 x IC 201092 could be adjudged as superior, since they recorded high significant negative sca for the characters related to bruchid resistance.

References

REFERENCES

Adjadi, O., Singh, B.B. and Singh, S.R. 1985. Inheritance of bruchid resistance in cowpea. *Crop Sci.* **25**:740-742

Ahmed, K., Khalique, F., Afzal, M., Tahir, M. and Malik, B.A. 1989. Variability in chick pea (*Cicer arietinum* L.) genotypes for resistance to *Callosobruchus maculatus* F. *J. Stored Prod. Res.* **25**(2):97-99

Allard, R.W. 1960. *Principles of Plant Breeding*. John Wiley and Sons, Inc. New York, p.89-98

Apte, U.B., Chavan, S.A. and Yadav, B.B. 1987. Genetic variability and heritability in cowpea. *Indian J. agric. Sci.* **57**(8):596-598

Apte, U.B., Chavan, S.A. and Yadav, B.B. 1991. Correlation studies in cowpea. *Agric. Sci. Digest* **11**(2):59-62

Aravindhan, S. and Das, L.D.V. 1996. Heterosis and combining ability in fodder cowpea for green fodder and seed yield. *Madras agric. J.* **83**(1):11-14

Backiyarani, S. and Nadarajan, N. 1996. Variability studies in cowpea. *Legume Res.* **19**(1):59-61

Bahl, B.N. and Kumar, J. 1989. Evaluation and utilization of high yielding hybrids of chickpea. *Indian J. Genet.* **49**(1):53-58

Baker, T.A., Nielsen, S.S., Shade, R.E. and Singh, B.B. 1989. Physical and chemical attributes of cowpea lines resistant and susceptible to *Callosobruchus machulatus*. *J. Stored Prod. Res.* **25**(1):1-8

Bapna, G.S., Joshi, S.N. and Kabaria, M.M. 1972. Correlation studies on yield and agronomic characters in cowpeas. *Indian J. Agron.* **17**:321-324

Biradar, B.D., Goud, J.V. and Patil, S.S. 1991. A study on character association and path coefficient in cowpea. *J. Maharashtra agric. Univ.* **16**(1):27-29

Biradar, B.D., Goud, J.V. and Patil, S.S. 1996. Association of grain yield with other characters in three F_2 populations of cowpea (*Vigna unguiculata* (L.) Walp.). *Crop Res. Hisar* **11**(2):179-183

Booker, R.H. 1967. Observation on three bruchids associated with cowpea in Northern Nigeria. *J. Stored Prod. Res.* **3**:1-15

Borida, P.C., Yadavendra, J.P. and Kumar, S. 1973. Genetic variability and correlation studies in cowpea. *Rajastan J. agric. Sci.* **4**(1):39-44

*Burton, G.W. 1952. Quantitative inheritance in grass. 6th *Int. Grassld. Cong. Proc.* **1**:277-283

Burton, G.W. and Devane, E.H. 1953. Estimating heritability in tall fescue from replicated clonal material. *Agron. J.* **45**:478-481

Bushana, H.O., Viswanatha, K.P., Manjunatha, A., Kulkarni, R.S. and Khyad, P.R. 1998. Combining ability for seed yield and its components in cowpea (*Vigna unguiculata* (L.) Walp.). *Crop Improvement* **25**(2):116-118

Chandrika, P. 1979. Genetic studies in cowpea. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur

Chattopadhyay, A., Dasgupata, T., Hazra, P. and Som, M.G. 1997. Estimation of genetic parameters in parental, F_1 and F_2 generations of cowpea (*Vigna unguiculata* L. Walp.). *Indian Agriculturist* **41**(1):49-53

Chaudary, J.B. 2001. *The Hindu*, Jan. 22

*Chaves, J.W.N. and Vendramin , J.D. 1995. Non-preference for oviposition and development of *Callosobruchus maculatus* on cultivars of cowpea. *Anais-da-Sociedade-Entomologica-do-Brasil.* **24**(2):239-245

Dabi, R.K., Gupta, H.C., Mehrotra, P. and Sharma, S.K. 1981. Note on the pigeon pea varieties preferred by *Callosobruchus maculatus. Indian J. agric. Sci.* **51**(7):533-534

Dharne, P.K., Salunkhe, G.N. and Ajri, D.S. 1984. Studies on susceptibility of pigeon pea (*Cajanus cajan* L.) varieties to pulse beetle, *Callosobruchus chinensis* L. *Bull. Grain Tech.* **22**(3):262-264

Dongre, T.K., Pawar, S.E., Thakare, R.G. and Harwalker, M.R. 1996. Identification of resistant sources to cowpea weevil (*Callosobruchus maculatus* F.) in *Vigna sp.* and inheritance of their resistance in black gram (*Vigna mungo* var. *mungo*). *J. Stored Prod. Res.* **32**(3):201-204

Fatunla, T. and Badaru, K. 1983a. Inheritance of resistance to cowpea weevil (*Callosobruchus maculatus* F.). *J. agric. Sci. Camb.* **101**:423-426

Fatunla, T. and Badaru, K. 1983b. Resistance of cowpea pods to *Callosobruchus maculatus* F. *J. agric. Sci. Camb.* **100**:205-209

Filho, J.X., Campos, F.A.P., Ary, M.B., Silva, C.P., Carvalho, M.M.M., Macedo, M.L.R., Lemos, F.J.A. and Grant, G. 1989. Poor correlation between the levels of proteinase inhibitors found in the seeds of different cultivars of cowpea (*Vigna unguiculata*) and the resistance/susceptibility to predation by *Callosobruchus maculatus. Journal of Agricultural and Food Chemistry* **37**(4):1139-1143

Fisher, R.A. 1954. A fuller theory of 'junctions' in breeding. *Heridity.* **8**:187-197

Gibson, K.E. and Raina, A.K. 1972. A simple laboratory method of determining the seed host preference of Bruchidae. *J. econ. Ent.* **65**:1189-1190

Golasangi, B.S., Parameswarappa, R. and Biradar, B.D. 1995. Variance components, heritabilities and gain from selection in cowpea (*Vigna unguiculata* L. Walp.). *Crop Res. Hisar* **9**(3):344-349

Gopalan, A. and Balasubramanian, M. 1993. Component analysis for fodder yield in cowpea. *Madras agric. J.* **80**(4):190-193

Gowda, T.H., Shantha, R., Hiremath, S.R. and Salimath, P.M. 1991. Estimation of genetic parameters in intervarietal crosses of cowpea (*Vigna unguiculata* L.) and their implication in selection. *Legume Res.* **14**(1):15-19

Gowda, T.H. 1996. Studies on the association of yield components in three F_2 populations of cowpea (*Vigna unguiculata* (L.) Walp.). *Karnataka J. agric. Sci.* **9**(2):270-274

Gupta, D.S. and Mishra, R.C. 1970. Further studies on the relative resistance of some important varieties of bengal gram *Cicer arietinum* L. to pulse beetle, *Callosobruchus chinensis*. *Bull. Grain Tech.* **8**(1&2):14-17

Hebbal, S.N. 1988. Genetic analysis of yield and yield components in cowpea. *Mysore J. agric. Sci.* **22**(1):155

Jagtap, D.R. 1986. Combining ability in upland cotton. *Indian J. agric. Sci.* 56:833-840

Jalajakumari, M.B. 1981. Variability studies in cowpea. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur

Jana, S., Som, M.G. and Das, M.D. 1982. Genetic variability and correlation studies in cowpea. *Veg. Sci.* **9**(2):96-107

Jayarani, L.S. and Manju, P. 1996. Combining ability in grain cowpea. *J. Trop. Agric.* **34**(2):93-95

Jindal, S.K. and Gupta, B.S. 1984.Component analysis of yield in cowpea. *Indian J. agric. Sci.* **54**(3):183-185

Johnson, H.W., Robinson, H.P. and Comstock, R.E. 1955a. Estimates of genetical and environmental variability in soyabeans. *Agron. J.* **47**:314-318

Johnson, H.W., Robinson, H.P. and Comstock, R.E. 1955b. Genotypic and phenotypic correlations in soyabean and their implications in selection. *Agron. J.* **47**(10):477-482

Kalaiyarasi, R. and Palanisamy, G.A. 2000. Estimation of genetic parameters in five F_4 populations of cowpea. *Ann. agric. Res.* **21**(1):100-103

Kandaswamy, G., Kandambhavanasundaram, M. and Rajasekharan, S. 1989. Variability in cowpea under different environmental conditions. *Madras agric. J.* **76**(4):197-199

Karthikeyan, V.K. 1963. Correlation studies and the application of discriminant function for selection for yield in cowpea (*Vigna sinensis* L.) M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur

KAU. 1996. *Package of Practices Recommendations 'Crops 1996'*. Kerala Agricultural University, Thrissur, Kerala, p.44-47

Kempthorne, O. 1957. *An introduction to genetic statistics*. John Willey and Sons, Inc., New York

Khokhar, K.S. and Singh, D. 1987. Relative susceptibility of different genotypes of pigeon pea to pulse beetle, *Callosobruchus chinensis*. *Bull. Grain Tech.* **25**(3):244-251

*Kumar, P., Prakash, R. and Haque, M.P. 1976. Interrelationship between yield and yield components in cowpea (*Vigna sinensis* L.). *Proc. Bihar Acad. agric. Sci.* **24**(2):13-16

Lakshmi, P.V. and Goud, J.V. 1977. Variability in cowpea (*Vigna sinensis* L.). *Mysore J. agric. Sci.* **11**(2):144-147

Lush, J.L. 1949. *Animal Breeding Plans*. Lown state University Press. Annes. P.473

Madhusudan, K., Ramesh, S., Rao, A.M., Kulkarni, R.S. and Savithramma, D.L. 1995. Combining ability in cowpea. *Crop Improvement.* **22**(2):241-243

Marconi, E., Ruggeri, S. and Carnovale, E. 1997. Chemical evaluation of wild under exploited *Vigna spp.* seeds. *Food-Chemistry* **59**(2):203-212

Ofuya, T.I. and Credland, P.F. 1995. Difference in the susceptibility of seeds of selected varieties of cowpea to *Bruchidius atrolineatus*. *Bull. Entomol. Res.* **85**(2):259-265

Oigiangbe, N.O. and Onigbinde, A.O. 1996. The association between some physio chemical characteristics and susceptibility of cowpea (*Vigna unguiculata* L.) to *Callosobruchus maculates* F. *J. Stored Prod. Res.* **32**(1):7-11

Oseni, T.O., Lenge, D.D. and Tal, U.R. 1992. Correlation and path coefficient analysis of yield attributes in diverse lines of cowpea (*Vigna unguiculata*). *Indian J. agric. Sci.* **62**(6):365-368

Pandita, M.L., Vasishta, R.N., Bhutani, R.D. and Batia, B.R. 1982. Genetic variability studies in cowpea (*Vigna sinensis* L.) under dry farming conditions. *HAU J. Res.* **12**(2):241-245

Parihar, M.S., Saraf, P.K., Tiwari, J.P. and Upadhyay, P.C. 1997. Correlation of growth and yield parameters with seed yield under varying plant densities and fertilizer doses in cowpea (*Vigna unguiculata* L. Walp.). *Orissa J. Hort.* **25**(1):73-75

Patel, B.C. 1990. Heterosis and combining ability in cowpea (*Vigna unguiculata* L. Walp.). M.Sc. (Ag.) thesis, Hariyana Agricultural University, 19-50

Patel, R.N., Godhani, P.R. and Fougat, R.S. 1994. Combining ability in cowpea (*Vigna unguiculata* (L.) Walp.). *Gujarat Agric. Univ. Res. J.* **20**(1):70-74

Patil, R.B. and Baviskar, A.P. 1987. Variability studies in cowpea. *J. Maharashtra agric. Univ.* **12**:63-66

Puttaswamy, S., Gowda, T. and Krishnamurthy, K. 1976. Determination of leaf area in pulses. *Current Research.* **5**(3):48-49

Ram, D. and Singh, K.P. 1997. Variation and character association studies in cowpea (*Vigna unguiculata* (L.) Walp.). *Hort. J.* **10**(2):93-99

Ramachandran, C., Peter, K.V. and Gopalakrishnan, P.K. 1980. Variability in selected varieties of cowpea (*Vigna unguiculata* L. Walp.). *Agric. Res. J. Kerala* **18**(1):94-97

Ranganna, S. 1986. *Manual of Analysis of Fruit and Vegetable products*. Tata McGraw Hill Publishing Co. Ltd., New Delhi, p.2240

Regupathy, A. and Rathnaswamy, R. 1970. Studies on comparative susceptibility of seeds of certain red gram (*Cajanus cajan* L.) varieties to pulse beetle, *Callosobruchus chinensis* L. *Madras agric. J.* **57**(2):104-109

Rejatha. 1992. Combining ability in vegetable cowpea. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur

Rewale, A.P., Birari, S.P. and Jamadagni, B.M. 1995. Genetic variability and heritability in cowpea. *Agric. Sci. Dig. Karnal* **15**(1&2):73-76

Roquib, M.A. and Patnaik, R.K. 1990. Genetic variability in grain yield and its components in cowpea (*Vigna unguiculata*). *Env. Ecol.* **81A**:197-200

Rusoke, D.G. and Fatunla, T. 1987. Inheritance of pod and seed resistance to the cowpea seed beetle (*Callosobruchus maculatus* F.). *J. agric. Sci. Camb.* **108**:655-660

Sachdeva, J.S., Seth, R.K. and Sehgal, S.S. 1986. Relative susceptibility of twelve promising varieties of cowpea to Callosobruchus infestation. *Bull. Grain Tech.* **24**(3):201-205

Sachdeva, J.S. and Seghal, S.S. 1987. Natural resistance of pulses to bruchid during storage. *Bull. Grain Tech.* **25**(1):59-64

Samiullah, R., Imtiaz, S.H., Chikkadavaiah, R.A., Sadiqullakhan, S. and Bhargava, B.S. 1993. Association analysis in vegetable cowpea. Report of Golden Jubilee Symposium, Horticultural Research Changing Scenario. UAS Bangalore. May 24-28

Sandhu, G.S., Bassi, G.S. and Sohoo, M.S. 1986. Evaluation of susceptibility in seeds of rice bean and different genotypes of cowpea to pulse beetle, *Callosobruchus maculatus* preference for oviposition. *J. Res. Punjab agric. Univ.* **23**(2):253-262

Sandhu, G.S., Bassi, G.S. and Sohoo, M.S. 1987. Evalution of susceptibility in seeds of rice bean and different genotypes of cowpea to pulse beetle, *Callosobruchus maculatus* F. *J. Res. Punjab agric. Univ.* **24**(3):423-432

Sanghi, A.K. and Kandalkar, V.S. 1991. Gene effects and heterosis in forage cowpea (*Vigna unguiculata* L. Walp). In: Golden jubilee symposium on genetic research and education : Current trends and next fifty years. Abst., Vol.II. Feb. 12-15, 1991. Indian Society of Genetics and Plant Breeding, IARI, New Delhi

Savithramma, D.L. 1992. Genetic variability in cowpea. *Agric. Res. J. Kerala* **30**(1):50-53

Schandert, S.H. 1970. *Method in Food Analysis*. Academic Press., New York, p.709

*Senanayake, S.G.J.N. and Wijarathne, V. 1988. Heritability and genotypic and phenotypic correlations of yield, yield components and protein content in cowpea (*Vigna unguiculata* L. Walp.). *Beitrage zur Tropischen Landwirtshaft and Veterinarmedizin* **26**(3):279-283

Sharma, P.C., Mishra, S.N., Singh, A. and Verma, J.S. 1988. Genetic variation and correlation in cowpea. *Ann. agric. Res.* **9**(1):101-105

Sharma, T.R. 1999. Genetic variability studies in cowpea. *Legume Research* **22**(1):65-66

Singal, S.K. 1986. Relative susceptibility of some genotypes of cowpea, *Vigna unguiculata* (L.) Walp. to pulse beetle, *Callosobruchus chinensis* (L.). *Bull. Grain Tech.* **24**(3):219-223

Singal, S.K. 1987. Studies on the relative resistance of some genotypes of chickpea, *Cicer arietinum* L. to pulse beetle, *Callosobruchus chinensis* L. *Bull. Grain Tech.* **25**(3):235-239

Singh, G.B., Reddy, R.C. and Krishnaiah, V.V. 1977. Studies on heritability, genetic advance and character association in cowpea (*Vigna unguiculata* L.). *Andhra Agri. J.* **24**(5&6):209-212

Singh, N.B., Ariyanayagam, R.P., Gupta, S.C. and Rao, A.N. 1995. Relationship of plant height, days to flowering and maturity to grain yield in short duration determinate pigeonpea. *Indian J. Genet.* **55**(1)1-5

Singh, N., Singh, V.P., Singh, J.V. and Singh, N. 1998. Correlation and path coefficient analysis in cowpea (*Vigna unguiculata* (L.) Walp.). *Forage Research* **24**(3):139-141

Singh, P. and Narayanan, S.S. 1993. *Biometrical techniques in plant breeding.* Kalyani publishers, New Delhi, pp.74-198

Sreekumar, K., Inasi, K.A., Antony, A. and Nair, R.R. 1996. Genetic variability, heritability and correlation studies in vegetable cowpea (*Vigna unguiculata* var. sesquipedalis). *S. Indian. Hort.* **44**(1&2):15-18

Sreekumar, S.G., Nair, R.N., Saraswathy, P., George, M.K. and Thomas, E.J. 1978. Genetic variability and correlations in cowpea, *Vigna sinensis* L. *Agri. Res. J.* Kerala (In press)

Tamilselvam, A. and Das, L.D.V. 1994. Correlation studies in cowpea (*Vigna unguiculata* (L.) Walp.) for seed yield. *Madras agric. J.* **81**(8):445-446

Thiagarajan, K. 1989. Genetic variability for yield and component characters in cowpea (*Vigna unguiculata* L.). *Madras agric. J.* **76**(10):564-567

Thiagarajan, K. and Natarajan, C. and Rathnaswamy, R. 1990. Combining ability and inheritance studies in cowpea (*Vigna unguiculata* L. Walp.). *Madras agric. J.* 77(7&8):305-309

Thiagarajan, K., Natarajan, C., Rathinaswamy, R. and Rajasekharan, S. 1993. Combining ability for yield and its components in cowpea. *Madras agric. J.* **80**(3):124-129

Tikka, S.B.S., Jaimini, S.N., Asawa, B.M. and Mathur, J.R. 1977. Genetic variability interrelationships and discriminant function analysis in cowpea. (*Vigna unguiculata* L.). *J. Hered.* **9**:1-9

Tyagi, P.C. and Koranne, R.D. 1988. Correlation and path analysis in cowpea (*Vigna unguiculata* subsp. Cylindrica). *Indian J. agric. Sci.* **58**(1):57-58

Vaid, I.K. and Singh, K.B. 1983. Genetic variability in F_3 and F_4 populations of a cross in cowpea (*Vigna sinensis* L.). *Madras agric. J.* **70**(5):281-283

*Vardhan, P.N.H. and Savithramma, D.L. 1998a. Variability, character association, path analysis and assessment of quality parameters in cowpea (*Vigna unguiculata*) germplasm for vegetable traits. *ACIAR-Food-Legume-Newsletter* **28**:7-8

*Vardhan, P.N.H. and Savithramma, D.L. 1998b. Evaluation of cowpea genotypes for vegetable purpose (*Vigna unguiculata* (L.) Walp.). *ACIAR-Food-Legume-Newsletter* **28**:5-6

Veeraswamy, R., Palaniswamy, G.A. and Rathnaswamy, R. 1973. Genetic variability in some quantitative characters of *Vigna sinensis*. L. *Madras agric. J.* **60**(9&12):1359-1360

*Verdcourt, B. 1970. Studies in Leguminosae - papilionoidea - for the flora of Tropical East Africa. *Kew Bull.* **24**:507-567

Vijayakumar, G. 1989. Study of heterosis and combining ability for yield and yield components in cowpea (*Vigna unguiculata* L. Walp.). M.Sc. (Ag.) thesis, Tamil Nadu Agricultural University, Coimbatore

Vir, S. 1980. Oviposition response and development of *Callosobruchus maculatus* on different varieties of cowpea. *Bull. Grain Tech.* **18**(3):200-203

Vir, S. 1981. Note on the relative susceptibility of different varieties of cowpea to *Callosobruchus maculatus. Indian J. agric. Sci.* **51**(11):813-815

Vir, S. 1982. Varietal preference in moth (*Vigna acontifolia* Jacq.) for the pulse beetle, *Callosobruchus maculatus* Fabricius. *Bull. Grain Tech.* **20**(1):3-7

*Waly, E.A., Saa, E.A., Hussein, M.H., El, S.A. and Sa, A.E. 1987. Diallel analysis of five faba bean parents for cowpea seed beetle infestation. *FABIS Newsletter* **17**:35

* Originals not seen

Appendices

APPENDIX-I

Mean performance of parents for different yield and bruchid resistance traits

Parents	Plant height (m)	No. of branches/plant	No. of flowers/plant	Days to flowering	LAI (45 DAP)	LAI (90DAP)	Pod yield /plant (g)	No. of pods/plant	Pod weight (g)	Seeds/pod	100 seed weight (g)	Length of seed (cm)	Breadth of seed (cm)	Weight of seed (g)	No. of eggs laid (No choice)	No. of bore holes (No choice)	No. of adults emerged (No choice)	No. of legs laid (Free choice)	No. of bore holes (Free choice)	No. of adults emerged (Free choice)	Loss of weight/seed (g)	Moisture content (Harvest %)	Moisture content (Storage %)	Seed coat thickness (mm)	Tannin (mg/g)
EC390231	2.25	15	119	46	1.21	1.34	152.31	84	1.81	13	9.34	0.9	0.6	0.11	22	3	3	24	4	3	0.044	8.7	6.4	1.14	6.10
EC367711	1.75	13	126	45	1.17	1.51	141.45	88	1.85	13	9.37	0.7	0.7	0.10	24	4	4	26	1	1	0.047	8.8	6.8	1.16	2.25
IC201092	3.1	16	216	51	1.20	1.48	328.50	151	2.17	15	12.28	1.1	0.8	0.13	30	2	2	30	4	4	0.014	8.5	7.2	1.12	3.47
V240	1.7	9	68	41	1.11	1.2	83.31	49	1.70	13	7.19	1.0	0.6	0.09	54	9	8	45	8	8	0.084	8.8	7.2	1.08	1.91
V16	1.25	12	64	47	0.67	1.17	80.45	45	1.71	13	8.38	0.8	0.6	0.10	38	7	7	42	8	8	0.057	8.5	7.6	1.08	5.78
Kanakamoni	1.3	13	90	48	1.05	1.10	117.50	63	1.61	12	8.42	0.8	0.6	0.09	32	10	10	35	8	7	0.088	8.9	6.8	1.12	6.18
C152	1.6	12	72	47	1.12	1.17	93.85	50	1.87	12	8.38	0.8	0.6	0.10	32	7	7	34	9	9	0.083	8.1	6.5	1.10	3.09

APPENDIX II

Mean performance of F_1 genotypes for different yield and bruchid resistance traits

F_1	Plant height (m)	No. of branches/plant	No. of flowers/plant	Days to flowering	LAI (45 DAP)	LAI (90DAP)	Pod yield /plant (g)	No. of pods/plant	Pod weight (g)	Seeds/pod	100 seed weight (g)	Length of seed (cm)	Breadth of seed (cm)	Weight of seed (g)	No. of eggs laid (No choice)	No. of bore holes (No choice)	No. of adults emerged (No choice)	No. of legs laid (Free choice)	No. of bore holes (Free choice)	No. of adults emerged (Free choice)	Loss of weight/seed (g)	Moisture content (Harvest %)	Moisture content (Storage %)	Seed coat thickness (mm)	Tannin (mg/g)
V240xEC390231	3.50	22	272	46	1.61	2.33	447.63	191	1.76	13	16.57	1.0	0.8	0.15	25	5	5	16	3	3	0.082	7.4	6.1	1.14	6.41
V240xEC367711	1.8	15	178	46	1.17	1.21	243.50	122	1.32	10	12.60	0.8	0.7	0.11	48	4	4	26	1	0	0.063	8.3	6.5	1.12	5.70
V240xIC201092	3.35	18	194	44	1.40	1.81	269.28	136	1.66	9	14.61	0.9	0.8	0.13	30	1	1	22	0	0	0.010	8.5	6.5	1.14	6.12
V16xEC390231	3.4	17	262	45	1.65	2.30	451.00	180	1.97	13	19.63	1.3	0.6	0.15	20	4	4	10	2	2	0.093	8.2	6.3	1.11	6.70
V16xEC367711	1.9	13	187	45	1.25	1.68	282.51	127	1.26	9	14.92	1.0	0.7	0.10	22	2	2	14	1	1	0.062	9.0	7.4	1.17	5.91
V16xIC201092	2.4	17	213	45	1.55	1.87	375.33	149	1.54	10	16.02	1.0	0.8	0.13	32	2	2	20	1	1	0.092	8.5	6.7	1.16	5.79
Kanakamoni xEC390231	3.5	24	329	43	1.80	2.34	558.89	230	1.79	12	16.32	1.0	0.8	0.14	46	4	4	26	1	1	0.053	8.8	6.9	1.12	4.50
Kanakamoni xEC367711	4.4	21	236	46	1.56	2.18	495.97	165	2.32	14	17.82	1.1	0.6	0.17	44	5	5	26	1	1	0.043	8.1	5.9	1.16	2.57
Kanakamoni xIC201092	3.5	21	342	42	1.72	2.70	636.80	235	1.75	12	20.10	0.9	0.7	0.14	38	2	2	22	0	0	0.032	7.6	5.5	1.14	2.57
C152xEC390231	3.9	22	278	42	1.50	1.80	524.13	192	1.94	13	15.30	0.9	0.6	0.15	30	2	2	16	1	1	0.060	8.6	6.4	1.12	2.50
C152xEC367711	2.1	14	180	38	1.31	1.73	265.53	126	1.67	11	11.03	1.1	0.6	0.10	22	0	0	10	1	0	0.070	8.2	6.2	1.18	4.50
C152xIC201092	2.1	15	191	47	1.17	1.75	262.48	134	1.58	8	12.06	0.8	0.5	0.09	35	1	1	22	1	1	0.087	8.3	6.3	1.16	5.10

APPENDIX III

Mean performance of F_2 genotypes for different seed characters and bruchid resistance traits

F_1	Pod weight (g)	Seeds/pod	100 seed weight (g)	Length of seed (cm)	Breadth of seed (cm)	Weight of seed (g)	No. of eggs laid (No choice)	No. of bore holes (No choice)	No. of adults emerged (No choice)	No. of legs laid (Free choice)	No. of bore holes (Free choice)	No. of adults emerged (Free choice)	Loss of weight/seed (g)	Moisture content (Harvest %)	Moisture content (Storage %)	Seed coat thickness (mm)	Tannin (mg/g)
V240xEC390231	2.35	16	11.42	1.1	0.6	0.13	39	10	9	26	11	10	0.055	8.4	6.3	1.12	5.79
V240xEC367711	1.99	14	9.68	0.9	0.7	0.11	54	10	9	20	6	6	0.056	8.6	6.3	1.11	1.31
V240xIC201092	1.98	13	10.81	1.0	0.7	0.12	54	8	8	25	5	4	0.073	8.8	7.5	1.19	3.92
V16xEC390231	2.52	15	13.23	1.1	0.8	0.15	29	10	10	18	9	9	0.063	8.5	5.9	1.10	2.12
V16xEC367711	2.22	15	11.02	1.2	0.7	0.12	53	9	8	24	7	7	0.019	8.7	6.2	1.16	1.68
V16xIC201092	2.54	17	9.77	1.0	0.7	0.12	40	7	7	23	6	6	0.053	8.8	6.7	1.18	4.51
Kanakamoni xEC390231	2.46	17	13.37	1.2	0.8	0.14	50	10	9	28	10	1	0.054	8.4	7.0	1.14	5.15
Kanakamoni xEC367711	2.94	18	12.81	1.2	0.7	0.14	46	10	10	30	10	1	0.063	8.5	6.8	1.11	2.81
Kanakamoni xIC201092	2.68	18	15.18	1.3	0.7	0.15	37	10	8	22	4	0	0.057	8.3	6.9	1.14	4.50
C152xEC390231	2.72	18	12.43	1.1	0.7	0.14	47	8	7	16	10	1	0.067	8.9	6.8	1.12	2.57
C152xEC367711	2.08	15	9.75	1.0	0.7	0.11	43	8	7	10	6	0	0.074	8.1	6.2	1.21	1.68
C152xIC201092	1.94	14	9.62	1.0	0.7	0.11	40	7	7	22	7	1	0.036	8.0	6.3	1.12	1.19

GENETICS OF BRUCHID (*Callosobruchus* sp.) RESISTANCE AND YIELD IN COWPEA

By

JYOTHI. C.

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
Kerala Agricultural University

Department of Plant Breeding and Genetics
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA

2001

ABSTRACT

The present study 'Genetics of bruchid (*Callosobruchus* sp.) resistance and yield in cowpea' was undertaken in the Department of Plant Breeding and Genetics, College of Horticulture, Kerala Agricultural University, Vellanikkara. The study was carried out to estimate the various genetic parameters of characters, to identify the yield components, to study association of characters related to pulse beetle resistance and to identify superior genotypes and hybrids having high yield and tolerance to pulse beetle.

High variability among parents and hybrids was observed for most of the yield and bruchid resistance traits. The characters namely number of eggs laid, number of adult beetles emerged, number of bore holes produced, loss of weight per seed and tannin content exhibited higher values of heritability, genetic advance and genotypic coefficient of variation, indicating the preponderance of additive gene effects.

A positive association was found to exist among yield attributes and also with yield in parents and hybrids. Genotypes having a thicker seed coat showed better resistance to pulse beetle attack and this character was found to be independent in gene action. Kanakamoni among the lines and EC 390231 among the testers were found to be the most promising genotypes for hybridization and selection since they recorded high positive gca. For heterosis breeding the crosses Kanakamoni x IC 201092 followed by C 152 x EC 390231 were found to be superior for pod yield. Kanakamoni and C 152 among the lines and EC 390231 and IC 201092 among the testers showed high tolerance to pulse beetle attack and are recommended for evolving resistant varieties using these genotypes through hybridization and selection. For evolving hybrids showing resistance to pulse beetle the crosses, C 152 x EC 367711 and V 240 x IC 201092 were rated supreme.