GENETIC VARIABILITY FOR YIELD AND RESISTANCE TO LEGUME POD BORER, *Maruca vitrata* (Fab.) IN YARD LONG BEAN (*Vigna unguiculata* subsp. *sesquipedalis* (L.) VERDCOURT)

by

ASOONTHA
(2015-11-042)

THESIS

Submitted in partial fulfilment of the

requirements for the degree of

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DEPARTMENT OF PLANT BREEDING AND GENETICS

COLLEGE OF AGRICULTURE

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DECLARATION

I, hereby declare that this thesis entitled **"GENETIC VARIABILITY FOR YIELD AND RESISTANCE TO LEGUME POD BORER, *Maruca vitrata* (Fab.) IN YARD LONG BEAN (*Vigna unguiculata* subsp. *sesquipedalis* (L.) VERDCOURT)"** 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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Asoontha

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LIST OF ABBREVIATIONS AND SYMBOLS USED

ANOVA	Analysis of Variance
&	and
et al.,	And others or co-workers
cm	Centimetre
CD	Critical difference
ECV	Environmental coefficient of variation
FYM	Farm yard manure
Fig.	Figure
GA	Genetic advance
GCV	Genotypic coefficient of variation
g	Gram
ha	Hectare
KAU	Kerala Agricultural University
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
MSSRF	M. S. Swaminathan Research Foundation
m	metre
viz.,	Namely
NBPGR	National Bureau of Plant Genetic Resources
NS	Non significant
No.	Number
%	Per cent

ha^{-1}	Per hectare
$Plant^{-1}$	Per plant
Pod^{-1}	Per pod
mm^{-2}	Per square milli meters
PCV	Phenotypic coefficient of variation
Sl.	Serial
SE	Standard error
i.e.,	That is
t ha^{-1}	Tonnes per hectare

Introduction

1. INTRODUCTION

Cowpea, *Vigna unguiculata* (L.) Walp. belonging to Leguminosae family is a rich and inexpensive source of dietary protein for the economically deprived in many developing countries. It is also popular both as a vegetable and fodder crop. It's ability to fix atmospheric nitrogen even in poor soils makes it as an essential component of sustainable cropping systems in marginal lands of the tropics.

Cowpea is believed to have originated in Africa (Peter, 1998). Verdcourt (1970) had identified five subspecies of *Vigna unguiculata* among which V. *unguiculata* subsp. *unguiculata* is a cosmopolitan species that enjoys wide distribution. *Vigna unguiculata* subsp. *dekindtiana* and *V. unguiculata* subsp. *mensensis* are wild genotypes restricted to Africa, whereas *Vigna unguiculata* subsp. *cylindrica* and *V. unguiculata* subsp. *sesquipedalis* are found in India and the Far East.

Vigna unguiculata subsp. *sesquipedalis*, commonly called as the yard long bean is considered to be one of the most important vegetable crop in the South East Asian countries of Indonesia, Thailand, Philippines and Taiwan as well as in China. The crop is grown across an area of about 7.7 million ha throughout India. It is one of the most extensively cultivated vegetables in Kerala. The yard long bean is highly nutritious, being rich in protein (3.5 g/100 g of edible pods), calcium (72.0 mg/100 g of edible pods), phosphorus (59 mg/100 g of edible pods), iron (2.5 mg/100 g of edible pods), carotene (564 mg/100 g of edible pods), thiamine (0.07 mg/100 g of edible pods), riboflavin (0.09 mg/100 g of edible pods) and vitamin C (24 mg/100 g of edible pods)

Yard long bean is subjected to frequent and heavy infestations by several insects such as aphids, thrips and pod borers. Among these, the spotted pod borer, *Maruca vitrata* (Fab.) is the most important pest of yard long bean. The borer mostly attacks flowers and pods, boring into them and feeding on the internal contents. *M. vitrata* causes 13 to 31 per cent pod damage and 33 to 53 per cent yield loss (Karel, 1985). In high rainfall areas the crop loss due to the pest even goes up to 80 per cent (IITA, 1998).

Management of the pest often involves frequent and heavy applications of synthetic insecticides. In view of the environmental and health issues associated with the same, management strategies that reduce the dependence on insecticides have to be devised. Host plant resistance, which offers ecofriendly and durable pest management assumes significance in this context. However, plant resistance to insect pests in yard long been has hardly been explored.

In this background, it was considered appropriate to evaluate the available land races and cultivars of yard long bean in Kerala for resistance to the spotted pod borer, *M. vitrata*. The present study was therefore undertaken with the broad objective of evaluating a collection of yard long bean germplasm for yield and legume pod borer resistance.

Review of Literature

2. REVIEW OF LITERATURE

The present study involved evaluation of yard long bean germplasm for legume pod borer resistance and vegetable pod yield. The literature pertinent to the study is organised and presented in different headings.

2.1. LEGUME POD BORER RESISTANCE EVALUATION

2.1.1. About the Pest

Legume spotted pod borer, *Maruca vitrata* (Fab.) (Syn. *Maruca testulalis*, Geyer) Lepidoptera: Pyrallidae) is a highly damaging polyphagous post flowering borer pest of several leguminous crops including cowpea (Jackai and Adalla, 1997; Rouf and Sardar, 2011). This pest have extensive host range (Taylor, 1967; Margam *et al*., 2011). Among the 22 major host species *Cajanus cajan* (L.) Millsp. and *Vigna unguiculata* (L.) Walp. are the two highly susceptible species (Attachi and Djihou, 1994). The pest which was of minor importance in south east Asia earlier, has recently attained the status as a major pest of legumes in the region (Srinivasan *et al*., 2012; Yule and Srinivasan, 2013). Flower and pod feeding lepidopterans cause serious yield losses to edible legumes particularly in tropical and sub-tropical zones. *Maruca vitrata* is genetically a complex species (Margam *et al*., 2011; Periasamy *et al*., 2015).

Karel (1985) observed that the *M. vitrata* larvae are more abundant and injurious to cowpea than any other pest. The pod damages due to the pest range from 13 to 31 per cent, the seed damage is about 16 per cent and the total yield loss average between 33 to 53 per cent. Total yield loss of grains ranging from 30 to 50 per cent was reported by Jackai and Daoust (1986). According to Attachi and Djihou (1994) *V. unguiculata* is one of the most vulnerable species to the attack by pod borer.

Infestation by pod borers *M. vitrata* and *L. boeticus* was recorded as the major limiting factor in vegetable cowpea cultivation as they constitute 99.9% of all known cowpea borers in China (Qinghuai *et al*., 2003).

Over a wide range of environment, the pod borer survives (Jackai and Daoust, 1986; Ngugi *et al*., 1985). Jackai *et al*. (1990) reported that the legume pod borer develops and reproduces better under high relative humidity and moderate temperature whereas the population density tends to be lower in drier weather. According to Oghiakhe *et al*. (1991a) the per cent of pod damage and larval infestation on flowers were positively correlated with relative humidity and negatively correlated with temperature. Legume pod borer is the most devastating and abundant pest of cowpea in high rainfall areas, where the production losses due to infestation by the pest may go up to 80 per cent (IITA, 1998).

Anithakumari (1992) estimated that the crop loss in yard long bean is tremendous since the larvae feed on flowers and developing pods. The moth lays eggs on flower buds, flowers and developing pods and the eggs hatch within two to three days and their first instar larvae feed at oviposition sites. They bore into the pods and devour the developing seeds one after another. The larval burrow on pods is marked by a mass of brownish frass at the entrance of the gallery. The fifth instar larvae get pupated after about 10 days and the pupal period lasts for a week.

2.1.2. Trichome Density and Resistance

Jackai and Oghiakhe (1989) reported the presence of glandular and non-glandular trichomes in both cultivated and wild cowpea. Trichomes in the two types of cowpea differ significantly only in their number and non-glandular trichome length. Rather than density, trichome length and angle to pod surface seemed to be more important for resistance.

A study was conducted in cowpea by Oghiakhe *et al*. (1992a) and they found a negative and significant correlation between pod wall trichome density and pod damage by legume pod borer. They highlighted the role of trichome density in reducing pod damage. Studies have also shown that glandular trichomes contain high concentration of phenol and alkaloids which enhance their biochemical defense against insects. They also noticed a significant negative correlation between the total trichome density on the pod wall of cowpea and legume pod borer infestation on the pods

Oghiakhe (1995) concluded that trichomes in wild and cultivated cowpea adversely affected oviposition, mobility, food consumption and utilization of the pod borer.

In yard long bean, Panicker (2000) reported a non-glandular trichome density range of 1.50 to 7.00 numbers mm^{-2} area of pod wall surface, while Philip (2004) observed a pod trichome count of 1.67 to 6.83 mm^{-2} in grain cowpea.

Vidya (2000) reported that there was no significant correlation between pod damage severity and pod wall thickness in cowpea. The density of non glandular trichomes on the pod wall had significant negative correlation with infestation by legume pod borer (Panicker, 2000).

A study was conducted by Manju (2006) in cowpea for assessing the role of trichomes in imparting host plant resistance and she found that the mechanism of resistance depend upon one or more characteristics of trichomes *viz*., their density, erectness, length and shape. She also reported that a non glandular trichome density range of 1.87 to 6.03 numbers mm^{-2} area of the pod surface.

In an investigation conducted by Nasiya (2015) in cowpea, reported that the morphological characters contributing to resistance are pod wall thickness and trichome density.

2.1.3. Resistance Evaluation and Field Screening Techniques

Resistance to pod borers *L. boeticus* and *M. testulalis* were assessed in sixty *Vigna radiata* and fifty *Vigna mungo* cultivars in the field by exposing them to natural infestation. If natural infestation fails to develop at the desired time or magnitude either laboratory reared or field collected test insect population can be released into the field plots. Host plant resistance can be measured either by assessing the plant growth and damage or by assessing the insect population (Sahoo *et al.*, 1989).

Jackai (1982) suggested an appropriate field screening methodology by assessing the damage caused by legume pod borer on cowpea flowers, pods and seeds. He observed that seed damage was not correlated with flower and pod damage measurements. The pod damage was positively and significantly correlated with flower damage.

In cowpea, Echendu and Akingbohungbe (1989) reported that successful establishment of pod borer larvae occurs at the flower bud stage, and not in the flower primordia or open flowers. An infestation level of two larvae per plant was sufficient to cause noticeable yield reduction.

Oghiakhe *et al.* (1992b) emphasised the importance of flower and pod damages due to legume pod borer for field screening of resistance.

Reaction of host plant to an insect pest may vary from high level of resistance to extreme susceptibility. Host plant resistance of a variety is definable only in terms of other and usually more susceptible varieties. A variety that suffers lesser attack or pest loss in the event of comparable pest population can be considered partially resistant (Dent, 1995). The potential and profitability of partial resistance in combination with other control strategies are now well realized.

Pod damages caused by legume pod borer resulted in significant reduction of yield in cowpea (Panicker *et al.,* 2002). Pod damage caused by legume pod borer was significantly and positively correlated with seed damage in cowpea. Flower damage caused by the pest, however, was independent of pod damage.

The correlation among the flower, pod and seed damage parameters were studied and found that there was no correlation between flower damage assessed on the basis of larval count in flowers and pod damage assessed as per cent of infested pods on a random sample of pods (Vidya, 2000). Field screening programme for legume pod borer resistance in fifty yard long bean cultivars were evaluated on the basis of plant resistance index. The cultivars suffering least flower damage were VS 5 and VS 33. Lowest pod damage by VS 34, VS 39 and VS 42 VS 34 with the lowest plant resistance index value was identified as the most resistant among all the varieties (Vidya, 2000).

In yard long bean, screening for legume pod borer resistance was done by Panicker (2000), and observed a plant susceptibility index ranging from 33.13 to 109.37. Larval count in flowers was not correlated with any of the damage parameters.

Attachi and Hountondji (2000) reported that the legume pod borer larvae affected the flower buds, flowers and pods of almost all types of cowpea, the flowers being most preferred. Most of the first and second instar larvae were observed on flowers, while majority of fourth and fifth instar larvae were found on pods (Liao and Lin, 2000)

Screening of all the sixty six accessions for legume pod borer resistance was done by working out plant susceptibility indices based on flower, pod and seed damage parameters. VS 19 was the most tolerant with least damage to flowers, pods and seeds, while VS 42 was the most susceptible. On comparing the accessions for various characters VS 27, VS 8 and VS 19 were found to be promising based on their superiority in yield, quality and tolerance to legume pod borer (Manju, 2006).

A study conducted by Grigolli *et al.* (2015) in soyabean reported that the infestation and damage caused by the *M.vitrata* larvae was in the order of highest damage on flowers, flower buds and pods.

Abundance and level of infestation of *M.vitrata* varied with plant parts having a ranking from highest to lowest in the order of flower buds, flowers and pods (Jaisanghe *et al.*, 2015). Nasiya (2015) reported a significant difference in the damage caused by the pod borer larvae in flower buds, flowers and pods.

2.2 EVALUATION OF YARD LONG BEAN GERMPLASM FOR YIELD

2.2.1 Yield and Yield Components

Vegetable pod yield is the principal character in yard long bean in terms of economic return. Direct selection for yield is mostly misleading in yard long bean because vegetable pod yield is polygenically controlled. Hence, the selection for desirable types should not only be based on yield, but other yield components should also be considered. Knowledge about the degree of interrelationship among different component characters with vegetable pod yield is crucial for devising an efficient selection criterion for pod yield.

The basic requisite for an efficient selection is the availability of an array of diverse genotypes. Larger variability ensures the identification of superior genotypes. The information on the extent of variability in a population is very essential for the breeder to design his crop improvement programmes. The exact idea of variability in a population is provided by genetic parameters like coefficient of variation, heritability and genetic advance. An understanding of the variability existing in a crop is necessary to formulate and accelerate breeding program.

2.2.2 Genetic Variability

The breeding procedure and efficiency of selection basically depends on the variability available in the germplasm (Zelleke, 2000).

Panicker (2000) observed high variability for days to flowering, pods plant^{-1}, pod length and peduncle length in vegetable cowpea.

Significant variability among thirty two genotypes of cowpea was reported by Backiyarani *et al.* (2000) for days to 50 per cent flowering, plant height and yield plant^{-1}.

Tyagi *et al.* (2000) reported that days to 50 per cent flowering, pod length, pods plant^{-1} and 100 seed weight recorded high genetic variability in cowpea.

Vidya (2000) reported that there existed high variability among fifty cultivars of yard long bean for days to flowering, pods plant^{-1}, plant height, pod length, and number of seeds pod^{-1}.

In a study conducted by Ajith (2001) in cowpea, observed that the characters *viz.*, days to 50 per cent flowering, plant height, pods plant^{-1}, pod length, seeds pod^{-1} and yield plant^{-1} exhibited wide range of variability.

High range of genetic variability was noticed in a study with fifty genotypes of cowpea for characters *viz.*, days to 50 per cent flowering, plant height, pods plant^{-1}, pod length, seeds pod^{-1}, 100 seed weight and yield plant^{-1}(Anbuselvam *et al.*, 2001).

Significant variation was recorded by Chattopadhyay *et al.*, (2001) for pods plant^{-1} and pod length in cowpea.

Jyothi (2001) reported broad spectrum of variability for pods plant^{-1}, seeds pod^{-1}, 100 seed weight and yield plant^{-1} in cowpea.

In an experiment conducted in cowpea, Arunachalam *et al.* (2002) noticed high variability for important yield contributing characters.

Kavita *et al.* (2003) reported broad spectrum range of genetic variability for days to 50 per cent flowering, in cowpea.

In a set of 740 germplasm accessions of cowpea comprising of both indigenous and exotic origin, a wide range of variation was observed in almost all the characters studied, when evaluated for 25 descriptors (Mishra *et al.,* 2003).

All the yield contributing characters *viz.*, days to 50 per cent flowering, pods plant^{-1}, inflorescence plant^{-1}, pods inflorescence^{-1}, plant height, primary branches, pod length, seeds pod^{-1}, grain yield plant^{-1} and 100 seed weight exhibited high range of variation among the 50 genotypes of cowpea studied by Philip (2004). High genetic variability was reported for pod weight, pods plant^{-1} and yield plant^{-1} in yard long bean by Lovely (2005).

Jithesh (2009) reported broad spectrum genetic variability for pod weight, pods plant^{-1}, pod length, pod yield plant^{-1} and 100 seed weight in yard long bean. Variability studies in yard long bean revealed that all the biometric characters were predominately governed by additive gene action (Nehru *et al.*, 2009).

Significant variability for days to 50 per cent flowering, pods plant^{-1}, seeds pod^{-1}, pod length, and 100 seed weight was observed by Manggoel *et al.* (2012) by studying ten cowpea accessions.

On evaluation of forty four genotypes in yard long bean, the pod length ranged from 27.13 to 91.67 cm, pod girth ranged from 2.47 to 4.63 cm, pod weight ranged from 38.73 to 67.06 g, pods plant^{-1} ranged from 19.3 to 87.09 and average yield ranged from 500.5 to 1127.5 g plant^{-1} (Sivakumar, 2012)

Udensi and Edu (2015) noted that yield and yield related traits in yard long bean contributed to 82.2 per cent of total variability.

High variability in yard long bean for pod yield plant^{-1} was reported by Litty and Celine (2016).

2.2.3. Coefficient of Variance, Heritability and Genetic Advance

Variability available in a population could be partitioned into heritable and non-heritable components. This partitioning is done with the aid of genetic parameters such as Phenotypic Coefficient of Variation (PCV), Genotypic Coefficient of Variation (GCV), heritability and Genetic Advance (GA) (Johnson *et al.*, 1955).

Variation present in a population is of three types *viz.*, phenotypic, genotypic and environmental. In crop improvement programs only the genetic component is transmitted to the next generation and the extent of further improvement depends upon the intensity of selection and genetic advance obtained from the population. The estimates of PCV, GCV and ECV suggests the interaction of genotypes with the environment. Narrow differences between the PCV and GCV indicates that the characters are least influenced by environment.

Heritability measures the proportion of phenotypic variability that can be attributed to genetic variation. It is an essential concept in quantitative genetics, particularly in selective breeding. Robinson *et al.* (1949) suggested that heritability (%) can be categorised into low (0-30%), moderate (30-60%) and high above (60%). Higher heritability indicates that the characters are least influenced by environment.

Genetic advance is the difference between the mean phenotypic value of the progeny of selected plants and the base or parental population. Al-Jibouri *et al.* (1958) suggested in categorising it into low (<10%), medium (10-20%) and high (>20%). Higher value of GA indicates that the character is governed by additive gene action and lower GA shows the influence of non additive genes. Heritability along with GA helps in efficient prediction of the gene action and the method of breeding to be practised. High heritability is not always an indication of high genetic advance.

Panicker (2000) noticed high heritability and genetic advance in cowpea for pods plant^{-1}, yield plant^{-1}, and pod weight. PCV and GCV were found to be maximum for pods plant^{-1}followed by yield of vegetable pods.

High estimates of GCV, heritability and genetic advance in cowpea for days to 50 per cent flowering, plant height and days to maturity was recorded by Tyagi *et al*. (2000).

GCV and PCV were found to be moderate for plant height and pod length in cowpea (Kalaiyarasi and Palanisamy, 2000b).

In cowpea, high heritability coupled with genetic gain were observed for plant height and pod length. Moderate to high heritability coupled with high genetic advance as a per cent of mean was recorded for, pod length, 100 seed weight and pods plant^{-1} by Kumar *et al*. (2000).

In cowpea, Rangaiah (2000) observed high phenotypic and genotypic coefficients of variation for pods plant^{-1} and pod weight.

GCV, heritability and genetic advance were high in cowpea for plant height and days to 50 per cent flowering indicating the preponderance of additive gene effects (Selvam *et al*., 2000).

High heritability coupled with high genetic advance was recorded for yield plant^{-1}, pods plant^{-1} and pod weight in yard long bean. Yield plant^{-1}, pods plant^{-1}, and pod weight showed high PCV and GCV, where as it was low for days to first flowering (Vidya, 2000).

Ajith (2001) observed high heritability coupled with high genetic advance for pod weight, pod length and seeds pod^{-1} in cowpea. He also reported the high phenotypic and genotypic coefficients of variation for pod weight.

High PCV, GCV, heritability and genetic advance for pods plant^{-1} and yield plant^{-1} in cowpea was reported by Jyothi (2001).

Nehru and Manjunath (2001) obtained high heritability and high genetic advance for pods plant^{-1} and moderate values for 100 seed weight and yield plant^{-1} in cowpea. The PCV was highest for pods plant^{-1} followed by yield plant^{-1}.

High coefficient of variation was recorded for 100 seed weight and moderate variation was recorded for days to 50 per cent flowering and pod length in cowpea (Singh and Verma, 2002).

In vegetable cowpea, Narayankutty *et al.* (2003) recorded that high PCV and GCV as well as high heritability coupled with high genetic advance was observed for characters *viz.*, pod yield plant^{-1}, pods plant^{-1} and pod weight.

High heritability and moderate to high genetic advance for pods plant^{-1} was reported in cowpea by Pal *et al.* (2003). He also reported high heritability with low genetic advance for days to 50 per cent flowering, seeds pod^{-1} and 100 seed weight.

Twenty genotypes of cowpea were evaluated for variability, heritability and genetic advance for twelve characters. There it marked high GCV, PCV and heritability coupled with genetic advance for plant height and moderate values of GCV, PCV, heritability and genetic advance for 100 seed weight, pods plant^{-1} and pod length by Venkatesan *et al.* (2003).

High genetic advance was recorded for pods plant^{-1} and 100 seed weight and moderate values for days to 50 per cent flowering and plant height. The phenotypic coefficient of variation was high for 100 seed weight and pods plant^{-1}. Yield plant^{-1} had the highest genotypic coefficient of variation followed by 100 seed weight and pods plant^{-1}. High heritability was noticed in cowpea for all the yield characters except days to 50 per cent flowering, which exhibited moderate heritability (Philip, 2004).

Lovely (2005) observed high GCV for yield plant^{-1}, pod weight and pods plant^{-1} in yard long bean. High heritability and low genetic advance was noted for days to 50 per cent flowering and pod breadth. She also reported that the characters *viz.*, pod clusters plant^{-1}, pods per cluster^{-1}, pods per plant^{-1}, primary branches plant^{-1}, pod yield plant^{-1}, pod weight, pod length, seeds pod^{-1} and main stem length had high heritability coupled with high genetic advance.

High heritability coupled with high genetic advance was observed for yield plant^{-1}, pods plant^{-1}, pod length and pod weight in vegetable cowpea. Pod weight and yield plant^{-1} had the highest PCV and GCV (Manju, 2006).

Madhukumar (2006) reported that pod yield plant^{-1} in cowpea showed significant positive correlation with pods plant^{-1}, days to first harvest, pod weight, days to 50 per cent flowering, seeds pod^{-1}, pod length, and 100 seed weight at genotypic level. Path analysis showed that pods plant^{-1} and pod weight were the primary yield determinants due to their high direct effect on pod yield.

Suganthi and Murugan (2008) recorded high positive correlation between seeds pod^{-1} and pod length. Jithesh (2009) reported that yield plant^{-1} showed strong positive correlation with pod weight (0.4669), pods plant^{-1} (04393), seeds pod^{-1} (0.1626) and 100 seed weight (0.165) in yard long bean.

Sivakumar (2012) reported yield had significant positive phenotypic correlation with pod weight (0.158) and pods plant^{-1} (0.545) and high genotypic correlation with pod length (0.030), pod weight (0.173), and pods plant^{-1} (0.482).

Shanko *et al.* (2014) recorded that yield showed positive and significant environmental correlation with pods plant^{-1} and seeds pod^{-1} in yard long bean.

Udensi and Edu (2015) reported correlation coefficient on yield and yield contributing traits and the results obtained revealed that significant relationship existed between yield and yield contributing traits. Genotypic correlation coefficient was high and more significant than phenotypic and environment correlation coefficient.

2.2.4 Correlation and Path Coefficient Analysis

Panicker (2000) reported that pod yield plant^{-1} was positively correlated with seeds pod^{-1}, pods plant^{-1}, length of harvest period, pod weight and pod length, in cowpea.

Yield plant^{-1} showed high positive correlation with pods plant^{-1}, pod weight, length of harvest period, pod girth and pod length, in cowpea (Vidya, 2000). Path analysis revealed high direct effect for pods plant^{-1} and pod weight and indirect effect through other characters on yield.

Tyagi *et al.* (2000) reported that highest and lowest positive direct effects on seed yield in cowpea were observed for seed weight pod^{-1} and plant height respectively. Days to 50 per cent flowering recorded negative direct effect on seed yield plant^{-1}.

In cowpea, Rangaiah 2000 conducted path analysis and reported that pod weight plant^{-1} had the highest positive and direct effect on 100 seed weight and seeds plant^{-1}.

Kapoor *et al.* (2000) reported that seeds pod^{-1} and 100 seed weight were the main characters contributing towards the seed yield, in cowpea. It was also reported that pod length contributed indirectly towards seed yield *via* seeds pod^{-1} and 100 seed weight.

In cowpea, Kalaiyarasi and Palanisamy (2000a) reported that pod length, seeds pod^{-1} and 100 seed weight had strong positive correlation with seed yield.

Bastian *et al.* (2001) recorded a high positive direct effect of pod length on seed yield and the direct effects exhibited by seeds pod^{-1} and pod number were negligible and the indirect effects of pod length through other characters on seed yield was either low or negligible.

Plant height, pod yield, number of pods and pod length recorded positive direct effect on grain yield while seeds pod^{-1} had negative direct effect, in cowpea. The highest positive direct effect was recorded by pod yield and the lowest by pod length. The indirect effect was maximum for pod length *via* pod yield (Neema and Palanisamy, 2001).

Stoilova and Lozanov (2001) reported that pod weight $plant^{-1}$ was strongly correlated with seeds $plant^{-1}$ in cowpea.

Singh and Verma (2002) recorded that seed yield in cowpea was positively correlated with 100 seed weight and pod length. Pod length and plant height were positively correlated with 100 seed weight. A negative correlation between 100 seed weight and number of pods per peduncle, days to 50 per cent flowering and days to 50 per cent maturity was recorded.

In cowpea, Parmar *et al.* (2003), reported that seed yield had significant positive association with pods $plant^{-1}$ and pods $plant^{-1}$ registered the highest direct effect on seed yield and seeds pod^{-1}.

The cause and effect relationship among the different polygenic traits of cowpea was studied by Subbiah *et al.* (2003) and reported that number of pods $plant^{-1}$, pod length, number of seeds pod^{-1}, plant height and 100 seed weight had positive direct effect on yield $plant^{-1}$. Number of pods $plant^{-1}$ had positive indirect effect on yield $plant^{-1}$ through days to flowering, pod length and seeds pod^{-1}.

Venkatesan *et al.* (2003) observed that number of pods $plant^{-1}$ and pod yield had significant positive phenotypic and genotypic correlation with seed yield, in cowpea. Path coefficient analysis revealed positive direct effect of seed yield with number of pods $plant^{-1}$, pod length, number of seeds pod^{-1} and 100 seed weight. Number of pods $plant^{-1}$ and pod length were the most important yield determinants.

Seed yield plant^{-1} in cowpea exhibited highly significant positive correlation with number of pods plant^{-1}, seeds plant^{-1} and 100 seed weight both at genotypic and phenotypic level (Philip, 2004).

Lovely (2005) recorded that yield plant^{-1} showed strong positive genotypic correlation with pods per cluster, pods plant^{-1}, pod weight, pod length and seeds pod^{-1} in vegetable cowpea. She also noticed a negative correlation for days to 50 per cent flowering and days to first harvest. The characters pods plant^{-1}, pod weight, pod length, pod breadth and seeds pod^{-1} had positive direct effects while length of harvest period had negative direct effect.

In cowpea, Madhukumar (2006) reported that, pod yield plant^{-1} showed significant positive correlation with pods plant^{-1}, days to first harvest, pod weight, days to 50 per cent flowering, seeds pod^{-1}, pod length, and 100 seed weight at genotypic level. Path analysis showed that number of pods plant^{-1} and pod weight were the primary yield contributing characters due to their high direct effect on pod yield.

Shanko *et al.* (2014) reported that yield plant^{-1} exerted the maximum positive direct effect on seed yield followed by number of pods plant^{-1} in cowpea.

The correlation coefficients on yield and yield contributing traits were studied by Udensi and Edu (2015) in cowpea and they recorded a significant relationship between the yield and yield related traits. Path coefficient analysis showed that number of pods plant^{-1} had the highest direct effect to cowpea yield

2.2.5 Genetic Divergence Analysis

Knowledge of genetic diversity, its nature and degree is useful in the improvement of any heritable character. Genetic distance is a measure of genetic differences between populations or individuals. A properly maintained world collection of germplasm or genetic stock should be evaluated for the choice of genetically divergent parents for hybridization under transgressive breeding programme. Segregation and recombination produce many new gene combinations in F_2 and further generations, when genotypically different individuals are crossed. Generally eco-geographic diversity has been considered as an index of genetic variability in crop plants but, this may not be true for every case, as pointed out by many workers, that genetic diversity need not necessarily be related to geographic diversity.

Renganayaki and Rengaswamy (1991) made use of Mahalanobis D^2 statistic to cluster sixty genotypes of cowpea into four genetically divergent clusters. Pod length, 100 seed weight and yield plant^{-1} were the characters that attributed maximum to genetic divergence in cowpea. In cowpea, Thiyagarajan and Rajasekharan (1993) classified diverse genotypes in to 3 distinct groups based on several yield contributing attributes.

Sharma and Mishra (1997) measured the genetic divergence in forty two indigenous and exotic strains of cowpea and classified them in to six different clusters. Days to 50 per cent flowering, plant height and pods plant^{-1} contributed maximum towards genetic divergence.

Viswanathan *et al.* (1998) assessed the genetic divergence between cowpea populations consisting of seventy two genotypes and noticed high genetic diversity among them. To study the genetic divergence of thirty genotypes, Resmi (1998) used Mahalanobis D^2 analysis. Days to 50 per cent flowering, pod length, pods plant^{-1}and yield plant^{-1} contributed considerable to genetic divergence.

Information on nine traits from twenty four early maturing genotypes of cowpea from different geographical regions were subjected to D^2 analysis by Tyagi *et al.* (1999) and observed that genetic diversity was independent of geographical origin.

Kapoor *et al.* (2000) assessed the genetic divergence of sixty genotypes of cowpea and the genotypes were grouped in to fifteen clusters depending upon their genetic distance.

Ushakumari *et al.* (2000) grouped fifteen genotypes of cowpea into thirteen clusters using Mahalanobis D^2 analysis. The highest contributions towards divergence were noticed for plant height, seeds pod^{-1} and pod length.

Thirty two genotypes of cowpea were evaluated for genetic divergence based on physiological characters by Backyarani *et al.* (2000) and was grouped in to six clusters. He also noticed that geographic diversity showed no relation with genetic diversity.

Based on genetic divergence Anbuselvam *et al.* (2001) grouped twelve cowpea genotypes into four different clusters using Mahalanobis D^2 analysis.

Mahalanobis D^2 analysis was used to cluster 191 accessions of cowpea into ten clusters by Kohli and Agarwal (2001). Clusters I and V had thirty accessions each and the smallest cluster was cluster VIII which had eight accessions.

Mahalanobis D^2 statistic was employed to group the fifty genotypes of cowpea into ten clusters. Wide range of genetic divergence was found among the 50 genotypes. Maximum intercluster distance was noticed between clusters I and IV. Cluster VII registered the maximum mean value for pod length, seeds pod^{-1}, 100 seed weight and yield $plant^{-1}$ and it had the highest cluster mean value for pods $plant^{-1}$ and pod length. Cluster I recorded the least number of pods $plant^{-1}$ (Philip, 2004).

In yard long bean, Lovely (2005) clustered the 50 genotypes in to 4 groups with genotypes from different eco-graphic locations being grouped in the same clusters based on Mahalanobis D^2 analysis. The grouping of genotypes based on selection indices followed almost the same pattern as that of the clustering pattern in the D^2 analysis.

Based on Mahalanobis D^2 statistics, the sixty six accessions of yard long bean were grouped in to ten clusters. Cluster I was the largest containing 18 accessions, while cluster X was the smallest with two accessions (Manju, 2006).

Madhukumar (2006) in yard long bean, clustered the 30 genotypes into eight clusters by Mahalanobis D^2 analysis and found that Cluster I formed the largest cluster with 10 genotypes while clusters VI, VII and VIII had one genotype each.

Forty four grain cowpea genotypes were evaluated for thirteen traits to quantify the genetic diversity existing among them by Mahalonobis D^2 statistics. The analysis of variance revealed significant differences among the genotypes for each trait under study. The genotypes fell into nine clusters and the Cluster strength varied from single genotype (Cluster IV to IX) to 31 genotypes (Cluster I) (Pandey, 2007).

Suganthi *et al.* (2007) observed genetic divergence analysis among 30 genotypes of cowpea and reported the existence of considerable diversity. These genotypes fell in to XI clusters. The cluster III was the largest and consisted of seven genotypes followed by cluster X of 4, cluster II, IV, V and VIII (3 in each). Cluster I and VII (2 in each) and clusters VI, IX and XI contained only one genotype each. The diversity among the genotypes measured by inter cluster distance was important for improvement of cowpea by hybridization and selection. The genotypes included in those diverse clusters can be used as promising parents for hybridization to obtain better segregants in cowpea.

Genetic divergence recorded in fifty six genotypes of cowpea using D^2 statistics, for thirteen yield contributing characters, showed that the genotypes fell in to nine clusters. Cluster I contained the maximum number of genotypes. Characters *viz*; days to first harvest, 100 seed weight and days to 50 per cent flowering were the highest contributors to D^2 values. The geographical diversity was not related to genetic diversity (Sulanthi *et al.*, 2007).

Valarmathi *et al.* (2007) assessed sixty nine cowpea genotypes, which included 60 genotypes from *Vigna unguiculata* subsp. *unguiculata* and eight genotypes from *Vigna unguiculata* subsp. *sesquipedalis*. Days to first harvest contributed maximum to the genetic divergence followed by 100 seed weight and characters number of seeds pod^{-1} exhibited least contribution among the accessions.

Genetic divergence analysis was also performed by Huque *et al.* (2012) and grouped the genotypes into various clusters in cowpea.

Mahalanobis D^2 statistic was used to estimate genetic divergence of ten yield related traits in fifty cowpea genotypes by Santos *et al.* (2014). 100 seed weight and pod length were the important characters that affected divergence.

Sivakumar and Celine (2014) performed divergence analysis in yard long bean using, Mahalanobis D^2 statistic

2.2.6 Selection Index

The plant breeder has to give due consideration to characters of economic importance while selecting a desirable plant from a segregating population. Selection index is one such method of selecting plants for crop improvement. It was proposed by Smith (1937) with the use of discriminant function developed by Fisher (1936).

Superior genotypes (VS 6 and VS 11) were identified by working out selection indices in yard long bean using the characters *viz.*, vine length, primary branches, petiole length, length and breadth of leaflets, days to flowering, pod length, pod girth, pod weight, pods inflorescence^{-1}, pods kilogram^{-1}, pods plant^{-1} and yield (Resmi, 1998).

Philip (2004) worked out selection indices for 50 genotypes of cowpea on the basis of pods plant^{-1}, number of inflorescence plant^{-1}, pods inflorescence^{-1}, pod length, seeds pod^{-1} and 100 seed weight. Five superior genotypes were selected for hybridization programme as female parents to develop F_1 hybrids.

Selection index for the genotype was computed based on the nine characters having significant genotypic correlation coefficients namely pods cluster^{-1}, pods plant^{-1}, pod yield plant^{-1}, pod weight, pod length, pod breadth, seeds pod^{-1}, length of harvest period and main stem length. The maximum selection index value was obtained for VS 41, while the least value was for VS 7 by Lovely (2005).

Selection index analysis done by Madhukumar (2006) in yard long bean revealed that genotype VS 86 attained the maximum selection index value and the minimum estimates were recorded for Kayamkulam local, Malappuram local-2 and Kollengode local.

Manju (2006) observed selection indices involving the characters, peduncle length, pod length, pod girth, pod weight, pods plant^{-1}, seeds pod^{-1}, 100 seed weight, number of harvests, pod protein and yield plant^{-1}. Based on selection index, VS 27 ranked first followed by VS 8 and VS 19.

Jithesh (2009) used selection index to discriminate the desirable genotype on the basis of nine characters namely harvest period, primary branches plant^{-1}, pods plant^{-1}, pod weight^{-1}, pod length, pod breadth, seeds pod^{-1}, 100 seed weight and pod yield plant^{-1} .

Based on the selection index values, top ranking genotypes were identified in yard long bean on the basis of the characters like vine length, days to first flowering, pod length, pod girth, pod weight, pods plant^{-1} and yield plant^{-1} (Sivakumar, 2012).

Shanko *et al.* (2014) reported that yield plant^{-1} and pods plant^{-1} could be used as a selection index for improving cowpea genotypes.

In yard long bean top ranking accessions namely Githika, Neyyatinkara local, Hari Rani, Anand local, Rocket-77 and NS-634 suitable for polyhouse cultivation were identified based on selection index values (Litty, 2015).

Materials and Methods

3. MATERIALS AND METHODS

The present study entitled "Genetic variability for yield and resistance to legume pod borer, *Maruca vitrata* (Fab.) in yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)" was carried out at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during the period June 2016 to February 2017.

The necessary data for the investigation were collected from two separate field experiments. The first experiment involved screening of thirty genotypes for resistance to legume pod borer and the second experiment aimed at evaluating twelve selected genotypes for yield. The materials used and the methods followed are explained herein.

3.1. SCREENING FOR LEGUME POD BORER RESISTANCE.

3.1.1 Materials

The materials for the study consisted of thirty genotypes of yard long bean collected from within and outside the State, as well as from organisations such as NBPGR, MSSRF and KAU. The details of genotypes and sources are presented in Table 1.

3.1.2 Methods

3.1.2.1 Layout and Conduct of Experiment

The thirty genotypes were planted in a field experiment in randomised block design with three replications. The land was well prepared, incorporating farmyard manure at 20 t ha^{-1}. The entire field was divided into three blocks of thirty plots each. The treatments were allotted to the plots in each block at random. Plot size was 6.75 m^2. Spacing was 1.5 m between rows and 0.45 m between plants in a row (Plate 1A). Fertilizers were applied as per package of practices recommendations of Kerala Agricultural University (KAU, 2016). The

Table 1. List of genotypes used in the study and their source of collection.

Treatment No.	List of genotypes	Source
A1	IC 26029	NBPGR
A2	Adhityapuram local	MSSRF
A3	IC 19797	NBPGR
A4	IC 2532277	NBPGR
A5	IC 140823	NBPGR
A6	IC 402090	NBPGR
A7	IC 536626	NBPGR
A8	IC 397807	NBPGR
A9	IC 39945	NBPGR
A10	EC 101216	NBPGR
A11	Swarna Swetha	NBPGR
A12	IC 39874	NBPGR
A13	IC 39947	NBPGR
A14	Vijayanthi	KAU
A15	Mukkam local	MSSRF
A16	EC 725116	NBPGR
A17	IC 52107 A	NBPGR
A18	Puthuppady local	Local collection from Puthuppady
A19	EC 725115	NBPGR
A20	IC 39870	NBPGR
A21	Kollamkode local	MSSRF
A22	Nenmara local	MSSRF
A23	IC 39447	NBPGR
A24	EC 724307	NBPGR
A25	EC 300039	NBPGR
A26	IC 20720	NBPGR
A27	Githika	KAU
A28	Jyothika	KAU
A29	Wayanad local	Local collection from Wayanad
A30	Thiruvambady local	MSSRF

Plate 1. (A)

Plate 1

Plate 1. General view of the field from Experiment I

(A) View of the field with field board

(B) View of the field with susceptible variety along the borders observations were recorded on various damage parameters. The experimental crop was raised during June 2016 to September 2016. One week prior to the planting, Lola, a variety reported as susceptible to *M. vitrata* was planted along the borders of the field to serve as multiplication foci for the test insect (Plate 1B.). Plants were trailed on jute strings tied between wooden standards erected 70 cm apart along the rows of plants.

3.1.2.2 Data Collection

Different damage parameters were measured employing the field screening technique developed by Jackai (1982) as given below:

a. Infestation of flower buds

A sample of twenty five fully mature flower buds were randomly collected from each plot at peak flowering stage of the crop and the number of buds with pod borer infestation were counted and was expressed in per cent.

b. Number of larvae per twenty five flowers

This was determined by randomly collecting twenty five flowers, ten weeks after planting from each plot. The samples were collected in vails containing 30% alcohol and subsequently examined for larval counts.

c. Infestation of pods

Twenty pods at vegetable maturity stage were harvested at peak pod formation phase from each plot. Each sample was examined to determine the pods infested by pod borers and the infestation count was expressed in per cent.

d. Non glandular trichome density

Five pods at vegetable maturity stage (eight days after flowering) were taken at random from each plot. The skin was peeled from the middle portion of the pods and observed under compound microscope with a magnification of 45X. The non glandular trichomes observed in a microscopic field was counted. The non glandular type of trichome consists of single, long cell with enlarged base which tapers towards the distal portion to form a narrow needle like filiform top (Plate 2). The area of the microscopic field was calculated using ocular micrometer. Mean value of non glandular trichome counts mm^{-2} area of pod wall surface was calculated and expressed as non glandular trichome density on pods.

3.1.2.3. Statistical Analysis

a. Calculation of plant resistance index

Resistance index was worked out using metroglyph analysis and index scoring developed by Anderson (1957). Variation for each character was divided into three groups, *viz*., low, medium and high values and given an index score of 1, 2 and 3 respectively. Mean of the total score was worked out and least mean index value indicates least damage.

b. Analysis of variance

The data on damage parameters were subjected to analysis of variance for varietal differentiation.

c. Correlation analysis

Simple correlation analysis was done to determine the degree of association of plant resistance index with non glandular trichome density.

3.2 EVALUATION OF GERMPLASM FOR YIELD.

3.2.1 Materials

The materials for this experiment comprised of twelve genotypes selected from experiment I based on the plant resistance index values. The genotypes with least plant resistance index values indicated maximum resistance, since the criteria employed for assessing the resistance index was damage parameters.

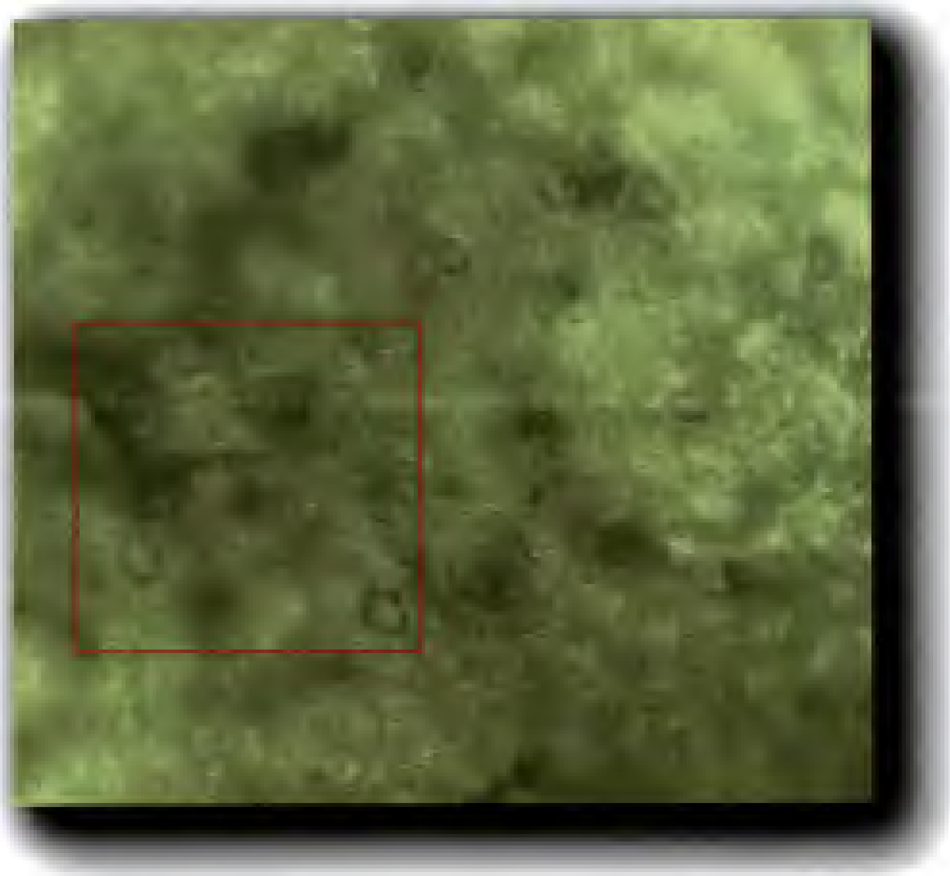

Plate 2. Non glandular trichome density (counts mm^{-2}) on pod wall.

3.2.2 Methods

3.2.2.1 Layout and Conduct of Experiment

The twelve genotypes were planted in RBD with three replications. Land preparation and application of manures and fertilisers were done as in experiment I. The entire field was divided into three blocks of twelve plots each and the treatments were allotted to plots in each block at random. Each plot of size. 6.75 m^2 and a spacing of 1.5 m between rows and 0.45 m between plants was given (Plate 3.). The experiment was conducted during November 2016 to February 2017. All the plant protection measures were timely adopted. The plants were individually trailed on jute wires tied between standards erected at 70 cm apart along the rows of plants.

3.2.2.2. Data Collection

Data on the following characters were obtained from observations recorded on five randomly selected observation plants from each plot and working out mean values.

1. Days to 50 per cent flowering

   Number of days taken from sowing to flowering of 50 per cent of the plants were recorded.

2. Days to first harvest

   Number of days taken from sowing to first harvest was recorded.

3. Pod yield $plant^{-1}$ (g)

   Weight of pods from observational plants were recorded after each harvest. Total weights of each observational plant was calculated and mean value was recorded.

Plate 3. Field view from Experiment II

4. Pods plant^{-1}

Pods obtained in each harvest from each of the observational plants were counted and recorded

5. Length of pod (cm)

Length of five randomly selected individual pods were recorded from each observational plant and mean worked out.

6. Weight of pod (g)

Weight of five randomly selected individual pods (replication wise) were recorded from each observational plant and mean worked out.

7. Seeds pod^{-1}

Number of seeds of five randomly selected individual pods were recorded from each observational plant and mean worked out

8. 100 seed weight (g)

The weight of 100 randomly selected seeds from each observational plants was worked out.

9. Length of harvest period (days)

Number of days taken from first harvest to last harvest was recorded.

10. Crop duration (days)

Number of days taken from sowing to last harvest was recorded.

3.2.2.3 Statistical Analysis

a. Analysis of variance (ANOVA)

The biometric observations recorded from the field evaluation were subjected to analysis of variance (Panse and Sukhatme, 1985) for the comparison among various genotypes and to estimate variance components.

The significance of mean sum of squares for each character was tested against the corresponding error degrees of freedom using F test (Fisher and Yates, 1967).

Standard Error of Mean (SE (m)) = $\sqrt{\frac{MSE}{r}}$

Where, MSE = Mean sum of squares of error

r = Number of replications

If the treatments were significant, critical difference will be calculated for comparison among the treatments.

Critical Difference (CD) = $t_{\alpha} \sqrt{\frac{2MSE}{r}}$

Where, t_{α} is the student's 't' table value at error degrees of freedom, 'α' is the level of significance, 'MSE' is the mean sum of squares of error and 'r' represents the number of replications.

b. Genetic Components of variance.

For each of the 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). The variance components equations are as follows:

i. Genotypic variance (GV)

$$GV = \frac{MST - MSE}{r}$$

ii. Environmental variance (EV)

$$EV = MSE$$

iii. Phenotypic variance (PV)

$$PV = GV + EV$$

Where, MSE=Mean sum of error, MST= Mean sum of treatments.

c. Coefficients of variation

The components namely, phenotypic, genotypic and environmental variances were used for estimation of coefficient of variation at both phenotypic and genotypic levels for all the characters and were computed the formula as suggested by Singh and Chaudhary (1985).

i. Phenotypic coefficient of variation (PCV)

$$PCV = \frac{\sqrt{PV}}{\bar{x}} \times 100$$

ii. Genotypic coefficient of variation (GCV)

$$GCV = \frac{\sqrt{GV}}{\bar{x}} \times 100$$

Where, $\bar{x}$ = The mean of each character estimated over all the treatments.

The PCV and GCV was classified by Sivasubramanian and Menon (1973) as,

Low	- (<10%)
Moderate	- (10-20%)

High - (>20%)

d. Heritability

For each character, broad sense heritability (H^2) was calculated as the ratio of genotypic variance to phenotypic variance and expressed as percentage (Allard, 1999).

$$\text{Heritability } (H^2) = \frac{GV}{PV} \times 100$$

Heritability was categorized by Robinson *et al.* (1949) as

Low - (<30%),
Moderate - (31-60%)
High - (>60%)

e. Genetic advance

Genetic advance, which is the measure of genetic gain under selection, depends upon standardized selection differential, heritability and phenotypic standard deviation. The genetic advance was estimated by the method proposed by Fehr *et al.* (1987).

$$\text{Genetic advance (GA)} = k.H^2 \sqrt{PV}$$

Where, k is the standardized selection differential (2.06 at 5% level of selection)

Genetic advance as percentage mean was estimated using the equation given by Johnson *et al.* (1955).

$$\text{GA as percentage of mean} = k.H^2 \frac{\sqrt{PV}}{\bar{X}} \times 100$$

Genetic advance (% mean) was categorized as per the suggestion of Al-Jibouri *et al.* (1958).

Low - (0-10%)
Moderate - (10-20%)

High - (>20%)

f. Correlation analysis

Phenotypic, genotypic and environmental correlation coefficients were calculated using the respective variances and covariances of the characters which showed significant variation in the ANOVA as suggested by Singh and Choudhary (1985).

Phenotypic correlation coefficients, $r_P = \frac{COV_P(X,Y)}{\sqrt{PV(X).PV(Y)}}$

Genotypic correlation coefficient, $r_G = \frac{COV_G(X,Y)}{\sqrt{GV(X).GV(Y)}}$

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. PV (X) and GV (X) denotes the phenotypic and genotypic variance for X and PV (Y) and GV (Y) indicate the phenotypic and genotypic variance for Y respectively.

g. Path Coefficient Analysis

Path analysis is a standardized partial regression coefficient which explains cause and effect relationship among the variables (Wright, 1960). It measures the direct effect of one independent variable upon dependent variable and other independent variables. It divides correlation coefficients into components of direct and indirect effects (Dewey and Lu, 1959). This method permits the breeder to identify relatively important components of a variable, on the basis of their direct and indirect influences.

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, $R = 1 - (r_{Y1}.P_{Y1} + r_{Y2}.P_{Y2} + ... + r_{Yn}.P_{Yn})$

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

Where, 'r' is the correlation between various traits and the direct effect of X_1 on Y is P_{12} and so on. Indirect effect of X_1 on Y depends on other correlated factors.

The direct and indirect effects were classified based on the scale given by Lenka and Mishra (1973).

>1.0	–	Very high
0.3 - 0.99	–	High
0.2 – 0.29	–	Moderate
0.10- 0.19	–	Low
0.00 – 0.09	–	Negligible

h. D^2 Analysis

The assessment of genetic variability present among different genotypes is one of the potent tools of measuring genetic divergence in various breeding materials. Genetic diversity arises due to geographical separation or due to genetic barriers of crossability. The genetic divergence of the ecotypes was studied using Mahalanobis D^2 statistic. The D^2 statistic measures the forces of differentiation at intracluster and intercluster levels (Mahalanobis, 1936). The genotypes were grouped into distinct clusters using their relative distances from each other (D^2 values). The accessions were clustered by Tocher's method.

i. Selection Index

The selection index developed by Smith (1937) using discriminant function of Fisher (1936) was used to discriminate the genotypes based on all the characters.

The selection index is described by the function, $I= b_1x_1+b_2x_2 +..........+b_nx_n$ and the merit of a plant is described by the function, $H= a_1G_1 +a_2G_2+..............+b_nG_n$, where x_1, x_2......x_n are the phenotypic values. G_1, G_2......................G_n are the genotypic values of the plants with respect to characters, $x_1,x_2,$........................x_n, H is the genetic worth of the plant.

It is assumed that the economic weight assigned to each character is equal to unity *i.e.*, a_1, a_2, a_3.....$a_n = 1$.

The regression coefficients (bi) are determined such that the correlation between H and I is maximum. The procedure will reduce to an equation of the form, $b= P^{-1}$ Ga where, P is the phenotypic variance-covariance matrix and G is the genotypic variance-covariance matrix.

Results

4. RESULTS

The study entitled "Genetic variability for yield and resistance to legume pod borer, *Maruca vitrata* (Fab.) in yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)" was taken up at the Department of Plant Breeding & Genetics, College of Agriculture, Vellayani, during June 2016 to February 2017. The study comprised of two field experiments. First experiment dealt with evaluation of 30 yard long bean genotypes for resistance to legume pod borer *M. vitrata*. In the second experiment, the twelve selected genotypes from first experiment were evaluated for yield. The results of the present investigation are presented under two major headings.

i. Screening for legume pod borer resistance
ii. Yield evaluation

4.1 SCREENING FOR LEGUME POD BORER RESISTANCE

The major feeding sites of legume pod borer larvae are the flower buds, flowers and pods. Screening of thirty genotypes based on the extent of damage on flower buds, flowers and pods were attempted in the present study (Plate 4). Larvae of the pod borer were present in most of the infested flowers. Larval entry-exit holes would be present on the infested pods.

4.1.1. Damage Parameters and Resistance Evaluation

The legume pod borer damage parameters and overall plant resistance index relating to thirty vegetable cowpea cultivars are presented in Table 2. Different damage parameters were measured and the results are detailed below:

Table 2. Legume pod borer damage measurements and plant resistance indices of thirty yard long bean genotypes.

Treatments		Per cent infestation of flower buds	Number of larvae per 25 flowers	Per cent pod infestation	Resistance index based on damage parameters	Remarks
A1	IC 26029	25.00 (2)	5.00 (1)	10.00 (18.38) (1)	1.33	selected
A2	Adhityapuram local	21.00 (1)	7.30 (1)	9.00 (17.21) (1)	1.00	selected
A3	IC 19797	50.00 (3)	19.00 (3)	68.00 (55.69) (3)	3.00	
A4	IC 2532277	48.00 (3)	11.00 (2)	30.00 (33.15) (2)	2.33	
A5	IC 140823	36.00 (2)	16.00 (3)	25.00 (29.98) (1)	2.00	
A6	IC 402090	33.00 (2)	13.00 (2)	16.00 (23.56) (1)	1.67	
A7	IC 536626	30.00 (2)	15.00 (3)	19.00 (25.81) (1)	2.00	
A8	IC 397807	33.00 (2)	9.00 (1)	63.00 (52.60) (3)	2.00	
A9	IC 39945	10.00 (1)	5.00 (1)	312.00 (20.23) (1)	1.00	selected
A10	EC 101216	23.00 (1)	14.00 (2)	26.00 (30.65) (2)	1.67	
A11	Swarna Swetha	32.00 (2)	17.00 (3)	25.00 (29.99) (1)	2.00	
A12	IC 39874	25.00 (2)	18.00 (3)	46.00 (42.70) (2)	2.33	
A13	IC 39947	18.00 (1)	8.00 (1)	11.00 (19.33) (1)	1.00	selected
A14	Vijayanthi	43.00 (2)	12.00 (2)	20.00 (26.53) (1)	1.67	selected
A15	Mukkam local	36.00 (2)	16.00 (3)	26.00 (30.65) (2)	2.33	

The values given in the parenthesis indicate the index score and those underlined within parenthesis indicate the arc sine transformed values.

Table 2 continued. Legume pod borer damage measurements and plant resistance indices of yard long bean genotypes.

Treatments		Per cent infestation of flower buds	Number of larvae per 25 flowers	Per cent pod infestation	Resistance index based on damage parameters	Remarks
A16	EC 725116	48.00 (3)	12.00 (2)	21.00 (1) (27.22)	2.00	
A17	IC 52107 A	43.00 (3)	14.00 (2)	21.00 (1) (27.26)	2.00	
A18	Puthuppady local	20.00 (1)	9.00 (1)	11.00 (1) (19.28)	1.00	selected
A19	EC 725115	17.00 (1)	16.00 (3)	42.00 (2) (40.38)	2.00	
A20	IC 39870	31.00 (2)	13.00 (2)	23.00 (1) (28.63)	1.67	selected
A21	Kollamkode local	35.00 (2)	17.00 (3)	26.00 (2) (30.54)	2.33	
A22	Nenmara local	26.00 (2)	18.00 (3)	21.00 (1) (27.19)	2.00	
A23	IC 39447	18.00 (1)	7.5.00 (1)	9.00 (1) (17.21)	1.00	selected
A24	EC 724307	31.00 (2)	16.00 (3)	25.00 (1) (29.92)	2.00	
A25	EC 300039	20.00 (1)	9.00 (1)	12.00 (1) (20.14)	1.00	selected
A26	IC 20720	22.00 (1)	8.00 (1)	11.00 (1) (19.33)	1.00	selected
A27	Githika	14.00 (1)	11.00 (2)	14.00 (1) (21.83)	1.33	selected
A28	Jyothika	32.00 (2)	12.00 (2)	21.00 (1) (27.19)	1.67	
A29	Wayanad local	16.00 (1)	10.00 (2)	16.00 (1) (23.55)	1.33	selected
A30	Thiruvambady local	26.00 (2)	18.00 (3)	8.00 (1) (16.21)	2.00	
CD(0.05)		5.308	3.549	4.788		

The values given in the parenthesis indicate the index score and those underlined within parenthesis indicate the arc sine transformed values.

Plate 4 (A)

Plate 4 (B)

Plate 4 (C)

Plate 4 (D)

Plate 4. *Maruca vitrata* damage symptoms on flower buds, flowers and pods

A. Damage on a flower bud B. Larva feeding inside a flower. C. Webbing of pods D. Larva inside a pod.

4.1.1.1 Infestation of Flower Buds

The genotypes differed significantly in terms of borer infestation on buds. The least damage was recorded for the genotype IC 39945 with ten per cent infestation while IC 19797 was the genotype that recorded highest infestation (50 per cent) on flower buds. The only genotype on par with IC 39945 was the variety Githika and suffered least damage on flower buds. IC 2532277 and EC 725116 were the genotypes on par with IC 19797 and they registered severe damage on the flower buds.

4.1.1.2 Number of larvae per 25 flowers

The genotypes showed significant differences in terms of mean number of larvae per 25 flowers. The value of mean number of larvae per 25 flowers ranged from 5.00 to 19.00. The least mean value was recoded as 5.00 for IC 26029 and IC 39945 and the genotypes on par with them were Adithyapuram local, IC 39447, IC 20720 and IC 39947. The genotype IC 19797 recoded highest mean value (19.00) for number of larvae per 25 flowers and the genotypes IC 140823, Swarna Swetha, IC 39874, Mukkam local, EC 725115, Kollamkode local, Nenmara local, EC 724307 and Thiruvambady local were found to be on par with IC 19797.

4.1.1.3 Per cent pod infestation

Per cent pod infestation also showed significant difference among the genotypes. Arc sine transformation as done and the transformed values are given in the parenthesis. Per cent pod infestation ranged from 16.21 to 55.69. The least infestation of 16.21 per cent was recorded for Thiruvambady local, while the maximum pod infestation of 55.69 per cent was noted for IC 19797. The genotypes on par with Thiruvambady local were Adithyapuram local and IC 39447 and showed lesser degree of pod infestation.

4.1.2 Calculation of Plant Resistance Index and Identification of Resistant Genotypes

Plant resistance index was calculated by metroglyph analysis using the three major damage parameters discussed above. The entire data on the mean values of the damage parameters were divided into three distinct classes and an index score of 1 to 3 were given for lowest to highest range of the classes respectively. The index score is represented in the parenthesis in Table 2. The average index score was worked out for each of the thirty genotypes. The genotypes with least index score was chosen as comparatively resistant genotypes as they showed least damage towards pod borer attack.

Based on the plant resistance index calculated using metroglyph analysis and index scoring, the genotypes were classified into four groups (Table 3). None of the genotypes were highly resistant or immune.

Moderate resistance was shown by the genotypes Adhityapuram local, IC 39947, Puthuppady local, IC 39447, IC 300039, IC 20720, IC 26029, Githika, Wayanad local, EC 101216, Vijayanthi, IC 402090, IC 39945, Jyothika and IC 39870 with an index value range of 0.1 to 1.68.

The genotypes with index score of 1.68-2.99 was recorded for IC 2532277, IC 140823, IC 536626, IC 397807, Swarna Swetha, Mukkam local, EC 725116, IC 52107 A, EC 725116, Kollamkode local, Nenmara local, EC 724307 Thiruvambady local and IC 39870.

IC 19797 was the only genotype that showed high susceptibility and it recorded highest values for all the damage parameters.

Table 3. Classification of thirty genotypes of yard long bean based on extend of damage by *Maruca vitrata.*

Susceptibility rating	Average resistance index range	Genotypes
Highly resistant/ immune	0	-
Moderately resistant	0.1-1.68	Adhityapuram local, IC 39947, Puthuppady local, IC 39447, EC 300039, IC 20720, IC 26029, Githika, Wayanad local, EC 101216, Vijayanthi, IC 402090, IC 39945, Jyothika and IC 39870
Susceptible	1.68-2.99	IC 2532277, IC 140823, IC 536626, IC 397807, Swarna Swetha, Mukkam local, C 725116, IC 52107 A, EC 725115, Kollamkode local, Nenmara local, EC 724307 Thiruvambady local and IC 39874.
Highly susceptible	3.00	IC 19797

4.1.3 Trichome Density

Non glandular trichome density on pod wall surface ranged from 2.00 (IC 397807, EC 101216, IC 52107 A, IC 39870 and Kollamkode local) to 7.00 (Adhityapuram local). Genotypes IC 26029, IC 39945, IC 39947, Puthuppady local, IC 39447, Wayanad local EC 300039 and Thiruvambady local were statistically on par with Adhithyapuram local, while all other genotypes were statistically on par with the lowest count mentioned above (Table 4).

Table 4. Non glandular trichome density (counts mm^{-2}) in thirty yard long bean genotypes.

Treatment No.	List of genotypes	Non glandular trichome density (count mm^{-2})	Treatment No.	List of genotypes	Non glandular trichome density (count mm^{-2})
A1	IC 26029	5	A16	EC 725116	3
A2	Adhityapuram local	7	A17	IC 52107 A	2
A3	IC 19797	2	A18	Puthuppady local	5
A4	IC 2532277	4	A19	EC 725115	3
A5	IC 140823	3	A20	IC 39870	2
A6	IC 402090	3	A21	Kollamkode local	2
A7	IC 536626	3	A22	Nenmara local	3
A8	IC 397807	2	A23	IC 39447	6
A9	IC 39945	5	A24	EC 724307	3
A10	EC 101216	2	A25	EC 300039	5
A11	Swarna Swetha	3	A26	IC 20720	4
A12	IC 39874	3	A27	Githika	4
A13	IC 39947	6	A28	Jyothika	3
A14	Vijayanthi	4	A29	Wayanad local	5
A15	Mukkam local	3	A30	Thiruvambady local	5

4.1.4 Correlation between Non glandular Trichome Density and Plant Resistance Index

The simple correlation of plant resistance index with non glandular trichome density was found to be highly significant and negative (-0.757).

4.2 YIELD EVALUATION OF SELECTED GENOTYPES

The data collected on vegetable pod yield and other morphological characters from the field experiment with moderately resistant cultivars were statistically analysed and the results obtained are presented below.

4.2.1. Mean Performance of the Genotypes

The mean values of each of the twelve genotypes for the ten characters studied are presented in Table 5.

Among the genotypes, days to 50 per cent flowering ranged from 40.67 to 50.67. IC 39870 was the earliest to flower and IC 26029 and IC 20720 were the latest to flower. Githika was statistically on par with IC 39870.

Regarding days to first harvest Adithyapuram local (50 days) was the earliest and IC 20720 (58 days) was the latest. The genotypes Githika, IC 39447, EC 300039, Puthuppady local, Wayanad local, Vijayanthi and IC 39870 were on par with Adithyapuram local.

The number of pods plant^{-1} was highest for Puthuppady local (26). The only genotype statistically on par with Puthuppady local was IC 26029. IC 39945 had the lowest number of pods plant^{-1} (15).

The pod characters *viz.*, pod length, pod weight and number of seeds pod^{-1} differed significantly among varieties. Pod length ranged from 29.67 cm (Wayanad local) to 54 cm (EC 300039). IC 39447 and IC 26029 are statistically

Table 5. Mean values of ten biometric characters in yard long bean

Treatment No	Genotype	Days to 50 per cent flowering	Days to first harvest	Pods plant^{-1}	Length of pod (cm)	Pod yield plant^{-1} (g)	Weight of pod (g)	Seeds pod^{-1}	100 seed weight (g)	Length of harvest period (days)	Crop duration (days)
A27	Githika	42.33	51.33	22.00	45.33	394.83	17.33	18.33	14.77	25.67	75.67
A26	IC 20720	50.67	58.00	16.33	37.67	242.15	13.00	14.67	15.13	28.33	83.33
A23	IC 39447	50.00	50.67	18.33	33.00	225.67	12.00	15.33	12.13	25.67	82.00
A13	IC 39947	48.00	57.67	20.67	45.67	312.33	15.07	16.67	13.50	27.33	83.67
A25	EC 300039	47.67	54.33	18.67	54.00	231.00	11.40	15.33	13.77	23.67	75.00
A18	Puthupady Local	45.33	54.67	26.00	43.67	485.03	16.23	17.67	15.87	27.33	75.00
A1	IC 26029	50.67	57.33	24.67	32.00	305.13	11.80	16.33	14.70	25.00	84.33
A29	Wayanad local	44.67	54.67	17.67	29.67	210.00	10.30	15.33	14.57	26.33	80.67
A9	IC 39945	48.67	57.67	15.00	48.00	176.97	13.53	15.67	13.27	26.00	76.67
A2	Adithyapuram Local	44.34	50.00	20.33	44.67	298.14	13.67	18.67	14.03	27.33	74.67
A14	Vijayanthi	47.33	54.67	18.67	43.00	213.00	14.43	15.67	15.30	25.33	77.33
A20	IC 39870	40.67	51.33	17.33	44.67	246.67	13.13	16.00	14.33	25.67	78.67
Mean		46.69	54.36	19.64	41.78	278.41	13.49	16.31	14.28	26.14	78.92
±SE		0.94	0.85	0.95	2.09	25.39	0.59	0.37	0.29	0.37	1.07
CD(0.05)		3.15	4.75	3.65	5.38	81.14	1.64	1.21	.55	NS	6.46

on par with Wayanad local. Pod weight was minimum for Wayanad local (10.30 g), while Githika (17.33 g) recorded maximum weight.

Number of seeds pod^{-1} was maximum for Adithyapuram local (18.67). The genotypes Puthuppady local and Githika were on par with Adithyapuram local. Seeds pod^{-1} recorded lowest value for the variety IC20720 (14.67).

Puthuppady local (15.87 g) recorded highest value for 100 seed weight while it was lowest for IC 39945 (13.27 g).

Length of harvesting period was maximum for IC 20720 (28.33 days) and minimum for EC 300039 (23.67 days).

IC 26029 was the genotype that has extended crop duration (84.33 days) and Adithyapuram local was the genotype with least duration (74.67 days). The varieties IC 39870, Wayanad local, IC 39447, IC 39947 and IC 20720 were on par with IC 26029.

The yield of vegetable pods plant^{-1} ranged from 176.97 g (IC 39945) to 485.03 g (Puthuppady local). The results indicated the superiority of Puthuppady local over the other varieties.

4.2.2. Coefficient of Variation

The phenotypic genotypic and environmental variance and coefficients of variation for the ten characters are presented in Table 6. Fig. 1 indicates the phenotypic and genotypic coefficients of variation for ten characters. The maximum value for GCV was observed for pod yield plant^{-1} (29.99) followed by length of pod (16.72), weight of pod (14.53) and pods plant^{-1} (9.18). GCV was least for length of harvest period (2.4).

The highest PCV was observed for pod yield plant^{-1} (34.58) followed by length of pod (18.37), weight of pod (16.20) and pods plant^{-1} (13.84)

Table 6. Components of variance, heritability and genetic advance for the ten biometric characters in yard long bean.

Sl No.	Characters	GCV%	PCV%	Heritability (%)	Genetic gain (as % of mean)
1	Days to 50 per cent flowering	6.52	7.69	73.09	11.58
2	Days to first harvest	4.52	6.86	43.36	6.13
3	Pods plant^{-1}	9.18	13.84	66.36	25.90
4	Length of pod (cm)	16.72	18.37	82.87	31.36
5	Pod yield plant^{-1}	29.99	34.58	75.22	53.58
6	Weight of pod (g)	14.53	16.20	80.36	26.83
7	Seeds pod^{-1}	7.45	8.64	74.21	13.22
8	100 seed weight (g)	6.99	7.35	90.49	13.70
9	Length of harvest period (days)	2.40	7.73	19.63	1.54
10	Crop duration (days)	3.77	6.13	37.83	4.78

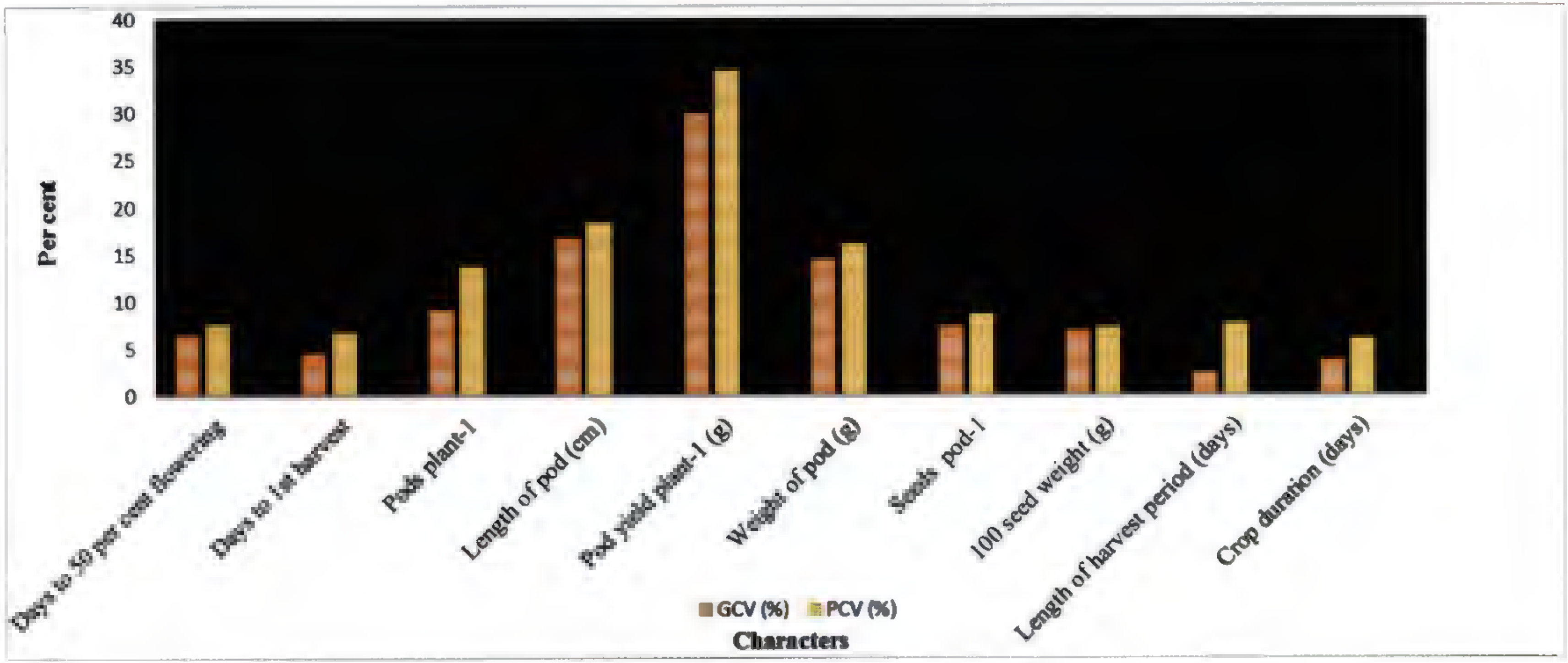

Fig. 1. Phenotypic and genotypic coefficients of variation for the ten biometric characters in yard long bean.

The difference between genotypic and phenotypic coefficients of variation was least for 100 seed weight.

4.2.3. Heritability and Genetic advance

The estimates of heritability and genetic advance are presented in Table 6. The heritability estimates recorded were high for the characters *viz.*, 100 seed weight (90.49 %), length of pod (82.87 %), weight of pod (80.36 %), pod yield plant^{-1} (75.22 %), seeds pod^{-1} (74.21 %), days to 50 per cent flowering (73.09 %) and number of pods plant^{-1} (66.36 %). Days to first harvest, and crop duration recorded medium heritability. The lowest value of heritability was observed for length of harvest period.

Expected genetic gain as percentage of mean was high for pod yield plant^{-1} (53.58), length of pod (31.36), weight of pod (26.83), number of pods plant^{-1} (25.90). Days to first harvest and crop duration exhibited low genetic advance with the least value for length of harvest period.

High values of heritability coupled with high genetic advance were observed for pod yield plant^{-1}, length of pod, weight of pod and number of pods plant^{-1}. Fig. 2 indicates the heritability and genetic advance of 10 characters in yard long bean

4.2.3. Correlation Coefficient Analysis

The correlation between different traits was computed as genotypic, phenotypic and environmental correlation coefficients and are presented below.

4.2.3.1. Genotypic Correlation Coefficient

The Genotypic correlation coefficients are given in Table 7. High positive correlation was recorded for pod yield plant^{-1} with all the characters except days to 50 per cent flowering, days to first harvest and crop duration. Pods plant^{-1} (0.936) recorded very high positive and significant correlation with yield followed by

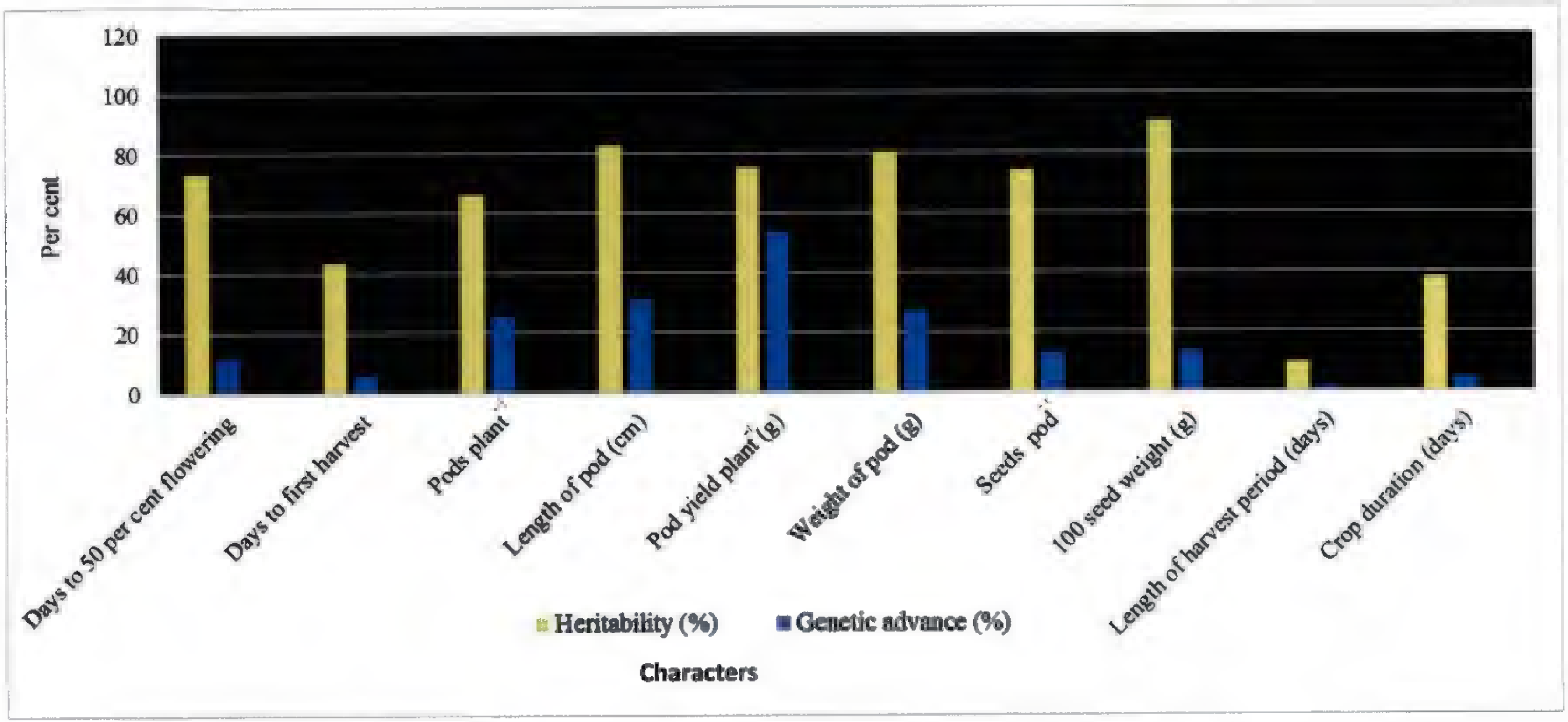

Fig. 2. Heritability and genetic advance for the 10 biometric characters in yard long bean.

Table 7. Genotypic correlation coefficients of the ten biometric characters in yard long bean

	Days to 50 per cent flowering	Days to first harvest	Pods plant^{-1}	Length of pod (cm)	Pod yield plant^{-1}(g)	Weight of pod (g)	Seeds pod^{-1}	100 seed weight (g)	Length of harvest period (days)	Crop duration (days)
Days to 50 per cent flowering	1									
Days to first harvest	0.823**	1								
Pods plant^{-1}	-0.046	-0.082	1							
Length of pod (cm)	-0.283*	-0.095	-0.113	1						
Pod yield plant^{-1}(g)	-0.346*	-0.142	0.936**	0.149	1					
Weight of pod (g)	-0.338*	-0.104	0.468**	0.469**	0.754**	1				
Seeds pod^{-1}	-0.519**	-0.515**	0.711**	0.285*	0.828**	0.719**	1			
100 seed weight (g)	-0.298*	0.262*	0.475**	-0.029	0.527**	0.384**	0.218	1		
Length of harvest period (days)	0.081	0.409**	-0.012	-0.496**	0.546**	0.406**	0.406**	0.632**	1	
Crop duration (days)	0.685**	0.638**	-0.123	-0.878**	-0.310**	-0.481**	-0.645**	-0.279*	0.255*	1

* significant at 5% level ** significant at 1% level

seeds pod^{-1} (0.828), weight of pod (0.754), length of harvest period (0.546), and 100 seed weight (0.546). Days to 50 per cent flowering (-0.346) and crop duration (-0.310) recorded significant negative correlation with yield.

Positive and significant genotypic correlation was observed for days to 50 per cent flowering with days to first harvest (0.823), and crop duration (0.685). Significant negative correlation was recorded for days to 50 per cent flowering with seeds pod-^{1} (-0.591), weight of pod (-0.338), 100 seed weight (-0.298) and length of pod (-0.283).

The correlation was significant and positive for days to first harvest with crop duration (0.638), length of harvest period (0.409) and 100 seed weight (0.262), while seeds pod^{-1} (-0.515) recorded significant negative correlation.

Pods plant^{-1} showed significant positive correlation with seeds pod^{-1} (0.711), 100 seed weight (0.475) and weight of pod (0.468).

The correlation was positive and significant for length of pod with weight of pod (0.469) and seeds pod^{-1} (0.285), while length of harvest period (-0.496) and crop duration (-0.878) showed significant negative correlation.

Significant positive correlation at the genotypic level was recorded for weight of pod with seeds pod^{-1} (0.719), 100 seed weight (0.384) and length of harvest period (0.406), while it marked significantly negative for crop duration (-0.481).

Significant positive correlation was observed for seeds pod^{-1} with length of harvest period (0.406) while crop duration (-0.645) has shown significant negative correlation.

100 seed weight has shown significant positive correlation with length of harvest period (0.632), while crop duration (-0.279) has shown significant negative correlation.

Length of harvest period recorded significant negative correlation for crop duration (-0.279).

4.2.3.2. Phenotypic Correlation Coefficient

Table 8 summarises the phenotypic correlation coefficients of the ten biometric characters in yard long bean. Positive correlation was recorded for pod yield plant^{-1} with all the characters except days to 50 per cent flowering (-0.245), days to first harvest (-0.141) and crop duration (-0.177). Pods plant^{-1} (0.771) recorded high positive and significant correlation with yield followed by seeds weight of pod (0.621), pod^{-1} (0.604), and 100 seed weight (0.441).

Days to 50 per cent flowering recorded significant negative phenotypic correlation with weight of pod (-0.356), seeds pod^{-1} (-0.434) and length of pod (-0.270) while it recorded significant positive correlation with days to first harvest (0.412) and crop duration (0.436).

Days to first harvest showed significant positive correlation with crop duration (0.346) days to 50 per cent flowering (0.412) while seeds pod^{-1} (-0.390) recorded significant negative correlation. Seeds pod^{-1} (0.533), 100 seed weight (0.373) and weight of pod (0.369) showed significant positive correlation at phenotypic level with pods plant^{-1} .

Weight of pod (0.381) alone showed significant positive phenotypic correlation with length of pod while crop duration (-0.462) and days to 50 per cent flowering (-0.270) recorded significant negative correlation.

Weight of pod recorded significant positive correlation with seeds pod^{-1}(0.599), pods plant^{-1}(0.369), length of pod (0.381), 100 seed weight (0.305) and length of harvest period (0.333) while significant negative correlation as recorded for crop duration (-0.276) and days to 50 per cent flowering (-0.356).

Seeds pod^{-1} recorded significant positive correlation with pods plant^{-1} (0.533) weight of pod (0.599), 100 seed weight (0.305) and length of harvest

Table 8. Phenotypic correlation coefficients of the ten biometric characters in yard long bean.

	Days to 50 per cent flowering	Days to first harvest	Pods plant^{-1}	Length of pod (cm)	Pod yield plant^{-1}	Weight of pod (g)	Seeds pod^{-1}	100 seed weight (g)	Length of harvest period (days)	Crop duration (days)
Days to 50 per cent flowering	1									
Days to first harvest	0.412**	1								
Pods plant^{-1}	-0.131	-0.036	1							
Length of pod (cm)	-0.270*	-0.014	-0.050	1						
Pod yield plant^{-1}	-0.245	-0.141	0.771**	0.057	1					
Weight of pod (g)	-0.356**	-0.114	0.369**	0.381**	0.621**	1				
Seeds pod^{-1}	-0.434**	-0.390**	0.533**	0.240	0.604**	0.599**	1			
100 seed weight (g)	-0.203	0.138	0.373**	-0.032	0.44**	0.305*	0.229	1		
Length of harvest period (days)	-0.003	0.112	0.032	-0.086	0.206	0.333*	0.138	0.072	1	
Crop duration (days)	0.436**	0.347*	-0.020	-0.462**	-0.177	-0.276*	-0.344*	-0.096	0.216	1

* significant at 5% level   ** significant at 1% level

period(0.333) while crop duration (-0.344), days to 50 per cent flowering (-0.434) and days to first harvest (-0.39) recorded significant negative correlation.

100 seed weight recorded significant and positive correlation for pods plant^{-1} (0.373) and weight of pod (0.305).

Length of harvest period recorded significant positive correlation only with weight of pod (0.333).

Significant and positive correlation was recorded for days to 50 per cent flowering (0.436) and days to first harvest(0.346) with crop duration, while length of pod (-0.462), weight of pod (-0.276) and seeds pod^{-1}(-0.344) showed significant negative correlation.

4.2.3.3 Environmental Correlation Coefficient

Environmental correlation coefficients of the ten biometrical characters are tabulated in Table 9. On considering the environmental correlation of yield with other characters, pods plant^{-1} had the highest and significant correlation coefficient (0.379) with yield, while length of pod have shown significant but negative correlation (-0.293).

The correlation was significant and negative for days to 50 per cent flowering with pods plant^{-1} (-0.327) and weight of pod (-0.423).

Days to first harvest recorded significant negative correlation with seeds pod^{-1} (-0.255).

Environmental correlation was significant and positive for weight of pod with length of harvest period (0.522).

The correlation was significant and positive for seeds pod^{-1} with 100 seed weight (0.317).

Table 9. Environmental correlation coefficients of the 10 biometric characters in yard long bean

	Days to 50 per cent flowering	Days to first harvest	Pods plant^{-1}	Length of pod (cm)	Pod yield plant^{-1}	Weight of pod (g)	Seeds pod^{-1}	100 seed weight (g)	Length of harvest period (days)	Crop duration (days)
Days to 50 per cent flowering	1									
Days to first harvest	-0.131	1								
Pods plant^{-1}	-0.327*	0.018	1							
Length of pod (cm)	-0.230	0.138	0.152	1						
Pod yield plant^{-1}	0.043	-0.159	0.379*	-0.293*	1					
Weight of pod (g)	-0.423**	-0.159	0.107	-0.012	0.158	1				
Seeds pod^{-1}	0.005	-0.255*	0.116	0.079	-0.059	0.198	1			
100 seed weight (g)	0.247	-0.113	0.027	-0.056	0.041	-0.164	0.317*	1		
Length of harvest period (days)	-0.049	0.041	0.063	0.137	0.124	0.522**	0.062	-0.391**	1	
Crop duration (days)	0.186	0.148	0.102	0.088	-0.020	-0.031	-0.006	0.278*	0.224	1

* significant at 5% level   ** significant at 1% level

75

100 seed weight recorded significant positive correlation with crop duration (0.278) and significant negative correlation with length of harvest period (-0.391).

4.2.4 Path Analysis

In path coefficient analysis, the genotypic correlation coefficients among yield and its component factors were partitioned into different component characters to find the direct and indirect contribution of each character to pod yield (Table 10). The characters like days to 50 per cent flowering, pods plant^{-1}, weight of pod (g), seeds pod^{-1}, 100 seed weight (g), length of harvest period (days) and crop duration were selected for path coefficient analysis. These component characters have highly significant genotypic correlation with yield. Path diagram showing the direct and indirect effects of the component characters on yield is provided in Fig. 3.

The maximum direct effect on yield was shown by seeds pod^{-1} (0.598), followed by pods plant $^{-1}$ (0.396), weight of pod (0.359), crop duration (0.355) and 100 seed weight (0.283).

Length of harvesting period and days to 50 per cent flowering had shown direct negative correlation with yield.

Significant direct effect as well as indirect effects on yield was marked by pods plant^{-1} (0.936), seeds pod^{-1} (0.831) and weight of pod (0.752).

Seeds pod^{-1} recorded the maximum positive indirect effects on pods plant^{-1} (0.425) and weight of pod (0.430). The path analysis revealed that the residual effect was 0.122.

4.2.5 Genetic Divergence Analysis

Following Mahalanobis statistic, the twelve genotypes of yard long bean were subjected to D^2 analysis based on the characters taken for the study.

Table 10. Direct and indirect effects of yield components in yard long bean

	Days to 50 per cent flowering	Pods plant^{-1}	Weight of pod (g)	Seeds pod^{-1}	100 seed weight (g)	Length of harvest period (days)	Crop duration (days)	Total genotypic correlation
Days to 50 per cent flowering	**-0.045**	-0.014	-0.088	-0.354	-0.084	-0.005	0.243	-0.347
Pods plant^{-1}	0.002	**0.396**	0.121	0.425	0.134	0.001	-0.044	0.936
Weight of pod (g)	0.015	0.138	**0.359**	0.430	0.109	-0.026	-0.171	0.752
Seeds pod^{-1}	0.027	0.211	0.186	**0.598**	0.062	-0.026	-0.229	0.831
100 seed weight (g)	0.013	0.141	0.099	0.131	**0.283**	-0.041	-0.099	0.527
Length of harvest period (days)	-0.004	-0.004	0.105	0.243	0.179	**-0.064**	0.090	0.552
Crop duration (days)	-0.031	-0.036	-0.125	0.186	-0.079	-0.016	**0.355**	0.321

Residual Effect = 0.12

The diagonal values given in bold indicate the direct effects of yield components in yard long bean.

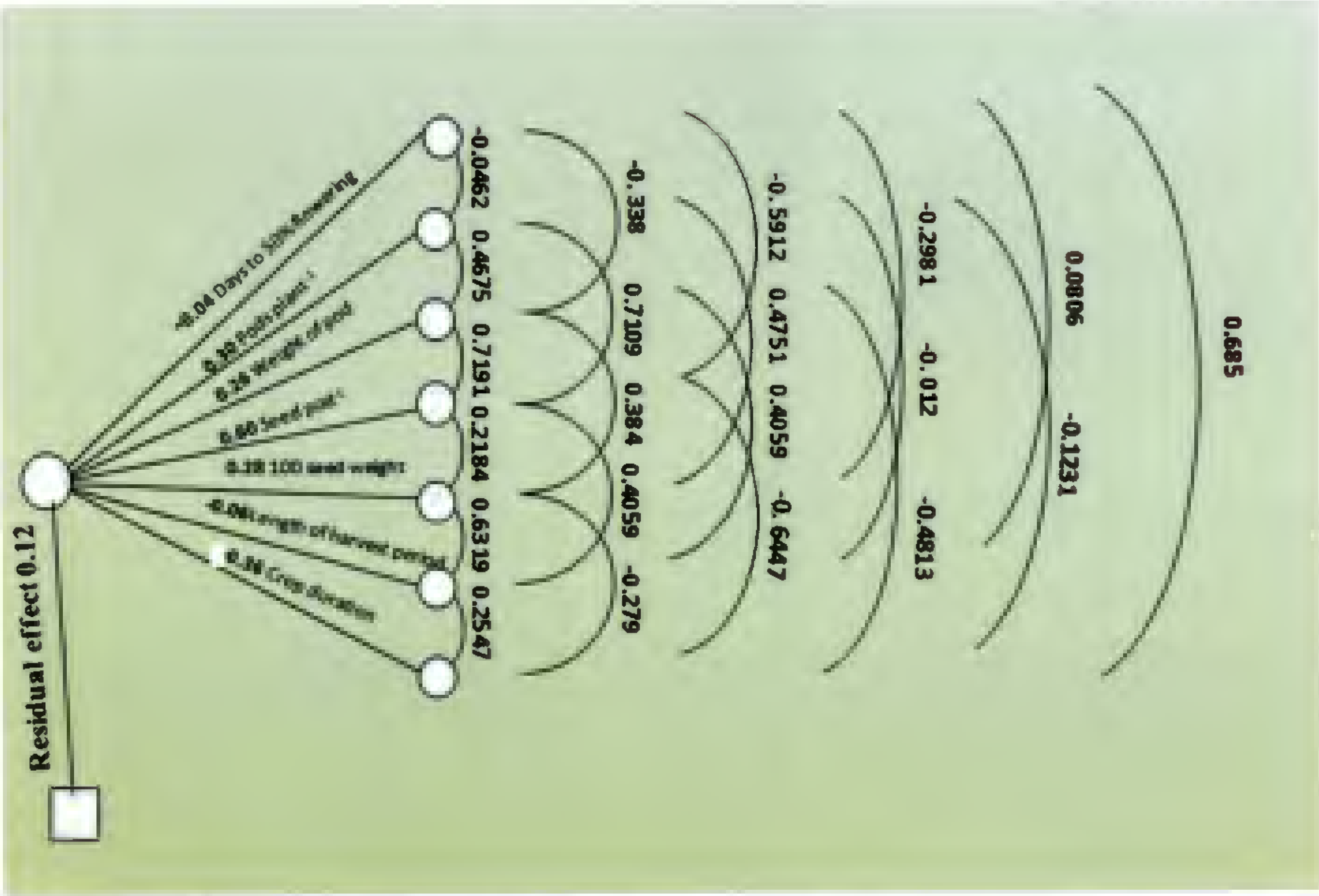

Fig.3. Path diagram showing direct and indirect effects of yield components in yard long bean

The twelve genotypes fell under 5 clusters. The clustering pattern is furnished in Table 11. Cluster II was the largest with four genotypes followed by cluster I and III each with three genotypes. Cluster IV and V were solitary clusters.

The cluster means of 10 characters are presented in the Table 12. Cluster V showed the highest cluster mean for the characters *viz.*, pod yield plant^{-1}, length of pod, weight of pod and seeds pod^{-1}. It also showed the lowest cluster mean for days to 50 per cent flowering and days to first harvest.

The highest cluster mean for days to 50 per cent flowering (50.67 days), days to first harvest (57.33 days), pods plant^{-1} (24.67 g) and crop duration (84.33 days) were noticed in cluster IV. It also had lowest cluster mean for length of harvest period (25 days), length of pod (32 cm) and weight of pod (11.8 g).

Cluster II and III showed intermediate cluster means for all of the characters studied.

Cluster I had the highest cluster mean for 100 seed weight (15.43 g) and length of harvest period (27 days) and second highest mean for days to first harvest (55.78 days), pod yield plant^{-1}(313.39 g) and weight of pod (14.55 g).

The average inter and intracluster distances are presented in Table 13. The inter cluster distance was maximum for cluster I and cluster II (10.93) followed by cluster II and cluster V (8.91) and cluster II and cluster III (8.87). The least intercluster distance was recorded between cluster I and cluster IV (6.99).

The intracluster distance was highest for cluster III (5.73) followed by cluster II (5.69) and cluster I (5.41). The intracluster distances was least and zero for cluster IV and cluster V as they are the solitary ones. The cluster diagram is provided in the Fig. 4.

Table 11. Clustering pattern of 12 genotypes of yard long bean

Cluster No.	No of genotypes	Genotypes
I	3	Vijayanthi, IC 20720 and Puthuppady local
II	4	IC 39945, IC 39947, EC 300039 and IC 39447
III	3	IC 39870, Wayanad local and Adityapuram local
IV	1	IC 26029
V	1	Githika

Table 12. Cluster means of the ten biometric characters in yard long bean

SI No.	Character	Clusters				
		I	II	III	IV	V
1	Days to 50 per cent flowering	47.778	48.58	43.22	**50.67**	42.33
2	Days to first harvest	55.78	55.08	52	**57.33**	51.33
3	Pods plant^{-1}	20.33	18.17	18.44	**24.67**	22
4	Length of pod (cm)	41.44	45.17	39.67	32	**45.33**
5	Pod yield plant^{-1} (g)	313.39	236.49	251.60	305.13	**394.83**
6	Weight of pod (g)	14.55	13	12.37	11.8	**17.33**
7	Seeds pod^{-1}	16	15.75	16.67	16.33	**18.32**
8	100 seed weight (g)	**15.43**	13.17	14.31	14.7	14.77
9	Length of harvest period (days)	**27**	25.67	26.44	25	25.67
10	Crop duration (days)	78.55	79.33	78	**84.33**	75.67

The higher mean values are given in block letters.

Table 13. Average intra and inter cluster distances between the five clusters of twelve genotypes of yard long bean

	I (Vijayanthi, IC 20720 and Puthuppady local)	II (IC 39945, IC 39947, EC 300039 and IC 39447)	III (IC 39870, Wayanad local and Adityapuram local)	IV (IC 26029)	V (Githika)
I (Vijayanthi, IC 20720 and Puthuppady local)	29.28 (5.41)	119.42 (10.93)	67.76 (8.23)	48.81 (6.99)	51.67 (7.19)
II (IC 39945, IC 39947, EC 300039 and IC 39447)		32.39 (5.69)	78.60 (8.87)	51.43 (7.17)	79.44 (8.91)
III (IC 39870, Wayanad local and Adityapuram local)			32.87 (5.73)	55.65 (7.46)	62.79 (7.92)
IV (IC 26029)				0	56.28 (7.50)
V (Githika)					0

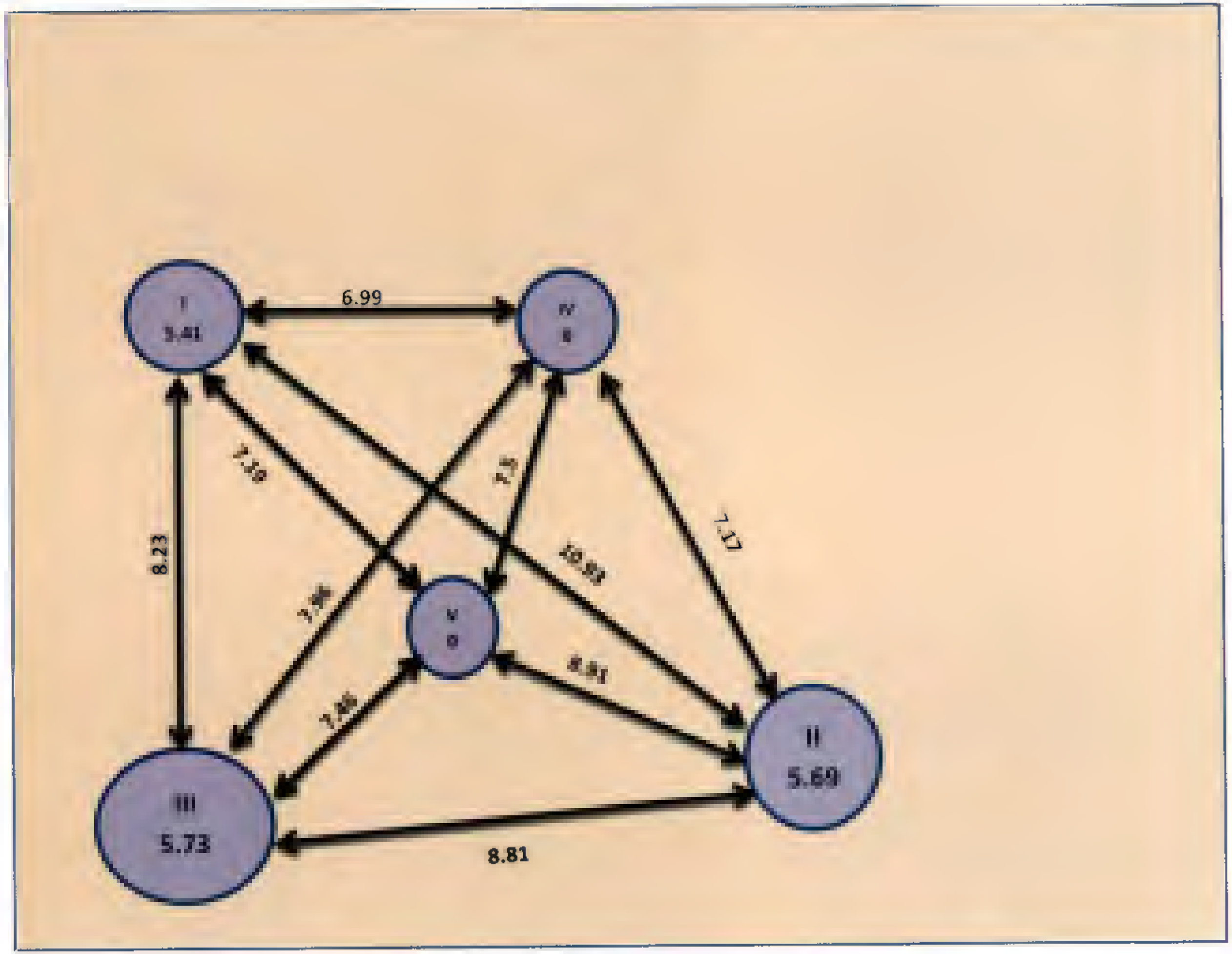

Fig.4. Cluster diagram showing average intra and inter cluster distance

4.2.6 Selection Index

Calculation of selection index was aimed to discriminate the desirable genotypes from a group of genotypes. Discriminant function analysis was adopted for the construction of selection index. For computing the index all the 10 biometrical characters were selected.

The index value for each genotype was determined and they were ranked. The values obtained for the treatments based on the selection index are given in Table 14.

Maximum value of selection index was recorded for Puthuppady local (1040.17) followed by Githika (988.36) and IC 39947 (911.52).

Table 14. Selection indices of the twelve genotypes of yard long bean in descending order

List of Genotypes	Selection index	Ranking of genotype
Puthuppady local	1040.17	1
Githika	988.36	2
IC 39947	911.52	3
IC 26029	908.99	4
Kollamkode local	904.30	5
Vijayanthi local	856.24	6
IC 20720	832.18	7
IC 39870	830.17	8
EC 300039	822.68	9
IC 39945	807.11	10
Wayanad local	792.63	11
IC 39447	790.16	12

Discussion

5. DISCUSSION

Yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt) is one of the most widely grown vegetable crops in Kerala. Legume pod borer, *Maruca vitrata* is one of the serious pests of yard long bean and host plant resistance is an ecofriendly sound approach for the management of pod borer.

Attempts at improvement of any trait in a crop plant or variety should always go hand in hand with yield improvement. Selection of desirable genotypes with high yield is thus important. Germplasm collection from diverse ecogeographical sources and evaluation under uniform conditions is a prerequisite for any breeding programme.

The present investigation was conducted at the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani, during June 2016 to February 2017 with the objectives of screening vegetable cowpea germplasm for legume pod borer resistance and evaluation of yield performance of selected cultivars. In this chapter attempts are made to describe salient experimental findings.

5.1. SCREENING FOR LEGUME POD BORER RESISTANCE

5.1.1 Variation in Damage Parameters and Plant Resistance Index

A genotype that suffers lesser insect attack or lesser damage in the event of comparable pest population can be considered as partially resistant (Dent, 1995). Tingey (1986) suggested that assessment of plant resistance index through measurement of insect damage should be made employing damage criteria closely associated with the ultimate loss in crop yield and quality. Flowers, pods and seed damage should be considered while evaluating cowpea genotypes for legume pod borer resistance as these are the stages that show maximum damage as reported by Jackai (1982) and Vidya (2000) in yard long bean. Some of the recent reports in yard long bean suggested that flower bud damage is more prominent than the pod damage (Jayasinghea *et al*., 2015). Thus in the present study resistance evaluation was based on the plant resistance index computed using a combination of damage parameters on flower buds, flowers and pods.

There were significant differences among the genotypes for all the damage parameters *viz*., mean infestation of flower buds, mean number of larvae per 25 flowers and mean pod infestation. Significant differences among yard long bean genotypes in damage parameters of flower buds, flowers and pods were also reported by Jayasinghea *et al*. (2015) and Nasiya (2015).

The genotypes evaluated in the present study also exhibited significant variation in terms of infestation of flower buds, flowers and pods. IC 19797 suffered more than three times from flower damage compared to the least affected genotype (IC 39945).

Variation was also observed in mean number of larvae per 25 flowers. The range of mean larval counts per 25 flowers varied from 5.00 to 19.00. Jackai (1982) also reported wide differences in larval population in flowers of cowpea genotype in a legume pod borer screening programme. He opined that information on larval count in flowers provides an insight on the pest population intensity in each genotype since larvae tend to migrate from one flower to the other.

The criteria employed for pod damage assessment was per cent pod infestation. Thiruvambady local was found to be the genotype with lesser degree of pod infestation. Genotypes IC 26029, Adithyapuram local, IC 39945, IC 39947, IC 39447, EC 300039, IC 20720 and Puthuppady local also registered low level of per cent pod infestation while per cent pod infestation was high for IC 19797 and IC 397807.

The plant resistance index, values reflected the above variations in flower bud, flower and pod damage. None of the genotypes evaluated had shown an immunity to pod borer. Fifteen genotypes *viz*., Adithyapuram local, IC 39945, IC

39947, Puthuppady local, IC 39447, EC 300039, IC 20720, IC 26029, Githika, Wayanad local, EC 101216, Vijayanthi, IC 402090, IC 39870 and Jyothika recorded the low plant resistance index values of the range 0.1 to 1.67 and were rated as moderately resistant genotypes. Most of the released varieties as well as genotypes collected from farmers' fields proved to be susceptible, underlining the axiom that selection for yield and consumer preference is often at the cost of plant resistance to pests. The released varieties like Githika and Vijayanthi had shown moderate resistance. The results of Nasiya (2015) were also in line with the present findings. Twelve genotypes belonging to the category of moderate resistant were selected and these genotypes are presented in Plate 5. The selected genotypes were further evaluated for yield.

5.1.2 Correlation between non glandular trichome density and plant resistance index

Plant resistance to insects is often attributed to morphological as well as biochemical bases. Physical characters such as non glandular trichome density and biochemical characters such as polyphenol oxidase activity have been implicated as contributing to plant resistance in several crops (Panda and Khush, 1995). Negative and significant correlation between trichome density and legume pod borer infestation has been reported in cowpea by Ogiakhe (1995) and Nasiya (2015). Among the trichomes, non glandular trichomes are considered to be particularly important as they offer mechanical resistance and thus impede the movement as well as feeding by borer larvae.

The findings of the present study are in conformity with the above reports. Plant resistance index and non glandular trichome density were found to enjoy significant negative correlation. Since damage parameters were taken for assessing the plant resistance index, it indicated that the resistance increased with a lower value of plant resistance index. Genotypes grouped in the moderately resistant groups such as Adithyapuram local, IC 39945, IC 39947, Puthuppady local, IC 39447, IC 300039, IC 20720, IC 26029, Githika, Wayanad local, EC


Plate 5. (A)

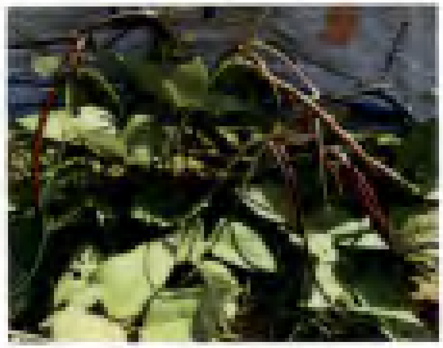
Plate 5. (B)


Plate 5. (C)

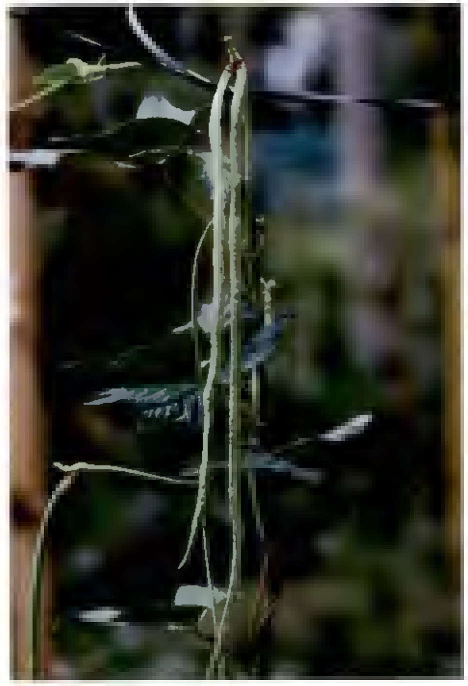
Plate 5. (D)

Plate 5. Genotypes with moderate resistance taken for yield evaluation study.
(A) Adithyapuram local (B) IC 39447 (C) IC 20720 (D) Puthuppady local

Plate 5 (E)

Plate 5 (F)

Plate 5 (G)

Plate 5 (H)

Plate 5 continued. Genotypes with moderate resistance taken for yield evaluation study.
(E) IC 39945 (F) IC 39947 (G) EC 300039 (H) Wayanad local

Plate 5 (J)

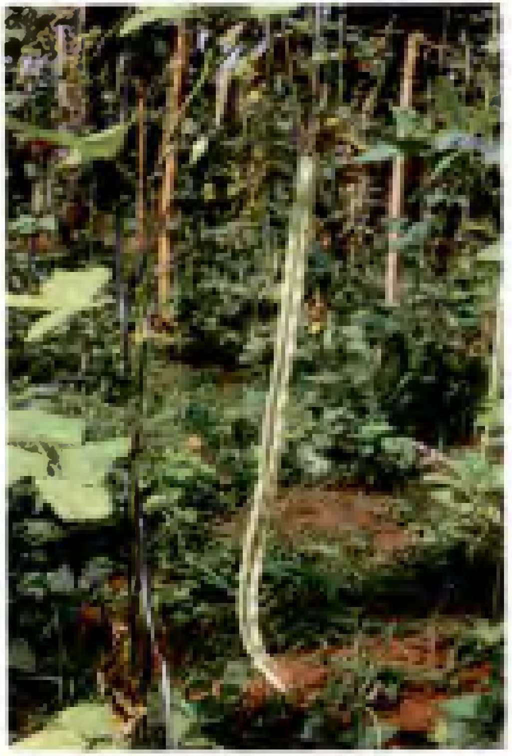

Plate 5 (I)

Plate 5 (K)

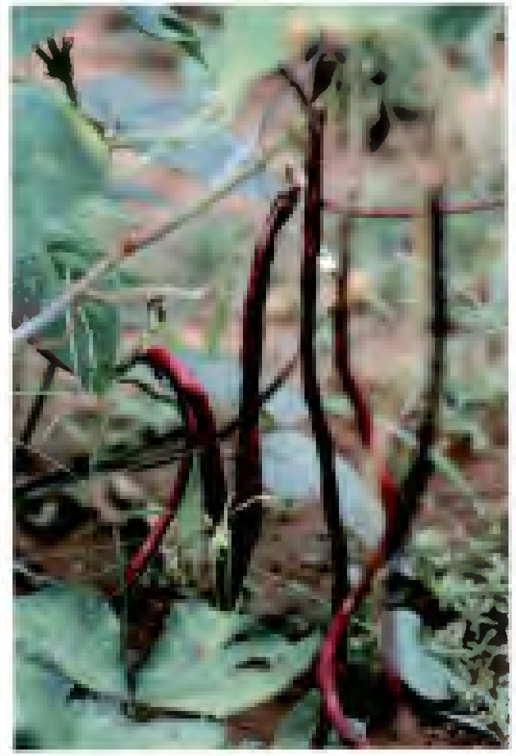

Plate 5 (L)

Plate 5 continued. Genotypes with moderate resistance taken for yield evaluation study.
(I) Githika (J) IC 26029 (K) IC 39870 (L) Vijayanthi

101216, Vijayanthi, IC 402090, IC 39870 and Jyothika possess relatively higher trichome density, supported fewer borer larvae and consequently suffered lesser damage. Use of pubescent varieties has been successfully employed in cotton for the management of leaf hoppers and can also be considered in other crops, including cowpea.

5.2 EVALUATION OF YIELD AND YIELD COMPONENT CHARACTERS

Selection of high yielding genotypes from among the partially resistant genotypes formed the next step in the present research programme. Phenotypic selection is likely to be misleading, as yield and its component characters are quantitative in nature and influenced by environment in their expression. Genetic analysis of yield and its component characters is inevitable, as efficiency of selection is dependent on the existing variability as well as heritability and interrelationships of characters. The discussion that follows is based on the results of the field experiment conducted with this precise objective.

5.2.1. Mean performance of accessions

Analysis of variance revealed significant differences among the 12 genotypes of yard long bean for all the characters studied *viz*., days to 50 per cent flowering, days to first harvest, pod yield plant $^{-1}$ (g), pods plant^{-1}, length of pod (cm), weight of pod (g), seeds pod^{-1}, 100 seed weight (g), crop duration (days) except length of harvesting period. Similarly the existence of high variability for several characters in vegetable cowpea was reported by Vidya (2000), Manju (2006), Sivakumar (2012) and Litty (2015).

Wide variation was evident for the days taken for 50 per cent flowering and crop duration. These results were in line with the earlier reports of Sivakumar (2012).

Yield is the vital character considered for selection. Pod yield plant^{-1} showed remarkable variation among genotypes. The highest pod yield plant^{-1} was recorded for A 18 (Puthuppady local).

5.2.2 Coefficient of Variation

An estimate of the magnitude of variability present in a population is of great importance as it provides the basis for effective selection. The observed variation in a population is the total variation arising due to genotypic and environmental effects. Only the genetic component of total variability contributes to gain under selection. So knowledge on the nature and magnitude of genetic variation governing the inheritance of quantitative characters like yield and its components is essential. The components used to measure the variability present in a population are PCV and GCV. The GCV provides a valid basis for comparing and assessing the range of genetic variability for quantitative characters and PCV measures the extend of total variation.

In the present study, high values of PCV and GCV were observed for pod yield plant^{-1}. Moderate PCV and GCV were recorded for length of pod and weight of pod. Pods plant^{-1} recorded moderate PCV but low GCV. The study thus revealed that the character with high PCV and GCV contributes maximum to variability. The results were in agreement with earlier reports in cowpea by Panicker (2000), Selvam *et al.* (2000), Jyothi (2001), Kutty *et al.* (2003), Madhukumar (2006), Jithesh (2009), Sivakumar and Celine (2014) and Litty (2015).

Low GCV and PCV were recorded for days to 50 per cent flowering, days to first harvest, seeds pod^{-1}, 100 seed weight, length of harvest period and crop duration indicating low variability which limits the scope for improvement of these characters through selection. Similar results were reported by Lovely (2005), Manju (2006), Jithesh (2009) Sivakumar (2012) and Litty and Celine (2016).

5.2.3 Heritability and genetic advance

The sum total of heritable and non-heritable components constitute the existing variability in a population. The information on the degree of inheritance of characters from the parents to the progeny is provided by the heritability values. Heritability (>60 %) indicates that the phenotype of the trait strongly reflects the genotype. A good knowledge of heritability is a prerequisite in any breeding programme, as it is a measure in separating genotypes by selection. Characters with high heritability can be improved directly through selection as they are less affected by environment. The magnitude of heritability indicates the effectiveness with which selection of the genotypes can be based on the phenotype.

In the present study high heritability was noted for days to 50 per cent flowering, pods plant^{-1}, length of pod, pod yield plant^{-1}, weight of pod, seeds pod^{-1} and 100 seed weight. Days to first harvest and crop duration recorded moderate heritability while length of harvest period is the only character that recorded low heritability. High values of heritability can be attributed to the greater role of additive x additive gene action, which can be exploited by simple selection. The results were in line with the findings of Mary and Gopalan (2006), Nwosu *et al.* (2013) Sivakumar and Celine (2014) and Litty (2015).

High heritability estimates indicate the effectiveness of selection based on good phenotypic performance but does not necessarily imply high genetic gain for the particular trait. High values of genetic advance as per cent of mean were recorded for pod yield plant^{-1}, length of pod, pods plant^{-1} and weight of pod. Similar results were reported by Philip (2004), Mary and Gopalan (2006), Sivakumar and Celine (2014) and Litty (2015) in yard long bean.

High heritability with high genetic advance of characters is indicative of additive gene action suggesting the possibity of genetic improvement of those characters through selection. In the present study, high estimates of heritability in conjunction with high genetic advance was observed for pods plant^{-1}, length of pod, pod yield plant^{-1} and weight of pod. These results are similar to the reports of Jithesh (2009), Sivakumar (2012), Nwosu *et al*. (2013) and Litty (2015) in cowpea.

High heritability coupled with low to moderate genetic gain was observed for days to 50 per cent flowering, seeds pod^{-1} and 100 seed weight suggesting that improvement in these characters would be more effective by selecting specific combinations followed by intermating of lines. These results were in accordance with the works of earlier workers *viz*., Panicker (2000), Resmi *et al*. (2004) and Litty (2015) in yard long bean.

5.2.4 Correlation studies

Yield being a quantitative trait is influenced by many characters either in positive or negative direction. So selection for yield should also take in consideration of other associated characters as well. Correlation provides information on the nature and extent of relationship between pairs of characters. Therefore analysis of yield in terms genotypic and phenotypic correlation coefficients of component characters leads to the understanding of characters that can form the basis of selection of high yielding genotypes.

In the present investigation, yield had significant positive phenotypic and genotypic correlation with pods plant $^{-1}$, weight of pod, seeds pod^{-1} and 100 seed weight. Sobha (1994) reported positive and significant correlation in bush cowpea for pod yield with pod weight and pod length. Resmi (1998), Vidya (2000), Lovely (2005), Madhukumar (2006), Jithesh (2009) and Litty and Celine (2016) also reported similar results in yard long bean.

5.2.5 Path Aanlysis

During crop improvement programmes breeders have to deal with correlated characters. Although correlation studies of yield and its component characters are useful, it does not give an exact picture of the relative importance of various yield attributes. Rate of improvement is expected to be rapid if differential emphasis is laid on the component characters during selection. The difference in the emphasis would be based on the degree of direct and indirect influence of various component character on the economic character of interest. Path coefficient analysis splits the correlation coefficients into direct and indirect effects of the component characters on yield based on which crop improvement can be done more effectively.

If the correlation between yield and any of its component trait is due to its direct effect, it reveals that a true relationship exists between them. Selection can be practised for such characters in order to improve yield. But if the correlation is mainly due to indirect effect of the character through another component character, then the selection is done in the later character through which the indirect effect is exerted.

In the present investigation, path coefficient analysis was used to separate the genotypic correlation coefficients of pod yield plant^{-1} with days to 50 per cent flowering, pods plant^{-1}, weight of pod, seeds pod^{-1}, 100 seed weight, length of harvest period and crop duration. Seeds pod^{-1}exhibited the highest positive direct effect on yield followed by pod plant^{-1}, weight of pod, crop duration and 100 seed weight indicating the importance of these characters in yield improvement programmes. Length of harvest period and days to 50 per cent flowering exhibited negative direct effect on pod yield plant^{-1}. These results were in accordance with earlier reports of Vidya (2000), Lovely (2005), Madhukumar (2006), Jithesh (2009) and Litty (2015) in yard long bean.

The residual effect of 0.12 indicated that the selected seven characters contributed 88 percent to the yield.

5.2.6 Genetic divergence analysis

One of the most important techniques for crop improvement is hybridisation programme, success of which mainly depends on the genetic diversity of the parents chosen for the purpose. To produce higher heterotic effects genetically diverse parents have to be crossed. However, maximum heterosis is obtained at an intermediate level of genetic diversity. To measure the genetic diversity the widely adopted method is Mahalanobis D^2 statistic (Mahalanobis, 1936). It measures the degree of differentiation at the intracluster and intercluster levels and thus provides a basis for selection of divergent parents in breeding programmes and thus it permits accurate comparison among all possible pairs of genotypes in any population.

The twelve genotypes fell under five clusters. Cluster II is the largest with IV genotypes followed by cluster I and III each with three genotypes. Cluster IV and V are solitary clusters.

Cluster V showed the highest cluster mean for the characters *viz.*, pod yield plant^{-1}, length of pod, weight of pod and seeds pod^{-1}. It also showed the lowest cluster mean for days to 50 per cent flowering and days to first harvest.

The highest cluster mean for days to 50 per cent flowering, days to first harvest, pods plant $^{-1}$and crop duration were noticed in cluster IV. It also had lowest cluster mean for length of harvest period, length of pod and weight of pod. Cluster II and III have shown intermediate cluster means for all of the characters under study. Cluster I had highest cluster mean for 100 seed weight and length of harvest period and second highest mean for days to first harvest pod yield plant^{-1} and weight of pod. For crop improvement programmes, intercrossing of genotypes from those clusters with outstanding mean performance would be effective.

Maximum divergence would be shown by clusters which possess maximum intercluster distance between them. Huque *et al.* (2012) and Sivakumar and Celine (2014) worked out divergence analysis and concluded the same. The inter cluster distance was maximum between cluster I and cluster II. The least intercluster distance was recorded between cluster I and cluster IV.

The intracluster distance was highest for cluster III followed by cluster II and cluster I. The intracluster distances was least and zero for cluster IV and cluster V as they are the solitary ones. The genotype Puthuppady local was identified as the highest pod yielder. Hybridisation of this genotype with genotypes from other clusters having high pods plant^{-1} and pod weight would be worthy.

5.2.7 Selection index

Selection of genotypes based on suitable index is highly efficient in any breeding programme. Discriminant function analysis developed by Fischer (1936) gives information on the proportionate weightage to be given to a yield component. Thus, selection index was formulated to increase the efficiency of selection by taking into account the important characters that contribute to yield. Selection based on suitable index was more efficient than individual selection based on individual characters (Hazel, 1943). Identification of superior accessions of vegetable cowpea using discriminant function analysis was also done by Resmi (1998), Manju (2006), Jithesh (2009), Sivakumar (2012) and Litty (2015).

Characters like days to 50 per cent flowering, days to first harvest, pods plant^{-1}, length of pod, pod yield plant^{-1}, weight of pod, seeds pod^{-1}, 100 seed weight, length of harvest were used for constructing the selection index. Based on the selection index values, top ranking genotypes namely Puthuppady local, Githika and IC 39947 were identified as superior ones in terms of yield and tolerance to legume pod borer in yard long bean. Promising genotypes identified on the basis of yield performance and resistance to legume pod borer are shown in the Plate 6.

Plate 6(A) Puthuppady local

Average yield-28.62kg/cent
Moderately resistant (index score-1)

Plate 6(B) Githika

Average yield-23.29kg/cent
Moderately resistant (index score-1.3)

Plate 6(C) IC 39947

Average yield-20.23kg/cent
Moderately resistant (index score-1)

Plate 6. Identified superior genotypes of yard long bean showing comparatively higher resistance and yield

Summary

6. SUMMARY

The present study entitled "Genetic variability for yield and resistance to legume pod borer, *Maruca vitrata* (Fab.) in yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)" was carried out in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during June 2016 to February 2017, with the objective to evaluate yard long bean germplasm for yield and legume pod borer resistance and to identify promising genotypes.

The study was conducted in two separate field experiments. In experiment I legume pod borer resistance was evaluated in a Randomized Block Design (RBD) with three replications, using thirty genotypes collected from different locations. Since the season was congenial for the outbreak of pest, there was natural infestation. Adequate pest population was also ensured by planting the susceptible variety (Lola) along the borders one week prior to the sowing. The following damage parameters *viz.*, per cent of infested flower buds, number of larvae per 25 flowers and per cent infestation of pods were recorded at flower bud initiation, flowering and pod formation stages of the crop respectively for finding the plant resistance index. Non glandular trichome density on pod wall (count mm^{-2}) was assessed at the vegetable maturity stage using a compound microscope at 45 X magnification.

The genotype which recorded the least degree of flower damage in terms of both per cent infestation of flower buds and larval counts per 25 flowers was IC 39945. Maximum flower bud infestation and flower damage was recorded for IC 19797 and it registered more than thrice flower damage compared to IC 39945. The criteria employed for pod damage assessment was per cent pod infestation. Thiruvambady local was the genotype with lesser degree of pod infestation. Genotypes IC 26029, Adhityapuram local, IC 39945, IC 39947, IC 39447, EC 300039 and IC 20720 also registered low level of per cent pod infestation while the per cent pod infestation was severe for IC 19797 and IC 397807.

Based on these damage parameters plant resistance index was worked and the thirty genotypes were grouped into four classes *viz.*, highly resistant (immune), moderately resistant, susceptible and highly susceptible. None of the genotypes was found immune. Hence twelve genotypes belonging to moderately resistant category were chosen for yield evaluation.

Correlation studies revealed that the plant resistance index and non-glandular trichome density are highly negatively correlated. Since damage parameters were taken for assessing the plant resistance index, it indicated that the resistance increased with a lower value of plant resistance index. Thus, the negative correlation indicated that the overall plant resistance increased with increase in trichome density.

For the second experiment the twelve moderately resistant genotypes were evaluated in a Randomized Block Design (RBD) with three replications and the following observations *viz.*, days to 50 per cent flowering, days to first harvest, pod yield plant $^{-1}$ (g), pods plant^{-1}, length of pod (cm), weight of pod (g), seeds pod^{-1}, 100 seed weight (g), length of harvest period (days), crop duration (days) were recorded. Wide variation was evident for the days taken for 50 per cent flowering and crop duration.

Yield is the vital character considered for selection. Pod yield plant^{-1} showed remarkable variation among genotypes. The highest pod yield plant^{-1} was recorded for Puthuppady local. Characters like number of pods plant^{-1}, length of pod and weight of pod also showed significant variation between genotypes.

The components used to measure the variability present in a population are PCV and GCV. High values of PCV and GCV were observed for pod yield plant^{-1}. Moderate PCV and GCV were recorded for length of pod and weight of pod. Pods plant^{-1} recorded moderate PCV but low GCV. Low GCV and PCV were recorded for days to 50 per cent flowering, days to first harvest, seeds pod^{-1}, 100 seed weight, length of harvest period and crop duration indicating low variability which limits the scope for improvement of these characters through selection.

The information on the degree of inheritance of characters from the parents to the progeny is provided by the heritability values. High heritability was noted for days to 50 per cent flowering, pods plant^{-1}, length of pod, pod yield plant$^{-1,}$ weight of pod, seeds pod^{-1} and 100 seed weight. Days to first harvest and crop duration recorded moderate heritability while length of harvest period is the only character that recorded low heritability. High values of heritability can be attributed to the greater role of additive x additive gene action, which can be exploited by simple selection. High heritability with high genetic advance of characters is indicative of additive gene action suggesting the possibity of genetic improvement of those characters through selection. High estimates of heritability in conjunction with high genetic advance was observed for pods plant^{-1}, length of pod, pod yield plant^{-1} and weight of pod. High heritability coupled with low to moderate genetic gain was observed for days to 50 per cent flowering, seeds pod^{-1} and 100 seed weight suggesting that improvement in these characters would be more effective by selecting specific combinations followed by intermating of lines.

Path coefficient analysis splits the genotypic correlation coefficients into direct and indirect effects of the component characters on yield based on which crop improvement can be done more effectively. Seeds pod^{-1}exhibited the highest positive direct effect on yield followed by pod plant^{-1}, weight of pod, crop duration and 100 seed weight indicating the importance of these characters in yield improvement programmes. Length of harvest period and days to 50 per cent flowering exhibited negative direct effect on pod yield per plant. The residual effect of 0.12 indicated that the selected seven characters contributed 88 percent to the yield.

To measure the genetic diversity the widely adopted method is Mahalanobis D^2 statistic. The twelve genotypes fell under five clusters. Cluster

II is the largest with four genotypes followed by cluster I and III each with three genotypes. Cluster IV and V are solitary clusters. Cluster V showed the highest cluster mean for the characters *viz.*, pod yield plant^{-1}, Length of pod, weight of pod and seeds pod^{-1}. It also showed the lowest cluster mean for days to 50 per cent flowering and days to first harvest. The highest cluster mean for days to 50 per cent flowering, days to first harvest, pods plant $^{-1}$ and crop duration were noticed in cluster IV. Cluster II and III have shown intermediate cluster means for all of the characters under study. Cluster I had highest cluster mean for 100 seed weight and length of harvest period and second highest mean for days to first harvest pod yield plant^{-1} and weight of pod. For crop improvement programmes, intercrossing of genotypes from those clusters with outstanding mean performance would be effective. Maximum divergence would be shown by clusters which possess maximum intercluster distance between them. The inter cluster distance was maximum between cluster I and cluster II. The least intercluster distance was recorded between cluster I and cluster IV. The intracluster distance was highest for cluster III followed by cluster II and cluster I. The intracluster distances was least and zero for cluster IV and cluster V as they were the solitary ones. Puthuppady local was the genotype identified as the highest pod yielder. Hybridisation of this genotype with genotypes from other clusters having high pods plant^{-1} and pod weight would be worthy.

Selection of genotypes based on suitable index is highly efficient in any breeding programme. Discriminant function analysis developed by Fischer (1936) gives information on the proportionate weightage to be given to a yield component. Characters like days to 50 per cent flowering, days to first harvest, pods plant^{-1}, length of pod, pod yield plant^{-1} , weight of pod, seeds pod^{-1} , 100 seed weight, length of harvest were used for constructing the selection index. Based on the selection index values, top ranking genotypes identified were Puthuppady local, Githika and IC 39947. Hence Puthuppady local and IC 39947 can be considered for further crop improvement programmes for developing high yielding legume pod borer resistant varieties.

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GENETIC VARIABILITY FOR YIELD AND RESISTANCE TO LEGUME POD BORER, *Maruca vitrata* (Fab.) IN YARD LONG BEAN (*Vigna unguiculata* subsp. *sesquipedalis* (L.) VERDCOURT)

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ABSTRACT

The present study entitled "Genetic variability for yield and resistance to legume pod borer, *Maruca vitrata* (Fab.) in yard long bean (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Verdcourt)" was carried out in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2016-2017, with the objective to evaluate yard long bean germplasm for yield and legume pod borer resistance as well as identification of promising genotypes.

The study involved two separate field experiments. In the first experiment thirty genotypes, collected from different locations were evaluated in a Randomized Block Design (RBD) with three replications for legume pod borer resistance. The following damage parameters *viz.*, per cent of infested flower buds, number of larvae per 25 flowers and per cent infestation of pods were recorded at flower bud initiation, flowering and pod formation stages of the crop respectively. Non glandular trichome density on pod wall (counts mm^{-2}) was also recorded at the vegetable maturity stage to assess the morphological basis of resistance. Plant resistance index was worked out using metroglyph analysis and twelve genotypes showing moderate resistance to legume pod borer was identified. They were subjected to yield evaluation in the second field experiment.

The twelve moderately resistant genotypes were evaluated in a Randomized Block Design (RBD) with three replications and the following observations *viz.*, days to 50 per cent flowering, days to first harvest, pod yield plant $^{-1}$ (g), pods plant^{-1}, length of pod (cm), weight of pod (g), seeds pod^{-1}, 100 seed weight (g), length of harvest period (days), crop duration (days) were recorded. Analysis of variance was calculated for all the characters under study. The highest mean yield of 485.03 g was recorded in case of Puthuppady local and lowest mean yield of 176.97 g was observed in case of IC 39945. Highest mean pod weight was recorded for Githika and

minimum for Wayand local. Pod yield plant^{-1} exhibited the highest PCV (34.58%) and GCV (29.9%).

High heritability coupled with high genetic advance was observed for pod yield plant^{-1}, pods plant^{-1}, length of pod and weight of pod. Significant positive correlation with yield was observed for all characters except days to 50 per cent flowering. Path coefficient analysis revealed that yield was directly and positively correlated with seeds pod^{-1}, crop duration, number of pods plant^{-1} and 100 seed weight.

The genetic divergence was studied using Mahanalobis D^2 statistics and the genotypes were grouped into five clusters. Cluster V showed the highest cluster mean for the characters *viz*., pod yield plant^{-1}, length of pod, weight of pods and seeds pod^{-1}. It also showed the lowest cluster mean for days to 50 per cent flowering and days to first harvest. The inter cluster distance was maximum between cluster I and cluster II and least between cluster I and cluster IV. Intracluster distance was highest for cluster III followed by cluster II. Cluster IV and cluster V were the solitary ones. Selection index was also calculated to discriminate the desirable genotypes and it was observed that Puthuppady local, Githika and IC 39947 recorded high values of selection index.

The results from the study revealed that the genotypes Puthuppady local, Githika a released variety from KAU and IC 39947 were superior for yield and resistance to legume pod borer. Hence Puthuppady local and IC 39947 can be considered for further crop improvement programmes for developing high yielding legume pod borer resistant varieties.