EVALUATION OF COWPEA [*Vigna unguiculata* (L.) Walp.] GENOTYPES FOR YIELD AND RESISTANCE TO PULSE BEETLE [*Callosobruchus* spp.]

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"EVALUATION OF COWPEA [*Vigna unguiculata* (L.) Walp.] GENOTYPES FOR YIELD AND RESISTANCE TO PULSE BEETLE [*Callosobruchus* spp.]"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

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LIST OF ABBREVIATIONS AND SYMBOLS USED

^{0}C	Degree Celsius
%	Per cent
CD	Critical Difference
cm	Centimetre
CRD	Completely Randomised Design
RBD	Randomised Block Design
et al.	And others
Fig.	Figure
gm	Gram
mg g^{-1}	Milli gram per gram
ha^{-1}	Per hectare
KAU	Kerala Agricultural University
kg ha^{-1}	Kilogram per hectare
AN	After Noon
FN	Fore Noon
RH	Relative Humidity
Temp.	Temperature
via	Through
mm	Millimetre
No.	Number
Cluster^{-1}	Per Cluster

&	And
Pod^{-1}	Per Pod
C.	*Callosobruchus*
$Plant^{-1}$	Per Plant
Sl.	Serial
spp.	Species (Plural)
GCV	Genotypic Coefficient of Variation
PCV	Phenotypic Coefficient of Variation
viz.	Namely

Introduction

1. INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp.] also called as black-eyed pea, southern pea, lobia etc. is a leguminous crop (2n=22), native of Africa. It is rich in proteins, vitamins and minerals and is mainly grown for grain, vegetable and fodder purposes. It is a shade and drought tolerant crop, well suited to incorporate in most of the cropping systems. It is an excellent cover crop having soil restoring properties. Due to the high amount of seed protein present in it, it is also known as poor man's meat or vegetable meat. It is widely cultivated in tropics and subtropics of Asia, Africa, central and southern America and parts of southern Europe and USA. In India pulses are grown in an area of about 26.57 million hectares with the production of 19.82 million tonnes and productivity of 746 kg ha^{-1} (Tiwari and Shivhare, 2016). Pulse production in India has been almost stagnant for the last few decades. The cropped area as well as production is fluctuating in recent years. Low productivity is certainly one of the major constraints in pulse production. Considerable research is essential to increase the productivity of pulses to meet the increasing demands of growing population. Necessity has always been felt to preserve the seeds from harvesting until sowing and it is often desirable to store the carryover seeds for more than one season. Numerous factors like crop variety, seed moisture content, temperature, relative humidity of storage, gaseous exchange, micro flora insect infestation etc. will decide the longevity of seeds under natural or controlled storage conditions.

About 500 species of insects have been associated with stored grain products and in that 25 species of insects attack pulses (Prabhakara, 1979). Of these, the attacks of coleopteran insects causes major damage to stored grains and grain products worldwide. Among the insect pests, bruchid popularly called pulse beetle, *Callosobruchus* spp. belonging to the family Bruchidae is a major problem in stored cowpea in all regions. Low germination, decreased seed weight, insect adulteration, mould spoilage, low food value, etc. are some of the after effects of bruchid infestation. They multiply rapidly in storage and by the time they are detected, the infested grain more often becomes unmarketable. Bruchid infestation normally results in substantial reduction in the quantity and quality of the seed. The estimated losses due to bruchids in various pulses ranged from 30-40 per cent within a period of six months and the post harvest seed losses due to bruchids can reach upto 100 per cent during periods of severe infestation (Mahendaran and Mohan, 2002). Though it is considered as a storage pest, its infestation starts in the field itself, where there is only minor damage and which is usually unnoticed. While infested seeds are harvested and stored, the larva of insect continues to feed as hidden infestation and population builds up large number in storage. Emerging adult causes secondary infestation resulting in huge losses. The infested seeds are usually unfit for human consumption and also for sowing purposes.

Indiscriminate use of chemicals has led to the development of insecticide resistant strains of storage pests as well as objectionable residues in treated commodities and also difficulty in handling and application due to its hazardous nature. Host plant resistance is one of the most satisfactory and sustainable methods of pest control, mainly as a basic element in integrated pest management strategies. Host plant resistance can be defined as the relative amount of heritable qualities possessed by the plant which influence the ultimate degree of damage caused by the insects (Painter, 1951). Varieties show differences considerably in their susceptibility to pulse beetle attack and this can be determined by screening different genotypes for resistance against the pest (Giga,1981). An essential pre-requisite for characterization of resistance factors and their key utilization in breeding for resistant varieties is to find out the mechanisms underlying 'antixenosis' (morphological and biochemical factors). Certain morphological and physiological characteristics inherited by plants form a core of defense against insects that would otherwise attack them.

Keeping these aspects in view, the present investigation was undertaken with the following objectives:

- Identify high yielding genotypes of cowpea with resistance to pulse beetle.
- To study genetic variability for different traits by estimating phenotypic and genotypic coefficient of variation.
- To estimate heritability and genetic advance for different characters.
- To determine phenotypic and genotypic correlation between yield and component characters in cowpea.
- To understand the direct and indirect effects of yield contributing characters by path coefficient analysis.
- To study on morphological and biochemical basis of resistance in cowpea against infestation of pulse beetles.

Review of Literature

2. REVIEW OF LITERATURE

The present study aimed at evaluation of cowpea [*Vigna unguiculata* (L.) Walp.] genotypes for yield and resistance to pulse beetle [*Callosobruchus* spp.]. The relevant literature on crop improvement is reviewed under different headings.

2.1 GRAIN YIELD AND ITS COMPONENTS

The literature related to the grain yield and its component characters are reviewed hereunder.

2.1.1. Genetic variability, Heritability and Genetic Advance

Greater genetic variability increases the chances for selection of better genotypes. The genetic parameters like genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) give an idea about magnitude of variability present in a genetic population. The estimates of genetic parameters like heritability and genetic advance help the plant breeder in selection of elite genotypes from diverse genetic populations. Therefore plant breeding efforts should aim at the manipulation of available genetic diversity in the desired direction through suitable selection criteria.

Thiyagarajan (1989) conducted genetic variability studies in cowpea and reported moderate variability for plant height, number of clusters plant^{-1}, number of pods plant^{-1} and yield plant^{-1}. High heritability estimates were recorded for characters like days to 50 per cent flowering, pod length, number of seed pod^{-1} and 100 seed weight. Genetic advance was high for the characters like plant height, number of seed pod^{-1} and 100 seed weight.

Rewale *et al.* (1995) studied seventy diverse genotypes of cowpea and claimed high estimates of heritability and genetic advance for 100 seed weight and plant height.

In a variability study conducted with seventy two genotypes of cowpea for nine yield related characters, Kumar and Sangwan (2000) found moderate to high heritability coupled with high genetic advance as percentage of mean for plant height, pod length, 100 seed weight, grain yield plant^{-1}, number of branches plant^{-1} and number of pods plant^{-1}.

After studying genotypic and phenotypic variability, heritability and genetic advance on yield and yield attributes in cowpea, Kalaiyarasi and Palanisamy (2000) stated that seed yield plant^{-1} and number of pods plant^{-1} had high estimates of genotypic coefficient of variation followed by 100 seed weight, number of seeds pod^{-1} and plant height. High heritability coupled with high genetic advance was observed in seed yield plant^{-1}, number of pods plant^{-1}, 100 seed weight, and number of seed pod^{-1}.

The variability in twenty genotypes of vegetable cowpea studied (Ajith, 2001) and reported high heritability in characters like length of main stem (99.81 %), pod length (95.39 %), and number of primary branches (92.21 %). High genetic advance coupled with heritability was noticed in length of main stem.

Ahmed *et al.* (2005) evaluated thirty two genotypes of cowpea for variability, heritability and genetic advance. Significant variation was recorded for 100-seed weight, plant height, number of pods plant^{-1}, number of seeds pod^{-1} and pod length. PCV was higher than (GCV) for all the traits studied. High GCV and PCV were recorded for plant height, number of pods plant^{-1} and 100-seed weight. High heritability coupled with high genetic gain was also observed for these characters.

In another study in cowpea, Suganthi and Murugan (2008) reported that seed yield plant^{-1}, number of pods plant^{-1} and number of clusters plant^{-1} showed high GCV and PCV. The highest heritability was recorded for seed yield plant^{-1} followed by number of seeds pod^{-1}, pod length and 100-seed weight. Seed yield plant^{-1} showed highest genetic advance as per cent of mean, followed by number of pods plant^{-1} and number of clusters plant^{-1}.

The grain yield components were studied by Adewale *et al.* (2010) and it was reported that among the eleven genotypes of cowpea, pods plant^{-1}, seeds pod^{-1}, 100 seed weight, and grain yield differ significantly. Seeds pod^{-1}, 100 seed weight and pod length had high GCV, PCV, heritability and genetic gain and also PCV was higher than the GCV for all the traits studied.

After estimating genetic variability and heritability on grain yield of ten cowpea accessions, Manggoel *et al.* (2012) found that analysis of variance was highly significant for all the characters studied. 100-seed weight (41.46 % and 38.47 %) showed the highest PVC and GCV followed by grain yield, number of pods plant^{-1} and days to 50 per cent flowering. Low PCV and GCV were recorded for traits like number of seeds pod^{-1} and pod length. Heritability estimates was high for grain yield (90.91%), number of pods plant^{-1} (89.23%), 100 seed weight (86.84%), days to 50 per cent flowering (79.05%), number of seeds pod^{-1} (73.40%) and pod length (63.16%).

Thorat and Gadewar (2013) assessed GCV, heritability and genetic advance in thirty genotypes of cowpea. All the genotypes indicated significant difference from all the characters studied. Days to 50 per cent flowering (40.04 %), plant height (34.71 %), number of branches plant^{-1}(27.99 %), number of pods plant^{-1} (24.84 %), and number of clusters plant^{-1} (24.73 %) showed high GCV. Plant height, days to 50 per cent flowering, days to maturity, number of branches plant^{-1}, number of pods plant^{-1}, 100 seed weight and number of clusters plant^{-1} showed high heritability.

Heritability and genetic advance were high for plant height, number of pods plant^{-1} and number of branches plant^{-1}.

After evaluating genetic variability, heritability and genetic advance for different characters in twenty two diverse genotypes of bush cowpea Vavilapalli *et al.* (2013) found that analysis of variance showed the occurrence of adequate genetic variation among the genotypes from all the characters studied. The magnitude of GCV and PCV were closer for majority of the characters studied. The high PCV and GCV were recorded for pod weight, plant height, and pod length. High heritability coupled with genetic advance was reported for yield plant^{-1}, plant height, primary branches, pod length, pod girth, pod weight and pods plant^{-1}.

Ajayi *et al.* (2014) noticed that traits like plant height, number of main branches, number of days to flowering, , number of pods plant^{-1}, pod length, pod weight, number of seeds pod^{-1}, and 100-seed weight showed high significant differences among the cowpea genotypes. The magnitude of PCV was higher than GCV in all the characters studied. All traits had high PCV and GCV values except number of main branches which had moderate PCV and GCV. All characters had high heritability estimates except for plant height (54 %) which was moderate and heritability values ranged from 54 per cent to 99 per cent. Most of the studied traits had high genetic advance as per cent of means (24% to 110%).

Evaluating genetic variability in twenty genotypes of cowpea, Kharde *et al.* (2014) stated significant differences among the genotypes assessed for all the characters. Along with high PCV and GCV, high heritability and genetic advance was reported for characters like plant height, pod length, average pod weight, number of seeds pod^{-1} and number of pods plant^{-1}.

Vir and Singh (2014) assessed thirty three indigenous and exotic accessions of cowpea during summer and kharif seasons and reported high degree of genetic variability for seed yield plant^{-1}, 100-seed weight, pod length, number of seeds pod^{-1}, number of pods plant^{-1}, number of pods cluster^{-1}, number of branches plant^{-1}, number of cluster plant^{-1}, plant height and days to 50 per cent flowering. Moderate to high heritability coupled with moderate to high expected genetic advance was observed for all studied traits studied. Superiority in terms of seed yield plant^{-1} was exhibited by accessions C-791, C-896, C-721, C-1023, and C-727 during summer season and accessions C-791, C-731, C-875, C-720 and C-1023 during kharif season.

Analysis of variance showed significant for all the character evaluated, except for 100 seed weight in twenty genotypes of cowpea. PCV were greater than GCV for all the character (Santos *et al.,* 2014).

According to Selvakumar *et al.* (2015), the highest estimates of PCV and GCV in cowpea were observed for yield plant^{-1} followed by plant height, pod length, number of clusters plant^{-1}, number of pods clusters^{-1}, 100 grain weight and number of branches plant^{-1}. All the ten traits studied recorded high value of heritability and it ranged from 74.20 per cent to 99.76 per cent. Genetic advance ranged from 12.77 to 129.90 and was high for yield plant^{-1}, pod length, plant height and number of cluster plant^{-1}. Days to maturity, number of seeds pod^{-1} and days to 50 per cent flowering recorded moderate genetic advance. All other traits recorded high value in both heritability and genetic advance except days to maturity, number of seeds per pod and days to 50 per cent flowering.

Aliyu *et al.* (2016) conducted a study for phenotypic analysis of seed yield components in twenty one cowpea breeding lines. High PCV compared to GCV was reported across all the yield components studied. 100 seed weight showed highest heritability estimate. All other components showed high heritability estimate.

High PCV and GCV was observed for characters *viz*., number of pods plant^{-1} (35.69 % and 34.24 %), number of pods cluster^{-1} (27.86 % and 25.44 %), pod weight

(24.81 % and 23.79 %)) and pod length (23.83 % and 23.62 %) in a study comprised of 15 genotypes of cowpea (Khandait *et al.*, 2016). Pod length (98.29 %), number of pods plant^{-1} (92.04 %), pod weight (91.98 %), and pod width (91.78%) showed high heritability estimates. Genetic advance as percentage of mean was recorded high for number of pods plant^{-1} (67.67%), pod length (48.24 %), number of pods cluster^{-1} (47.84 %), pod weight (47.01 %), and pod width (38.17 %).

Rajput (2016) estimated genetic variability for yield and its attributing traits in cowpea. Analysis of variance revealed highly significant difference for all the characters studied among the genotypes. PCV was higher than the corresponding GCV for all the traits studied. High PCV and GCV was reported for number of pod plant^{-1}, number of pods cluster^{-1}, pod weight and pod length. Low estimates PCV and GCV were exhibited by days to 50 per cent flowering and plant height.

In a study carried out on genetic variability, heritability and genetic advance on thirty genotype of cowpea for 16 traits Srinivas *et al.* (2017) reported significant differences among the genotypes for all the characters indicating the existence of sufficient variability. GCV and PCV were high for number of branches plant^{-1}, number of pods plant^{-1} and number of seeds pod^{-1}. The estimates of PCV were higher than corresponding GCV for all the characters. High heritability coupled with high genetic advance was observed for number of branches plant^{-1}, number of pods plant^{-1} and number of seeds pod^{-1} .

2.1.2 Correlation Studies

Yield is determined by several component characters. The relationship of yield with other characters is of great significance while formulating any selection programme for crop improvement. Some of the research works done in cowpea to bring out different characters with seed yield and among the yield contributing factors is briefly reviewed hereunder.

Correlation among nine traits in cowpea was evaluated by Kalaiyarasi and Palanismy (2000). It was observed that seed yield plant^{-1} showed strong positive correlation with 100 seed weight, number of seed pod^{-1}, plant height, number of pods plant^{-1} and number of branches plant^{-1}.

Venkatesan *et al.* (2003) reported that at genetic and phenotypic levels the number of branches plant^{-1}, number of clusters plant^{-1}, number of pods cluster^{-1} and number of pods plant^{-1} were positively correlated with seed yield in cowpea.

Deepa and Balan (2006) reported that in the case of grain yield plant^{-1} of cowpea, correlation coefficients at genotypic level was significantly positively associated with number of branches plant^{-1}, pod length, number of seeds pod^{-1} and 100 seed weight.

The seed yield plant^{-1} in cowpea showed significant positive correlation with number of clusters plant^{-1}, number of pods plant^{-1}, pod length, number of seeds pod^{-1} and 100-seed weight. but it was negatively correlated with plant height (Dahiya *et al.*, 2007).

According to Suganthi and Murugan (2008) seed yield had a significant positive correlation with pod length in cowpea. Manggoel *et al.* (2012) found a significant positive association between grain yield in cowpea and number of pods plant^{-1} (0.640), pod length (0.621), and 100 seed weight (0.690). but grain yield had significant negative correlation with days to 50 per cent flowering (-0.521). However, days to 50 per cent flowering had significant positive correlations with 100 seed weight ($r = 0.767$).

Thorat and Gadewar (2013) reported that at phenotypic as well as genotypic level, plant height exhibited significant positive correlation with days to 50 per cent flowering and days to maturity. Both at genotypic and phenotypic level number of branches plant^{-1} showed significant positive correlation with days to 50 per cent flowering, days to maturity and plant height. A highly significant negative correlation was observed for number of clusters plant^{-1} with days to 50 per cent flowering, days to maturity and plant height. Number of pods clusters^{-1} showed highly significant positive correlation with number of cluster plant^{-1}. Seed yield showed highly significant positive correlation with clusters plant^{-1}and number of pods plant^{-1}.

Plant height was found to be highly significant and positively correlated with number of main branches in both at genotypic and phenotypic correlation, while plant height was found to be highly significant and negatively correlated with number of pods plant^{-1} and seed weight. Number of main branches was found to be highly significant and negatively correlated with number of pods plant^{-1}and seed weight (Ajayi *et al.* 2014)

Santos *et al.* (2014) found highly significant positive correlations between the character pairs; pod weight and number of seeds pod^{-1}, pod length and pod weight and number of pods plant^{-1} and grain yield.

Positive and significant correlation of seed yield plant^{-1} with number of seeds pod^{-1}, number of pods plant^{-1}, number of pods cluster^{-1}, number of cluster plant-1, and days to 50 per cent flowering was reported in cowpea by Vir and Singh (2014).

Meena *et al.* (2015) estimated the correlations coefficients for ten polygenic characters in seventy two germplasms of cowpea. Seed yield plant^{-1} showed significantly positive genotypic correlation with seeds pod^{-1}, primary branches plant^{-1}, pod length, plant height, 100 seed weight, days to maturity, days to 50 per cent flowering and pods plant^{-1}. Days to 50 per cent flowering exhibited significant positive correlation with days to maturity, pod length, seeds pod^{-1}, primary branches plant^{-1} and 100-seed weight. However, days to 50 per cent flowering had significant negative correlation with pods plant^{-1}. Days to maturity showed significant positive correlation with seeds pod^{-1}, pod length, primary branches plant^{-1} and 100-seed weight. but a significant negative correlation was observed between pods plant^{-1} and days to maturity. Pod length had significant positive correlation with seeds per pod^{-1} and 100-seed weight. Pods plant^{-1} had significant negative phenotypic correlation with 100 seed weight, pod length and seeds pod^{-1}. 100 seed weight showed significant positive correlation with seeds pod^{-1}.

According to Aliyu *et al.* (2016) highly significant positive correlation was observed for pods plant^{-1} with seed-yield while, 100-seed weight recorded significant negative correlation with seeds pods^{-1}.

In a correlation study conducted using sixty genotypes of cowpea Sharma *et al.* (2016) found that at genotypic level seed yield plant^{-1} exhibited significant positive correlation with number of pods plant^{-1} (0.453), test weight (0.421), number of pods cluster^{-1} (0.373), pod length (0.351), number of seeds pod^{-1} (0.343), number of clusters plant^{-1} (0.318) and plant height (0.252). Number of seeds pod^{-1} exihibited significant positive correlation with pod length (0.366), number of primary branches plant^{-1} (0.217) and plant height (0.160), while significant negative correlation was showed by number of seeds pod^{-1} with days to 50 per cent flowering (-0.496).

2.1.3 Path Coefficient Analysis

Path analysis is a standardized partial regression coefficient which explains cause and effect relationship among the variables (Wright, 1960). It helps in partitioning of the correlation coefficients into direct and indirect effects of independent variable on dependent variable (Dewey and Lu, 1959). As seed yield is a dependent character influenced by several other factors, selection based on only seed yield without considering the component characters is not effective. Hence, path analysis reveals whether association of these characters with yield is due to their effect on yield or is a consequence of their indirect effect *via* other component character. The information obtained from path analysis helps in indirect selection for genetic improvement of yield.

Belhekar *et al.* (2003) stated that plant height, number of pods plant^{-1} and 100 seed weight exhibited direct effect on seed yield plant^{-1} in cowpea.

According to Venkatesan *et al.* (2003) path coefficient analysis revealed that seed yield exihibited positive direct effect with number of pods plant^{-1}, pod length, number of clusters plant^{-1}, number of seeds pod^{-1}, and 100-seed weight.

Mittal and Singh (2005) found that pods plant^{-1}, pod length and 100 seed weight had high positive direct effects on seed yield in cowpea.

Path coefficient analysis was conducted in cowpea by Manggoel *et al.* (2012) and revealed highest positive direct effect of 100 seed weight (1.45) on grain yield and it was followed by number of seeds pod^{-1} (0.49). Pod length, days to 50 per cent flowering and number of pods plant^{-1} exhibited negative direct effects on grain yield. Regardless of the high negative direct effects of days to 50 per cent flowering, its indirect effects *via* 100 seed weight were positive. Also, the indirect effects of pod length and number of pods plant^{-1} on grain yield *via* 100 seed weight were significantly high and positive.

In a path coefficient analysis study with forty four genotypes of cowpea Nath and Tajane (2014) observed that number of pods plant^{-1} (0.5537) recorded highest direct effect on seed yield plant^{-1} and followed by 100 seed weight (0.5127) and number of seeds pod^{-1} (0.2497). Through indirect effect *via* number of pods plant^{-1}, days to maturity, plant height at maturity, number of seeds pod^{-1} showed significant positive correlation with seed yield plant^{-1}. Number of seeds pod^{-1} had highly significant positive correlation with seed yield plant^{-1} through its indirect effect *via* number of pods plant^{-1} followed by 100 seed weight. Residual effect obtained was 0.1748.

According to Santos *et al.* (2014) pod length in cowpea showed highest direct positive effect (1.8128) on grain yield, however total correlation of pod length exhibited a low value (0.0847). Number of pods plant^{-1} had a total positive correlation of 0.7982 with grain yield. Nevertheless its direct effect was negative (-0.7521), while the indirect effect of the other variables like number of pods plant^{-1} (1.8946) makes total correlation positive. Days to flowering obtained high direct effect on grain yield, but the indirect effects of the other variables ratified the total correlation, resulting to low association with grain yield (0.1959). Number of seeds pod^{-1} showed direct negative effect with grain yield.

By studying path coefficient analysis of growth characters to seed yield in cowpea Shanko *et al.* (2014) revealed that maximum direct effect on seed yield was contributed by number of pods plant^{-1} while, days to 50 per cent flowering and number of seed pod^{-1} contributed negative direct effect on seed yield.

Path coefficient analysis revealed high direct positive effect of primary branches plant^{-1} and 100-seed weight on seed yield plant^{-1} in cowpea (Meena *et al.*, 2015).

Sharma *et al.* (2016) reported that highest positive direct effect on seed yield plant^{-1} was showed by number of pods plant^{-1}, while pod length contributed negative direct effect on seed yield. Number of pods plant^{-1} exhibited considerable positive indirect effect on seed yield plant^{-1} *via* number of pods cluster^{-1}. The component of residual effect of path analysis obtained was 0.155. The low residual effect indicated that character for path analysis were adequate and appropriate.

2.2 THE PEST

Callosobruchus spp commonly called pulse beetle, cowpea weevil etc. is a serious storage pest of leguminous seeds. The damage of the pest generally starts from field where they are carried to storage. There are four developmental stages for this pest *viz.,* egg, grub, pupa and adult (Plate 1). Freshly laid eggs are transluscent, smooth and shiny, which later become yellowish white colour. The beetle pupate inside the grain. Grubs are responsible for causing the damage. The beetle is sexually dimorphic.

Prevett (1961) claimed that *Callosobruchus maculatus* is very well adapted to cowpea culture in the tropics, and reported efficient dispersal from stores to crops ripening in the field.

According to Howe and Currie (1964), cowpea is a superior food for *C. maculatus* and also found that a single female insect in its life time laid an average of 100 eggs. It was reported that odour of seeds may provide a stimulus for oviposition which could come from the chemical composition of the seed.

Raina (1970) studied the comparative biology of *Callosobruchus spp.* on mung bean at 30^0C and 70 per cent relative humidity. The insect had an average incubation period of 3.5 days. The combined larval and pupal period was 18.8 days. The total number of days taken for the completion of life cycle (from the day of oviposition till adult emergence) was an average of 22.3 days with a range of 21 to 27 days. The males had a life span of 6 to 11 days with an average of 7.6 days, at the same time females had a life span of 5 to 10 days with an average of 7.4 days

Ishimoto *et al.* (1996) reported various species of bruchids including *Callosobruchus chinensis, C. maculatus* and *Callosobruchus analis* causing post-harvest damage to East Asian grain legumes. The comparative biology and management of the three species of the pulse beetles on soybean and cowpea with

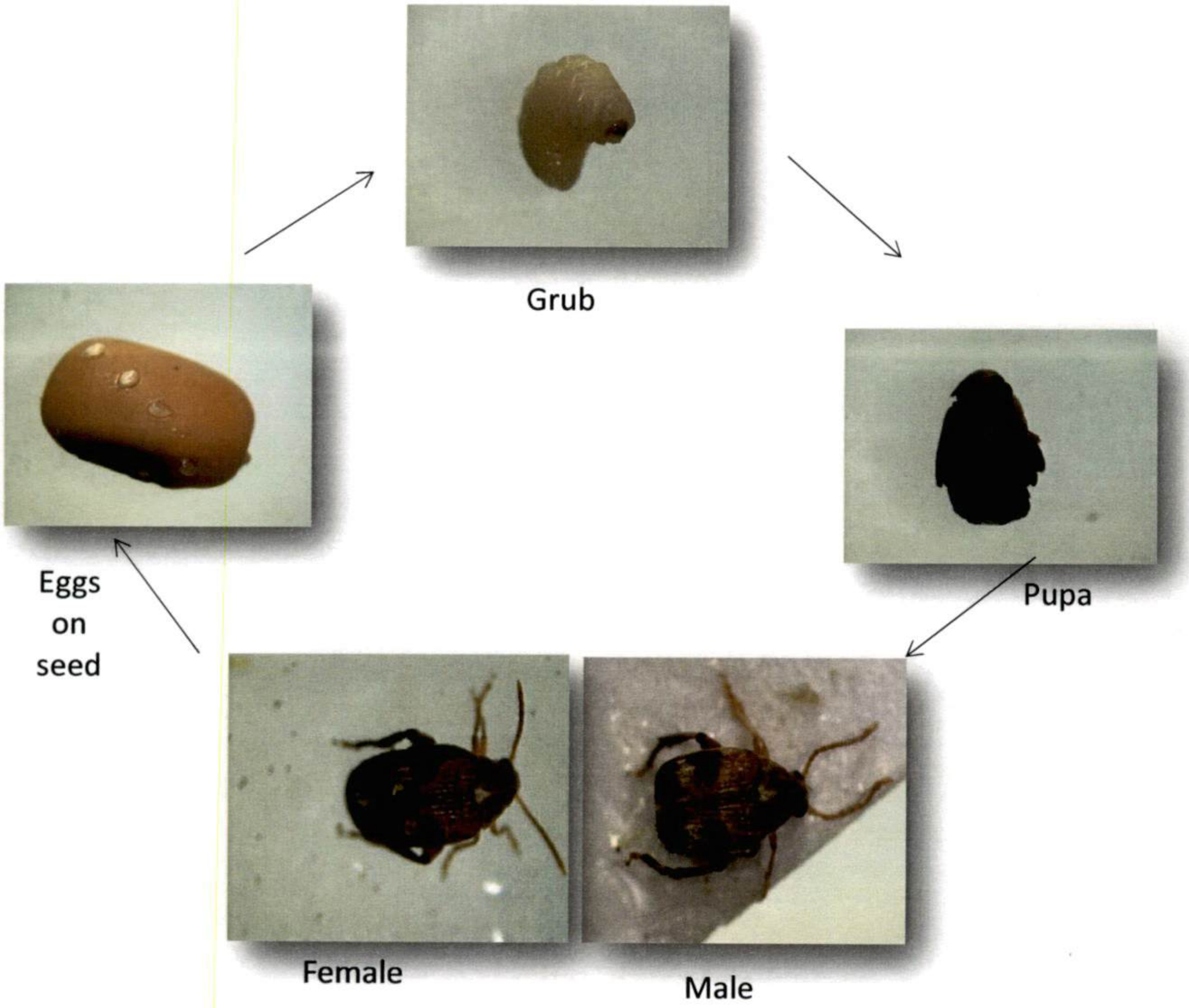


Plate 1. Lifecycle of *Callosobruchus* spp.

special reference to *C. analis* (Fab.) was studied by Sibi (2003) under laboratory condition. On cowpea the incubation period, total larval and pupal period and total developmental period were 6.0, 25.0 and 30.0 days respectively for *C. analis* and corresponding figures for *C. maculatus* were 5.0, 27.0 days and 27.0 days and for *C. chinensis* were 5.0, 26.5 and 27.0 days. The pre-mating (minutes), mating (minutes), pre-oviposition period(minutes) and oviposition period (days) for the three species on cowpea averaged 40.0, 10.0, 20.0 minutes and 7 days for *C. analis*, 32.0, 6.0, 12.0 minutes and 4.5 days for *C. maculatus*, 25.0, 7.0, 16.0 minutes and 5.5 days for *C. chinensis*. It was found that females lived longer than males in all three species which had an average life span of 8.5 and 7.5 days for females and males respectively.

2.3 SCREENING FOR RESISTANCE TO PULSE BEETLE

Prabhakara (1979) reported 0.18 per cent field incidence of bruchid in cowpea. Pusa 2 and Pusa 4 recorded high infestation.

In India 12.5 million tonnes of edible legumes are produced every year and nearly 18.6 per cent of cowpea alone is damaged by bruchids during storage (Agarwal *et al.*,1988). Giga and Smith, (1981) conducted studies to find out the varietal preference in six cowpea varieties and found that the varieties TVx 66/2H, TVu 1977/oD and TVu 1190 were notably more resistant to infestation by *C. maculatus* than the fairly susceptible variety Prima TVu 76.

The estimated germination loss was up to 79.6 per cent in mung bean as a consequent to pulse beetle infestation was reported by Singh and Sharma (1982).

In a study conducted on relative resistance and susceptibility of ten cowpea cutivars to pulse beetle, *C. maculatus* Manohar and Yadava (1990) were found that the cultivar Udaipur 2 suffered maximum loss (56.78 %), whereas CO 1 had the least loss (20.40 %). They also reported that Udaipur 2 and P 1309 were the most preferred while, the CO 1 was the least prefered for oviposition.

The studies by Khattak *et al.* (1991) revealed that none of the chickpea cultivars were completely resistant to pulse beetle infestation, however their response varied significantly. The variety CM-72 was found to be significantly resistant followed by CM-68 and CM- 1918 while, variety CM-6153 was found highly susceptible followed by CM-1913.

According to Lara (1997) the genotypes with the most oviposition are not always the most susceptible; there may be other factors that prevent insect larval development. In this way, a genotype with heavy oviposition can still prove to be resistant.

Jyothi (2001) conducted a study to identify superior genotypes and hybrids of cowpea having high yield and tolerance to pulse beetle and found that four genotypes *viz.*, Kanakamoni, C-152, EC 390231 and IC 201092 showed tolerance to pulse beetle attack.

The cowpea cultivars *viz.,* Ife Brown, Maiduguri-A, Maiduguri-B and TVu 2027 were screened by Jackai and Asante, (2003) to study resistance to *C. maculatus* (F.). Significantly more eggs were found to be laid on the seeds of TVu 2027 (the resistant control) than other cultivars including Ife Brown which is known to be highly susceptible to bruchids. It was found that general egg count have not been shown to be predictive enough in resistance studies while per cent weight loss was one of the most reliable indicators for resistance of cowpea damage by the insect.

The laboratory experiment on chickpea was conducted using *C. analis* and observations on seed germination percentage were recorded. Significantly high germination of 93.46 per cent was obtained where no pulse beetle was released. Low germination level of 61.0 per cent was observed for seeds stored with eight pairs of adult beetles. (Patil *et al.,* 2003).

Suja *et al.* (2004) conducted an experiment to assess the damage by bruchus beetle *Callosobruchus* spp on common cowpea varieties and found that out of the grains of seven cowpea varieties screened V-118 had the lowest incidence followed by the variety New era.

According to the study conducted by Shaheen *et al.* (2006) to evaluate the resistance of fifteen chickpea cultivars against pulse beetle, cultivars with rough, wrinkled, hard and thick seed coat were more resistant compared to those having smooth, soft and thin seed coat. The minimum number of eggs of pulse beetle was recorded to be laid in Dasht and the maximum eggs were observed in Paidar- 91. The minimum grain damage and minimum grain weight loss was reported in Bittle-98 and Dasht respectively whereas, the maximum damage and maximum weight loss was seen in Flip 97-192C and CM-2000 respectively.

Parameshwarappa *et al.* (2007) screened twelve varieties of chickpea for finding out extent of damage, seed quality, varietal resistance and susceptibility to pulse beetle (*C. chinensis* L.). None of the varieties was found immune to the infestation by *C. chinensis* L. However there was significant difference in relative susceptibility of different varieties to bruchid attack. It was found that ICCV-10 was the most susceptible one while, ICCV-03311 was the least susceptible variety when compared to other varieties. The highest loss in germination was for ICCV-10 and lowest was for ICCV-03311 after the infestation of 60 days by pulse beetle.

On evaluating the susceptibility of eight varieties of cowpea to pulse beetle, *C. maculatus* (Fab.) and *C. analis* by Shivanna *et al.* (2011) reported that CP-17 was observed with lesser oviposition, followed by IT-38956. The highest oviposition was recorded for local variety followed by C-152, TVX-44 and KBC-1. The weight loss of grains was less in the case of IT-38956 followed by CP-17. Local variety recorded highest weight loss of grains, which is on par with C-152.

Lephale *et al.* (2012) found significant variation in cowpea cultivars with respect to per cent weight loss. Small drum with the highest rate of infestation suffered the highest weight loss of 37.2 per cent while, Red caloona with the lowest rate of infestation suffered 1.81 per cent weight loss.

Seventy three cowpea genotypes collected from different states of India were evaluated for their relative resistance to pulse beetle, *C. maculatus* under field conditions. Of these, thirty five genotypes were found to be infested under field condition for carryover of pulse beetle population and seed damage ranged from 3.03 to 35.71 per cent. Five genotypes found absolutely free from pulse beetle damage were identified as resistant ones. The study regarding the relative resistance of the 38 uninfested field genotypes was conducted under laboratory condition. The significant difference in the reaction of these genotypes in terms of per cent seed damage and seed weight loss was reported. Fourteen genotypes were rated as highly susceptible genotypes since it had high seed damage (6.33 to 100%) as well as the seed weight loss (59.13 to 100%). It was reported that five genotypes *viz.,* ACM 0502, PGCP 3, NBC 13, CP 235 and PGCP 5 were absolutely free from pulse beetle damage and rated as resistant genotypes (Nalini *et al.,* 2012).

The significant variation among the cowpea accessions with respect seed damage was observed by Divya (2012). Based on damage parameters like oviposition, per cent insect infestation and weight loss, Palem-2, Palem-1, AK-21 and NSB-27 were considered as resistant accessions while, NS/05/42 and NSJ/NAIP/BD-ADB-35-1 were found as susceptible accessions.

Amusa *et al.* (2013) evaluated four cowpea lines to bruchid tolerance and found significant variation in percentage weight loss, number of damaged seeds, and number of undamaged seeds. It was also observed that the genotype with lowest per cent weight loss had the highest number of undamaged seeds (IT81D-994) whereas the genotype with the highest per cent weight loss had the highest number of damaged seeds (TVx 3236).

Badii *et al.* (2013) used twenty two cowpea varieties to study the varietal susceptibility to the storage beetle *C. maculatus* and found that the number of eggs laid on the seeds was significantly different among the genotypes. SARC 3-122-2, Marfo-Tuya and SARC 1-119-2 recorded more egg load on seeds while SARC 1-132-1, SARC 1-91-1 and SARC1-13-2 had the minimum egg load. High percentage weight loss (24.0 % - 29.4 %) was recorded in varieties Apabgaala, SARC 1-36-1 and Marfo-Tuya while, it was low (4.3 % - 9.6 %) for SARC 1-132-1, SARC 3-90-2 and SARC 3-103-1 therefore, should be incorporated into further breeding programmes.

After studying the impact of twenty cowpea genotypes, insecticides and their interaction effect on field infestation of bruchids Sunitha *et al.* (2013) found that, in selective genotypes PGCP-3, KBC-2, DCP-17, TPTC-l, TPTC-2, PCP-9711 maintained minimum seed damage and per cent weight loss of seeds in interaction with 0.05 per cent pre harvest spray Quinolphos 25 EC.

Mogbo *et al.* (2014) reported that among the three varieties of cowpea Ex-potiskum and Brown-variety exhibits more resistance qualities to the weevil attack than Kafanji which was more susceptible to the weevil attack. since Kafanji suffered more damage and weight loss while the Brown variety and Ex-potiskum suffered less damage. The least weight loss was observed on Ex-potiskum.

Sharma and Thakur (2014) conducted studies varietal preference of *C. maculatus* on thirteen genotypes of soyabean and found that except the variety Harasuya, all other varieties of soyabean were highly preferred for egg laying. Maximum percentage weight loss was recorded in genotype P13-4 (11.22 %) and Himasuya (10.38 %). The result revealed that the genotype Bragg was totally resistant with zero per cent weight loss.

Chandel and Bhadauria (2015) found that the varieties showed their varied response to pulse beetle infestation. The maximum infestation and total weight loss were found in Bahar, followed by Type-21 against its minimum in Prabhat. The infestation and losses were found to be positively associated with moisture content. There was no role of protein content of seeds neither on losses nor on infestation of the pest and also the total numbers of eggs laid in each sample were not found to affect the losses.

After screening fifty two accessions of cowpea for resistance to pulse beetle, *C. chinensis* under no-choice artificial infestation conditions Tripathi *et al.* (2015) found significant differences among the accessions in terms of oviposition of *C. chinensis.* The oviposition ranged from 72 to 475.7 eggs per 20 seeds. Minimum number of eggs were laid in Pusa Komal followed by IC106837 while, maximum number of eggs were laid in IC280014 followed by IC313300. It was found that weight loss also varied significantly among different accessions and percentage weight loss was observed minimum in IC091598 (22.01 %) and maximum in IC363747 (58.697 %) followed by Local variety (55.297 %).

Based on the studies conducted by Ahmed *et al.* (2016) on growth and development of the pulse beetle, *C. chinensis* (L.) on eleven chickpea varieties it was found that fecundity of the pulse beetle female varied significantly on different chickpea varieties, minimum being on PBG 1 and maximum on PKG 1.

Kamble *et al.* (2016) reported ovipositional preference of *C. chinensis* L. on different chick pea varieties. The minimum number of eggs was laid on the variety Vijay and maximum number of eggs on the variety PG-5 followed by Virat and PG-12. Vijay exhibited wrinkled seed coat and yellowish brown colour which were found to be least prefered for oviposition as compared to bold seeded Virat, PG-12 and PG-5 which was having white to brown colour characteristics.

Parmar *et al.* (2016) carried out experiment on ten mung bean varieties for their susceptibility against *C. chinensis* L. under storage. Vishal, Samrat, GM-3, GM-4 and K-851 were found resistant based on oviposition preference, per cent weight loss and per cent germination loss against pulse beetle.

According to the laboratory experiment conducted by Swamy *et al.* (2016) to evaluate relative susceptibility of black gram varieties to pulse beetle, *C. maculatus* there was significant difference among genotypes in terms of oviposition by bruchids and grain damage under no choice conditions. The variety LBG 752 recorded highest number of eggs and it was on par with TU 94-2 and LBG 623. The least number of eggs was recorded in variety TU 80 and it was on par with TU 68. The highest per cent of grain damage was observed in variety LBG 752. The varieties TU 80 and TU 68 recorded less per cent of grain damage and weight loss, whereas the maximum loss in weight was observed in LBG 752 followed by TU 72.

2.3 ROLE OF MORPHOLOGICAL AND BIOCHEMICAL CHARACTERS IN HOST PLANT RESISTANCE

The relative resistance of gram varieties to *C. chinensis* Linn., on the basis of biochemical parameters was studied by Singh *et al.* (1995). Venugopal *et al.* (2000) conducted an experiment on factors associated with *C. maculatus* (Fab.) resistance in cowpea and they correlated the important primary and secondary metabolites in the seed to the developmental parameters of the bruchid. It was found that all the cultivar varieties studied showed higher amounts of primary metabolites *viz.,* proteins showed a positive correlation with infestation rate however, the wild varieties, showed significantly lower amounts of these primary metabolites *viz.,* proteins and as a result lower level of infestation was noticed. The non-protein anti-metabolites such as total phenols were significantly lower in the wild cultivars showing a negative correlation with infestation rate. The study revealed that these non-protein anti-metabolites were important in providing resistance to the seeds.

Bhattacharya and Banerjee (2001) reported that the penetration capacity of the neonate larvae was inversely related to phenol contents of the seed. Chakraborty *et al.* (2004) reported that moisture content and protein content of seeds were found to have no influence on susceptibility of mung bean to pulse beetle.

After evaluating thirteen cowpea genotypes for bruchid resistance Nagaraja (2006) reported that the genotypes KM-1, Goa local T-1 and TV × 944 showed least susceptible to *C. chinensis* which had low weight loss, low germination loss, low protein and high phenol content compared to the susceptible genotypes were CO-7, C-3, V-118 and DCP-2.

The protein concentration differed significantly in each group cultivar. Resistant bean species were the least in protein concentration while, sensitive cowpea cultivars were the greatest in protein concentration (Abdel-Sabour *et al.,* 2010).

Fawki *et al.* (2012) screened four varieties of cowpea seeds to study resistance to the bruchid *C. maculatus* and reported that morphological characters like seed coat texture were not found to be responsible for offering resistance to *C. maculatus*. But it was revealed that female weevil preferred the smooth surface for oviposition.

According to Divya (2012), less protein content and high phenols were detrimental to the growth and development of *C. chinensis* while, high protein content and low phenols of the test accessions favoured the successful development of bruchids of pulse beetle.

Divya *et al.* (2013) studied the effect of bruchids (*C. chinensis* L.) on biochemical and physico-chemical characters of fifty horse gram and found that among the biochemical and physico-chemical characters, proteins and phenol content showed significant influence on seed infestation. It was reported that less protein content and high phenols of the accessions were detrimental to the growth and development of *C. chinensis* while high protein content and low phenols of the test accessions privileged the successful development of bruchids. Accessions with low phenol content *viz.,* KSAS/ 06/280, NS/05/103 and PSRJ-13089-1 recorded more per cent insect infestation and per cent weight loss.

Based on laboratory studies in cowpea by Tripathi *et al.* (2013) to understand the basis of resistance against pulse beetle due to variability in physical and biochemical parameters it was found that the colour and texture had no influence on the resistance or susceptibility of cowpea accessions to pulse beetle. According to the study it was reported that resistance found in different cowpea accessions to *C. chinensis* may be due to biochemical factors rather than the physical parameters of the seed. Correlation studies between growth index of *C. chinensis* and biochemical parameters of different cowpea accessions indicated that seed moisture had a positive relation with the growth index of bruchid whereas, Phenol had negative relation with growth index of *C. chinensis*.

Mogbo *et al.* (2014) reported that the Kafanji variety had the highest protein content (21.8%) which could be the reason of high weight loss due to weevil infestion than the other two varieties studied. It was reported that seed properties including seed testa colour and moisture content generally do not influence the susceptibility of cowpea seeds while, in the case of seed texture of the cowpea varieties, it was found that the susceptible variety Kafanji possessed a smooth coat while the other two varieties are rough.

Sowmya (2015) conducted experiments on seed storability against pulse beetle in thirty three greengram genotype and found that less protein content and high phenol content of the seed were harmful to growth and development of *C. chinensis* and it resulted in minimum insect damage and weight loss whereas high protein content and low phenols were found amiable for the development of bruchids and lead to susceptibility with increased damage.

After evaluating susceptibility of cowpea weevil on four main varieties of chickpea Kouser *et al.* (2017) observed that, cowpea weevil highly consumed KP-8mm which was a smooth seed coated variety followed by KC-12 mm while KE-9 mm showed relatively low consumption, and Desi kala chana was least consumed. The susceptible varieties exhibited soft, moreover, smooth seed coat and white in colour whereas least susceptible had hard and wrinkled seed coat.

Materials and Methods

3. MATERIALS AND METHODS

The present study aimed at evaluating cowpea [*Vigna unguiculata* (L.) Walp.] genotypes for yield and resistance to pulse beetle [*Callosobruchus* spp.] was carried out in a farmer's field, at Kayamkulam during 2015-2017. The information on the materials used and techniques adopted during the course of investigation are presented hereunder. Two experiments were conducted to take up the objectives. The experiment-I was to evaluate and screen out the cowpea genotypes for yield and resistance to pulse beetle. Experiment- II was conducted to study the factors associated with the resistance to pulse beetle in five relatively resistant genotypes and five relatively susceptible ones which were identified through experiment-I.

3.1 EXPERIMENT I: EVALUATION FOR YIELD AND LABORATORY SCREENING

3.1.1 Evaluation of Yield and Screening for Carryover Population

3.1.1.1 Materials

The materials in the first experiment comprised of thirty genotypes of cowpea, which included the released varieties (Hridya, Kanakamani, and Sreya) and local cultivars. The varieties are denoted by treatment numbers T_1 to T_{30}. The details of the genotypes are given in Table 1.

3.1.1.2 Methods

3.1.1.2.1 Layout and Conduct of the Field Experiment

The experimental crop was raised during the period of April 2016 to July 2016 in a farmer's field at Kayamkulam in randomized block design with three replications. The area is located in coastal humid tropics ($9^0 8^1$ North latitude, $76^0 30^1$

Table 1. List of cowpea genotypes used in the study

No.	Genotype	Source	No.	Genotype	Source
T_1	Ambalappuzha local	Alappuzha	T_{16}	Thuravoor local	Alappuzha
T_2	Kayamkulam local-1	Alappuzha	T_{17}	Karikode local	Kollam
T_3	Kayamkulam local-2	Alappuzha	T_{18}	Clappana local	Kollam
T_4	Kulashekarapuram local	Kollam	T_{19}	Haripad local	Alappuzha
T_5	Kottayam local	Kottayam	T_{20}	Nilambur local	Malappuram
T_6	Mannuthy local	Thrissur	T_{21}	Chittoor local	Palakkad
T_7	Dhavengarae local	Karnataka	T_{22}	Kolllengode local	Palakkad
T_8	Hanumanmattti local	Karanataka	T_{23}	Panmana local	Kollam
T_9	Nenmara local	Palakkad	T_{24}	Wayanad local	Wayanad
T_{10}	Oachira local	Kollam	T_{25}	Piravom local	Alappuzha
T_{11}	Belagum local	Karnataka	T_{26}	Champakulam local	Alappuzha
T_{12}	Adoor local	Kollam	T_{27}	Bijapur local	Karnataka
T_{13}	Hridya	RARS, Pattambi	T_{28}	Mankara local	Palakkad
T_{14}	Alathur local	Palakkad	T_{29}	Sreya	RARS, Pattambi
T_{15}	Kanakamani	RARS, Pattambi	T_{30}	Vallikunnam local	Alappuzha

Plate 2. General field view (a&b)

East longitude and 3.05 m above mean sea level). The data on average temperature and relative humidity during the experiment period were obtained from the meteorological observatory, Central Plantation Crop Research Institute, Regional Station, Kayamkulam and is given in Appendix 1. The experimental field was divided into three blocks of thirty plots each and the treatments were allotted to each block at random. The plot size was $3m^2$. Spacing was 30cm between rows and 10cm between plants in a row. Recommended agronomic practices were followed during crop growth period as per the "Package of Practices recommendations" of Kerala Agricultural University (KAU, 2016) except the usage of plant protection chemicals. Plate 2 shows a general view of the experimental field.

3.1.1.2.2 Biometric Observation

The observations on the following characters were recorded.

a. Days to 50 per cent flowering

Number of days taken from sowing to the day at which 50 per cent of the plants in the each plot attained flowering.

For the following characters, observations were recorded from five randomly selected plants in each plot. The data for statistical analysis were obtained from the mean values worked out thereafter.

b. Number of primary branches plant^{-1}

Branches originating from the main stem were counted at full maturity of the plant.

c. Length of main stem (cm)

Length of main stem measured from the ground level to its tip at the time of final harvest was recorded and expressed as centimeter.

d. Number of pod clusters plant^{-1}

The number of pod clusters on each observational plant was recorded and the average was worked out.

e. Number of pods cluster^{-1}

The total number of pods in ten randomly chosen clusters in the observational plants were counted and the average was worked out.

f. Number of pods plant^{-1}

Total number of pods harvested from each observational plant was separately counted and the average worked out.

g. Pod characters viz., pod length (cm), pod girth (mm), pod weight(g) and number of seeds pod^{-1}

These observations were recorded from ten randomly selected pods after grain maturity stage from observational plants in each plot and mean value for each character was worked out.

h. 100 seed weight (g)

100 seed weight was obtained by weighing 100 randomly selected uniform sized seeds from each observational plant and mean weight was recorded in grams.

i. Seed yield plant^{-1} (g)

Total grain yield from each of the observational plant was recorded in gram and average was worked out.

j. Crop duration (days)

The number of days from the date of sowing to the final harvest was counted for each observational plant and mean was calculated.

k. Percentage of seeds damaged by pulse beetle

Four hundred seeds were randomly collected based on seed weight from each genotype in labelled cloth bags (Plate 3) and were observed for adult pulse beetle emergence after five weeks and percentage seed damage due to carry over population from field was worked out.

$$\text{Percentage seed damage} = \frac{\text{Number of damaged seeds}}{\text{Total number of seeds}} \times 100$$

3.1.2 Laboratory Screening for Resistance to Pulse beetle

3.1.2.1 Materials

The materials in the second part of the first experiment comprised of seeds of all the thirty genotypes of grain cowpea which were used to evaluate yield in three replications. A stock culture of pulse beetles, bottles, Muslin cloth (to cover the mouth of the bottles) and rubber band (to fasten mouth of the bottles) were needed to assess varietal resistance to pulse beetle.

3.1.2.2 Methods

***3.1.2.2.1 Maintenance of Stock Culture of Test Organism, Callosobruchus* spp.**

The pulse beetle infested seeds were collected from Onattukara Regional Agricultural Research Station, Kayamkulam. The stock culture was maintained on cowpea seeds by releasing 10-20 pairs of adult beetles into bottles containing locally available cowpea seeds. The mouth of each bottle was covered with muslin cloth and fastened it with rubber band. Such bottles were maintained for the mass culturing of the test insect. The bottles were kept undisturbed under room temperature till the emergence of beetles. The newly emerged adult obtained from the culture after 25-30 days of the release were utilized to maintain sub cultures by following the same procedure as described above. Sub culturing of the beetle was done to ensure continuous supply of test insects for conducting the laboratory experiments for screening resistance. Thus the pulse beetle was mass cultured and the freshly emerged adult beetles were used in the experimental studies.

3.1.2.2.2 Screening of Cowpea Genotypes for Pulse beetle Resistance

The experiment was conducted during the period of September 2016 to October 2016. The data on average temperature and relative humidity during the experiment period were obtained from the meteorological observatory, Central Plantation Crop Research Institute, Regional Station, Kayamkulam and is given in Appendix 1.The screening was done by adopting no choice confinement test (Plate 4). A no-choice confinement test is commonly used in laboratory experiments for screening genotypes for storage pest resistance (Giga, 1995; Nalini *et al.*, 2012). Insects were restricted in choice of grain from the sample. Samples were put in bottles and newly emerged adult insects of known sex were introduced and allowed for oviposition. Two hundred healthy, sound and disinfested seeds from each experimental plot were taken in a bottle separately and five pairs of newly emerged

Plate 3. Field screening for pulse beetle resistance

Plate 4. Laboratory screening for pulse beetle resistance

pulse beetles were confined for a week. In the present study, male and female beetles were sorted out based on appearance of their abdominal features in accordance to Bandaara and Saxena (1995). Males have comparatively shorter abdomen. In contrast, the females have comparatively longer abdomen.

After one week the insects (dead and alive) were removed from the bottles. The mouth of glass bottles were covered with pieces of muslin cloth firmly and fastened with rubber band to prevent the contamination and escape of beetles. After 45 days, test varieties were screened based on the following parameters. Observations on the number of damaged and undamaged seeds were taken on 45th day after the confinement and percentage damage were worked out. The weight of the damaged and undamaged seeds were also taken on 45th day after confinement and per cent seed weight loss were worked out (Nalini *et al.*, 2012).

a. Percentage seed damage

The number of damaged seeds in each replication was counted at 45th day after confinement and converted to per cent seed damage.

$$\text{Percentage seed damage} = \frac{\text{Number of seeds with bored holes} \quad \text{x } 100}{\text{Total number of seeds}}$$

b. Seed weight loss percentage

The final weight of the seed was taken at 45th day after confinement and the weight loss due to insect infestation was calculated by deducting the final weight from the initial weight and converting to per cent weight loss.

$$\text{Percentage weight loss} = \frac{W_i - W_f}{W_i} \times 100$$

Where,

W_i = Initial weight of the sample (200 seeds)

W_f = Final weight of the sample (200 seeds)

c. Number of eggs per 100 seeds

Hundred grains were randomly selected from each genotypes and eggs laid on those grains were counted.

d. Number of damaged seeds, Weight of damaged seeds, Number of undamaged seeds and Weight of undamaged seeds

These damage parameters were taken for 200 seeds and the weights and numbers were then converted for 100 seeds.

e. Germination percentage

Twenty five seeds from the samples kept for artificial infestation was collected randomly from each genotype and placed in Petri dish lined with blotting paper. These Petri dishes were kept at room temperature for four days. The number of sprouted seeds were counted and percent seed germination was calculated by the formula.

$$\text{Per cent seed germination} = \frac{\text{Number of germinated seeds} \times 100}{\text{Total number of seeds}}$$

f. Moisture content of seed

The moisture content of the pulse beetle infested cowpea grains were determined using grain moisture meter at ORARS, Kayamkulam.

3.2 EXPERIMENT II: STUDY OF FACTORS ASSOCIATED WITH RESISTANCE

Seed morphological and biochemical factors associated with resistance were studied using the seed samples from five relatively resistant genotypes and five relatively susceptible ones which were identified through laboratory screening. Here the design used was CRD with 10 treatments and 3 replication.

3.2.1 Morphological Basis for Bruchid Resistance in Cowpea Genotypes

1. Seed coat colour

Seed coat colour was determined by comparing colour of the seed coat with different shades of various colours in the Royal Horticultural Society (RHS) Colour Chart Fan-4.

2. Seed coat texture

Seed texture was examined under the stereo-binocular microscope and recorded using Cowpea Descriptors (IBPGR, 1983). As per the descriptor, the testa texture categories comprised Smooth, Smooth to rough, Rough (fine reticulation), Rough to wrinkled, and Wrinkled (coarse folds on the testa).

3.2.2 Biochemical Basis for Bruchid Resistance in Cowpea Genotypes

The biochemical parameters *viz.,* protein content and phenol content in the seeds of cowpea accessions were estimated.

1. Protein content of seeds (mg/g)

Protein content in cowpea seeds was determined by Bradford's colorimetric method (Bradford,1976).

2. Total phenol content of seeds (mg/g)

Total phenols from cowpea seeds was estimated using Folin-ciocaltean reagent method (Singleton *et al.,* 1999).

3.2.2.4 Statistical Analysis

3.2.2.4.1 Analysis of Variance (ANOVA)

The analysis of variance (Panse and Sukhatme, 1967) was carried out for all biometric characters recorded from the field evaluation for comparison among the ecotypes and to estimate variance components as given below.

Sources of variation	**Degrees of freedom**	**Sum of squares**	**Mean square**	**F ratio**
Replications	t-1	SSR	MSR	MSR/MSE
Treatment	r-1	SST	MST	MST/MSE
Error	(r -1)(t -1)	SSE	MSE	
Total	rt-1	TSS		

Where,

r = number of replications

t = number of treatments

SSR = sum of squares for replications

MSR = mean squares for replication

SST = sum of squares for treatments MST = mean squares for treatments

SSE = sum of squares for error MSE = mean squares for error

TSS = Total sum of squares

Critical difference (CD) = $t_{\alpha}\sqrt{\frac{2\times MSE}{r}}$ where,

t_{α} = table value of students' distribution at error degrees of freedom

α = level of significance (5 % or 1 %).

3.2.2.4.2 Estimation of Genetic Parameters

a. Genetic Components of Variance

For each character, the phenotypic and genotypic components of variance were estimated by equating the expected value of mean squares (MS) to the respective variance components (Jain, 1982). Based on this, the following variance components were estimated.

i. Genotypic variance (V_G) $V_G = \frac{MST - MSE}{r}$

ii. Phenotypic variance (V_P) $V_P = V_G + V_E$

iii. Environmental variance (V_E), V_E = MSE

b. Coefficient of Variation

Genotypic, phenotypic and environment co efficient of variation were worked out using the estimates of V_G, V_P and V_E and expressed in percentage for each trait.

i. Genotypic coefficient of variation, $\text{GCV} = \sqrt{\frac{V_G}{\bar{X}}} \times 100$

ii. Phenotypic coefficient of variation, $\text{PCV} = \sqrt{\frac{V_P}{\bar{X}}} \times 100$

iii. Environmental coefficient of variation, $\text{ECV} = \sqrt{\frac{V_E}{\bar{X}}} \times 100$

Where, $\bar{X}$ = grand mean

Categorization of the range of variation was followed as reported by Sivasubramanian and Menon (1973).

Low : < 10%

Moderate : 10-20%

High : > 20%

c. Heritability

Proportion of genotypic variance to the total observed variance in the total population is referred as heritability in the broad sense. It was calculated and expressed in percentage (Allard, 1999).

$$\text{Heritability, } H^2 = \frac{V_G}{V_P} \times 100$$

As suggested by Johnson *et al.* (1955) the range of heritability estimates were categorized as:

Low : < 30%

Medium : 30- 60%

High : > 60%

d. Genetic Advance

Genetic advance refers to the expected genetic gain or improvement in the next generation by selecting superior individuals under certain amount of selection pressure. From the heritability estimates the genetic advance was estimated by the following formula given by Burton (1952).

$$\text{GA} = k.H^2\sqrt{V_P}$$

Where k= Standardized selection differential (2.06 at 5 % selection intensity).

For visualizing the relative utility of genetic advance among the characters, genetic advance as percent of mean was also estimated.

$$\text{GA as percent of mean} = \frac{GA}{\overline{X}} \times 100$$

The range of genetic advance as percent of mean was classified according to Johnson *et al.* (1955).

Low : 0-10 %

Moderate : 10-20 %

High : >20 %

3.2.2.4.3 Correlation Analysis

Character association refers to the association of characters which estimates the magnitude and direction of change of one character with respect to the change in another character.

Genotypic and phenotypic correlation coefficients were calculated using the formulae suggested by Falconer (1964).

Genotypic coefficient of correlation (r_G) = $\dfrac{COV_G\,(X, Y)}{\sqrt{V_P(X).V_P(Y)}}$

Phenotypic coefficient of correlation (r_P) = $\dfrac{COVp\,(X, Y)}{\sqrt{V_G(X).V_G(Y)}}$

Where, COV_P (X,Y) and COV_G (X,Y) respectively denotes the phenotypic and genotypic co-variances between the two traits X and Y. $V_P(X)$ and $V_G(X)$ denotes the phenotypic and genotypic variance for X and $V_P(Y)$ and $V_G(Y)$ indicate the phenotypic and genotypic variance for Y respectively.

3.2.2.4.4 Path Co-efficient Analysis

Path coefficient analysis is a standardized partial regression coefficient which measures the direct effect of one variable upon another and permits the separation of correlation coefficients into components of direct and indirect effects (Dewey and Lu, 1959).The set of equations obtained from the path diagram were solved to get the information on the direct and indirect contribution of the casual factors on the effect.

The residual effect is computed as $R = 1 - (r_{Y1}.P_{Y1} + r_{Y2}.P_{Y2} + ... + r_{Yn}.P_{Yn})$

$$R = 1 - \Sigma(r_{Y_i}.P_{Yi})$$

Where 'r' is the correlation between various traits and the direct effect of X_1 on Y is P_{Y1} and so on. Indirect effect of X_1 on Y depends on other correlated factors.

3.2.2.4.5 Construction of Index Score

Index scores of the relatively resistant genotypes along with mean values were worked out. The characters studied in a genotype were classified into three groups using suitable class intervals. The maximum and minimum score that an individual can get is *nx3* and *nx1* respectively where '*n*' is the total number of character considered (Singh and Chaudhary, 1985). The characters considered include the parameters which were identified relevant to yield and resistance to pulse beetle and were ranked as '1', '2' and '3'. 100 seed weight, number of pods plant^{-1}, number of seeds pod^{-1} and seed yield plant^{-1}, germination percentage and total phenol content contributed positively for yield and resistance to pulse beetle while percentage seed damage, percentage seed weight loss and moisture content of the seed had negative influence on resistance to pulse beetle. So for positively influenced character highest rank was given to the character which was above (Mean+SD) while for negatively influenced character highest rank was given to the character which was below (Mean-SD).

Results

4. RESULTS

Thirty genotypes of cowpea [*Vigna unguiculata* (L.) Walp.] were used in experiment-I to evaluate and screen out for yield and resistance to pulse beetle. In experiment-II, five relatively resistant genotypes and five relatively susceptible ones were studied to find out the factors associated with resistance to pulse beetle. The results of present study are presented in this chapter.

4.1 EXPERIMENT-I

4.1.1 Analysis of Variance

Analysis of variance (Table 2) revealed that there was significant differences among the thirty genotypes for all the biometric characters studied.

4..1.2 Mean Performance

The mean values of each of the thirty genotypes for the following observations are presented in Table 3. It was observed that there was considerable variation among all the thirty genotypes for the characters under study (Plate 5).

The days to 50 per cent flowering ranged from 30.67 and 60.67. The genotype T_{13} (Hridya) was the earliest to come to 50 per cent flowering which was statistically on par with genotype T_{23} (35.33) and T_{28} (37.67). The genotype T1 (Ambalappuzha local) was the latest to come to 50 per cent flowering and was found to be statistically on par with genotypes T_{14} (58.67), T_{18} (58.67), T_{11} (57.33), T_7 (57.00) and T_{24} (57.00). Among the thirty genotypes studied, seventeen genotypes were having values less than the general mean of 48.21 days.

The number of primary branches plant^{-1} ranged from 2.78 to 6.15. The genotype T_{29} (Sreya) had the highest number of primary branches. However,

Table 2. Analysis of variance of thirteen characters in thirty genotypes of cowpea

Sl. No.	Characters	Mean square		
		Replication	Treatment	Error
1.	Days to 50 per cent flowering	10.811	171.436**	8.512
2	No. of primary branches plant^{-1}	0.024	3.485**	0.280
3	Length of main stem (cm)	14.317	121.864**	13.172
4	No. of pod clusters plant^{-1}	2.098	14.852**	2.388
5	No. of pods cluster^{-1}	0.008	0.535**	0.008
6	No. of pods plant^{-1}	15.381	38.197**	7.509
7	Pod weight (g)	0.026	3.553**	0.214
8	Pod length (cm)	0.294	44.633**	0.189
9	Pod girth (mm)	0.162	34.835**	0.124
10	Number of seeds pod^{-1}	0.728	9.855**	0.247
11	100 seed weight (g)	0.104	19.513**	0.038
12	Seed yield plant^{-1} (g)	16.790	105.708**	19.682
13	Crop duration (days)	49.633	249.268**	21.070

** Significant at 1 percent level

* Significant at 5 percent level

genotypes T_9 (6.02), T_7 (5.50), T_5 (5.31), T_6 (5.31), T_2 (5.04), and T_{21} (4.92) were statistically on par with it. It was the least for T_{26} (Champakulam local) and was followed by the genotypes T_{23} (3.17), T_3 (3.22), T_{19} (3.23), T_{15} (3.24) and T_{12} (3.25).

Length of main stem (cm) ranged from 21.00 to 45.39 cm. The highest mean value for length was recorded for genotype T_1 (Ambalappuzha local) which was statistically on par with T_{22} (45.00 cm) and T_{30} (44.57 cm). The length of main stem was lowest for the genotype T_{13} (Hridya). However, genotype T_{27} was statistically on par with it.

Number of pod clusters plant^{-1} was the highest for the genotype T_{21} (Chittoor local) (11.89) which was statistically on par with genotypes T_4 (11.5), T_{24} (10.86), T_{14} (10.72), T_{26} (10.56), T_{13} (10.26), T_{18} (10.19), T_{22} (10.00), T_{27} (9.52) and T_2 (9.43). The genotype T_{12} (Adoor local) (4.03) had the lowest number of pod clusters plant^{-1} followed by genotypes T_{11} (4.73), T_{30} (4.81) and T_{23} (5.03)

Number of pods cluster^{-1} was the maximum for the genotype T_8 (Hanumanmattti local) (3.36). None of the genotypes were statistically on par with genotype T_8. The genotype T_{22} (Kollengode local) (1.73) was having minimum number of pod clusters and was followed by T_{24} (1.76), T_{17} (1.76), and T_2 (1.76).

The maximum number of pods plant^{-1} was recorded for genotype T_{21} (Chittoor local) (21.87) followed by T_4 (21.09), T_{13} (19.48), T_{26} (18.79), T_{18} (18.77), and T_{14} (18.73). Minimum value was recorded for genotype T_{12} (Adoor local) (8.03) and was followed by T_{30} (9.15), T_1 (9.55) and T_{11} (9.91).

The genotype T_1 (Ambalappuzha local) (5.98 g) exhibited the highest pod weight. No other genotypes was statistically on par with it. T_{13} (Hridya) (0.82 g) was noticed with the lowest pod weight and it was followed by T_{19} (0.85 g) and T_{23} (0.92 g).

Table 3. Mean performance of thirty cowpea genotypes for fourteen characters

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
T_1	60.67	4.39	45.39	5.33	1.90	9.55	5.98	27.53	22.23	18.83	16.04	27.17	102.67	0
T_2	40.33	5.04	41.31	9.43	1.76	15.90	1.35	13.52	12.43	14.07	6.16	13.02	82.00	0.25
T_3	52.00	3.22	38.16	6.98	1.80	12.21	1.85	12.49	18.67	12.10	8.62	12.55	89.67	0.33
T_4	45.33	4.12	42.27	11.50	1.86	21.09	2.29	17.77	17.43	15.83	8.42	27.27	84.33	0
T_5	54.00	5.31	40.68	7.44	1.90	13.11	2.20	16.14	18.67	14.97	11.22	20.54	84.00	0.83
T_6	55.33	5.31	43.52	5.59	2.00	11.23	3.12	16.87	18.10	13.84	9.57	14.80	89.00	0.33
T_7	57.00	5.50	34.49	8.78	1.90	16.17	2.67	18.53	19.03	16.80	10.46	29.95	88.00	0
T_8	51.67	4.16	30.61	5.63	3.36	17.78	1.46	14.65	21.60	12.82	9.01	19.61	82.33	0
T_9	45.00	6.02	37.80	7.94	1.84	13.47	2.45	15.66	19.80	13.39	12.12	19.76	80.67	0
T_{10}	52.00	4.44	35.20	9.21	1.88	17.00	2.12	16.77	22.19	14.65	11.22	27.63	93.00	0
T_{11}	57.33	3.47	44.07	4.73	1.88	9.91	4.23	26.03	23.69	16.93	14.75	23.64	95.33	0
T_{12}	44.67	3.25	35.28	4.03	1.97	8.03	1.13	15.81	14.10	14.96	10.15	11.45	84.00	0.25
T_{13}	30.67	3.78	21.00	10.26	2.00	19.48	0.82	9.13	9.47	12.94	4.51	11.07	56.67	0
T_{14}	58.67	4.89	41.28	10.72	1.84	18.73	1.86	15.90	18.80	12.58	13.92	30.97	89.67	0

Table 3. Continued

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
T_{15}	52.33	3.24	32.99	8.51	1.95	16.37	2.06	17.82	20.47	15.20	10.70	25.07	89.00	0
T_{16}	41.67	3.67	35.79	9.29	1.80	16.47	1.96	15.55	18.53	15.74	10.98	26.28	82.00	0.5
T_{17}	45.33	4.04	42.96	8.75	1.76	14.72	1.49	17.38	15.50	15.91	11.34	25.42	85.67	0
T_{18}	58.67	3.72	39.57	10.19	1.93	18.77	2.64	16.88	16.97	15.80	11.02	25.99	94.00	0.33
T_{19}	41.00	3.23	33.76	8.15	1.95	15.14	0.85	15.11	13.17	9.90	12.13	16.75	79.33	0
T_{20}	46.67	3.46	43.41	6.69	1.81	11.72	3.13	18.54	19.57	17.28	11.52	21.38	93.00	0.08
T_{21}	47.33	4.92	41.66	11.89	1.92	21.87	1.74	12.89	17.20	13.25	9.92	28.23	80.00	0.66
T_{22}	45.33	3.70	45.00	10.00	1.73	16.03	2.13	14.20	17.80	13.88	10.63	22.37	79.67	0
T_{23}	35.33	3.17	30.45	5.03	3.15	15.42	0.92	9.98	12.47	12.88	7.51	15.29	67.33	0.16
T_{24}	57.00	3.37	33.67	10.86	1.76	18.28	1.64	16.07	18.10	14.73	10.16	24.32	85.67	0
T_{25}	45.33	3.31	36.36	7.84	1.97	14.89	2.40	15.75	21.17	14.11	10.90	21.58	87.67	1
T_{26}	45.33	2.78	37.63	10.56	1.89	18.79	1.63	14.24	15.80	14.03	9.63	24.52	74.33	0.75
T_{27}	40.67	3.81	21.15	9.52	1.82	17.02	1.81	13.38	22.03	12.18	10.24	20.24	82.00	0.66

Table 3. Continued

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
T_{28}	37.67	3.29	29.98	6.04	3.19	18.39	1.47	13.94	17.33	14.97	6.68	17.60	69.33	0
T_{29}	47.67	6.15	32.97	9.01	1.97	17.59	3.00	16.83	18.33	15.52	12.56	32.91	90.00	0
T_{30}	54.33	4.08	44.57	4.81	1.82	9.15	3.90	22.62	23.37	13.87	15.49	20.15	92.67	0
Mean	48.21	4.09	37.10	8.16	2.01	15.48	2.21	16.27	18.13	14.47	10.59	21.92	84.43	0.20
S.E.	1.68	0.44	2.10	0.89	0.05	1.58	0.27	0.25	0.20	0.29	0.11	2.56	2.65	
C.D. 5%	4.79	1.25	5.96	2.54	0.15	4.50	0.76	0.71	0.58	0.81	0.32	7.25	7.50	

X1	Days to 50 per cent flowering
X2	Number of primary branches plant^{-1}
X3	Length of main stem (cm)
X4	Number of pod clusters plant^{-1}
X5	Number of pods cluster^{-1}
X6	Number of pods plant^{-1}
X7	Pod weight (g)
X8	Pod length (cm)
X9	Pod girth (mm)
X10	Number of seeds pod^{-1})
X11	100 seed weight (g))
X12	Seed yield plant^{-1} (g)
X13	Crop duration (days)
X14	Percentage of seeds damaged by pulse beetle

S.E. : Standard Error

C.D. : Critical Difference

Plate 5. Variation in pod and seed characters (a)

Plate 5. Variation in pod and seed characters (b)

The pod length ranged from 9.13 cm to 27.53 cm. The genotype T_1 (Ambalappuzha local) and T_{13} (Hridya) had the highest and lowest pod length respectively. None of the genotypes were statistically on par with them.

The average pod girth was maximum for T_{11} (Belagum local) (23.69 mm) and was statistically on par with T_{30} (Vallikunnam local) (23.37 mm). The minimum pod girth was observed for genotype T_{13} (Hridya) (9.47 mm). None of the genotypes were statistically on par with it.

Among thirty genotypes, number of seeds pod^{-1} exhibited significant variation with a range of 9.90 to 18.83. T_1 (Ambalappuzha local) had the maximum number of seeds pod^{-1} while T_{19} (Haripad local) was found with the minimum number of seeds pod^{-1}.

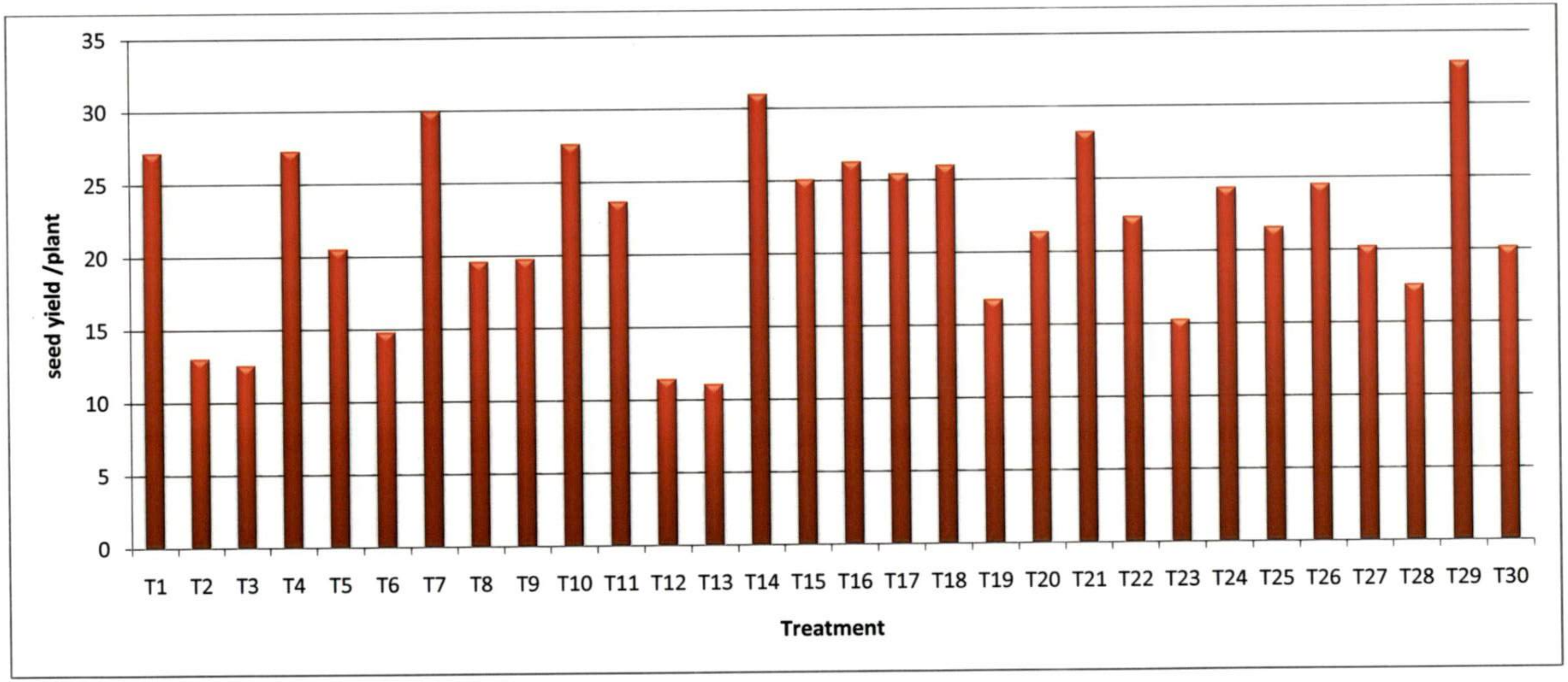
The genotype T_1 (Ambalappuzha local) (16.04 g) exhibited the highest 100 seed weight and T_{13} (Hridya) (4.51) was noticed with the lowest 100 seed weight.

Range obtained for the character, seed yield plant^{-1} was from 11.07 g to 32.29 g (Fig.1). The genotype T_{29} (Sreya) had maximum seed yield plant^{-1} and was followed by T_{14} (30.97 g), T_7 (29.95 g) and T_{21} (28.23 g) while T_{13} (Hridya) recorded minimum seed yield plant^{-1} followed by the genotypes T_{12} (11.45 g), T_3 (12.55 g) and T_2 (13.02 g)

Crop duration exhibited a range between 56.67 and 102.67 days. The genotype T_1 (Ambalappuzha local) had the longest crop duration and T_{13} (Hridya) was recorded the shortest crop duration.

Thirteen genotypes were found to be infested under field condition and only very low seed damage *via* carry over population was noticed.

Fig.1. Performance of thirty genotypes for seed yield plant^{-1}(g)



4.1.3 Genetic Parameters

The various genetic parameters like GCV, PCV, heritability and genetic advance were calculated for different characters for all the thirty genotypes and recorded in the table 4.

4.1.3.1 Phenotypic Coefficient of Variation

The phenotypic coefficient of variation (PCV) ranged from 11.67 (crop duration) to 52.12 (pod weight). The highest PCV was for pod weight (52.12) followed by seed yield plant^{-1} (31.72), number of pod clusters plant^{-1} (31.36), number of pods plant^{-1} (27.21), number of primary branches plant^{-1} (26.92), 100 seed weight (24.13), pod length (23.81) and number of pods cluster^{-1} (21.32). Length of main stem (18.94), pod girth (18.85), days to 50 per cent flowering (16.44) and number of seeds pod^{-1} (12.84) and crop duration (11.67) exhibited moderate level PCV. None of the characters exhibited low PCV.

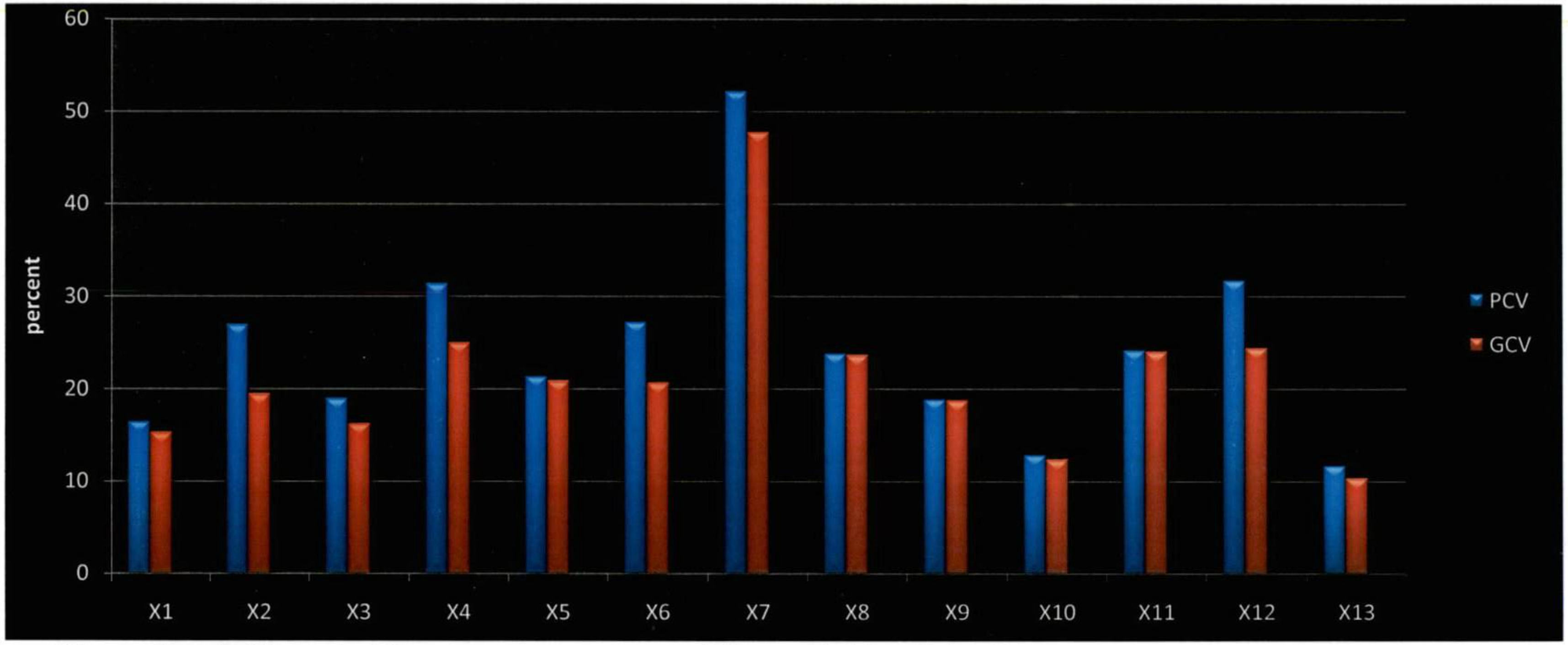
4.1.3.2 Genotypic Coefficient of Variation

Genotypic coefficient of variation (GCV) ranged from 10.33 (crop duration) to 47.73 (pod weight). The highest GCV was observed for pod weight (47.73) followed by number of pod clusters plant^{-1} (24.99), seed yield plant^{-1} (24.43), 100 seed weight (24.07), pod length (23.66), number of pods cluster^{-1} (20.86) and number of pods plant^{-1} (20.66). Number of primary branches plant^{-1} (19.46), pod girth (18.75), length of main stem (16.22), days to 50 per cent flowering (15.28), number of seeds pod^{-1} (12.37) and crop duration (11.67) exhibited moderate level of GCV. None of the characters exhibited low GCV (Fig.2).

Table 4. Genetic parameters of thirteen characters in thirty genotypes of cowpea

Sl no.	Characters	Coefficient of variation		Heritability	Genetic advance (as % of mean)
		GCV	PCV		
1	Days to 50 per cent flowering	15.28	16.44	86.45	29.28
2	Number of primary branches plant^{-1}	19.46	26.92	52.26	28.98
3	Length of main stem (cm)	16.22	18.94	73.34	28.62
4	Number of pod clusters plant^{-1}	24.99	31.36	63.5	41.02
5	Number of pods cluster^{-1}	20.86	21.32	95.73	42.04
6	Number of pods plant^{-1}	20.66	27.21	57.67	32.33
7	Pod weight (g)	47.73	52.12	83.86	90.05
8	Pod length (cm)	23.66	23.81	98.74	48.44
9	Pod girth (mm)	18.75	18.85	98.94	38.43
10	Number of seeds pod^{-1}	12.37	12.84	92.83	24.55
11	100 seed weight (g)	24.07	24.13	99.41	49.43
12	Seed yield plant^{-1} (g)	24.43	31.72	59.30	38.75
13	Crop duration (days)	10.33	11.67	78.31	18.83

Fig.2. Phenotypic and genotypic coefficients of variation for thirteen characters in cowpea



X1	Days to 50 per cent flowering
X2	Number of primary branches plant^{-1}
X3	Length of main stem (cm)
X4	Number of pod clusters plant^{-1}
X5	Number of pods cluster^{-1}
X6	Number of pods plant^{-1}
X7	Pod weight (g)
X8	Pod length (cm))
X9	Pod girth (mm)
X10	Number of seeds pod^{-1}
X11	100 seed weight (g)
X12	Seed yield plant^{-1} (g)
X13	Crop duration (days)

4.1.3.3 Heritability and Genetic Advance

Heritability (in broad sense) values for the studied traits ranged from 52.26 per cent to 99.41 per cent. The highest heritability was obtained for 100 seed weight (99.41 %) followed by pod girth (98.94 %), pod length (98.74 %), number of pods cluster^{-1} (95.73 %), number of seeds pod^{-1} (92.83 %), days to 50 per cent flowering (86.45 %), pod weight (83.86 %), crop duration (78.31 %), length of main stem (73.34 %) and number of pod clusters plant^{-1} (63.50 %) while moderate heritability was observed for seed yield plant^{-1} (59.30 %), number of pods plant^{-1} (57.67 %) and number of primary branches plant^{-1} (52.26 %).

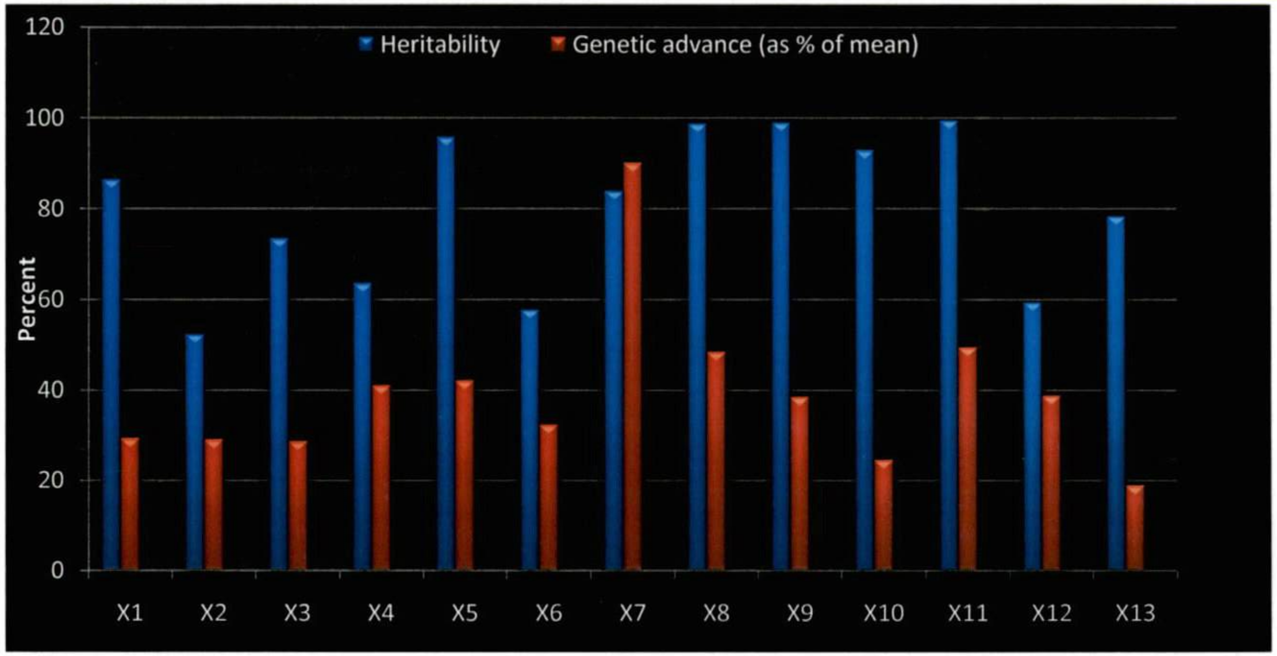
All the characters exhibited high genetic advance (as % of mean) except crop duration (18.83 %) which exhibited moderate genetic advance (Fig.3). The highest estimate was obtained for pod weight (90.05 %) followed by 100 seed weight (49.43 %), pod length (48.44 %), number of pods cluster^{-1} (42.04 %), number of pod clusters plant^{-1} (41.02), seed yield plant^{-1} (38.75 %), pod girth (38.43 %), number of pods plant^{-1} (32.33 %), days to 50 per cent flowering (29.28 %), number of primary branches plant^{-1} (28.98 %), length of main stem (28.62 %) and number of seeds pod^{-1} (24.55 %).

High heritability coupled with high genetic advance was observed for days to 50 per cent flowering, length of main stem, number of pod clusters plant^{-1}, number of pods cluster^{-1}, pod weight, pod length, pod girth, number of seeds pod^{-1}, and 100 seed weight.

4.1.4 Correlation Studies

The association between yield and yield contributing traits was worked out. The genotypic, phenotypic correlation coefficients for the biometric characters were worked out.

Fig.3. Heritability and genetic advance of thirteen characters in cowpea



X1	Days to 50 per cent flowering
X2	Number of primary branches plant^{-1}
X3	Length of main stem (cm)
X4	Number of pod clusters plant^{-1}
X5	Number of pods cluster^{-1}
X6	Number of pods plant^{-1}
X7	Pod weight (g)
X8	Pod length (cm))
X9	Pod girth (mm)
X10	Number of seeds pod^{-1}
X11	100 seed weight (g)
X12	Seed yield plant^{-1} (g)
X13	Crop duration (days)

4.1.4.1 Genotypic Correlation Coefficients

The genotypic correlation coefficients are given in Table 5.

Highly significant positive correlation was recorded between 100 seed weight and seed yield plant^{-1} (0.577) followed by days to 50 per cent flowering (0.554), crop duration (0.551), number of seeds per pod (0.494), pod girth (0.483), pod length (0.455), pod weight (0.419) and number of pod clusters plant^{-1} (0.382).

Days to 50 per cent flowering had significant positive correlation with crop duration (0.833) followed by pod length (0.700) 100 seed weight (0.676), pod girth (0.656) pod weight (0.655), length of main stem (0.603), seed yield plant^{-1} (0.554), number of seeds pod^{-1} (0.413) and number of primary branches plant^{-1}(0.291). The association was significantly negative with number of pods plant^{-1} (-0.323) and number of pods cluster^{-1}(-0.286).

Number of primary branches plant^{-1} was noticed with significant positive correlation with pod girth (0.439) followed by pod length (0.411), days to 50 per cent flowering (0.291) and pod weight (0.288).

It was observed that significant positive correlation existed between length of main stem and crop duration (0.669) followed by pod length (0.614), days to 50 per cent flowering (0.603), pod weight (0.592), 100 seed weight (0.553), number of seeds pod^{-1} (0.431), seed yield plant^{-1} (0.323) and pod girth (0.288). This trait exhibited negative association with number of pods plant^{-1} (-0.478) and number of pods cluster^{-1} (-0.431).

Number of pod clusters plant^{-1} exhibited positive correlation with number of pods plant^{-1} (0.790) followed by seed yield plant^{-1} (0.382). However, it exhibited negative association with number of pods cluster^{-1} (-0.457) followed by pod length (-0.406) and pod weight (-0.377).

Highly significant negative correlation was noticed between number of pods cluster^{-1} and number of pod clusters plant^{-1} (-0.457) followed by crop duration (-0.432), length of main stem (-0.431) and 100 seed weight (-0.376).

Though number of pods plant^{-1} possessed positive correlation with number of pod clusters plant^{-1} (0.790), it had negative correlation with pod length (-0.606), pod weight (-0.573), 100 seed weight (-0.536), crop duration (-0.514), length of main stem (-0.478), pod girth (-0.325) and days to 50 per cent flowering (-0.323).

Pod weight showed highly significant positive correlation with pod length (0.887) followed by crop duration (0.758), 100 seed weight (0.722), pod girth (0.674), number of seeds pod^{-1} (0.658), days to 50 per cent flowering (0.655), length of main stem (0.592) and seed yield plant^{-1} (0.419). It had highly significant negative association with number of pods plant^{-1} (-0.573) followed by number of pod clusters plant^{-1}(-0.377).

It was noticed that pod length had highly significant positive correlation with pod weight (0.887) followed by crop duration (0.806), 100 seed weight (0.803), days to 50 per cent flowering (0.700), number of seeds pod^{-1} (0.680), pod girth (0.656), length of main stem (0.614) and seed yield plant^{-1} (0.455). It had negative association with number of pods plant^{-1} (-0.606), number of pod clusters plant^{-1} (-0.406) and number of pods cluster^{-1} (-0.286).

Significant positive correlation was observed between pod girth and crop duration (0.723) followed by pod weight (0.674), 100 seed weight (0.669), pod length (0.656), days to 50 per cent flowering (0.656), seed yield plant^{-1} (0.483), number of primary branches plant^{-1} (0.439), number of seeds pod^{-1} (0.331) and length of main stem (0.288). It had significant negative association with number of pods plant^{-1} (-0.325).

Table 5. Genotypic correlation coefficients

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
X1	1	0.291*	0.603**	-0.127	-0.286*	-0.323*	0.655**	0.700**	0.656**	0.413**	0.676**	0.554**	0.833**
X2		1	0.184	0.040	-0.204	-0.084	0.288*	0.411**	0.439**	0.127	0.209	0.225	0.249
X3			1	-0.141	-0.431**	-0.478**	0.592**	0.614**	0.288*	0.431**	0.553**	0.323*	0.669**
X4				1	-0.457**	0.790**	-0.377**	-0.406**	-0.264	-0.166	-0.261	0.342*	-0.223
X5					1	0.181	-0.275*	-0.286*	-0.101	-0.179	-0.376**	-0.279*	-0.432**
X6						1	-0.573**	-0.606**	-0.325*	-0.278*	-0.536**	0.259	-0.514**
X7							1	0.887**	0.674**	0.658**	0.722**	0.419**	0.758**
X8								1	0.656**	0.680**	0.803**	0.455**	0.806**
X9									1	0.331*	0.669**	0.483**	0.723**
X10										1	0.326*	0.494**	0.516**
X11											1	0.577**	0.772**
X12												1	0.551**
X13													1

X1	Days to 50 per cent flowering
X2	Number of primary branches plant^{-1}
X3	Length of main stem (cm)
X4	Number of pod clusters plant^{-1}
X5	Number of pods cluster^{-1}
X6	Number of pods plant^{-1}
X7	Pod weight (g)
X8	Pod length (cm)
X9	Pod girth (mm)
X10	Number of seeds pod^{-1}
X11	100 seed weight (g)
X12	Seed yield plant^{-1}(g)
X13	Crop duration (days)

Number of seeds pod^{-1} showed positive correlation with pod length (0.680) followed by pod weight (0.658), crop duration (0.516), seed yield plant^{-1} (0.494), length of main stem (0.431) days to 50 per cent flowering (0.413), pod girth (0.331) and 100 seed weight (0.326) .

Highly significant negative correlation was observed between 100 seed weight and number of pods plant^{-1} (-0.536) followed by number of pods cluster^{-1} (-0.376), but it had positive correlation with pod length (0.803) followed by crop duration (0.772), pod weight (0.722), days to 50 per cent flowering (0.676), pod girth (0.669), seed yield plant^{-1} (0.577), length of main stem (0.553) and number of seeds pod^{-1} (0.326).

Crop duration exhibited high positive correlation with days to 50 per cent flowering (0.833) followed by pod length (0.806), 100 seed weight (0.772), pod weight (0.758), pod girth (0.723), length of main stem (0.669), seed yield plant^{-1} (0.551) and number of seeds pod^{-1} (0.516) However, it exhibited negative association with number of pods plant-1 (-0.514) followed by number of pods cluster^{-1} (-0.432).

4.5.1.2. Phenotypic Correlation Coefficients

The phenotypic correlation coefficients are presented in Table 6. Highly significant positive correlation was recorded between seed yield plant^{-1} with number of pod clusters plant^{-1} (0.577) followed by number of pods plant^{-1} (0.529), 100 seed weight (0.462), days to 50 per cent flowering (0.425), crop duration (0.405), number of seeds pod^{-1} (0.388), pod girth (0.379) and pod length (0.360).

Days to 50 per cent flowering had highly significant positive correlation with crop duration (0.822) followed by pod length (0.650), 100 seed weight (0.629), pod girth (605), pod weight (0.605), length of main stem (0.442), seed yield plant^{-1} (0.425) and number of seeds pod^{-1} (0.373).

Length of main stem showed highly significant positive correlation with pod length (0.525) followed by crop duration (0.504), pod weight (0.488), 100 seed weight (0.475), days to 50 per cent flowering (0.442) and number of seeds pod^{-1} (0.373). It had negative association with number of pods cluster^{-1}(-0.360).

Number of pod clusters plant^{-1} was noticed with highly significant positive correlation with number of pods plant^{-1} (0.855) followed by seed yield plant^{-1} (0.577). It exhibited negative association with number of pods cluster^{-1} (-0.365) followed by pod length (-0.320) and pod weight (-0.320).

It was observed that highly significant negative correlation existed between number of pods cluster^{-1} and crop duration (-0.386) followed by 100 seed weight (-0.366), number of pod clusters plant^{-1} (0.365) and length of main stem (-0.360).

Number of pods plant^{-1} exhibited positive correlation with number of pod clusters plant^{-1} (0.855) followed by seed yield plant^{-1} (0.529). This trait exhibited negative association with pod length (-0.456) followed by pod weight (-0.409), 100 seed weight (-0.403) and crop duration (-0.370).

Highly significant positive correlation was found between pod weight and pod length (0.874) followed by 100 seed weight (0.713), crop duration (0.704), pod girth (0.665), number of seeds pod^{-1} (0.646), days to 50 per cent flowering (0.605) and length of main stem (0.488) while a negative association had been noticed with number of pods plant^{-1} (-0.409) followed by number of pod clusters plant^{-1} (-0.280).

Pod length possessed negative correlation with number of pods plant^{-1} (-0.456) followed by number of pod clusters plant^{-1} (-0.320) and number of pods cluster^{-1} (-0.281). however it showed positive correlation with pod weight (0.874) followed by 100 seed weight (0.800), crop duration (0.762), number of seeds pod^{-1} (679), days to 50 per cent flowering (650), pod girth (0.649), length of main stem (0.525), and seed yield plant^{-1} (0.360).

Table 6. Phenotypic correlation coefficients

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
X1	1	0.220	0.442**	-0.071	-0.248	-0.207	0.605**	0.650**	0.605**	0.373**	0.629**	0.425**	0.822**
X2		1	0.207	0.246	-0.140	0.172	0.224	0.097	0.116	0.090	0.150	0.312*	0.168
X3			1	-0.051	-0.360*	-0.263	0.488**	0.525**	0.250	0.373**	0.475**	0.231	0.504**
X4				1	-0.365**	0.855**	-0.280*	-0.320*	-0.213	-0.131	-0.205	0.577**	-0.166
X5					1	0.138	-0.266	-0.281*	-0.096	-0.175	-0.366**	-0.212	-0.386**
X6						1	-0.409**	-0.456**	-0.249	-0.213	-0.403**	0.529**	-0.370**
X7							1	0.874**	0.665**	0.646**	0.713**	0.349*	0.704**
X8								1	0.649**	0.679**	0.800**	0.360**	0.762**
X9									1	0.324*	0.665**	0.379**	0.679**
X10										1	0.325*	0.388**	0.481**
X11											1	0.462**	0.730**
X12												1	0.405**
X13													1

X1	Days to 50 per cent flowering
X2	Number of primary branches plant^{-1}
X3	Length of main stem (cm)
X4	Number of pod clusters plant^{-1}
X5	Number of pods cluster^{-1}
X6	Number of pods plant^{-1}
X7	Pod weight (g)
X8	Pod length (cm)
X9	Pod girth (mm)
X10	Number of seeds pod^{-1}
X11	100 seed weight (g)
X12	Seed yield plant^{-1}(g)
X13	Crop duration (days)

Pod girth showed positive correlation with crop duration (0.679) followed by 100 seed weight (0.665), pod weight (0.665), pod length (0.649), days to 50 per cent flowering (0.605), seed yield plant^{-1} (0.379) and number of seeds pod^{-1} (0.324).

It was noticed that number of seeds pod^{-1} had significant positive correlation with pod length (0.679) followed by pod weight (0.646), crop duration (0.481), seed yield plant^{-1} (0.388), length of main stem (0.373), days to 50 per cent flowering (0.373), 100 seed weight (0.325) and pod girth (0.324).

Highly significant positive correlation was observed between 100 seed weight and pod length (0.800) followed by crop duration (0.730), pod weight (0.713), pod girth (0.665), days to 50 per cent flowering (0.629), length of main stem (0.475) and seed yield plant^{-1} (0.462) while it exhibited negative association with number of pods plant^{-1} (-0.403) followed by number of pods cluster^{-1}(-0.366).

Crop duration showed positive correlation with days to 50 per cent flowering (0.822) followed by pod length (0.762), 100 seed weight (0.730), pod weight (0.704), pod girth (0.679), length of main stem (0.504), number of seeds pod^{-1} (0.481) and seed yield plant^{-1} (0.405). However, there existed negative association with number of pods cluster^{-1} (-0.386) followed by number of pods plant^{-1} (-0.370).

4.1.5 Path Analysis

The direct dependence of a set of characters was analysed using the path anlalysis. Here the dependence of seed yield plant^{-1} on all the other biometric characters was estimated. The direct and indirect effects of seed yield plant^{-1} are presented in Table 7. The component characters selected for the analysis were days to 50 per cent flowering, length of main stem, number of pods plant^{-1}, pod weight, pod length, pod girth, number of seeds pod^{-1}, 100 seed weight, and crop duration. Path diagram showing the direct and indirect effects of the component characters on seed yield plant^{-1} is given in Fig. 4.

The highest direct effect was shown by 100 seed weight followed by number of pods plant^{-1} (0.819), number of seeds pod^{-1} (0.545) and pod length (-0.390). The lowest direct effect was recorded by days to 50 per cent flowering (-0.009).

The direct effect of days to 50 per cent flowering was negligible and negative; but its indirect effect *via* 100 seed weight was high and positive (0.634) which nearly accounted for the total genotypic correlation with yield (0.554).

The genotypic correlation (0.323) of length of main stem on seed yield plant^{-1} was positive while it had a negligible positive direct effect on seed yield plant^{-1} (0.034). However, it had high positive indirect effect through 100 seed weight (0.519).

Pod weight showed negligible negative direct effect (-0.042), but its genotypic correlation with yield was positive and high (0.419) because even though there was high negative indirect effect was there due to number of pods plant^{-1} (-0.469) and pod length (-0.346), its positive indirect effect *via* 100 seed weight (0.677) and number of seeds pod^{-1} (0.358) overcomed it.

The direct effect of pod length was high and negative (-0.390). The indirect effect through pods per plant was also high and negative (-0.496). but its high positive indirect effect *via* 100 seed weight (0.753) and number of seeds pod^{-1} (0.370) which accounted for the genotypic correlation high and positive (0.455).

Pod girth had very low positive direct effect (0.012) and high positive genotypic correlation (0.483) in association with seed yield plant^{-1}. It had high positive indirect effect *via* 100 seed weight (0.628).

Number of seeds pod^{-1} exhibited high positive genotypic correlation (0.494)) and direct effect (0.545) on seed yield plant^{-1}. It exerted high positive indirect effect via 100 seed weight (0.306).

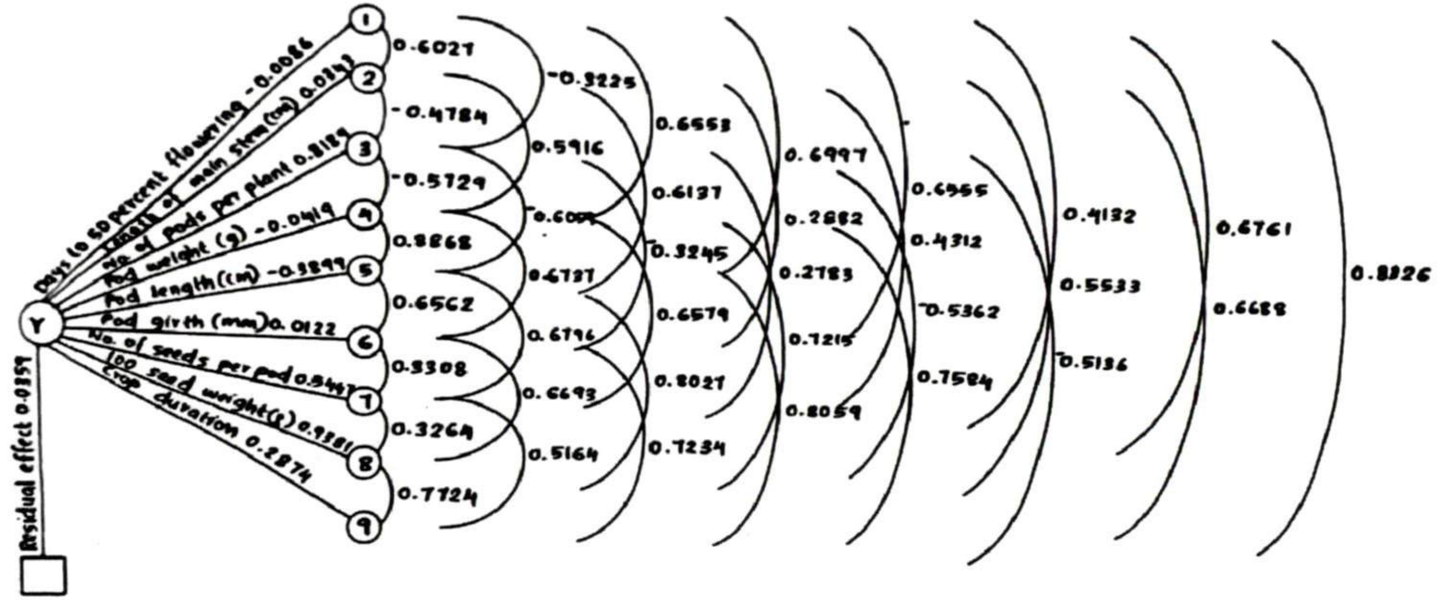
Table 7. Path analysis (direct diagonal / indirect off diagonal)

Characters	X1	X2	X3	X4	X5	X6	X7	X8	X9	Genotypic correlation co-efficiencies
X1	**-0.009**	0.021	-0.264	-0.028	-0.273	0.008	0.225	0.634	0.239	0.554
X2	-0.005	**0.034**	-0.392	-0.025	-0.239	0.004	0.235	0.519	0.192	0.323
X3	0.003	-0.016	**0.819**	0.024	0.236	-0.004	-0.152	-0.503	-0.148	0.259
X4	-0.006	0.020	-0.469	**-0.042**	-0.346	0.008	0.358	0.677	0.218	0.419
X5	-0.006	0.021	-0.496	-0.037	**-0.390**	0.008	0.370	0.753	0.232	0.455
X6	-0.006	0.010	-0.266	-0.028	-0.256	**0.012**	0.180	0.628	0.208	0.483
X7	-0.004	0.015	-0.228	-0.028	-0.265	0.004	**0.545**	0.306	0.148	0.494
X8	-0.006	0.019	-0.439	-0.030	-0.313	0.008	0.178	**0.938**	0.222	0.577
X9	-0.007	0.023	-0.421	-0.032	-0.314	0.009	0.281	0.725	**0.287**	0.551

Residual effect (R) = 0.036

X1	Days to 50 per cent flowering
X2	Length of main stem (cm)
X3	Number of pods plant^{-1}
X4	Pod weight (g)
X5	Pod length (cm)
X6	Pod girth (mm)
X7	Number of seeds pod^{-1}
X8	100 seed weight (g)
X9	Crop duration (days)

Fig.4. Path diagram showing direct and indirect effect of nine characters on yield



100 seed weight had found to have high positive direct effect (0.938) and genotypic correlation (0.577). It had high negative indirect effect via number of pods plant^{-1} (-0.439) and pod length (-0.313)

Crop duration was observed to have moderate positive direct effect (0.287) and exhibited high positive genotypic correlation (0.551). It expressed high negative indirect effect on the same through number of pods plant^{-1} (-0.421) and pod length (-0.314). but indirect effect through 100 seed weight (0.725) and number of seed pod^{-1} was positive as well as high and moderate respectively and this accounts for high positive genotypic correlation.

The residual effect obtained was 0.036.

4.1.6 Mean Performance in Laboratory Screening

From the mean value obtained for various bruchid damage parameters, it was observed that there was considerable variation among all the thirty genotypes for the characters under study (Table 8).

Number of eggs per 100 seeds ranged from 612.35 to 2506.11. The lowest value was recorded for genotype T_2 (Kayamkulam local-1). The number of eggs per 100 seeds was highest for the genotype T_{29} (Sreya) followed by T_1 (Ambalappuzha local) (2152.78).

Number of damaged seeds per 100 seeds was the lowest for T_7 (Dhavengarae local) (43.83). The genotype T_{13} (Hridya) (90.67) had the highest number of damaged seeds and was statistically on par with T_{11} (Belagum local) (90.50) and T_{27} (Bijapur local)(88.50). The highest percentage weight loss was recorded for T_{27} (Bijapur local)(26.64) and lowest for T_7 (Dhavengarae local) (13.50) (Fig. 5).

Weight of damaged seeds per 100 seeds was the minimum for T_7 (Dhavengarae local) (3.15). None of the genotypes were statistically on par with genotype T_7. Weight of damaged seeds per 100 seeds was the maximum for the genotype T_{11} (Belagum local) (10.21) which was statistically on par with T_1 (Ambalappuzha local)(10.02).

Maximum number of undamaged seeds was recorded for genotype T_7 (Dhavengarae local) (56.17). None of the genotypes was statistically on par with genotype T_7. The minimum value was recorded for genotype T_{13} (Hridya) (9.33). None of the genotypes was statistically on par with genotype T_{13}.

Mean value of weight of undamaged seeds per 100 seeds ranged from 0.51 to 5.90. It was lowest for the genotype T_7 (Dhavengarae local)(0.51) and highest for genotype T_{13} (Hridya) (5.90). None of the genotypes were statistically on par with these entries.

Among thirty genotypes, germination percentage of infested seeds exhibited significant variation ranged of 48.67 to 82.33. The genotype T_{16} (Thuravoor local) had maximum germination percentage which was statistically on par with T_{22} (Kollengode local) (80.33) whereas, T_6 (Mannuthy local) (48.67) was recorded with minimum germination percentage. None of the genotypes were statistically on par with T_6.

The genotype T_{27} (Bijapur local) had the highest seed moisture content (14.33) and T_{20} (Nilambur local) had the lowest moisture content. None of the genotypes were statistically on par with these entries.

Significant variation was observed for seed weight loss percentage which ranged from 13.50 to 26.64. The highest seed weight loss percentage was recorded for genotype T_{27} (Bijapur local). The genotypes T_{15} (Kanakamani) (22.74) and T_{13} (Hridya) (21.67) were statistically on par with genotype T_{27}. The genotype T_7

Table 8. Mean performance in laboratory screening of thirty genotypes of cowpea

	X1	X2	X3	X4	X5	X6	X7	X8
T_1	2152.78(3.33)	81.33	10.02	18.67	3.05	62.00	12.57	18.53
T_2	612.35(2.79)	76.33	3.44	23.67	1.59	61.00	13.00	18.36
T_3	920.44(2.96)	70.33	4.57	29.67	2.50	65.67	12.77	18.09
T_4	774.46(2.89)	54.16	3.22	45.83	3.85	75.33	12.37	16.06
T_5	1185.76(3.07)	78.33	6.57	21.67	2.70	66.33	13.07	17.37
T_6	851.13(2.93)	69.00	4.88	31.00	2.79	48.67	13.37	19.78
T_7	696.62(2.84)	43.83	3.15	56.17	5.90	67.00	12.63	13.50
T_8	1303.16(3.12)	80.00	5.40	20.00	1.86	78.00	12.73	19.45
T_9	1648.16(3.22)	65.66	5.98	34.33	4.18	75.33	11.53	16.14
T_{10}	1927.52(3.29)	75.00	6.39	25.00	2.95	65.00	12.40	16.78
T_{11}	1857.80(3.27)	90.50	10.21	9.50	1.46	71.33	12.46	20.90
T_{12}	922.57(2.97)	72.83	5.59	27.17	2.79	51.00	12.83	17.44
T_{13}	760.32(2.88)	90.66	3.02	9.33	0.51	65.00	13.70	21.67
T_{14}	1409.28(3.15)	47.66	4.73	52.33	7.16	76.33	12.43	14.63
T_{15}	1674.94(3.22)	82.50	6.90	17.50	1.56	66.67	12.76	22.74
T_{16}	977.24(2.99)	75.33	6.43	24.67	2.73	82.33	12.70	16.58
T_{17}	827.94(2.92)	69.50	5.96	30.50	3.46	57.00	11.87	16.99
T_{18}	1042.32(3.02)	61.83	5.18	38.17	4.03	72.33	12.70	16.44
T_{19}	751.62(2.88)	79.00	7.46	21.00	2.56	59.67	13.63	17.44
T_{20}	899.50(2.95)	70.83	6.46	29.17	3.12	75.33	11.47	16.88
T_{21}	727.77(2.86)	80.50	6.16	19.50	1.86	65.00	12.77	19.11
T_{22}	1140.25(3.06)	75.67	6.10	24.33	2.54	80.33	12.87	18.69
T_{23}	623.74(2.80)	82.00	4.75	18.00	1.37	73.33	13.43	18.50
T_{24}	1233.10(3.09)	70.33	5.50	29.67	2.96	63.33	12.27	16.71
T_{25}	1870.68(3.27)	78.33	6.70	21.67	2.38	72.33	12.57	16.66
T_{26}	885.12(2.95)	79.00	5.92	21.00	2.10	63.67	12.47	16.75
T_{27}	1158.78(3.06)	88.50	6.32	11.50	1.19	64.67	14.33	26.64

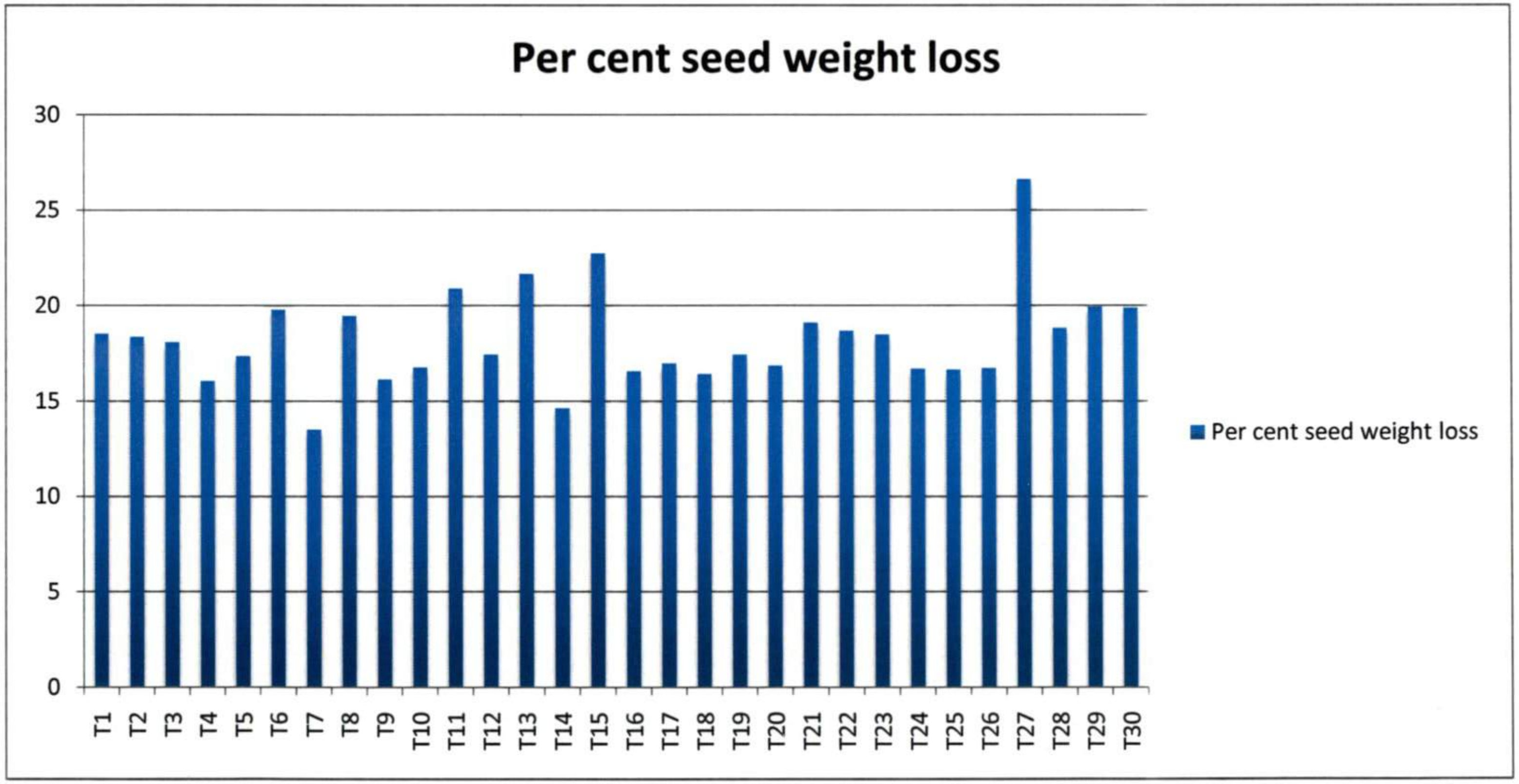
	X1	X2	X3	X4	X5	X6	X7	X8
T_{28}	939.72(2.97)	80.83	4.00	19.17	1.43	64.33	13.13	18.83
T_{29}	2506.11(3.40)	84.00	8.03	16.00	2.03	69.67	12.80	19.93
T_{30}	1879.31(3.27)	78.83	9.32	21.17	3.09	65.00	12.47	19.88
Mean	1205.35	74.42	5.95	25.58	2.72	67.43	12.74	18.25
S.E.	0.04	2.18	0.33	2.18	0.25	2.07	0.14	1.86
CD(0.05%)	0.10	6.18	0.92	6.18	0.70	5.86	0.39	5.29

X1	Number of eggs per 100 seeds
X2	Number of damaged seeds
X3	Weight of damaged seeds
X4	Number of undamaged seeds
X5	Weight of undamaged seeds
X6	Germination percentage
X7	Moisture content of seed
X8	Seed weight loss percentage

S.E. : Standard Error

C.D. : Critical Difference

Fig. 5. Per cent seed weight loss of thirty genotypes of cowpea



(Dhavengarae local) recorded minimum seed weight loss percentage and was followed by T_{14} (14.63), T_4 (16.06) and T_9 (16.14).

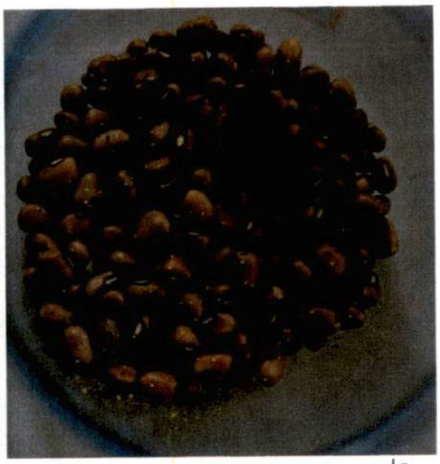
4.2 EXPERIMENT-II

The relatively resistant genotypes which had low percentage seed damage and per cent seed weight loss include T4 (Kulashekarapuram local), T7 (Dhavengarae Local), T9 (Nenmara local), T14 (Alathur Local) and T18 (Clappana local) while relatively susceptible genotypes include T11(Belagum local), T13 (Hridya), T15 (Kanakamani), T27 (Bijapur local) and T29 (Sreya) which had high percentage seed damage and per cent weight loss compared to others (Plate 6 & 7).

4.2.1 Morphological and Biochemical Analysis

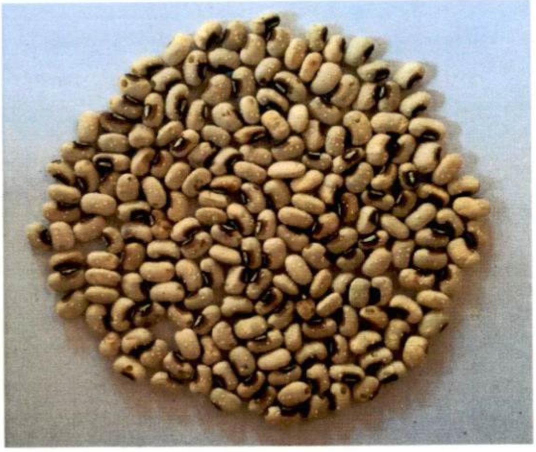
The morphological characters like seed coat colour and seed coat texture were studied in five relatively resistant genotypes and five relatively susceptible ones and are presented in Table 9 and 10. The seed coat colour of the genotypes varied from different shades of brownish orange, pale yellow, light yellow, moderate orange, moderate purplish red and moderate orangish yellow. Two kinds of seed coat texture was found i.e., smooth and wrinkled. All the nine genotypes except relatively susceptible T_{11} (Belagum local) showed smooth seed coat texture (Plate 8 & 9).

The mean values of protein and total phenol content of of relatively resistant genotypes and relatively susceptible genotypes are presented in Table 11. Protein content of seeds (mg g^{-1}) ranged from 154.67 mg g^{-1} to 286.33 mg g^{-1}. The lowest as well as highest protein content was recorded in relatively resistant genotypes T_9 (Nenmara local) and T_{18} (Clappana local) respectively. The total phenol content of seed (mg g^{-1}) ranged from 0.65 to 1.30. The highest total phenol content was for T_{14} (Alathur local) which was a relatively resistant genotype and lowest for T_{13} (Hridya) which was a relatively susceptible one.



T4 (Kulashekarapuram Local)

T7 (Dhavengarae Local)



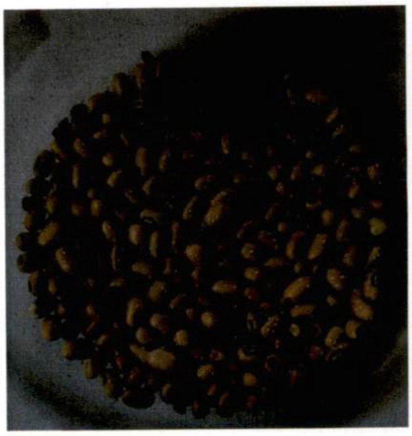
T14 (Alathur Local)

T9 (Nenmara local)

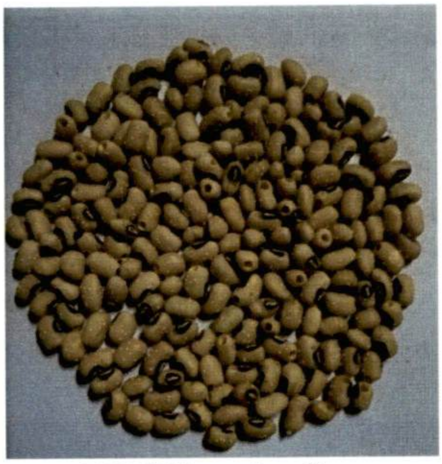
T18 (Clappana local)

Plate 6. Relatively resistant genotypes

T11(Belagum local)



T13 (Hridya)



T27 (Bijapur local)

T15 (Kanakamani)

T29 (Sreya)

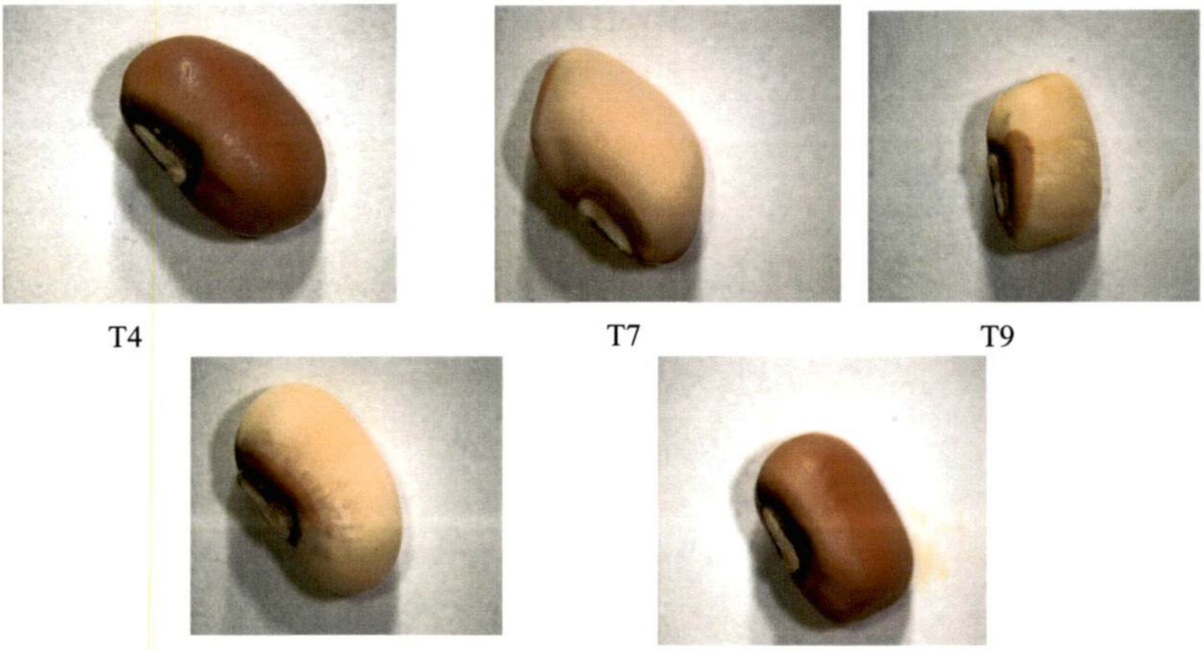
Plate 7. Relatively susceptible genotypes

Table 9. Seed coat colour and texture of relatively resistant genotypes of cowpea

Treatment	Seed colour	Seed texture
T_4	Brownish Orange-164-A	Smooth
T_7	Pale yellow-161C	Smooth
T_9	Light yellow-11B	Smooth
T_{14}	Pale Yellow-12D	Smooth
T_{18}	Brownish orange-165-B	Smooth

Table 10. Seed coat colour and texture of relatively susceptible genotypes of cowpea

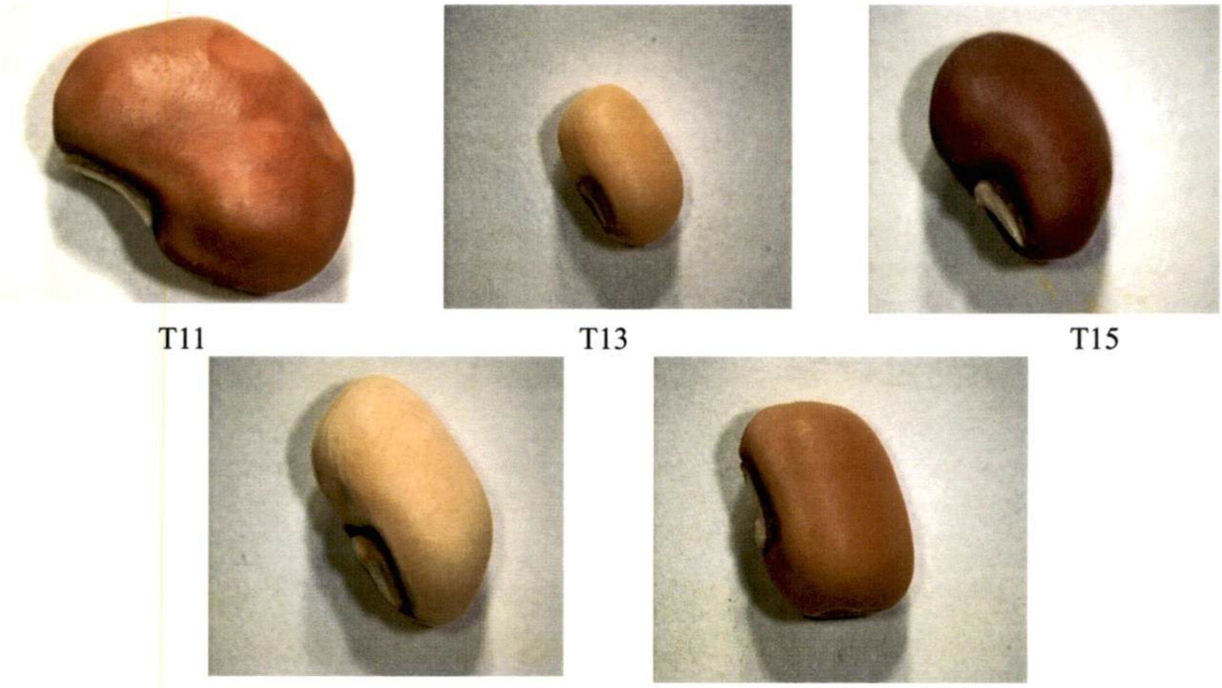
Treatment	Seed colour	Seed texture
T_{11}	Brownish Orange-171B	Wrinkled
T_{13}	Moderate Orange -167C	Smooth
T_{15}	Moderate Purplish Red-186A	Smooth
T_{27}	Pale Yellow-11C	Smooth
T_{29}	Moderate Orangish Yellow-164B	Smooth



T4 T7 T9

T14 T18

Plate 8. Seed coat colour and texture of relatively resistant genotypes



T11 T13 T15

T27 T29

Plate 9. Seed coat colour and texture of relatively susceptible genotypes

Table 11. Mean value of protein and total phenol content of relatively resistant and relatively susceptible seeds

	Conc. of protein (mg/g of sample)	Conc. of total phenol (mg/g of sample)
T_4 (R.R.)	255.00	0.90
T_7 (R.R.)	234.33	1.12
T_9 (R.R.)	154.67	1.22
T_{11} (R.S.)	177.33	0.80
T_{13}(R.S.)	202.67	0.65
T_{14} (R.R.)	167.67	1.30
T_{15}(R.S.)	228.00	0.95
T_{18} (R.R.)	286.33	1.10
T_{27} (R.S.)	268.00	0.70
T_{29} (R.S.)	248.33	0.95
S.E.	1.91	0.02
C.D. 5%	5.504	0.058

R.R. : Relatively Resistant cowpea genotypes

R.S. : Relatively Susceptible cowpea genotypes

Table 12. Analysis of variance of protein and total phenol content of five relatively susceptible and five relative resistant genotypes of cowpea

Sl. No.	Characters	Mean square		
		Replication	Treatments	Error
1	Protein content of seeds (mg/g)	5.433	6026.522**	10.98889
2	Total phenol content of seeds (mg/g)	0.001843	0.139898**	0.000866

Table 13. Correlation relating the damage parameters of five relatively susceptible and five relative resistant genotypes of cowpea

	Per cent seed weight loss	Per cent seed damage	Germination percentage	Moisture content	Protein content of seeds (mg/g)	Total Phenol content of seeds (mg/g)
Per cent seed weight loss	1					
Per cent seed damage	0.663**	1				
Germination percentage	-0.490**	-0.470**	1			
Moisture content of seed	0.531**	0.518**	-0.657**	1		
Protein content of seeds(mg/g)	0.171	0.014	-0.303	0.474**	1	
Total Phenol content of seeds(mg/g)	-0.609**	-0.767**	0.556*	-0.711**	-0.296	1

4.2.2 Analysis of Variance

The analysis of variance (Table 12) revealed significant differences among the genotypes for the protein and total phenol content of seeds.

4.2.3 Correlation of Damage Parameters

Correlation study was done by considering the parameters percentage seed weight loss, percentage seed damage, germination percentage and moisture content of the five relatively resistant and five relatively susceptible genotypes from first experiment along with protein and total phenol content of seed obtained from the second experiment in order to identify the relation between them (Table 13).

Percentage seed damage (0.663), and moisture content of the seed (0.531) showed high positive correlation with seed weight loss percentage while high negative correlation was seen with germination percentage (-0.490) and total phenol content (-0.609). Protein content of seed was found to have no significant correlation with percentage seed damage and seed weight loss percentage. Positive correlation (0.518) was observed between moisture content of seed and percentage seed damage while percentage seed damage exhibited negative association with total phenol content (-0.767) and germination percentage (-0.470).

4.2.4 Index Score

Index scores of the relatively resistant genotypes along with mean values are presented in Table 14. The genotype T7 (Dhavengarae local) had the highest total index score of 20 followed by T14 (19) followed by T18 (18), T4 (17) and T9 (16).

Table 14. Mean data and the index scores (in brackets) of five relatively resistant genotypes of cowpea based on selected characters

	X1	X2	X3	X4	X5	X6	X7	X8	X9	Total score
T_4	8.42 (1)	21.09 (3)	15.83 (2)	27.27 (2)	54.17 (2)	16.06 (2)	75.33 (2)	12.37 (2)	0.90 (1)	17
T_7	10.46 (2)	16.17 (2)	16.80 (3)	29.96 (2)	43.83 (3)	13.50 (3)	67.00 (1)	12.63 (2)	1.12 (2)	20
T_9	12.12 (2)	13.47 (1)	13.39 (2)	19.76 (1)	65.67 (1)	16.14 (2)	75.33 (2)	11.53 (3)	1.22 (2)	16
T_{14}	13.92 (3)	18.73 (2)	12.58 (1)	30.97 (2)	47.67 (2)	14.63 (2)	76.33 (2)	12.43 (2)	1.30 (3)	19
T_{18}	11.02 (2)	18.77 (2)	15.80 (2)	25.99 (2)	61.83 (2)	16.44 (2)	72.33 (2)	12.70 (2)	1.10 (2)	18
SD	2.03	2.91	1.80	4.41	9.21	1.25	3.81	0.47	0.15	
Mean	11.19	17.65	14.88	26.79	54.63	15.35	73.27	12.33	1.13	
Mean+SD	13.22	20.56	16.68	31.20	63.84	16.60	77.08	12.80	1.28	
Mean-SD	9.16	14.73	13.08	22.38	45.43	14.10	69.46	11.87	0.98	

X1	100 seed weight (g)
X2	Number of pods plant^{-1}
X3	Number of seeds pod^{-1}
X4	Seed yield plant^{-1}
X5	Percentage seed damage
X6	Percentage seed weight loss
X7	Germination percentage
X8	Moisture content of seed
X9	Total phenol content of seed

Discussion

5. DISCUSSION

The present investigation was carried out to evaluate thirty cowpea genotypes for yield and resistance to pulse beetle. Most of the released varieties were normally found to be susceptible to the pulse beetle attack compared to local cultivars. It is essential to develop varieties which are not only high yielding but also having resistance to pulse beetle. The discussion that follows is based on two experiments conducted for evaluation of the yield and resistance of cowpea genotypes against the pest. The topic is discussed under different headings.

5.1 VARIABILITY STUDIES

There were significant differences among the thirty genotypes of cowpea for all the characters studied *viz.,* days to 50 per cent flowering, number of primary branches plant^{-1}, length of main stem (cm), number of pod clusters plant^{-1}, number of pods cluster^{-1}, number of pods plant^{-1}, pod weight (g), pod length (cm), pod girth (mm), number of seeds pod^{-1}, 100 seed weight (g), seed yield plant^{-1} (g) and crop duration (days). Ajith (2001), Venkatesan *et al.* (2003), Adewale *et al.* (2010), Manggoel *et al.* (2012), Vavilapalli *et al.* (2013), Ajayi *et al.* (2014), Kharde *et al.* (2014), Vir and Singh (2014), Rajput (2016) and Srinivas *et al.* (2017) also observed significant differences of several characters in grain cowpea including those considered in the present study.

There was remarkable variation in days to 50 per cent flowering ranging from 30.66 to 60.66 with an overall mean performance of 48.21. The genotype T13 (Hridya) was the earliest to 50 per cent flowering (short duration) while the genotype T1 (Ambalappuzha local) recorded maximum number of days to 50 per cent flowering. Studies by Malarvizhi (2002), Manggoel *et al.* (2012) and Vir and Singh (2014) also revealed high variation for the same character in cowpea.

Conspicuos variation was noticed for number of primary branches plant^{-1} which ranged from 2.78 to 6.15. Similiarly, Ajith (2001), Malarvizhi (2002) and Vir and Singh (2014) also reported wide varietal variation for number of branches in cowpea.

Length of main stem ranged from 21.00 to 45.39 cm. The main stem attaining more length in some of the varieties may be due to the availability of favourable condition while, in some others it is a varietal character. Studies by Ajith (2001) also revealed high variation for length of the main stem. Number of pods plant^{-1} also showed high variability with mean values ranged from 8.03 to 21.87. This was in agreement with the reports of Ajith (2001), Suganthi and Murugan (2008), Manggoel *et al.* (2012) and Vir and Singh (2014). High variability in pod characters *viz.*, pod length, pod weight and number of seeds pod^{-1} was observed in the present study. Earlier reports of Ajith (2001) supports these findings also. 100 seed weight showed impressive variation with values ranging from 4.51 to 16.04. Similiarly, high variability in 100 seed weight was supported by Ajith (2001), Manggoel *et al.* (2012) and Vir and Singh (2014). Seed yield plant^{-1} had a range from 11.07 to 32.91. This was in accordance with Adewale *et al.* (2010), Manggoel *et al.* (2012) and Vir and Singh (2014).

The genotypes which were evaluated under field condition for pulse beetle resistance may be having variation in characters like pod thickness, pod hairiness and earliness in pod splitting which may decide the resistance and susceptibility of the genotypes.

The estimation of components of genetic parameters of variation for seed yield and its attributes exhibited a wide range of variation for the characters studied. The phenotypic coefficients of variation were higher in magnitude than that of genotypic coefficients of variation for all the characters which revealed that the environment had an important role in influencing the expression of these characters.

The studies of Ahmed *et al.* (2005), Adewale *et al.* (2010), Vavilapalli *et al.* (2013), Ajayi *et al.* (2014), (Santos *et al.* 2014), Aliyu *et al.* (2016), Rajput (2016) and Srinivas *et al.* (2017) supported the present findings.

High PCV and GCV were observed for pod weight, number of pod clusters plant^{-1}, seed yield plant^{-1}, 100 seed weight, pod length, number of pods cluster^{-1} and number of pods plant^{-1}. These findings were in close harmony with the results of Ahmed *et al.* (2005) for number of pods plant^{-1} and 100-seed weight; Suganthi and Murugan (2008) for seed yield plant^{-1}, number of pods plant^{-1} and number of clusters plant^{-1} ; Adewale *et al.* (2010) for 100 seed weight and pod length; Manggoel *et al.* (2012) for 100-seed weight, grain yield, number of pods plant^{-1} and Thorat and Gadewar (2013) for number of pods plant^{-1} and number of clusters plant^{-1}; Vavilapalli *et al.* (2013) for pod weight and pod length; Ajayi *et al.* (2014) for number of pods plant^{-1}, pod length, pod weight (g), number of seeds pod^{-1}, and 100-seed weight; Selvakumar *et al.* (2015) for yield plant^{-1} , pod length, number of clusters plant^{-1}, number of pods clusters^{-1} and 100 grain weight; Khandait *et al.* (2016) for number of pods plant^{-1}, number of pods cluster^{-1}, pod weight and pod length; Rajput (2016) for number of pod plant^{-1}, number of pods cluster^{-1}, pod weight and pod length and Srinivas *et al.* (2017) for number of pods plant^{-1} and number of seeds pod^{-1}. Hence phenotypic selection will be advantageous for the identified characters in the present study which had high PCV as well as GCV.

5.2 HERITABILITY AND GENETIC ADVANCE

High heritability of a character indicates low influence of environment in its expression and the phenotype of the trait strongly reflects the genotype. Thus heritability provides information on the degree of inheritance of characters from the parents to the progeny. Characters possessing high heritability can be improved directly through simple selection as they are less influenced by the environment (Johnson *et al.*, 1955).

In the present study high heritability was obtained for 100 seed weight, pod girth, pod length, number of pods cluster^{-1}, number of seeds pod^{-1}, days to 50 per cent flowering, pod weight, crop duration, length of main stem and number of pod clusters plant^{-1}. Similar findings were recorded by Thiyagarajan (1989) for days to 50 per cent flowering, pod length, number of seed pod^{-1} and 100 seed weight; Ajith(2001) for length of main stem and pod length; Suganthi and Murugan (2008) for number of seeds pod^{-1}, pod length and 100-seed weight; Adewale *et al.* (2010) for seeds pod^{-1}, 100 seed weight and pod length; Manggoel *et al.* (2012) for 100 seed weight, days to 50 per cent flowering, number of seeds pod^{-1} and pod length; Thorat and Gadewar (2013) for plant height, days to 50 per cent flowering, number of branches plant^{-1}, 100 seed weight and number of clusters plant^{-1}; Ajayi *et al.* (2014) for number of pods plant^{-1}, pod length, pod weight (g), number of seeds pod^{-1} and 100-seed weight; Aliyu *et al.* (2016) for showing highest heritability estimate for 100 seed weight and Khandait *et al.* (2016) for pod length and pod weight. Moderate heritability was observed in the present study for seed yield plant^{-1}, number of pods plant^{-1} and number of primary branches plant^{-1}. However, high heritability estimates in seed yield and number of pods plant^{-1} in cowpea was reported by Kumar and Sangwan (2000), Kalaiyarasi and Palanisamy (2000) and Manggoel *et al.* (2012).

All the characters exhibited high genetic advance (as % of mean) except crop duration which exhibited moderate genetic advance. High estimates of genetic advance was obtained for pod weight, 100 seed weight, pod length, number of pods cluster^{-1}, number of pod clusters plant^{-1}, seed yield plant^{-1}, pod girth, number of pods plant^{-1}, days to 50 per cent flowering, number of primary branches plant^{-1}, length of main stem and number of seeds pod^{-1}. Corroborative findings were reported by Thiyagarajan (1989) for number of seed pod^{-1} and 100 seed weight; Suganthi and Murugan (2008) for seed yield plant^{-1}, number of pods plant^{-1} and number of clusters plant^{-1}; Manggoel *et al.* (2012) and Khandait *et al.* (2016) for number of pods plant^{-1}, pod length, number of pods cluster^{-1}, and pod weight.

High heritability coupled with high genetic advance was observed for days to 50 per cent flowering, length of main stem, number of pod clusters plant^{-1}, number of pods cluster^{-1}, pod weight, pod length, pod girth, number of seeds pod^{-1}, and 100 seed weight. These are in conjunction with the reports from Kumar and Sangwan (2000) for pod length, 100 seed weight and grain yield plant^{-1}; Kalaiyarasi and Palanisamy (2000) for 100 seed weight, and number of seed pod^{-1}; Ajith (2001) for length of main stem ; Ahmed *et al.* (2005) for 100-seed weight; Vavilapalli *et al.* (2013) for pod length, pod girth and pod weight; Kharde *et al.* (2014) pod length, average pod weight and number of seeds pod^{-1}; Selvakumar *et al.* (2015) for number of pods clusters^{-1} and 100 grain weight, Srinivas *et al.* (2017) for number of pods plant^{-1} and number of seeds pod^{-1}. High heritability along with high genetic advance indicated additive gene action for the character under consideration and it helped more in predicting gain under selection than heritability estimates alone.

5.3 CORRELATION STUDIES

A thorough understanding of association among the characters is valuable for plant breeder to improve the efficiency of selection. Correlation coefficient analysis measures the mutual relationship between plant characters and determines the component character on which selection can be made for genetic improvement of yield. The information of genetic association between yield and its component characters helps in improving the efficiency of selection for yield by making proper choice and balancing one component with another (Miller *et al.,* 1958).

In the present study, relationship of seed yield plant^{-1} with twelve yield components along with their relationship among themselves were examined using correlation coefficient analysis. Highly significant positive correlation coefficient was found for 100 seed weight, days to 50 per cent flowering, crop duration, number of seeds pod^{-1}, pod girth, pod length, pod weight and number of pod clusters plant^{-1} with seed yield plant^{-1} both at genotypic and phenotypic levels. Earlier reports on positive genotypic correlation of seed yield with 100 seed weight (Deepa and Balan , 2006; Dahiya *et al.,* 2007; Manggoel *et al.,* 2012 and Meena *et al.,* 2015), days to 50 per cent flowering (Vir and Singh, 2014 and Meena *et al.,* 2015), crop duration (Meena *et al.*, 2015), number of seeds pod^{-1} (Deepa and Balan ,2006; Dahiya *et al.,* 2007; Vir and Singh 2014; Meena *et al.,* 2015 and Sharma *et al.,* 2016), pod length (Deepa and Balan, 2006; Dahiya *et al.,* 2007; Suganthi and Murugan, 2008; Manggoel *et al.,* 2012 and Meena *et al.,* 2015) and number of pod clusters plant^{-1} (Dahiya *et al.,* 2007; Vir and Singh, 2014 and Sharma *et al.,* 2016) supports the findings of present study. However, according to Suganthi and Murugan (2008) seed yield had significant negative correlation with days to 50 per cent flowering which was a contradictory to the current finding.

The above mentioned characters except pod weight and crop duration exhibited high heritability coupled with high genetic advance. Therefore indirect selection based on these characters would simultaneously lead to the improvement of seed yield as their phenotypic values reflect the genotypic worth.

For efficient indirect selection for seed yield on the basis of yield attributes, estimates of interrelationships among yield components is essential as it provides more reliable information for efficient selection.

In the present study days to 50 per cent flowering had significant positive correlation with crop duration, pod length, 100 seed weight, pod girth, pod weight, length of main stem, seed yield plant^{-1}, number of seeds pod^{-1} and number of primary branches plant^{-1}. Similar results for crop duration (Ajith, 2001), pod length (Santos *et al.* 2014, Meena *et al.* 2015), 100 seed weight (Santos *et al.*, 2014; Meena *et al.,* 2015), pod weight (Thorat and Gadewar, 2013), length of main stem (Thorat and Gadewar, 2013), seed yield plant^{-1} (Vir and Singh, 2014 and Meena *et al.,* 2015), number of seeds pod^{-1} (Santos *et al.* 2014) and number of primary branches plant^{-1} (Thorat and Gadewar, 2013; Santos *et al.,* 2014) supported the present study. The association was significantly negative with number of pods plant^{-1} and number of pods cluster^{-1}. Number of primary branches plant^{-1} was noticed with significant positive correlation with pod girth, pod length, days to 50 per cent flowering and pod weight. Thorat and Gadewar (2013) and Santos *et al.* (2014) also reported significant positive correlation number of primary branches plant^{-1} with days to 50 per cent flowering. Significant positive correlation existed in length of main stem with crop duration, pod length, days to 50 per cent flowering, pod weight, 100 seed weight, number of seeds pod^{-1}, seed yield plant^{-1} and pod girth. Similar results of positive correlation of length of main with crop duration and days to 50 per cent flowering was obtained by Thorat and Gadewar (2013). However, it exhibited negative association with number of pods plant^{-1} and number of pods cluster^{-1}. Ajayi *et al.* (2014) also found negative association between length of main stem and number pods plant^{-1}. Number of pods plant^{-1} possessed positive correlation with number of pod clusters plant^{-1} while it had negative correlation with pod length, pod weight, 100 seed weight, crop duration, length of main stem, pod girth and days to 50 per cent flowering. Pod weight showed highly significant positive correlation with pod length which was in accordance with Santos *et al.,* 2014 and it was followed by crop duration, 100 seed weight, pod girth, number of seeds pod^{-1}, days to 50 per cent flowering, length of main stem and seed yield plant^{-1}. It had highly significant negative association with number of pods plant^{-1} and number of pod clusters plant^{-1}. It was noticed in the present study that pod length had highly significant positive correlation with pod weight, crop duration, 100 seed weight, days to 50 per cent flowering, number of seeds pod^{-1}, pod girth , length of main stem and seed yield plant^{-1}. Similar results of significant positive correlation with pod length was obtained earlier for days to 50 per cent flowering (Santos *et al.* 2014, Meena *et al.* 2015), number of seeds pod^{-1} (Meena *et al.* 2015). Pod length had negative association with number of pods plant^{-1}, number of pod clusters plant^{-1} and number of pods cluster^{-1}. The number of seeds pod^{-1} showed positive correlation with pod length, pod weight, crop duration, seed yield plant^{-1}, length of main stem, days to 50 per cent flowering, pod girth and 100 seed weight. Sharma *et al.* (2016) and Santos *et al.* (2014) reported significant positive correlation of number of seeds pod^{-1} with pod length and days to 50 per cent flowering respectively. Highly significant negative correlation was observed in 100 seed weight with number of pods plant^{-1}, number of pods cluster^{-1}. However, it had positive correlation with pod length, crop duration, pod weight, days to 50 per cent flowering, pod girth, seed yield plant^{-1}, length of main stem and number of seeds pod^{-1}. Santos *et al.* (2014) and Meena *et al.* (2015) earlier reported significant positive correlation of 100 seed weight with 50 per cent flowering.

5.4 PATH COEFFICIENT ANALYSIS

The association among the component characters themselves and with yield is quite important for making an efficient selection criterion for yield. Because of the direct and indirect effect of different variables, the total correlation between yield and its component characters may sometimes be misleading as it might be an over-estimate or under-estimate. Hence, sometimes indirect selection by correlated response may not be purposeful. When many characters are affecting a given character, splitting the total correlation into direct and indirect effects based on association between the dependent variable like yield and independent variables like yield components could be useful. It will help in making the basis of selection more clear.

In the present investigation maximum positive direct effect on seed yield plant^{-1} was shown by 100 seed weight followed by number of pods plant^{-1}, number of seeds pod^{-1} and pod length.

Earlier reports on positive direct effect of 100 seed weight (Belhekar *et al.*, 2003; Venkatesan *et al.,* 2003; Mittal and Singh, 2005; Manggoel *et al.,* 2012; Nath and Tajane, 2014 and Meena, *et al.*, 2015), number of pods plant^{-1}(Belhekar *et al.,* 2003; Venkatesan *et al.,* 2003; Mittal and Singh, 2005; Nath and Tajane, 2014 and Sharma *et al.,* 2016), number of seeds pod^{-1}(Venkatesan *et al.,* 2003; Manggoel *et al.,* 2012; Nath and Tajane, 2014 and Shanko *et al*., 2014) and pod length (Venkatesan *et al.,* 2003; Mittal and Singh, 2005 and Santos *et al.,* 2014) was in concordance with the findings in the present study. However, Sharma *et al.* (2016) reported negative direct effect of pod length on seed yield and Santos *et al.* (2014) reported direct negative effect of number of seeds pod^{-1} on seed yield. These were contradictory to the present findings.

It is concluded that as maximum positive direct effect on yield plant^{-1} was exhibited by 100 seed weight followed by number of pods plant^{-1}, number of seeds pod^{-1} and pod length. Therefore these characters should be given due weightage in selection programmes for improving seed yield plant^{-1}.

5.5 SCREENING FOR PULSE BEETLE RESISTANCE

Pulse beetle is a dominant storage pest of legumes. In the field, the damage caused by the pest is often unnoticed and carried to storage as a hidden infestation. The management of the pest is very difficult since it causes great damage and spread due to its mass multiplication in limited time period. Screening varieties for pulse beetle resistance were carried out in different legumes by so many research workers. The host preference studies on *Callosobruchus* spp in different pulses Chakraborty *et al.* (2015), Mainali *et al.* (2015), and Hosamani *et al.* (2016) reported that cowpea was the most preferred host for pulse beetle. Many varieties of cowpea were screened earlier for studying resistance against the pulse beetle. It showed that some varieties possessed a high level of resistance compared to others. Giga and Smith (1981), Manohar and Yadava (1990), Jackai and Asante (2003), Shivanna *et al.* (2011), Lephale *et al.* (2012), Nalini *et al.,* (2012), Divya (2012), Amusa *et al.* (2013), Badii *et al.* (2013), Mogbo *et al.* (2014) and Tripathi *et al.* (2015) worked in cowpea to evaluate resistance against pulse beetle.

In the present study all the damage parameters showed remarkable variability with respect to different genotypes. Number of eggs per 100 seeds ranged from 612.35 to 2506.11 . The lowest value was recorded for genotype T_2 (Kayamkulam local-1) and highest for the genotype T_{29} (Sreya). This variability may be due to the reasons reported by Howe and Curie, (1964), Raina (1970), Messina and Renwick (1985) and Cope and Charles (2003). The differential preference for ovipositon of *C. chinensis* and *C. maculatus* on different accessions might be due to odour of the seed which emitted from its chemical constituents, may provide the stimulus for oviposition (Howe and Curie, 1964). Raina (1970) observed that number of eggs laid on single seed depend on the size of the host seed and bruchid species involved. Messina and Renwick (1985) reported that a rough seed coat was preferred less for oviposition than smooth seed coat. However comparing the seed coat texture of five resistant and five susceptible genotypes in the present study except susceptible genotype T_{11} (Belagum local) which possessed wrinkled seed coat all other genotypes had smooth seed coat texture. Cope and Charles (2003) found that pulse beetle deposited more eggs on larger seeds (more surface area) and dispersed eggs uniformly on among the seeds in a manner that maximizes the amount of resources allocated to each offspring (Plate 10). Lara (1997) reported that the genotypes with the most oviposition are not always the most susceptible, a genotype with heavy oviposition can still prove to be resistant. In the present study the genotype T_{29} (Sreya) had the maximum oviposition and one among the relatively susceptible variety. Eventhough the genotypes T_9 and T_{14} had high egg load they are relatively resistant among the genotypes. The possible reason behind the resistance may be the longer development period of insect in a resistant genotype than in a susceptible one. The seed coat thickness could also be considered as a factor conferring resistance to the grubs to penetrate and reach the cotyledons (Lephale *et al.* 2012). The death of the grubs may occur due to the presence of biochemical factors present in the seed coat which offer resistance to the genotype (Singh *et al.* 1995). Significant variation was also found among cowpea genotypes in percentage seed damgae, percentage seed weight loss and germination percentage. Percentage seed damage was the minimum for T_7 (Dhavengarae local) (43.83) and maximum for T_{13} (Hridya) (90.67). Nalini *et al.,* (2012), Divya (2012), Amusa *et al.* (2013), Sunitha *et al.* (2013) and Mogbo *et al.* (2014) found significant variation among the cowpea genotypes in the case of percentage seed damage.

Percentage seed weight loss also showed significant variation ranged from 13.50 to 26.64. Highest per cent seed weight loss was for T_{27} (Bijapur local) and lowest was for T_7 (Dhavengarae local). Jackai and Asante, (2003), Shivanna *et al.* (2011), Lephale *et al.* (2012), Nalini *et al.,* (2012), Amusa *et al.* (2013), Badii *et al.* (2013), Sunitha *et al.* (2013), Mogbo *et al.* (2014) and Tripathi *et al.* (2015) reported significant variation among the cowpea genotypes in the case of percentage seed weight loss.

Among thirty genotypes, germination percentage of infested seeds exhibited significant variation ranged from 48.67 per cent to 82.33 per cent (Plate 11). The genotype T_{16} (Thuravoor local) had maximum germination percentage followed by T_{22} (Kollengode local). However, these genotypes recorded above 75 per cent seed damage. This may be due to no particular damage on plumule and radical during the infestation. The pulse infestion along with fungal infestation mainly reduced the germination percentage. The genotype T_6 (Mannuthy local) recorded minimum germination percentage. Singh and Sharma (1982), Patil *et al.* (2003), Parameshwarappa *et al.* (2007) also reported that varieties varied significantly in germination percentage after pulse beetle infestation.

The highest moisture content was recorded for the genotype T_{27} (Bijapur local) and lowest was recorded for T_{20} (Nilambur local) followed by T_9 (Nenmara local). In the present study the genotype with highest moisture content i.e., T_{27} (Bijapur local) was more susceptible to the beetle attack. The genotype T_9 (Nenmara local) was relatively resistant to pulse beetle attack. The result indicated that the grain moisture content in different genotypes played some significant role in the susceptibility to the insect pest. The findings of Deeba *et al.* (2006) Tripathi *et al.* (2013), and Bhattacharya and Banerjee (2001) supported these results of present study while Chakraborty *et al.*(2004) and Mogbo*et al.* (2014) reported that moisture didn't shown any influence in providing resistance.

The present study revealed that the genotype T_7 (Dhavengarae local) was found to be a good yielder with relative resistance to pulse beetle followed by the genotype T_{14} (Alathur local) (Plate 12).

5.6 MORPHOLOGICAL AND BIOCHEMICAL ANALYSIS

An essential prerequisite for characterization of resistance factors and their exploitation in breeding resistant varieties is to determine the mechanisms underlying morphological and biochemical aspects. Morphological factors such as seed coat colour and seed coat texture and biochemical factors like protein and total phenol content were evaluated in five relatively resistant and five relatively susceptible genotypes identified through experiment- I of the present study.

In the present study seed coat colour was found to have no influence on resistance to pulse beetle. Relatively resistant ones didn't had a dominant colour which confirm resistance compared to susceptible one. This was in agreement with Tripathi *et al.* (2013) and Mogbo *et al.* (2014). Seed texture was smooth in relatively resistant and relatively susceptible genotypes except in the case of the relatively susceptible T_{11} (Belagum local) which had wrinkled seed coat. Since relatively resistant genotypes didn't had a varied seed coat texture compared to relatively susceptible genotypes, seed coat texture also found to had no influence in providing resistance. Fawki *et al.* (2012) and Tripathi *et al.* (2013) were in agreement with these finding. While Mogbo *et al.* (2014) and Kouser *et al.* (2017) reported contradictory to the present finding.

The protein content in the seed ranged from 167.67 mg g^{-1} to 286.33 mg g^{-1}. The lowest protein as well as highest protein content was recorded in relatively resistant genotypes T_9 (Nenmara local) and T_{18} (Clappana local) respectively. Correlation analysis with per cent seed damage and per cent seed weight loss confirmed that protein content in the seed had no role in contributing resistance. This was in accordance with Chakraborty *et al.* (2004). However, It was contradictory to the findings of Venugopal *et al.* (2000), Nagaraja, (2006), Abdel-Sabour *et al.* (2010), Divya (2012), Divya *et al.* (2013) and Sowmya (2015). The highest total phenol content was for T_{14} (Alathur local) which was a relatively resistant genotype and lowest for T_{13} (Hridya) which was relatively a susceptible one. Correlation analysis confirmed that total phenol content had significant negative correlation with per cent seed damage and per cent seed weight loss. This was in accordance with the results of Venugopal *et al.* (2000), Bhattacharya and Banerjee (2001), Nagaraja, (2006), Divya (2012), Divya *et al.* (2013), Tripathi *et al.* (2013) and Sowmya (2015).

Even though genotypes varied significantly in damage, none of the genotypes tested was completely resistant against pulse beetle attack. It reveals that varietal resistance alone will not eliminate the infestation fully but it can reduce the damage to a more acceptable level in the absence of control measures. Since most of the high yielding varieties are suceptible to this storage pest, promoting resistance breeding based on local cultivars is very much essential.

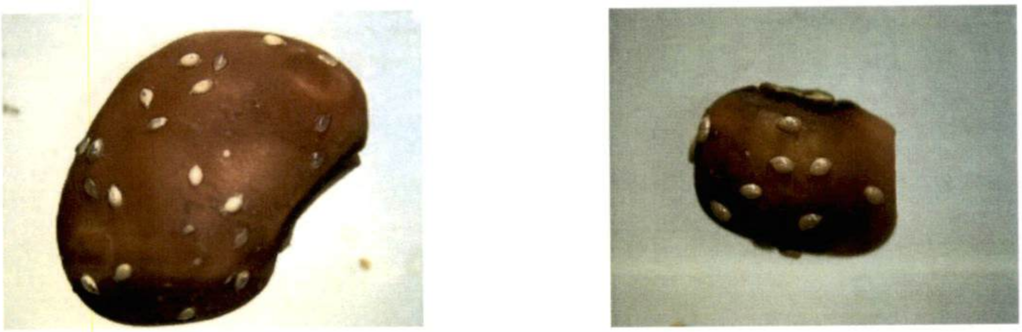
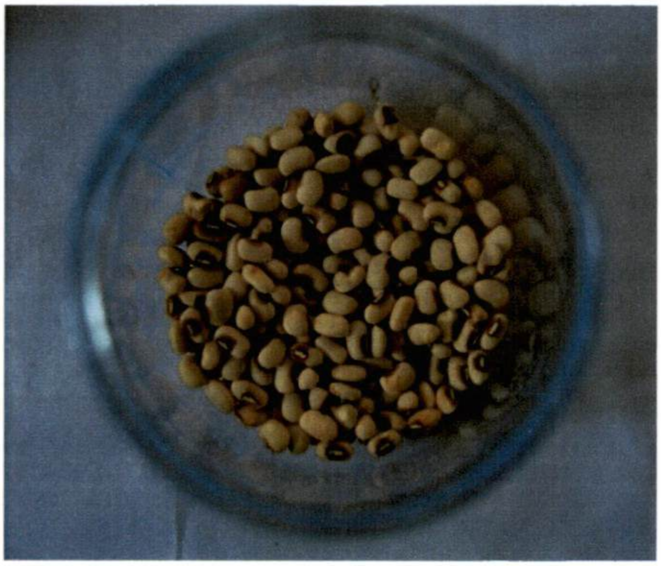


Plate 10. Seed infested with eggs of *Callosobruchus* spp

Plate 11. Germination of infested seeds

T7 (Dhavengarae Local)



T14 (Alathur Local)

Plate 12. High yielding and relatively resistant genotypes to pulse beetle

Summary

6. SUMMARY

The study entitled "Evaluation of cowpea [*Vigna unguiculata* (L.) Walp.] genotypes for yield and resistance to pulse beetle [*Callosobruchus* spp.]" was carried out in a farmer's field at Kayamkulam during 2015-2017. The study was conducted in two experiments. In experiment-I, yield and resistance to pulse beetle was evaluated in randomised block design with three replications. Thirty cowpea genotypes were collected from different sources. The genotypes denoted by treatment numbers, T_1 to T_{30} included three released varieties (Hridya, Kanakamani, and Sreya) and 27 local cultivars. These were first evaluated in a field experiment for yield, yield component characters and carry over population of pulse beetle from field. Observations were recorded for days to 50 per cent flowering, number of primary branches plant^{-1}, length of main stem (cm), number of pod clusters plant^{-1}, number of pods cluster^{-1}, number of pods plant^{-1}, podweight (g), pod length (cm), pod girth (mm), number of seeds pod^{-1}, 100 seed weight (g), seed yield plant^{-1} (g), crop duration (days) and percentage of seeds damaged by pulse beetle.

Analysis of variance revealed significant differences among the genotypes for all the characters studied. The genotype T_{29} (Sreya) recorded the highest yield plant^{-1}(32.91g) followed by T_{14} (Alathur local) and T_7 (Dhavengarae local), whereas the lowest yield plant^{-1}(11.07g) was for the genotype T_{13} (Hridya). The genotype T_1 (Ambalappuzha local) showed the highest mean values for days to 50 per cent flowering, length of main stem, pod weight, pod length, number of seeds pod^{-1}, 100 seed weight and crop duration. T_{21} (Chittoor local) recorded the highest number of pods plant^{-1} (21.87). Thirteen genotypes were found to be infested under field condition and only very low seed damage *via* carry over population was noticed. The phenotypic coefficient of variation was found to be higher than the genotypic coefficient of variation for all the traits studied. The highest magnitude of GCV was observed for pod weight (47.73) followed by number of pod clusters plant^{-1}, seed yield plant^{-1}, 100 seed weight, pod length, number of pods cluster^{-1} and number of pods plant^{-1}. All the characters considered except number of primary branches plant^{-1}, number of pods plant^{-1} and seed yield plant^{-1} recorded high estimates of heritability ranged from 63.5 per cent to 99.41 per cent. High heritability coupled with high genetic advance was observed for days to 50 per cent flowering, length of main stem, number of pod clusters plant^{-1}, number of pods cluster^{-1}, pod weight, pod length, pod girth, number of seeds pod^{-1}, and 100 seed weight.

Highly significant positive correlation coefficient were found for 100 seed weight, days to 50 per cent flowering, crop duration, number of seeds pod^{-1}, pod girth, pod length, pod weight and number of pod clusters plant^{-1} with seed yield plant^{-1} both at genotypic and phenotypic levels. The path analysis revealed that 100 seed weight, number of pods plant^{-1} and number of seeds pod^{-1} had the maximum positive direct effect on seed yield plant^{-1}. 100 seed weight exerted positive indirect effect on all other characters except number of pods plant^{-1}. The low residual effect (0.036) indicated that the major portion of the variation in yield could be accounted by the characters studied in path analysis.

In no choice confinement test under experiment-I, seeds of all the thirty genotypes of cowpea with three replications were used to evaluate the resistance of these genotypes to pulse beetle. Eventhough none of the genotypes were completely resistant to pulse beetle attack, there were significant differences among the genotypes in terms of oviposition, percentage seed damage and percentage seed weight loss. The genotype T_2 (Kayamkulam local-1) had the least egg load while, more eggs were laid on seeds of T_{29} (Sreya) and T_1 (Ambalappuzha local). The lowest percentage seed damage and percentage seed weight loss were observed for the genotype T_7 (Dhavengarae local) whereas, the highest percentage seed damage was recorded for T_{13} (Hridya) and the highest percentage seed weight loss was recorded for T_{27} (Bijapur local) followed by T_{15} (Kanakamani). Moisture content of the seed was the highest for T_{27} (Bijapur local) and the lowest for T_{20} (Nilambur local) followed by T_9 (Nenmara local). The highest germination percentage was for T_{16} (Thuravoor local) and the lowest was for T_6 (Mannuthy local).

In the experiment-II, seed morphological and biochemical factors associated with resistance to pulse beetle were studied in five relatively resistant genotypes *viz.,* T_4 (Kulashekarapuram local), T_7 (Dhavengarae Local), T_9 (Nenmara local), T_{14} (Alathur Local) and T_{18} (Clappana local) and five relatively susceptible ones *viz.,* T_{11} (Belagum local), T_{13} (Hridya), T_{15} (Kanakamani), T_{27} (Bijapur local) and T_{29} (Sreya) which were identified through experiment-I. It was found that the total phenol content was having significant negative correlation with percentage seed weight loss. However, seed coat texture, seed coat colour and protein content in the seeds were found to have no influence on resistance to pulse beetle. The percentage seed weight loss and percentage seed damage were found to be increased with increase in moisture content of the seed, while germination percentage was found to be decreased with increase percentage seed weight loss and percentage seed damage.

An index score was worked out to find out the genotypes with good yield and relative resistance to pulse beetle. It was observed that the genotype T_7 (Dhavengarae local) had the highest index score followed by T_{14} (Alathur local), T_{18} (Clappana local), T_4 (Kulashekarapuram local) and T_9 (Nenmara local).

The present study revealed that the genotype T_7 (Dhavengarae local) was found to be a good yielder with relative resistance to pulse beetle followed by the genotype T_{14} (Alathur local). Hence these genotypes can be recommended for future resistance breeding programmes.

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EVALUATION OF COWPEA [*Vigna unguiculata* (L.) Walp.] GENOTYPES FOR YIELD AND RESISTANCE TO PULSE BEETLE [*Callosobruchus* spp.]

by

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ABSTRACT

The present study entitled "Evaluation of cowpea [*Vigna unguiculata* (L.) Walp.] genotypes for yield and resistance to pulse beetle [*Callosobruchus* spp.]" was carried out at farmer's field, Kayamkulam during 2015-2017, with an objective to evaluate cowpea genotypes for yield and resistance to pulse beetle.

The study was conducted in two experiments. In experiment-I, yield and resistance to pulse beetle was evaluated in a Randomised Block Design (RBD) with three replications using 30 genotypes collected from different places. Experiment-II was to study the seed morphological and biochemical factors associated with resistance to pulse beetle in five relatively resistant genotypes and five relatively susceptible ones which were identified through experiment-I.

The field experiment revealed that the genotype T_1 (Ambalappuzha local) showed the highest mean values for days to 50 per cent flowering, length of main stem, pod weight, pod length, number of seeds pod^{-1}, 100 seed weight and crop duration. The maximum yield plant^{-1} (32.91g) was obtained for the genotype T_{29} (Sreya) followed byT_{14} (Alathur local) and T_7 (Dhavengarae local), whereas the minimum yield plant^{-1} (11.07g) was for the genotype T_{13} (Hridya). Thirteen genotypes were found to be infested under field condition and only very low seed damage *via* carry over population was noticed. The characters studied were found to be significant for all the genotypes evaluated. The pod weight exhibited the highest GCV (47.73%) and PCV (52.12%). Heritability was high for all the characters except number of primary branches plant^{-1}, number of pods plant^{-1} and seed yield plant^{-1} which possessed moderate heritability. GA (% mean) was high for all the characters except crop duration. The association analysis revealed highly significant positive correlation for 100 seed weight, days to 50 per cent flowering, crop duration, number of seeds pod^{-1}, pod girth, and pod length with seed yield both at genotypic and

phenotypic levels. The path analysis revealed that 100 seed weight, number of pods plant^{-1} and number of seeds pod^{-1} had the maximum positive direct effect on seed yield plant^{-1}.

In no choice confinement test under experiment-I, there were significant differences among the genotypes in terms of oviposition, percentage seed damage and percentage seed weight loss. T_2 (Kayamkulam local-1) had the least egg load while more eggs were laid on seeds of T_{29} (Sreya) and T_1 (Ambalappuzha local). The highest percentage seed damage and the highest percentage weight loss were recorded for T_{13} (Hridya) and T_{27} (Bijapur local) respectively. The lowest percentage seed damage and percentage seed weight loss were observed for the genotype T_7 (Dhavengarae local).

In the study of seed morphological and biochemical factors associated with resistance under experiment-II, it was found that seed coat texture, seed coat colour and protein content of seeds were found to have no influence on resistance to pulse beetle. However, total phenol content of seed was having significant negative correlation with percentage seed weight loss. An index score was worked out to find out genotypes with good yield and relative resistance to pulse beetle. It was observed that the genotype T_7 (Dhavengarae local) had the highest index score followed by T_{14} (Alathur local).

The present study revealed that the genotype T_7 (Dhavengarae local) was found to be a good yielder with relative resistance to pulse beetle followed by the genotype T_{14} (Alathur local). Hence these genotypes can be recommended for future breeding programmes.

Appendices

Weather data (April 2016 – October 2016)

Appendix I

Month	Temp.		RH %	
	Max (^{0}C)	Min (^{0}C)	FN	AN
April 2016	34.8	26.2	91	65
May 2016	32.2	24	92	72
June 2016	30	22.8	93	82
July 2016	30	24.3	93	81
August 2016	30.3	23.5	92	76
September 2016	30.1	23	93	74
October 2016	31	23.9	93	66