

**STABILITY ANALYSIS IN ADVANCED BREEDING LINES
AND BRUCHID RESISTANCE STUDIES IN COWPEA [*Vigna
unguiculata* (L.) Walp.]**

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CERTIFICATE

This is to certify that the thesis entitled "STABILITY ANALYSIS IN ADVANCED BREEDING LINES AND BRUCHID RESISTANCE STUDIES IN COWPEA [*Vigna unguiculata* (L.) Walp.]" submitted by Mr. VISHWANATHREDDY K. H. for the degree of MASTER OF SCIENCE (AGRICULTURE) in GENETICS AND PLANT BREEDING to the University of Agricultural Sciences, Dharwad is a record of bonafide research work done by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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1. INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp.] is an important crop in many countries of tropical Africa, Asia and South America. Both grain and leaves are edible products of cowpea that are rich and cheap sources of high-quality protein. It is one of the most important pulse crop native to central Africa, belongs to the order *Rosales*, family *Leguminosae*, sub family *Fabaceae* and the genus *Vigna*. It is a diploid species with somatic chromosome number $2n = 22$ (Darlington and Wylie, 1955). Cowpea is called as vegetable meat due to high amount of protein in grain with better biological value on dry weight basis. On dry weight basis, cowpea seed contains 23.4 per cent protein, 1.8 per cent fat and 60.3 per cent carbohydrates and it is rich source of calcium and iron (Phillips *et al.*, 1988). Apart from this, cowpea forms excellent forage and it gives a heavy vegetative growth and covers the ground so well that it checks the soil erosion.

Cowpea plays a critical role in the lives of millions of people in Sub-Saharan Africa and other parts of the developing world, where it is a major source of dietary protein that nutritionally complements staple low-protein cereal and tuber crops, and is a valuable and dependable commodity that produces income for farmers and traders (Singh *et al.*, 2002; Langyintuo *et al.*, 2003). Cowpea is a valuable component of farming systems in many areas because of its ability to restore soil fertility for succeeding cereal crops grown in rotation with it (Carsky *et al.*, 2002). Early maturing cowpea varieties can provide the first food from the current harvest sooner than any other crop (as few as 55 days after planting), thereby shortening the “hungry period” that often occurs just prior to harvest of the current season’s crop in farming communities of the poor countries. Dry grain for human consumption is the most important product of the cowpea plant, but fresh or dried leaves (in many parts of Asia and Africa) (Nielsen *et al.*, 1997; Ahenkora *et al.*, 1998), fresh peas (the south eastern USA and Senegal), and fresh green pods (humid regions of Asia and in the Caribbean) may be the most important in some local situations. Cowpea hay plays a particularly critical role in feeding animals during the dry season in many parts of West Africa (Singh *et al.*, 1997).

It is widely adapted and capable of producing seeds even in low land and semi arid regions. However, grain yield of this legume varies widely when grown at different locations. It can be grown in a wide range of soil types and environmental conditions. As a pulse crop, it plays a key role in maintaining soil health and sustainability in the production from different cropping systems as it fixes atmospheric nitrogen. On an average, the grain legumes fix 250 to 312 kg nitrogen per hectare per year. In case of cowpea it fixes about 70 to 240 kg of nitrogen per hectare per year. This ensures the soil fertility as well as reduces the financial burden on poor farmers. It is a mostly versatile pulse crop because of its smothering nature, drought tolerant characteristics and soil restoring properties.

It is estimated that globally cowpea is cultivated on an area of 11.31 million hectares with production of 5.7 million tonnes and productivity is 505.3 kg ha^{-1} (FAO, 2013). Even though cowpea is minor pulse crop of India, it is one of the important pulse crops in South India. In India cowpea is grown on an area of 3.9 million hectares with a production of 2.21 million tonnes with productivity of 625 kg ha^{-1} . Karnataka accounts 12 per cent of area under pulses in the country. Cowpea stands

fourth in Karnataka among all pulses with an area of 78,900 hectares with a production of 22,659 tonnes with productivity of 302 kg ha⁻¹ (Anon, 2013). The productivity potential of cowpea in Karnataka is low as compared to the national productivity.

Considerable progress has been made in breeding improved cowpea varieties in the last decade. The major breeding objectives were to develop high yielding cowpea varieties for sole cropping as well as intercropping with acceptable seed types and resistance to major diseases, insect pests, nematodes, and the parasitic plants viz., striga, alectra and tolerance to heat and drought. Good progress was also made in breeding early maturing grain type, dual purpose and fast growing fodder type cowpea varieties. Because no single variety is suitable for all conditions, there is a need to develop varieties with different attributes and resistance to major biotic and abiotic constraints, to suit the specific needs of different regions and cropping systems. Broadening the genetic base by introducing new alleles present in exotic germplasm and a systematic exploitation of heterosis have been suggested to overcome some of the problems. However, identification of parental lines to exploit heterosis and to introduce valuable characters into the cowpea breeding programme will require more reliable information concerning the level of genetic similarity of available gene pools worldwide. Quantification and classification of diversity in germplasm collections is important for both plant breeders and germplasm curators.

Cowpea is grown in various regions of India and covers practically all agro-ecological zones. There are various genotypes of cowpea having variable yield potential, adaptability to different climatic conditions, and varied response to diseases, insects and pests. The performance of genotypes keeps changing in different environmental conditions. The genotypic and environmental interactions are usually present under all situations in pure lines, hybrids, synthetics or any other material used for breeding, which complicates the breeding work and hampers the progress of the crop improvement programme (Eberhart and Russell, 1966). Thus, it is imperative to study the performance of crop varieties in more than one environment to identify genotypes, which are highly productive over a wide range of environments. Such genotypes will be very useful for utilizing their potentials for the development of high yielding and stable varieties.

Stable genotypes are particularly of great importance in the country like India, where the crops are grown under varied environmental conditions. Genotype $\times$ environment (G $\times$ E) interaction certainly plays an important role in the evaluation and execution of breeding programmes. Allard and Bradshaw (1964) have critically reviewed this phenomenon and brought out its implications in applied plant breeding. Thus, G $\times$ E interaction is important in the expression of quantitative characters, which are controlled by polygenic systems and largely influenced by environmental fluctuations.

Though the information of genotype $\times$ environment interaction has been adequately worked out in other pulse crops like chickpea, pigeonpea, the relative basic information on the important pulse crop like cowpea is insufficient. The present investigation was an attempt to collect this information in cowpea, which may be of great use in launching a dynamic and efficient breeding programme.

Number of insects have been found to infest cowpea seed both in the field as well as under storage. Among the storage pests, bruchids are known to cause considerable loss. There are more than 100 species of bruchids belonging to 56 genera in five sub families (Southgate, 1979). In India, 117 species belonging to 11 genera have been recorded (Arora, 1977). The genus *Callosobruchus*, includes a number of economically important species that attack stored pulses throughout the world. But, *Callosobruchus maculatus* (Fabricus), *Callosobruchus chinensis* (Linnaeus) and *Callosobruchus analis* (Fabricus) are the important species in India. Among them *Callosobruchus maculatus* (Fabricus) is the most important and the common storage pest of cowpea.

It is evident that all pulses in general and cowpea in particular is susceptible for bruchids due to which the qualitative and quantitative losses during storage are increased. Especially, the cowpea bruchid (*Callosobruchus maculatus* F.) causes considerable loss to cowpea seeds during storage.

Keeping above points in view the present investigation was undertaken with the following objectives:

1. To study the stability of advanced breeding lines in cowpea.
2. Screening of breeding material for resistance to bruchids.

2. REVIEW OF LITERATURE

Cowpea [*Vigna unguiculata* (L.) Walp.] is grown in various regions of India and covers practically all agro-ecological zones. Good progress was also made in breeding early maturing grain type, dual purpose and fast growing fodder type cowpea varieties. Phenotypically stable genotypes are of great importance because the environmental condition vary from season to season and year to year. Wide adaptation to a particular environment and consistent performance of recommended varieties or hybrids are very important for successful cultivation of cowpea. Stable performance of cowpea genotypes across contrasting environments is essential for successful selection of stable and high yielding varieties. Therefore it is important to assess adaptation and yield stability of promising genotypes across environments. The review of literature is presented under the following headings:

2.1 Studies on genotype and environment interaction and stability analysis.

2.2 Studies on screening of breeding material for resistance to bruchids

2.1 Studies on Genotype × environment interaction and stability analysis

Lewis (1954) defined stability as the ability of an individual to produce a certain narrow range of phenotypes in different environments. Adaptation is the property of a genotype which permits subsequent alteration of the norms of the adaption in response to changed selection pressure (Simmonds, 1962).

A specific genotype does not exhibit the same genotypic characters including yield in all environment. The failure of genotype to give the same phenotypic performance when tested under different environment is the reflection of genotype environmental interaction. G × E interaction are of major importance to the plant breeder to develop stable variety (Eberhart and Russell, 1966).

Similarly, yield in cowpea is the result of many interacting yield components such as number of pods per plant, number of seeds per pod and mean seed weight. Yield and its components are affected by various factors including phenological development, planting date, genotypic differences and the environment (Gardener *et al.*, 1985).

Accordingly, Hanumanthraya (2003) evaluated twenty elite lines of cowpea over three locations and concluded that the genotype C-232 was the only genotype found suitable with higher mean value for grain yield. The genotype C-120 showed higher mean value for yield and stability along with adaptability to favorable environments ($b_i > 1$) whereas C-203 possessed stability with lower mean yield and significantly lower b_i value indicating its adaptability to less favorable environments.

Similar results were obtained by Ali *et al.* (2004) based on evaluation of five cowpea genotypes at five different locations. The results showed that varieties, environment and varieties × environment showed significant differences. Significant and highest seed yield (880 kg ha⁻¹) was observed in NIAB cowpea mutant-1 followed by Elite (729 kg ha⁻¹). The highest yielding genotypes *i.e.*, NIAB cowpea Mutant-1 and Elite showed non-significant differences of regression coefficient from

unity. These genotypes also exhibited non-significant difference of standard deviation to regression from zero. Based on three parameters *i.e.*, high mean seed yield, regression coefficient and standard deviation to regression, these genotypes showed excellent and trustworthy stable performance over different environment.

Likewise, Akande (2007) studied the grain yield and number of days to 50 per cent flowering of nine cowpea varieties over four locations within the forest and southern guinea savanna agro-ecologies of Nigeria. Five cowpea varieties were identified to be stable for grain production across locations.

Further, Aremu *et al.* (2007) assessed the $G \times E$ interaction of ten genotypes of cowpea which were grown in four environments comprising the early and late seasons of Ogbomoso and Abeokuta locations. The results showed that regression coefficient for each genotype differed significantly from each other suggesting that the genotypes responded differently to the seasons and the locations. The regression coefficient revealed that IT 97K-499-39, TVX-3236, AGRIBVI, Owode and Ife-brown were environment insensitive and could be cultivated in the early and late seasons.

The grain yield components of eleven cowpea genotypes were studied in 2006 and 2007 by Adewale *et al.* (2010) to understand the sensitivity of the quantitative traits to heterogeneous environments. Results revealed that days to 50 per cent flowering, 100 seed weight and pod yield were significantly ($p \leq 0.05$) influenced by the effect of genotype, year and their interactions. IT 97K-499-35, IT 97-568-18 and IT 95K-2011-11 were identified as the genotypes with high productivity and good genetic stability for pod yield, number of seeds per pod and 100 seed weight, respectively.

Contrastingly, Nelia (2013) reported that there were no significant interactions among the genotypes and the environments ($G \times E$), indicating that genotypes did not respond differently to varying environmental conditions. However, there was variability in the main effects which are genotypes (G) and environments (E)

Similarly, El-Shaieny *et al.* (2015) concluded that the interaction between genotypes and environments ($G \times E$) were non-significant for pod length, hundred seed weight and weight of pods per plant, indicates stability of the studied genotypes for these characters across the environments.

Gabriel *et al.* (2015) evaluated twenty nine cowpea genotypes, including four Ugandan genotypes for grain yield and adaptability under diverse environments. The analysis showed that cowpea grain yield was significantly ($p < 0.01$) affected by genotypes (G), environments (E), and interaction ($G \times E$). Genotype C-2T has the highest grain yield but it was adapted to specific environment. Genotypes C-1J, C-1V, C-2A, C-2O, and C-2R were adapted to three environments with high yield which was stable.

Similar results were obtained by Olayiwola *et al.* (2015) based on evaluation of seven improved cowpea genotypes in four environments during the late seasons of 2009, 2010, 2011 and 2012. Results revealed that there was highly significant genotype $\times$ environment interaction on seed yield ($p < 0.001$) indicating the need for $G \times E$ interaction analysis. Genotypes IT 04K-227-4, IT 04K-333-2, IT 98K-573-1-1 and IT 98K-573-2-1 were identified to have performed above average while IT99K-1060, LDP10-OBR1 and IFE-98-12 yielded below average. LDP10-OBR1 was the most stable genotype but was low yielding.

Olawale *et al.* (2016) reported that twenty one cowpea breeding lines were evaluated for phenotypic stability for seed yield components for two years (2013 and 2014). Results confirmed that all the yield components exhibited significant genotypic variation, while flowering, pod maturity and seed yield traits recorded significant variation for years and its interactions. The genotypes exhibited relative phenotypic stability for the yield components across years except for seed yield. Six cowpea lines (IT 10K-837-1, IT 07K-299-6, IT 10K-815-5, IT 10K-817-7, IT 08K-150-24 and IT 11K-61-82) with multiple quality yield traits were identified as stable genotypes over two years.

Torres *et al.* (2016) conducted six trials of different cowpea genotypes in 2005 and 2006 with the aim of selecting erect cowpea genotypes simultaneously for high adaptability, stability and grain yield. Results confirmed that MNC99542F-5 and MNC99-537F-4 genotypes could be grown in various environments, as they exhibited high grain yield, adaptability and stability.

2.1.1 Other pulses

Since very limited work has been done on stability analysis in cowpea, review of literature on other related pulse like greengram, chickpea and pigeonpea is presented as follows.

2.1.1.1 Greengram

Aparna *et al.* (2012) evaluated the performance of 44 elite mungbean genotypes for nine quantitative traits under three heterogeneous environments for genotype $\times$ environment interactions and stability parameters. Results indicated that, the genotype $\times$ environment interaction was significant for 100 seed weight, number of seeds per pod and days to 50 per cent flowering. Eighteen genotypes were recorded higher seed yields, of which only four genotypes MH-521, GM-9924, ML-1333 and Ganga-8 exhibited stability across environments indicating their adaption to arid and semi-arid regions.

Vijayata *et al.* (2013) reported that pooled analysis of variance indicated highly significant differences for genotypes (G), environments (E) and G $\times$ E interaction in greengram genotypes. Three stability parameters (mean, b_i , S^2di) were computed to judge the suitable and superior genotypes. The deviation from regression for majority of the genotypes was highly significant revealing the unpredictable response of these genotypes and better suitability for sites with better environments.

Mahbubul *et al.* (2014) conducted an experiment to identify mungbean genotypes showing yield stability. Sixteen genotypes were evaluated for two years (2011 and 2012) at three locations. An analysis of variance exhibited significant effects of genotype (G), environment (E) and genotype $\times$ environment (G $\times$ E) on grain yield. Considering G $\times$ E interaction, BM-6 was the best genotype at all three locations in both years. Based on grain yield and stability performance, BM-6 ranked first while the worst performing genotypes were BM-1 and G-10.

2.1.1.2 Chickpea

Babar and Tariq (2009) studied twelve elite chickpea genotypes along with two checks at four diverse locations in Punjab province to assess their stability. The analysis of stability based on mean grain yield, regression coefficient and deviation from regression revealed that the genotypes, CC119/00, CC117/00, CM256/99, CH38/00 and K-70022 were most stable and adapted to the diverse environmental conditions of Punjab.

Table 1: Review of literature on yield and yield contributing traits in cowpea

Material studied	Findings	Author/s
Days to 50 % flowering		
Eight improved genotypes of cowpeas <i>viz.</i> , GC-0119, GC-0121, GC-0203, GC-0502, GC-0510, GC-0521, GC-0525 and GC-0601 and three commercial Checks <i>viz.</i> , GC-3, GC-4 and GC-5 were evaluated over 2 locations for 2 years.	Genotype GC-5 and GC-4 were found to be most stable since they showed regression coefficient value (1.06, 1.16, 0.94 and 0.92, respectively) near to unity, least non-significant deviation from regression.	Patel and Jain (2012)
The study comprised of thirty six entries including eight parents, their twenty eight F ₁ s derived by crossing in all possible combinations excluding reciprocals. These genotypes were tested over four seasons.	Among parents RC-19, GC-3, GC-5 and GC-4 depicted non-significant b _i and S ² di values with desired mean and therefore, considered ideally stable. The three most stable hybrids out of 28 hybrids were GC-3 × V-240 (67.67 days), RC-19 × GC-4 (67.92 days) and GC-3 × RC-19 (69.25 days).	Chaudhari <i>et al.</i> (2013)
Plant height		
Twenty genotypes of cowpea <i>viz.</i> , eight mutants, two local landraces, two released varieties, three backcross derivatives, one tropical <i>vigna</i> variety, one IPS progeny, one germplasm collection and one recombinant line. These were evaluated over three seasons.	The genotypes IL-4, Goa local and IL-2 had higher mean with b _i value more than unity and non-significant deviation from b _i values indicated that they are specially adapted to favorable environments.	Sarvamangala <i>et al.</i> (2010)
Eight improved genotypes of cowpea <i>viz.</i> , GC-0119, GC-0121, GC-0203, GC-0502, GC-0510, GC-0521, GC-0525 and GC-0601 and three commercial Checks <i>viz.</i> , GC-3, GC-4 and GC-5 were evaluated over 2 locations and 2 years.	Genotypes GC-0521, GC-0510 and GC-0119 were found most stable since they showed regression coefficient value (1.04, 1.11 and 0.92, respectively) near to unity, least non-significant deviation from regression and higher mean values.	Patel and Jain (2012)

Contd.....

Table 1 contd.....

Material studied	Findings	Author/s
Seeds per pod		
Eight improved genotypes of cowpea viz., GC-0119, GC-0121, GC-0203, GC-0502, GC-0510, GC-0521, GC-0525 and GC- 0601 and three commercial checks viz., GC-3, GC-4 and GC-5 were evaluated over 2 locations and 2 years.	GC-5 was found most stable since it showed regression coefficient value (0.86) near to unity, least non-significant deviation from regression and higher mean.	Patel and Jain (2012)
The study comprised of thirty six entries including eight parents, their twenty eight F ₁ s derived by crossing in all possible combinations excluding reciprocals. These genotypes were tested over four seasons	Out of 8 parents three GC-3 (12.00), V-240 (12.85) and GC-5 (11.78) possessed non-significant bi and S ² di values coupled with high mean which revealed their average stability across environments. Eight hybrids were exhibit average stability across the environments owing to their higher mean along with non-significant linear and non-linear components.	Chaudhari <i>et al.</i> (2013)
Stability of yield and its attributes were assessed for nineteen genotypes of cowpea over twelve environments (two seasons 2009& 2010 × six planting dates).	IT 93K2042-20, Dokii-331, Cram-7 and Black crowder were considered superior because of their high mean values above the grand mean, besides their stability.	El-Shaieney <i>et al</i> (2015)
100 seed weight		
The study comprised of thirty six entries including eight parents, their twenty eight F ₁ s derived by crossing in all possible combinations excluding reciprocals. These genotypes were tested over four seasons	Two parents GC-4 and V-240 were averagely stable across the environments. Out of 28 hybrids, 8 were found to be averagely stable across the environments. The three best specific combinations were V-240 × HC-0301, GC-3 × GC-5 and GC-4 × DCP-10 having 13.97 g, 13.43 g and 13.10 g mean values, respectively	Chaudhari <i>et al.</i> (2013)

Contd.....

Table 1 contd.....

Material studied	Findings	Author/s
Seed yield (kg ha⁻¹)		
Six improved varieties of cowpea were evaluated for 3 seasons over 4 locations in Uganda.	Across locations and seasons MU-93 produced highest grain yield (1,586 kg ha ⁻¹)	Asio <i>et al.</i> (2005)
Twenty four cowpea varieties were evaluated over twelve locations.	The two lines <i>viz.</i> , Elite and NCP-1 were considered as most stable and adapted genotypes in a wide range of environments.	Yousaf and Sarwar. (2008)
Twenty genotypes of cowpea <i>viz.</i> , eight mutants, two local landraces, two released varieties, three backcross derivatives, one tropical <i>vigna</i> variety, one IPS progeny, one germplasm collection and one recombinant line were evaluated over three seasons	Three genotypes M-17, Bailhongal local, Goa local were considered to be more superior and stable across all the environments as indicated by their higher mean values, bi value lesser than unity and non-significant S ² di.	Sarvamangala <i>et al.</i> (2010)
Eight improved genotypes of cowpeas <i>viz.</i> , GC-0119, GC-0121, GC-0203, GC-0502, GC-0510, GC-0521, GC-0525 and GC-0601 and three commercial Checks <i>viz.</i> , GC-3, GC-4 and GC-5 were evaluated over 2 locations and 2 years	GC-0121 was found most stable since it showed regression coefficient value (1.07) near to unity, least non-significant deviation from regression and higher seed yield.	Patel and Jain (2012)

Adeel *et al.* (2012) evaluated fifteen genotypes of chickpea for stability of different yield parameters under three diverse environments. The results depicted that genotypes 01067, 3CC-113 and AZC-06 showed stable performance for days to flowering and number of pods per plant. The genotypes CMC-211-5 and 3CC-116 depicted stable performance for days to flowering and grain yield per plant. The genotype Bittal-98 was stable for number of pods per plant and grain yield per plant. The genotype CH-24100 was stable for days to flowering and 100 grain weight. The genotype Dasht with the highest grain yield per plant was found stable for 100 grain weight.

Homayoun *et al.* (2015) evaluated fourteen kabuli type chickpea genotypes for seed yield in four stations over three successive years (2010-2013). Several stability parameters were employed to investigate $G \times E$ interaction and to identify the best performing stable genotypes. Based on regression coefficient, genotypes V-1 and V-5 found to be stable and adapted to diverse environments and the other genotypes distributed among stability statistics.

Shivani and Sreelakshmi (2015) studied twenty five genotypes of chickpea for stability for various characters during *rabi* seasons of 2009-10, 2010-11 and 2011-12. Results revealed that none of the genotypes were stable over the environments. However the genotypes ICC-11574 followed by ICC-5034 and ICCV-09104 exhibited below average stability and were specifically adapted to favorable environments.

2.1.1.3 Pigeonpea

Thirty genotypes of pigeon pea were studied by Sreelakshmi *et al.* (2010) for the stability over three *kharif* seasons. They identified the genotypes, ICPL 98008, IC PHAL 4979-2 and ICP 77303 as desirable and stable for days to maturity. Stability parameters along with *per se* performance across seasons revealed that ICPL 20036 and ICPL 20058 were stable genotypes for seed yield and were found to be suitable for poor environment while, ICPL 13198 was found suitable for favorable environment.

Sawargaonkar *et al.* (2011) carried out a study during 2009-10 under four environments to evaluate phenotypic stability of 102 CMS based pigeonpea hybrids and their parents for the yield and yield contributing traits. The results showed that parents HPL 24-63, ICP 3963, ICPA 2043, PHULE T-00-4-11-6-2 and ICP 10934 exhibited general stability for grain yield. The stability analysis further revealed that the hybrids ICPA 2043 $\times$ ICPL 20106 and ICPA 2047 $\times$ ICPL 20106 were stable for days to flowering, days to maturity, pods per plant, pod weight per plant and yield per plant, while hybrids ICPA 2092 $\times$ AKT 9913 and ICPA 2092 $\times$ BSMR 203 exhibited stability for grain yield per plant, plant height and pods per plant.

Uttam *et al.* (2014) evaluated twelve pigeonpea genotypes comprising ten hybrids and two controls at three environments during rainy season of 2012-13 to study genotype $\times$ environment interaction for yield and related traits. They identified ICPH 2671, ICPH 2740, ICPH 3933 and ICPH 3762 as stable hybrids.

2.2 Screening of breeding material for resistance to bruchids

In cowpea, bruchid (*Callosobruchus maculatus*) is the most serious storage pest due to the fact that cowpea is the primary host in India. It causes 90 to 100 per cent loss in seed quality upon progressive storage.

Likewise, Mahgoub *et al.* (2005) conducted an experiment to study the infestation potential of *C. chinensis* and *C. maculatus* (F) on seeds of cowpea, mungbean, lentil, chickpea, kidney bean, peas and broad bean. The data were recorded for susceptibility index values, weight loss and some biological activities. The kidney bean seeds were completely resistant to infestation by both bruchids, while seeds of cowpea and mungbean were completely susceptible.

Similarly, thirty five cowpea genotypes were screened for bruchid resistance by Basavaraj (2010). Results confirmed that significant difference was observed among genotypes to their relative susceptibility to immunity. Comparatively least susceptible genotypes were IC 202784, IC 212872, IC 4506 and IC 198701 while highly susceptible genotypes were IC 214757, IC 198361 and Mumbai local and rest of all were moderate to highly susceptible to bruchid infestation.

Sankie *et al.* (2012) screened seven local cowpea cultivars for susceptibility to *C. maculatus*, in storage for a period of thirty seven days. It is recommended that the Red caloona and Black eye were the least susceptible cultivars.

Shivanna *et al.* (2012) tested different cowpea varieties viz., C-152, KBC-2, KBC-1, KM-5, IT-38956, TVX-944 and CP-17 for their susceptibility to *Callosobruchus maculatus*. Among them, CP-17 was comparatively less preferred host with lesser oviposition (81.33 eggs/100 g seeds) and weight loss of grains (0.96 %) followed by IT-38956.

Badii *et al.* (2013) evaluated twenty two cowpea genotypes for their susceptibility to infestation and damage by the storage beetle, *Callosobruchus maculatus*. The results showed that a significantly higher number of adults emerged from SARC 1-34-2, SARC 1-136-2 and Apabgaala, while SARC 1-132-1, SARC 3-103-1 and SARC 1-119-2 recorded the least. Moreover, Apabgaala, SARC 1-36-1 and Marfo-Tuya recorded the highest percentage weight loss (24.0-29.4 %) while SARC 1-132-1, SARC 3-90-2 and SARC 3-103-1 recorded the least (4.3-9.6 %). Overall, SARC 1-132-1, SARC 3-90-2, SARC 1-91-1, SARC 1-13-2 and SARC 3-103-1 consistently demonstrated high tolerance to infestation by *C. maculatus*.

Ileke *et al.* (2013) investigated on the characteristics of resistance to *Callosobruchus maculatus* in thirty one cowpea cultivars. The study showed that cultivars MIT04K-399-1, MIT07K-299-92, IT96-610, MIT06K-281-1, MIT07K-187-24, MIT06K-121, MIT07K-304-9 and EIT07K-291-69 were the least susceptible to *C. maculatus* with percentage seed damage of zero. The most susceptible cultivar was IFE BROWN with highest percentage adult emergence of 79.19 per cent, highest percentage seed damage of 31.45 per cent, highest percentage weight loss of 10.9 per cent and least percentage seed viability of 60 per cent.

Table 2: Review of literature on Screening of breeding material for tolerance to bruchids in different pulses

Material studied	Findings	Author/s
cowpea		
Sixty three genotypes of cowpea	Genotype IC -58905, EC-240922A and Nic-1066 with growth indices of 0.96, 1.06 and 1.30, respectively were found to be superior to others in terms of bruchid resistance.	Bhalla <i>et al.</i> (2002)
Nine different varieties of cowpea	KM-1, Goa local, T-I and TVx 944 were least susceptible to <i>C. chinensis</i> and the genotypes DCP-2, V-118, T-4, C-3 and KM-4 were susceptible.	Nagaraja (2006)
Ninety genotypes of cowpea	The extent of dry weight loss was significantly higher in the susceptible genotypes. In case of susceptible genotypes the weight loss is recorded upto 42.02 per cent in IT 97K-1069-2.	Debbyoti and Indra (2011)
Ten landraces of cowpea	The landraces B-339, B-383, B-013-F and B-261-B had significant lower percentage adult emergence and oviposition than the landraces B-001-B, B-055, B-109-C and B-154. The landraces B-339, B-383, B-013-F and B-261-B also significantly prolonged developmental period of beetles. The reduction in oviposition, beetle emergence and prolonged developmental period by these landraces indicate inherent level of resistance against <i>C. maculatus</i> .	Motshwari <i>et al.</i> (2011)
Greengram		
Six wild <i>Vigna radiata</i> germplasm and four popular cultivars.	Resistance to bruchids was identified in a wild greengram <i>Vigna radiata</i> var. <i>sublobata</i> namely Sub2. All the cultivars showed susceptibility against bruchids.	Sutanu and Somnath (2015)
Eighty five green gram accessions.	Two accessions viz, Km-12-5 and P-S-16 revealed lesser per cent adult emergence of 12.22 and 14.29, respectively. Prolonged developmental period (25.67 and 26.00 days, respectively) and lesser susceptibility index (0.042 and 0.044 respectively) in comparison to highly susceptible Ganga 8, which exhibited a survival of 71.67 %, developmental period of 20.67 days and susceptibility index of 0.09.	Soumia <i>et al.</i> (2015)
Chickpea		
Twelve chickpea varieties	ICC-10 was the most susceptible and IC CV-0331 was least susceptible to <i>Callosobruchus chinensis</i>	Parameshwarappa <i>et al.</i> (2007)

Amusa *et al.* (2014) screened ten bruchid resistant varieties collected from the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Nine of the varieties studied showed percentage seed damage above 80 per cent and percentage pest tolerance below 50 per cent. Susceptibility index indicates that seven of the studied varieties were moderately resistant and the remaining three were resistant to the bruchid infestation with TVu 11953 being the most resistant of all with index 1.78.

Likewise, three cowpea varieties namely Kafanji, Brown variety and Ex-potiskum were evaluated by Mogbo *et al.* (2014) for bruchid resistance. The results were analyzed statistically and the differences between the treatments with respect to weight loss and adult emergence were significant ($p > 0.05$). Kafanji suffered more damage while the Brown variety and Ex-potiskum suffered less damage. This indicates that Ex-potiskum and Brown-variety exhibits more resistance qualities to the weevil attack than Kafanji which is more susceptible to the weevil attack.

Kuldeep *et al.* (2015) screened 52 accessions of cowpea including two checks (Pusa Komal and Local variety) for resistance to pulse beetle, *Callosobruchus chinensis*. There were significant differences among the accessions in terms of number of eggs laid, adult emergence, number of emergence holes and weight loss. Among the 52 accessions screened, 11 accessions were resistant, 15 moderately resistant, 13 moderately susceptible, 8 susceptible and 5 were highly susceptible to *C. chinensis*.

3. MATERIAL AND METHODS

The performance of a variety is a result of interaction between the genetic constitution and environment in which it is grown. Practically it may be possible that same phenotypic performance may not be exhibited under different environments. This variation makes it difficult to judge the genetic potential of the varieties. Hence, to overrule the role of environment, it is essential to grow varieties over different environments to know the stable performance of genotypes.

The present study was undertaken as mentioned below.

3.1 To study the stability of advanced breeding lines in cowpea

This experiment was conducted for two seasons.

3.1.1 Season 1: Preliminary screening

Preliminary screening was undertaken during summer-2015.

3.1.2 Experimental material

The experimental material comprised of one hundred and eighty eight promising advanced breeding lines (F_4 , F_5 , F_7 , F_8 and BC_1F_5 generations) of different crosses, promising germplasm lines and four checks. The details of checks used is as follows.

Checks

DCS-47-1-Identified for Southern states of India in All India Co-ordinated Crop Improvement Project and notified variety for zone 8 of Karnataka

DC-15-Promising entry in state multilocation trials and also in national co-ordinated trials (AVT II) contributed by Dharwad centre.

C-152-Highly adapted popular variety in northern Karnataka.

DC-16-Promoted entry to AVT II under AICRP trials of Arid Legumes.

3.1.3 Experimental design and layout

The experiment was laid out in Augmented design-II. The plot size was three rows of three meter length. The row spacing was 45 cm and 15 cm between the plants. The crop was raised by following the recommended agronomic practices. The crop stand and growth were satisfactory.

3.1.4 Experimental location

The experimental material was grown in Botanical garden, Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad during summer season of 2015.

3.1.5 Methodology

All the promising advanced breeding lines (188 numbers) were sown in Augmented-II design along with checks. Thirty promising genotypes among these advanced breeding lines were selected based on high yield performance for the stability analysis.

3.1.6 Observations recorded

Five plants were randomly selected in each genotype and labeled. Observations on plant morphological characterization were recorded on these plants at different stages of crop growth.

3.1.6.1 Days to 50 per cent flowering

The number of days taken from sowing to the opening of flowers in 50 per cent of plant population in each genotype was recorded.

3.1.6.2 Plant height

The plant height was measured in centimeters (cm) from the ground level to tip of the main stem of the plant at the time of harvesting.

3.1.6.3 Pod length

It was measured from the randomly selected five pods from each genotype at the time of harvest and expressed in centimeters (cm)

3.1.6.4 Number of seeds per pod

Number of seeds per pod was taken as mean number of seeds of five representative pods measured for length.

3.1.6.5 Number of pods per plant

Total numbers of pods per plant were counted from five plants at the time of harvest.

3.1.6.6 100 seed weight

Hundred seeds each in three replications were counted and weighed separately and the mean weight was expressed in grams (g).

3.1.6.7 Seed yield

The seed yield obtained from the net plot area of each genotype was added with the yield obtained from five earlier tagged and harvested plants. The seeds were cleaned after threshing of pods manually with wooden mallet and dried in shade for five days up to 12 per cent moisture level. The seed yield per hectare was computed and expressed in kilo grams per hectare (kg ha^{-1}).

3.2 Stability analysis

A field experiment was conducted at three locations of north Karnataka during *kharif*-2015 and summer-2016 to ascertain the superiority in production and yield stability among thirty promising genotypes of cowpea. The details of the material used and techniques adopted for analysis and interpretation are described here under.

3.2.1 Experimental location

The experimental material was evaluated over three different environments. The locations were Botanical garden, Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad, Agriculture Research Station, Bailhongal and Agriculture Research Station Malgi. The experiment was conducted during *kharif*-2015 at Dharwad and Bailhongal and during summer-2016 at Malgi.

Location	Agro-climatic zones	Rainfall situation during crop growth period	Latitude	Longitude	Altitude (above MSL)	Soil Type	Season
Botanical Garden, Dharwad (Environment-1)	Northern transition zone (Zone-8)	Medium rainfall	15° 26` N	75° 07` E	768.0m	Shallow soil	<i>Kharif</i> -2015
Agriculture Research Station, Bailhongal (Environment-2)	Northern transition zone (Zone-8)	Poor/scanty rainfall	16° 00` N	75° 05` E	680 m	Medium black soil	<i>Kharif</i> -2015
Agriculture Research Station, Malgi (Environment-3)	Hilly zone (Zone-9)	Residual moisture (paddy fallows)	14° 74`N	75° 00`E	815.0m	Red loamy soil	Summer-2016

3.2.2 Experimental material

The experimental material consisted of 27 superior stabilised lines for yield *per se* in F₆ generation and 3 germplasm lines were selected out of 188 advanced breeding lines and promising germplasm lines. These were compared with four check varieties. The list of genotypes is given in Table 3.

3.3 Statistical analyses

Data collected on individual plants of each genotype at each location were used to calculate mean, genetic parameters and for stability analysis.

Table 3. List of advance stabilized lines in F₆ generation and germplasm lines selected for stability analysis

Sl. No	Genotypes	Sl. No	Genotypes
1	GC-3 × IC 198333	16	C-152 × IC 201079
2	DC -15 × JOB-129	17	GC-3 × IC 202872
3	C-152 × IC 202790	18	V-118 × IC 249141
4	DCS-47-1 × GC-3	19	C-152 × IC 202825
5	IC 202730 (Germplasm)	20	V-118 × IC 27502
6	IC 202779 (Germplasm)	21	V-118 × IC 249132
7	IC 249141 (Germplasm)	22	IC 202778 × IC 214836
8	DC -15 × NBC -1	23	IC 202778 × IC 202787
9	C-152 × DCS-5-3-20	24	V-118 × IC 249140 -1
10	DCS-47-1 × DC-15	25	V-118 × IC 68786
11	DC-15 × Subhra	26	C-152 × IC 97767
12	C-152 × CP-206	27	V-118 × IC 249140-2
13	GC-3 × C-152	28	DC-15 × DCS-47-1
14	V-118 × GL	29	C-152 × IC 202710
15	C-152 × IC 198701	30	C-152 × IC 249140



Experiment taken at Botanical garden, College of Agriculture, UAS, Dharwad



Experiment taken at Agricultural Research Station, Bailhongal



Experiment taken at Agricultural Research Station, Malgi

Plate 1: General view of the experimental plots

3.3.1 Analysis of variance

The mean values of the genotypes were used for analysis of variance. Replication wise mean values were subjected to RBD analysis (Snedecor and Cochran, 1967). The significant differences among the genotypes were tested using 'F' test.

Sources of variation	d.f.	MSS	Expectations	Variance ratio or 'F'
Replication	r-1	RMSS		
Genotypes	v-1	VMSS	$\sigma^2_e + r \sigma^2_g$	VMSS/ EMSS
Error	(r-1) (v-1)	EMSS	σ^2_e	
Total	(rv-1)			

Where,

r = number of replications

v = number of genotypes

σ^2_g = genotypic variance

σ^2_e = environmental variance

3.3.2 Mean and range

- General mean ($\bar{X}$) = Sum of observations of all the genotypes/number of genotypes
- Range = The minimum and maximum values for each trait among the genotypes.

3.3.3 Estimation of genetic parameters

In order to assess and quantify the genetic variability among the genotypes for quantitative characters under study, the following parameters were estimated.

a) Estimation of variance components

Phenotypic and genotypic variance were estimated using the following formula

$$\text{Genotypic variance } (\sigma^2_g) = \frac{\text{MSS (genotype)} - \text{MSS (error)}}{\text{Number of replications}} = \frac{M_2 - M_3}{r}$$

$$\text{Phenotypic variance } (\sigma^2_p) = \text{Genotypic variance } (\sigma^2_g) + \text{Environmental variance } (\sigma^2_e)$$

b) Coefficients of variability

Both genotypic and phenotypic coefficients of variability were computed as per the method suggested by Burton and Devane (1953).

$$\text{a) Genotypic coefficient of variability (GCV)} = \frac{\sigma_g}{\bar{X}} \times 100$$

$$\text{b) Phenotypic coefficient of variability (PCV)} = \frac{\sigma_p}{\bar{X}} \times 100$$

Where,

σ_g = Genotypic standard deviation

σ_p = Phenotypic standard deviation

$\bar{X}$ = General mean of the character.

GCV and PCV values were categorized as low, moderate and high by Shivasubramanian and Menon (1973) as given below.

0-10 % : Low

10-20 % : Moderate

20 % and above : High

c) Heritability (h^2)

Heritability in broad sense was estimated as the ratio of genotypic variance to the total phenotypic variance as suggested by Hanson *et al.* (1956) and expressed as percentage.

$$\text{Heritability } (h^2_{bs}) = (\sigma_g^2 / \sigma_p^2) \times 100$$

Where,

σ_g^2 = Genotypic variance

σ_p^2 = Phenotypic variance.

The heritability percentage was categorized as low, moderate and high as given by Robinson *et al.* (1949).

0-30 % : Low

30-60 % : Moderate

60 % and above : High

d) Genetic advance (GA)

Genetic advance was estimated by using the formula given by Johnson *et al.* (1955).

$$GA = h^2 k \sigma_p$$

Where,

h^2 = Heritability in broad sense

k = Selection differential which is equal to 2.06 at 5 per cent intensity of selection

σ_p = Phenotypic standard deviation.

e) Genetic advance as per cent of mean (GAM)

$$GAM = \frac{GA}{\bar{X}} \times 100$$

Where,

GA = Genetic advance

$\bar{X}$ = General mean of the character.

Genetic advance as per cent mean was categorized as low, moderate and high by Johnson *et al.* (1955).

0-10 % : Low
10-20 % : Moderate
20 % and above : High

3.3.4 Two way analysis of variance

The data obtained for all characters on all genotypes across locations was subjected to two way analysis of variance using the method outlined by Sundaraj *et al.* (1972). This was done for each character in order to find out the variation due to genotypes and environments and to reveal the existence of genotype $\times$ environment interaction, if any. Only after ascertaining the significance of genotypic $\times$ environment interaction in the two way analysis of variance, the data was further subjected to stability analysis.

Pooled analysis of variance

Source of variation	d.f.	MSS	Expected value of MSS	Cal F.
Environment	(e-1)			-
Genotype	(g-1)	M_1	$\sigma_e^2 + \sigma_{ge}^2 + e\sigma_g^2$	-
Genotype x Environment	(g-1) (e-1)	M_2	$\sigma_e^2 + \sigma_{ge}^2$	-
Pooled error	M^*	M_3	σ_e^2	-

* Degrees of freedom pooled over environments

3.3.5 Stability analysis

To analyze the data over three environments (locations) the stability model proposed by Eberhart and Russell (1966) was adopted. The model involves the estimation of three stability parameters *viz.*, mean, regression coefficient and deviation from regression, which are defined by the mathematical formula,

$$Y_{ij} = \bar{\mu}_i + b_i I_j + S_{ij}$$

Where,

Y_{ij} = Mean of the i^{th} genotype at the j^{th} environment.

$\bar{\mu}_i$ = Mean of i^{th} genotype over all environments.

b_i = The regression coefficient that measures the response of i^{th} genotype to varying environments.

I_j = The environmental index obtained by subtracting the grand mean from the mean of all genotypes at the j^{th} environment.

S_{ij} = The deviation from regression of the i^{th} genotype at the j^{th} environment.

These parameters were calculated as follows.

- a. Environment index = I_j = environment mean – grand mean

$$I_j = \bar{Y}_{.j} / t - \bar{Y}_{..} / ts$$

Where,

t = Number of genotypes

s = Number of environments

With $\sum_j y_j = 0$

- b. Regression coefficient (for each genotype)

$$b_i = \sum_j Y_{ij} I_j / \sum_j I_j^2$$

- c. Deviation from regression

$$S^2_{di} = (\sum_j s^2_{ij} / n - 2) - (S^2_e / r)$$

Where,

S^2_e / r = mean square for estimate of pooled error.

- d) Predicted performance of the genotype

$$Y_{ij} = X_i + b_i I_j$$

Where,

X is the estimate of $\bar{Y}_{.i}$

With this model, the variation due to environment and genotype $\times$ environment were partitioned into environment (linear), genotype $\times$ environment (linear) and deviation from the regression coefficients.

ANOVA for stability

Source	d.f.	M.S.S.	F test
Genotype (V)	(v-1)	MS ₁	MS ₁ /MS ₃
Environment (E)	v (n-1)		
Environment (E) (linear)	1		
Genotype $\times$ Environment (linear)	(v-1)	MS ₂	MS ₂ /MS ₃
Pooled deviations	v (n-2)	MS ₃	
Pooled error	n (r-1) (v-1)	Me	
Total	(nv-1)		

Where,

n : Number of environments

v : Number of genotypes

r : Number of replications

- a) To test the significance of pooled deviation mean square against the pooled error mean square *i.e.*, `F` test was conducted.

$$F = MS_3 / Me$$

If pooled deviation mean square is found significant then it would be the appropriate denominator to test the significance of all components including genotype and G × E (linear). Otherwise, pooled error mean square is appropriate denominator.

- b) To test the significance of the differences among the genotype means

$$F = MS_1 / MS_3$$

Where,

MS₁ : Mean sum of squares of varieties

MS₃ : Mean sum of squares of pooled deviation

- c) To test that genotypes do not differ for their regression on the environmental index

$$F = MS_2 / MS_3$$

Where,

MS₂ : Mean sum of squares of genotype × environment (linear)

MS₃ : Mean sum of squares of pooled deviation

- d) To test individual deviation from linear regression

$$F = (\sum_j \sigma_{ij}^2 / n - 2) / \text{Pooled error (Me)}$$

Where,

n : Number of environments

$\sum_j \sigma_{ij}^2$: Sum of squares of deviations from the regression line

Me : Pooled error

A joint consideration of the following three parameters is used to define the stability of a genotype,

- i) The mean performance of the genotype over the environments, X_i
- ii) The regression coefficient, b_i and
- iii) The deviation from linear regression, S^2_{di}

The estimate of deviation from regression suggests the degree of reliance that should be put on linear regression in interpretation of the data. If these values are significantly deviating from zero, the expected phenotype cannot be predicted significantly. When deviations are not significant, the conclusion may be drawn by the joint consideration of mean yield and regression values (Finlay and Wilkinson, 1963 and Eberhart and Russell, 1966) as given below.

Regression coefficient	Stability	Mean yield	Remarks
$b_i = 1$	Average	High	Well adapted to all environments
$b_i = 1$	Average	Low	Poorly adapted to all environments
$b_i > 1$	Below average	High	Specifically adapted to favourable environments
$b_i < 1$	Above average	High	Specifically adapted to unfavourable environment

Regression values of unity are interpreted as average stability.

3.4 Screening of cowpea genotypes for resistance to bruchid

Cowpea is an important legume in many developing countries, is facing varieties of biotic stresses among which, bruchid (*Callosobruchus maculatus*) a storage insect pest capable of causing high grain loss both in quantity and quality constitute a major problem to cowpea production. Several attempts to preserve the seeds through chemical means are expensive and have sometimes results in food poisoning and environmental toxicity (Olakojo *et al.*, 2007). This suggests the need for alternative management method that would protect both the crop and also the environment.

The present study was undertaken as mentioned below.

3.4.1 Material used for study

The F_2 population generated earlier between cross DC 615 × Dharwad local was used for the present study. The F_2 population was selfed using selfing nets to generate F_3 population during *kharif*-2015. Selected F_3 progenies of the cross were screened for resistance to bruchids during summer-2016.

3.4.2 Main rearing of test insects

Initial culture of *Callosobruchus maculatus* was obtained from the infected grains of cowpea from the farm stores. They were reared and maintained on cowpea by releasing ten pairs of freshly emerged larvae in stem jars and mouth of the jar was covered with muslin cloth fastened by rubber band.



Resistant parent - Dharwad local



Susceptible parent - DC-615



F₂ population of DC-615 x Dharwad local

Plate 2: Parents and F₂ Populations

3.4.3 Method

1. Seeds of each selected plants weighing 10 g were kept in a bottle of plastic glass of 100 ml capacity.
2. Four pairs of five days old weevils were introduced in each plastic glass and tops were kept covered with muslin cloth and tightly secured by rubber bands.
3. These were kept under normal room temperature and humidity for a period of 30 days.
4. After the specified period each bottle was examined for loss of weight and per cent damaged seeds.
5. Damaged seeds were counted and per cent damage was computed.

3.4.3.1 Initial observations recorded

3.4.3.1.1 Seed moisture

The moisture content of seeds was determined by the oven dry ($103 \pm 1^{\circ}\text{C}$ for 17 hours) method as per ISTA rules (Anon., 1999). The moisture content on wet basis was determined and expressed in percentage using the following formula.

$$\text{Moisture content (\%)} = \frac{M_2 - M_3}{M_2 - M_1} \times 100$$

Where

M_1 – Weight of the empty metal box (g)

M_2 – Weight of metal box with seed sample before drying (g)

M_3 – Weight of metal box with seed sample after drying (g)

3.4.3.1.2 Germination percentage

Hundred seeds were taken from each genotype and subjected for standard germination. Seeds were placed at equidistance between two layers of moist germination paper and then germination papers were rolled into towels and kept in the germinator at $30^{\circ} \pm 1^{\circ}\text{C}$ (Anon., 1999). Number of normal seedlings on seventh day was counted and germination was expressed in percentage.

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



Seeds of susceptible parent - DC-615



Seeds of resistant parent - Dharwad local



White seeded F₃ segregant



Brown seeded F₃ segregant

Plate 3: Seeds of resistant and susceptible and F₃, Segregants

3.4.3.1.3 Seedling length

From the germination test, ten random seedlings from each of the genotype were carefully removed on 8th day and used for measuring seedling length. The seedling length from tip of shoot to tip of root was measured and the average length of the seedling was expressed in centimeters (cm).

3.4.3.1.4 Seedling vigour index

Seedling vigour index was calculated by following formula as per Abdulbaki and Anderson (1973).

$$\text{Seedling vigour index} = \% \text{ germination} \times [\text{mean root length (cm)} + \text{shoot length (cm)}]$$

3.4.3.1.5 Seedling dry weight

From the germination test, ten normal seedlings from each of the genotype were taken and dried in hot air oven. The seedling dry weight was recorded and expressed in grams (g).

3.4.3.2 Final observations recorded

Germination percentage, seedling length (cm), seedling vigour index, seedling dry weight (g) from each genotype was recorded.

3.4.3.2.1 Determination of seed loss due to bruchid infestation

To estimate actual and apparent loss in weight of cowpea seeds caused by bruchid infestation, seeds from each genotype were taken after specified period (30 days) and below observations were recorded.

1. Number of damaged seeds [seeds showing emergent holes] (Nd).
2. Number of undamaged seeds (Nu).
3. Weight of damaged seeds (D).
4. Weight of undamaged seeds (U).
5. Total number of seeds in 10 g (Nd + Nu).

The per cent actual loss was calculated by using the following formula (Adams and Schulten, 1978).

$$\text{Per cent actual weight loss} = \frac{U (Nd) - D (Nu)}{U (Nu + Nd)} \times 100$$

The per cent loss in weight was worked out using the following formula (Girish *et al.*, 1975).

$$\text{Per cent apparent weight loss} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$



Plate 4. Experimental set up for screening of bruchid resistance

In general,

$$\text{Per cent apparent loss} = \frac{W_i - W_n}{W_i} \times 100$$

Where,

W_i = Initial weight of seeds at the beginning experiment

W_n = Weight of seeds after 'n' months (1 month)

$$\text{Per cent infestation} = \frac{\text{Number of seeds with emergent holes}}{\text{Total number of seeds observed}} \times 100$$

$$\text{Per cent damage} = \frac{(\text{Initial weight} - \text{Weight of undamaged seeds})}{\text{Initial weight}} \times 100$$

$$\text{Per cent loss in seed viability} = 100 - \frac{\text{Seed viability at the end}}{\text{Seed viability at the initial}} \times 100$$

Based on above parameters, cowpea genotypes were classified as moderately resistant, least susceptible, moderately susceptible and highly susceptible groups against the bruchid infestation during storage based on the earlier classification as reported by Nagaraj (2006). The classification is as follows:

Class	Per cent bruchid infestation
Highly resistant	0-20
Moderately resistant	21-40
Least susceptible	41-60
Moderately susceptible	61-80
Highly susceptible	81-100

4. EXPERIMENTAL RESULTS

The aim of this study was to analyze the stability of 30 promising advanced breeding lines of cowpea for yield and yield attributing traits and to find out reaction of 250 F₃ segregants of cowpea for bruchid (*Callosobruchus maculatus*) infestation. The experimental results are presented under the following seven broad heading.

Experiment-I

4.1 Analysis of variance

Experiment 2

4.2 Analysis of variance for the locations.

4.3 Variability studies across locations

4.4 Performance of genotypes in different environments

4.5 Genotype × environmental Interaction.

4.6 Stability analysis.

Experiment 3

4.7 Screening for bruchid (*Callosobruchus maculatus*) resistance.

4.1 Analysis of variance

The results pertaining to analysis of variance are presented in Table 4. The analysis of variance indicated significantly higher amount of variability for yield and yield attributing traits for 188 promising advanced breeding lines of cowpea. The characters studied viz., plant height, pod length, number seeds per pod, 100 seed weight and seed yield show significance at both 5 per cent and 1 per cent level of significance.

4.2 Analysis of variance for the locations

Location wise analysis of variance was carried out for yield and yield attributing traits in 34 cowpea genotypes to partition the total variance (mean sum of squares) due to known and unknown causes using the method suggested by Lush (1949). The results are presented in Table 5. As reflected by ANOVA, all the traits exhibited significant genotypic differences in all the environments.

4.3 Variability studies across locations

The data collected on each of the characters of thirty four genotypes of cowpea were pooled and analyzed to find out their performance across the locations. The values of mean, range and genetic parameters for different traits are presented in Table 6.

Table 4: Analysis of variance for yield and yield attributes in cowpea (summer -2015)

	df	Days to 50 % flowering	Plant height (cm)	Pod length (cm)	Number of seeds per pod	Number of pods per plant	100 Seed weight (g)	Seed yield (kg ha ⁻¹)
Block (eliminating Check+ Var)	3	0.40	0.00	0.00	0.00	47.83	0.39	79561
Entries (ignoring Blocks)	191	4.52	6.05**	2.79 **	1.90**	61.63	16343.57 **	201346.40 *
Checks	3	0.73	7.58**	6.98 **	6.51**	70.67	1.297 **	54733.22
Varieties	187	4.60	5.27**	2.69 **	1.73 **	61.81	16670.19 **	205036.38*
Checks vs. Varieties	1	0.91	148.14**	8.10 **	20.78**	0.10	4292.44**	3894972.00 **
Checks+Var vs. Var.	188	4.30	5.84**	2.35 **	1.74**	59.52	16302.70**	197482.00 *
ERROR	9	1.79	0.00	0.00	0.00	45.73	0.089	70702.20
Ci – Cj	1	2.14	0.00	0.02	0.01	10.82	0.478	425.33
Ci – VI	1	3.78	0.01	0.03	0.03	19.12	0.844	751.88

* - Significant at 5 % level of significance ** - Significant at 1 % level of significance

Table 5: Analysis of variance for yield and yield attributing traits across three locations in cowpea

	Characters	Bailhongal (<i>kharif</i> -2015)			Dharwad (<i>kharif</i> -2015)			Malgi (summer-2016)		
		Replication	Genotype	Error	Replication	Genotype	Error	Replication	Genotype	Error
1	Days to 50 % flowering	0.15	16.46**	0.23	2.12	14.56**	0.23	0.07	4.87**	0.28
2	Plant height (cm)	2.29	18.34**	2.62	4.34	11.29**	6.70	10.57	55.15**	3.48
3	Pod length (cm)	0.67	5.64**	0.32	0.12	2.69**	1.20	0.30	2.73*	0.58
4	Number of seeds per pod	1.66	5.72**	0.60	1.11	3.09**	1.27	16.54	9.92**	7.44
5	Number of pods per plant	7.94	62.96**	3.06	6.7	74.22**	2.10	12.07	123.06*	3.94
6	100 seed weight (g)	0.49	5.42**	2.69	0.79	3.53**	0.28	2.85	5.93**	0.61
7	Seed yield (kg ha ⁻¹)	9,562	1,41,914.39**	6,002.41	3428.36	2,39,445.61**	3,479.92	1,494.25	2,43,639.57**	7,239.57

* - Significant at 5 % level of significance ** - Significant at 1 % level of significance

4.3.1 Days to 50 % flowering

The overall mean of the genotypes for days to 50 % flowering was 57.92. Among all genotypes, the F₆ line DC-15 × JOB-129 required more number of days (60.11), while the F₆ line DCS-47-1 × GC-3 required less number of days (55.89) to 50 % flowering.

Low phenotypic coefficient of variation (3.55) and genotypic coefficient of variation (2.42) were observed for this character, indicating low environmental effect on this trait. Moderate heritability (46.30 %) and the low genetic advance (1.96) and genetic advance as per cent of mean (3.39) were noticed for this trait

4.3.2 Plant height

Plant height among the genotypes ranged from 32.07 cm to 39.9 cm with an overall mean of 36.64 cm.

Low phenotypic coefficient of variation (9.54) and genotypic coefficient of variation (5.00) were observed for this character, indicating low environmental effect on this trait. This trait exhibited low heritability estimate (27.5 %) coupled with low genetic advance (5.41) and genetic advance as per cent of mean (5.41 %).

4.3.3 Pod length

The variation for this trait was less as evident from the narrow range observed (14.99 cm to 17.88 cm). The F₆ line DCS-47-1 × GC-3 showed mean value of 17.88 having the longest pods, the C-152 (check 1) with mean value 14.99 cm having the shortest pods among all genotypes studied.

This trait shows low phenotypic coefficient of variation (8.02) and genotypic coefficient of variation (3.98) and exhibited low heritability (24.60 %) along with low genetic advance (0.66) and genetic advance as per cent of mean (4.06).

4.3.4 Number of seeds per pod

Overall mean of the genotypes for number of seeds per pod was 14.05. Among all genotypes, the highest number of seeds per pod was observed for F₆ progeny C-152 × DCS-5-3-20 (15.18) while C-152 (check 1) had the lowest seeds per pod (13.22).

The character showed moderate phenotypic coefficient of variation (12.69) and low genotypic coefficient of variation (8.29) and recorded moderate (42.73 %) heritability with low genetic advance (1.57) and moderate genetic advance as per cent of mean (11.57).

4.3.5 Number of pods per plant.

The variation for this trait was considerably high as evident from the wide range observed (8.22 to 21.53). The mean number of pods per plant was 13.95. The F₆ progeny DC-15 × DCS-47-1 borne maximum pods per plant (21.53) while GC-3 × IC 198333 borne the minimum number of pods per plant (8.22).

Table 6: Pooled analysis of mean, range and genetic parameter values for yield and yield attributing traits in cowpea across three locations

	Characters	Mean	Range		Coefficient of variation		GA	GAM	h ² (%)
			Min.	Max.	Genotypic	Phenotypic			
1	Days to 50 % flowering	57.92	55.20	60.11	2.42	3.55	1.96	3.39	46.30
2	Plant height (cm)	36.64	32.07	39.90	5.00	9.54	1.98	5.41	27.50
3	Pod length (cm)	16.25	14.99	17.88	3.98	8.02	0.66	4.06	24.60
4	Number of seeds per pod	14.05	13.15	18.00	8.29	12.69	1.57	11.57	42.73
5	Number of pods per plant	13.95	8.22	21.53	20.29	39.80	2.97	21.30	26.00
6	100 seed weight (g)	11.75	10.46	15.04	8.59	11.71	1.53	13.00	53.90
7	Seed yield (kg ha ⁻¹)	1,021.49	622.87	1,450.41	15.16	27.46	176.05	17.23	30.50

Table 7: Mean values and environmental indices for yield and yield attributing traits in cowpea genotypes over three locations.

Sl. No	Characters	Mean			Overall mean	Environmental Indices		
		Dharwad	Bailhongal	Malgi		Dharwad	Bailhongal	Malgi
1	Days to 50 % flowering	53.95	54.49	65.15	57.86	-3.91	-3.37	7.28
2	Plant height (cm)	33.09	34.13	43.50	36.91	-3.81	-2.77	6.58
3	Pod length (cm)	15.14	16.72	16.88	16.25	-1.10	0.47	0.63
4	Number of seeds per pod	12.49	14.67	15.26	14.10	-1.64	0.52	1.12
5	Number of pods per plant	15.77	12.37	13.88	14.00	1.76	-1.63	-0.12
6	100 seed weight (g)	10.98	10.90	13.36	11.75	-0.76	-0.84	1.61
7	Seed yield (kg ha ⁻¹)	1,031.49	782.39	1,287.53	1,021.50	-2.31	-251.41	253.72

High phenotypic coefficient of variation (39.80) and genotypic coefficient of variation (20.29) were observed for this character. This trait recorded low heritability (26.00 %) coupled with low genetic advance (2.97) and high genetic advance as per cent of mean (21.3).

4.3.6 100 seed weight

Overall mean of the genotypes for 100 seed weight was 11.75 g. Among all genotypes, the F_6 genotype of cross GC-3 $\times$ IC 198333 recorded maximum 100 seed weight (15.04 g), while F_6 genotype of cross V-118 $\times$ IC 249141 recorded minimum 100 seed weight (10.46 g).

Moderate phenotypic coefficient of variation (11.71) and genotypic coefficient of variation (8.59) were observed for this character. Moderate (53.90) heritability with low genetic advance (1.53) and moderate genetic advance as per cent of mean (13.00), was evident for this trait.

4.3.7 Seed yield

The variation for seed yield was considerably high as evident from the wide range observed (622.87 to 1,450.41 kg ha⁻¹). The F_6 line DC-15 $\times$ DCS-47-1 was the highest yielder (1,450.41 kg ha⁻¹) while, the F_6 line C-152 $\times$ IC 249140 was the lowest yielder (622.87 kg ha⁻¹) among all the genotypes. The overall mean was 1,021.49 kg ha⁻¹.

High phenotypic coefficient of variation (27.46) and moderate genotypic coefficient of variation (15.16) were observed for this character. This character exhibited moderate (30.50) heritability along with high genetic advance (176.05) and moderate genetic advance as per cent of mean (17.23).

4.4 Performance of genotypes in different environments

The data obtained from 30 advance breeding lines along with checks in cowpea for each of eight characters was analyzed individually to find out, the performance of genotypes in all the three environments. Mean, overall mean and environmental indices are presented in Table 7.

4.4.1 Days to 50 % flowering

The mean value for days to 50 % flowering was maximum at Malgi (65.15) and minimum at Dharwad (53.95). The environments for this character differed significantly as indicated by the environmental indices (-3.91 to 7.28).

4.4.2 Plant height

The mean value for plant height was maximum (43.50 cm) at Malgi and minimum at Dharwad (33.09 cm). The environmental indices differed much varying from -3.81 to 6.58. The environment at Malgi was found to be more favourable to plant height since the mean plant height was maximum with maximum environmental index (6.58).

4.4.3 Pod length

The mean value for pod length was maximum (16.88 cm) at Malgi and minimum at Dharwad (15.14 cm). The environmental indices ranges from -1.10 to 0.63, it indicates the influence of environment for this trait is minimum.

4.4.4 Number of seeds per pod

The maximum mean value for number of seeds per pod was observed at Malgi (15.26) while minimum mean value was observed at Dharwad (12.49). The environmental indices ranges from -1.64 to 1.12, it indicates the changes in environments did not differ trait significantly.

4.4.5 Number of pods per plant

The mean value for number of pods per plant was maximum (15.77) at Dharwad and minimum at Bailhongal (12.37). The environmental indices ranged from -1.63 to 1.76.

4.4.6 100 seed weight

The maximum mean value for 100 seed weight was observed at Malgi (13.36 g) while minimum mean value was observed at Bailhongal (10.90 g). The environmental indices ranged from -0.84 to 1.61.

4.4.7 Seed yield

The mean seed yield was maximum (1,287.53 kg ha⁻¹) at Malgi and minimum at Bailhongal (782.39 kg ha⁻¹). The environmental indices differed much varying from -251.41 to 253.72. The environment at Malgi was found to be more favorable since the mean seed yield was maximum with maximum environmental index.

4.5 Genotype × environmental interaction

The data was subjected to pooled analysis after the variances were found to be homogenous. Pooled analysis of variance for yield and yield attributing traits across the three locations are presented in Table 8. The results revealed that there were significant differences among the genotypes tested for days to 50 % flowering, plant height, pod length, number of seeds per pod, 100 seed weight and seed yield. The environments in which the observations were made differed significantly to influence significant variations among the genotypes for all the traits studied except for number of pods per plant.

The genotype × environment interaction component was found to be significant for days to 50 % flowering, plant height, pod length, number of seeds per pod, 100 seed weight and seed yield. Hence, further partitioning was done as per Eberhart and Russell (1966) model in order to know the magnitude of linear and non-linear components of variation which provide information on predictable and unpredictable sources of variation, each contributing to the G × E interaction for all the characters.

Table 8: Pooled analysis of variance for stability parameters for yield and yield attributing traits in cowpea

	df	Days to 50 % flowering	Plant height (cm)	Pod length (cm)	Number of seeds per pod	Number of pods per plant	100 Seed weight (g)	Seed yield (kg ha ⁻¹)
Genotypes (G)	33	6.50 **	12.57 **	1.83*	4.53*	32.70	3.35 **	90,167.39*
Env.+ (Gen.× Env.)	68	42.53 **	40.29 **	1.89 *	4.65*	29.81	2.74 **	1,24,178.96**
Environments (E)	2	1,357.16 **	1,115.78 **	31.29 **	72.30 **	98.50	66.43 **	14,02,167.79**
Gen.* Env. (G×E)	66	2.69 **	7.70 *	1.95*	4.51*	27.73	0.81 *	85,452.03*
Environments (Lin.)	1	2,714.32 **	2,231.57 **	62.59**	144.61 **	197.00 *	132.86 **	28,04,335.59**
Gen. × Env. (Lin.)	33	5.17 **	11.15 **	1.81*	1.47	13.33	1.137**	1,20,826.77**
Pooled Deviation	34	0.20 **	4.12 **	1.02 **	2.52 **	40.89 **	0.47 **	48,604.42**
Pooled Error	198	0.09	2.32	0.23	1.03	1.00	0.11	1,690.74
Total	101	30.75	31.23	1.82	3.47	30.75	2.94	1,13,066.28

* - Significant at 5 % level of significance ** - Significant at 1 % level of significance

Environment (linear) component was significant for all the characters. The variances due to genotype $\times$ environment (linear) were significant for days to 50 % flowering, plant height, pod length, 100 seed weight and seed yield. Since the G $\times$ E interactions were found significant, the data was further subjected to stability analysis as per Eberhart and Russell model (1966).

4.6 Stability analysis

In order to identify the stable genotypes for the yield and yield attributing traits, the stability analysis was carried out employing the linear regression model proposed by Eberhart and Russel (1966). The stability parameters viz., genotypic mean ($\bar{X}$), regression coefficient (b_i) and deviation from regression (S^2_{di}) were computed for all the characters. The stability parameters and performance of genotypes under different environments are presented in the following paragraphs.

4.6.1 Days to 50 % flowering

Stability parameters for days to 50 % flowering are summarized in Table 9. The environmental indices ranging from -3.91 to 7.28 indicate significant variations across the three locations (Table 7). The mean value of this character indicated that, among all genotypes, the F_6 progeny of cross DC-15 $\times$ JOB-129 required more number of days (60.11), while F_6 progeny of cross DCS-47-1 $\times$ GC-3 required less number of days to 50 % flowering (55.89). The overall mean for this trait was 57.86 days.

The regression coefficient (b_i) was found significantly different from unity at 5 % level for the F_6 lines GC-3 $\times$ IC 198333, DC-15 $\times$ NBC -1, DC-15 $\times$ Subhra and GC-3 $\times$ IC 202872 and significantly different from unity at 1 per cent level with respect to F_6 lines V-118 $\times$ IC 249140-2 and DCS-47-1 $\times$ GC-3. Of these DC-15 $\times$ Subhra, GC-3 $\times$ IC 202872 showed b_i values significantly less than unity while others had higher than unity values, while it was found to be non-significant with respect to remaining genotypes. The deviation from regression (S^2_{di}) was significantly different from zero at 5 per cent level with respect to F_6 line GC-3 $\times$ C-152 and for germplasm IC 202779 and at 1 per cent level with respect to F_6 lines of cross C-152 $\times$ IC 201079, C-152 $\times$ IC 202825 and for germplasm line IC 202730.

The F_6 lines C-152 $\times$ IC 202790, C-152 $\times$ DCS-5-3-20, DCS-47-1 $\times$ DC-15, IC 202778 $\times$ IC 202787, V-118 $\times$ IC 249140 -1, C-152 $\times$ IC 97767, V-118 $\times$ IC 68786, DC-15 $\times$ DCS-47-1, C-152 $\times$ IC 249140, DC-15 (check 2) and DC-16 (check 4) have the mean values lower than population mean in desirable direction and regression coefficient non-significantly different from unity and deviations from regression not significantly different from zero.

4.6.2 Plant height

The stability parameters for plant height are presented in the Table 10. The environmental indices ranging from -3.81 to 6.58 indicate significant variations across the three locations (Table 7). The F_6 genotype C-152 $\times$ IC 201079 was the tallest (40.84 cm) and the F_6 progeny line DC-15 $\times$ DCS-47-1 was the shortest (32.36 cm) among all the genotypes. Mean value for this trait over all the environments was 36.91 cm.

Table 9: Stability parameters for days to 50 % flowering across three locations in cowpea

Sl. No.	F ₆ Stabilized progenies	Dharwad K-2015	Bailhongal K-2015	Malgi S-2016	Genotypic mean	b _i	S ² di
1	GC-3 × IC 198333	51.67	52.33	64.00	56.00	1.09*	-0.10
2	DC -15 × JOB-129	56.67	57.67	66.00	60.11	0.81	0.06
3	C-152 × IC 202790	50.33	51.67	67.00	56.33	1.47	0.05
4	DCS-47-1 × GC-3	51.00	51.67	65.00	55.89	1.20**	-0.10
5	IC 202730	55.33	57.00	63.00	58.44	0.63	0.78 **
6	IC 202779	55.67	57.00	64.00	58.89	0.70	0.35 *
7	IC 249141	54.33	55.67	64.67	58.22	0.89	0.27
8	DC -15 × NBC -1	50.67	51.67	65.67	56.00	1.37*	-0.06
9	C-152 × DCS-5-3-20	53.67	53.67	65.67	57.67	1.10	0.07
10	DCS-47-1 × DC-15	53.00	53.00	64.67	56.89	1.07	0.06
11	DC -15 × Subhra	55.00	55.33	64.00	58.11	0.80*	-0.10
12	C-152 × CP-206	56.00	56.67	65.67	59.44	0.85	-0.08
13	GC-3 × C-152	55.33	56.67	64.33	58.78	0.77	0.32*
14	V-118 × GL	55.00	55.33	65.67	58.67	0.96	-0.08
15	C-152 × IC 198701	55.33	56.33	66.67	59.44	0.99	0.01
16	C-152 × IC 201079	55.33	57.00	65.00	59.11	0.81	0.65 **
17	GC-3 × IC 202872	58.00	58.00	64.00	60.00	0.58*	-0.06
18	V-118 × IC 249141	55.67	55.67	64.00	58.44	0.76	-0.02
19	C-152 × IC 202825	55.67	57.33	64.00	59.00	0.69	0.73**
20	V-118 × IC 27502	55.67	55.67	67.00	59.44	1.04	0.06
21	V-118 × IC 249132	55.33	56.33	64.67	58.78	0.81	0.06
22	IC 202778 × IC 214836	57.00	57.00	65.33	59.78	0.76	-0.02
23	IC 202778 × IC 202787	52.33	52.33	64.33	56.33	1.10	0.07
24	V-118 × IC 249140-1	52.00	52.33	65.00	56.44	1.17	-0.06
25	V-118 × IC 68786	51.33	51.67	66.33	56.44	1.36	-0.02
26	C-152 × IC 97767	52.33	52.33	65.67	56.78	1.22	0.11
27	V-118 × IC 249140 -2	51.00	51.67	65.00	55.89	1.25**	-0.10
28	DC -15 × DCS-47-1	51.33	51.33	63.00	55.22	1.07	0.06
29	C-152 × IC 202710	55.67	55.67	63.67	58.33	0.73	-0.02
30	C-152 × IC 249140	52.33	52.33	67.67	57.44	1.40	0.18
31	Check 1-C-152	54.11	54.11	68.67	58.96	1.33	0.16
32	Check 2-DC-15	51.44	51.44	65.00	55.96	1.24	0.12
33	Check 3-DCS-47-1	57.22	57.22	65.00	59.82	0.71	-0.03
34	Check 4-DC-16	51.67	51.67	66.00	56.44	1.31	0.15
	Mean	53.95	54.49	65.15			
	S. Em. ±	0.44	0.44	0.43			
	C.D. (5 %)	0.88	0.88	0.86			
	C. V. (%)	1.10	0.99	0.81			

Population Mean -57.86

* -Significant at 5 % level of significance

b_i - Regression coefficient

** - Significant at 1 % level of significance

S²di - Mean square deviation from regression

Table 10: Stability parameters for plant height (cm) across three locations in cowpea

Sl. No.	F ₆ Stabilized progenies	Dharwad K-2015	Bailhongal K-2015	Malgi S-2016	Genotypic mean	b _i	S ² di
1	GC-3 × IC 198333	34.40	34.87	50.73	40.00	1.62	-2.00
2	DC -15 × JOB-129	31.33	35.63	46.20	37.72	1.31	1.61
3	C-152 × IC 202790	31.00	32.40	44.60	36.00	1.30**	-2.74
4	DCS-47-1 × GC-3	30.77	33.47	45.33	36.52	1.35	-1.89
5	IC 202730	34.23	32.83	53.13	40.07	1.96	3.19
6	IC 202779	33.80	37.00	45.93	38.91	1.08	-0.57
7	IC 249141	32.20	35.83	49.07	39.03	1.54	-0.66
8	DC -15 × NBC -1	32.13	28.07	39.90	33.37	0.95	10.13 *
9	C-152 × DCS-5-3-20	32.40	37.80	44.67	38.29	1.00	6.83
10	DCS-47-1 × DC-15	36.13	32.60	40.97	36.57	0.63	6.12
11	DC -15 × Subhra	33.00	36.33	48.53	39.29	1.42	-1.00
12	C-152 × CP-206	34.13	35.37	40.73	36.74	0.61	-2.56
13	GC-3 × C-152	33.40	28.13	46.73	36.09	1.56	21.16 **
14	V-118 × GL	37.40	33.47	46.83	39.23	1.11	10.31 *
15	C-152 × IC 198701	34.60	37.40	47.27	39.76	1.15	-1.45
16	C-152 × IC 201079	35.67	37.30	49.57	40.84	1.32*	-2.71
17	GC-3 × IC 202872	31.47	34.23	44.10	36.60	1.15	-1.50
18	V-118 × IC 249141	33.33	31.93	44.70	36.66	1.20	0.79
19	C-152 × IC 202825	32.47	34.00	43.53	36.67	1.05	-2.64
20	V-118 × IC 27502	32.87	34.73	43.57	37.06	1.00	-2.39
21	V-118 × IC 249132	35.73	34.77	36.43	35.64	0.11	-2.15
22	IC 202778 × IC 214836	35.00	33.77	38.83	35.87	0.44	-1.31
23	IC 202778 × IC 202787	31.93	34.27	41.90	36.03	0.90	-1.76
24	V-118 × IC 249140-1	28.60	33.67	36.07	32.78	0.54	7.52
25	V-118 × IC 68786	31.60	39.40	39.37	36.79	0.45	24.36 **
26	C-152 × IC 97767	32.27	31.57	42.10	35.31	1.02	-1.19
27	V-118 × IC 249140 -2	32.40	32.73	42.03	35.72	0.95	-2.53
28	DC -15 × DCS-47-1	30.13	31.90	35.03	32.36	0.42	-1.85
29	C-152 × IC 202710	32.40	35.67	44.70	37.59	1.10	-0.46
30	C-152 × IC 249140	32.73	33.70	37.10	34.51	0.40	-2.59
31	Check 1-C-152	32.27	32.27	42.93	35.82	1.07	-2.12
32	Check 2-DC-15	31.65	31.65	42.67	35.32	1.11	-2.08
33	Check 3-DCS-47-1	36.42	36.42	43.27	38.70	0.69	-2.49
34	Check 4-DC-16	35.51	35.51	40.47	37.16	0.50	-2.61
	Mean	33.09	34.13	43.5			
	S. Em. ±	2.11	1.32	2.78			
	C.D. (5 %)	4.22	2.64	5.55			
	C. V. (%)	7.82	4.74	7.83			

Population Mean - 36.91

* -Significant at 5 % level of significance

b_i - Regression coefficient

** - Significant at 1 % level of significance

S²di - Mean square deviation from regression

The regression coefficient (b_i) was found significantly more than unity at 1 per cent level with respect to F_6 line C-152 $\times$ IC 202790 and at 5 per cent level in F_6 line C-152 $\times$ IC 201079. While in other genotypes it was found non-significant. The deviation from regression (S^2_{di}) was found significantly different from zero at 1 per cent level in F_6 lines GC-3 $\times$ C-152, V-118 $\times$ IC 68786 and at 5 per cent level F_6 lines DC-15 $\times$ NBC-1 and V-118 $\times$ GL. While in other genotypes it was found non-significant.

The F_6 lines namely GC-3 $\times$ IC 198333, DC15 $\times$ JOB-129, C-152 $\times$ DCS-5-3-20, IC 249141, DC-15 $\times$ Subhra, C-152 $\times$ IC 198701, V-118 $\times$ IC 27502, C-152 $\times$ IC 202710, germplasm lines IC 202730, IC 202779, DCS-47-1(check 3) and DC-16 (check 4) displayed the mean values higher than population mean and regression coefficient non-significantly different from unity and deviations from regression not significantly different from zero.

4.6.3 Pod length

The stability parameters for pod length are illustrated in the Table 11. The locations varied with regard to pod length as seen from environmental indices -1.10 to 0.63 (Table 7). The F_6 line DCS-47-1 $\times$ GC-3 with mean value 17.88 cm exhibited the longest pods, the C-152 (check 1) with mean value 14.99 cm having the shortest pods among all genotypes studied. The average pod length over the environments was 16.25 cm.

The regression coefficient (b_i) was found non- significantly different from unity for all the genotypes except F_6 lines namely DC-15 $\times$ NBC -1, C-152 $\times$ IC 97767, DC-15 $\times$ DCS-47-1, C-152 $\times$ 202825, V-118 $\times$ GL, C-152 $\times$ DCS-5-3-20, germplasm line IC 249141 and DC-15 (check-2). For F_6 lines namely DC-15 $\times$ NBC-1, C-152 $\times$ IC 97767, DC-15 $\times$ DCS-47-1and germplasm line IC 249141 it is significantly greater than unity at 5 per cent level of significance. Whereas for F_6 lines C-152 $\times$ IC 202825, V-118 $\times$ GL, C-152 $\times$ DCS-5-3-20 and DC-15 (check-2) it is significantly less than unity. The deviation from regression (S^2_{di}) was found significantly different from zero at 1 per cent level for the F_6 lines C-152 $\times$ DCS-5-3-20, DC-15 $\times$ Subhra, V-118 $\times$ GL, C-152 $\times$ IC 202825, V-118 $\times$ IC 27502, V-118 $\times$ IC 68786 and C-152 (check-1) and at 5 per cent level for the genotypes IC 249141, F_6 line IC 202778 $\times$ IC 202787 and DC -16 (Check 4). While in other genotypes it was found non-significant.

The genotypes which showed higher than population mean, non-significant b_i and non-significant S^2_{di} are F_6 lines progenies of cross DCS-47-1 $\times$ GC-3, GC-3 $\times$ C 152, V-118 $\times$ IC 249140 - 1, V-118 $\times$ IC 249140-2, C-152 $\times$ IC 249140 and germplasm line IC 202730.

4.6.4 Number of seeds per pod

The stability parameters for number of seeds per pod are summarized in the Table 12. The environmental indices ranging from -1.64 to 1.12 (Table 7) indicate significant variations across the three locations. The highest number of seeds per pod was observed in F_6 line C-152 $\times$ DCS-5-3-20 (15.18) while C-152 (check 1) had the lowest seeds per pod (13.22). The average number of seeds per pod over the environments was 14.14.

The F_6 progenies C-152 × DCS-5-3-20, C-152 × IC 202825, V-118 × IC 249132, DC-15 × Subhra and GC-3 × IC 202872 showed b_i value significantly less than unity at 5 per cent level. While all other genotypes showed non-significant b_i value. The deviation from regression (S^2_{di}) was found significantly different from zero at 1 per cent level for the F_6 line C-152 × DCS-5-3-20 and significantly different from zero at 5 per cent level for the F_6 lines DC-15 × NBC-1, V-118 × IC 249132, C-152 × IC 249140, C-152 (Check 1), DCS-47-1 (Check 3) and DC -16 (Check 4).

The F_6 progenies GC-3 × IC 198333, DCS-47-1 × GC-3, V-118 × IC 249140-1, C-152 × IC 97767, GC-3 × C-152, C-152 × IC 201079, C-152 × IC 198701, GC-3 × IC 202872, DC-15 × DCS-47-1, C-152 × IC 202710 and germplasm lines IC 202730, IC 249141 and DC-15 (check-2) showed higher mean values than population mean, non-significant b_i and non-significant S^2_{di} .

4.6.5 Number of pods per plant

The stability parameters for number of pods per plant are illustrated in the Table 13. The locations varied with regard to number of pods per plant as seen from environmental indices -1.63 to 1.76. The average number of pods per plant over the environments was 14.00. The F_6 progeny DC-15 × DCS-47-1 borne maximum number of pods per plant (21.90) while GC-3 × IC 198333 borne the minimum number of pods per plant (8.22).

The F_6 lines C-152 × IC 201079, V-118 × IC 27502, IC 202778 × IC 214836, V-118 × IC 249140-1, V-118 × IC 249140-2, C-152 × CP-206, germplasm line IC 202730 and C-152 (check 1), DC-15 (check -2), DCS-47-1 (check -3), DC-16 (check-4) showed the b_i value significantly different from unity. Among these, the F_6 lines V-118 × IC 27502, IC 202778 × IC 214836, V-118 × IC 249140-1 and V-118 × IC 249140-2 indicated b_i value significantly more than unity at 5 per cent level, while the remaining genotypes exhibited b_i values significantly less than unity. The deviation from regression (S^2_{di}) was found significantly different from zero at 1 per cent level for the F_6 genotypes C-152 × IC 202790, DC-15 × NBC-1, C-152 × DCS-5-3-20, DC-15 × Subhra, DCS-47-1 × DC-15, GC-3 × IC 202872, V-118 × IC 249141, IC 202778 × IC 202787, V-118 × IC 68786, C-152 × IC 97767, V-118 × IC 27502, DC-15 × DCS-47-1, C-152 × IC 249140, DC-15 (Check 2), DCS-47-1 (Check 3), DC-16 (Check 4) and germplasm lines IC 202730, IC 249141 and significantly different from zero at 5 per cent level for the F_6 genotypes DCS-47-1 × GC-3, IC 202778 × IC 214836 and C-152 × IC 202710.

The F_6 lines which displayed higher number of pods per plant higher than population mean, non-significant b_i and non-significant S^2_{di} are V-118 × GL and C-152 × IC 198701.

4.6.6 100 seed weight

The stability parameters for 100 seed weight are presented in the Table 14. The locations varied with regard to 100 seed weight as seen from environmental indices -0.84 to 1.61 (Table 7). The F_6 line GC-3 × IC 198333 with mean value of 15.04 g recorded maximum 100 seed weight, the F_6 line progeny V-118 × IC 249141 with mean value of 10.46 g displayed the minimum 100 seed weight, among all genotypes studied. The average 100 seed weight over the environments was 11.75 g.

Table 11: Stability parameters for pod length (cm) across three locations in cowpea

Sl. No.	F ₆ Stabilized progenies	Dharwad K-2015	Bailhongal K-2015	Malgi S-2016	Genotypic mean	b _i	S ² di
1	GC-3 × IC 198333	15.31	16.47	16.77	16.18	0.79	-0.22
2	DC -15 × JOB-129	13.85	15.75	16.77	15.45	1.49	0.08
3	C-152 × IC 202790	15.15	16.17	16.83	16.05	0.84	-0.09
4	DCS-47-1 × GC-3	16.25	18.91	18.50	17.88	1.46	-0.03
5	IC 202730	15.77	17.93	17.43	17.05	1.12	0.00
6	IC 202779	14.75	16.80	16.57	16.04	1.15	-0.15
7	IC 249141	14.58	18.55	17.50	16.88	2.02*	0.71*
8	DC -15 × NBC -1	13.93	18.58	18.10	16.87	2.62*	0.17
9	C-152 × DCS-5-3-20	17.33	19.14	16.03	17.50	0.02*	4.63 **
10	DCS-47-1 × DC-15	14.39	16.72	15.97	15.69	1.14	0.20
11	DC -15 × Subhra	16.99	14.76	17.50	16.41	-0.40	3.73 **
12	C-152 × CP-206	14.96	16.80	16.03	15.93	0.84	0.17
13	GC-3 × C-152	15.53	17.77	16.90	16.73	1.04	0.30
14	V-118 × GL	16.67	14.70	18.33	16.57	0.06*	6.37**
15	C-152 × IC 198701	14.33	15.65	16.53	15.50	1.10	0.02
16	C-152 × IC 201079	14.17	16.70	17.13	16.00	1.67	-0.22
17	GC-3 × IC 202872	14.67	14.99	15.40	15.02	0.33	-0.17
18	V-118 × IC 249141	14.72	15.76	15.47	15.32	0.52	-0.16
19	C-152 × IC 202825	16.49	18.03	15.50	16.67	0.06*	3.02**
20	V-118 × IC 27502	14.83	15.70	17.67	16.06	1.20	1.36 **
21	V-118 × IC 249132	15.50	15.39	14.91	15.27	-0.23	-0.13
22	IC 202778 × IC 214836	14.59	16.92	16.27	15.93	1.17	0.12
23	IC 202778 × IC 202787	15.25	17.78	16.30	16.44	1.01	1.12 *
24	V-118 × IC 249140-1	15.16	16.78	18.17	16.70	1.45	0.14
25	V-118 × IC 68786	15.32	18.28	16.53	16.71	1.18	1.64 **
26	C-152 × IC 97767	14.59	17.43	18.63	16.89	2.11*	0.15
27	V-118 × IC 249140 -2	15.11	16.69	17.93	16.58	1.37	0.30
28	DC -15 × DCS-47-1	13.91	18.30	17.73	16.65	2.44*	0.22
29	C-152 × IC 202710	14.05	15.81	16.30	15.38	1.22	-0.19
30	C-152 × IC 249140	15.67	18.21	17.87	17.25	1.41	-0.07
31	Check 1-C-152	14.17	14.17	16.63	14.99	0.84	2.50 **
32	Check 2-DC-15	17.22	17.22	17.20	17.21	-0.07**	-0.23
33	Check 3-DCS-47-1	15.06	15.06	16.27	15.46	0.41	0.43
34	Check 4-DC-16	14.72	14.72	16.27	15.23	0.53	0.85 *
	Mean	15.14	16.72	16.88			
	S. Em. ±	0.89	0.46	0.62			
	C.D. (5 %)	1.78	0.92	1.24			
	C. V. (%)	7.23	3.39	4.54			

Population Mean - 16.25

* -Significant at 5 % level of significance

b_i - Regression coefficient

** - Significant at 1 % level of significance

S²di - Mean square deviation from regression

Table 12: Stability parameters for number of seeds per pod across three locations in cowpea

Sl. No.	F ₆ Stabilized progenies	Dharwad K-2015	Bailhongal K-2015	Malgi S-2016	Genotypic mean	b _i	S ² di
1	GC-3 × IC 198333	11.60	14.57	16.60	14.26	1.69	-0.51
2	DC -15 × JOB-129	12.00	14.27	15.17	13.81	1.12	-1.04
3	C-152 × IC 202790	11.37	13.67	14.70	13.24	1.16	-1.01
4	DCS-47-1 × GC-3	11.63	16.90	15.50	14.68	1.67	1.92
5	IC 202730	11.83	15.13	16.30	14.42	1.59	-1.04
6	IC 202779	11.97	13.77	14.63	13.46	0.93	-1.02
7	IC 249141	13.40	14.57	15.37	14.44	0.66	-0.98
8	DC -15 × NBC -1	9.93	17.03	15.50	14.16	2.35	3.40*
9	C-152 × DCS-5-3-20	14.40	17.53	13.60	15.18	0.18*	7.44**
10	DCS-47-1 × DC-15	12.47	12.85	15.10	13.47	0.74	0.63
11	DC -15 × Subhra	13.80	14.40	14.43	14.21	0.24*	-1.06
12	C-152 × CP-206	12.67	13.73	14.83	13.74	0.70	-0.83
13	GC-3 × C-152	13.87	13.50	15.77	14.38	0.46	1.01
14	V-118 × GL	12.30	15.00	14.70	14.00	0.97	-0.67
15	C-152 × IC 198701	12.67	14.50	15.70	14.29	1.03	-0.89
16	C-152 × IC 201079	13.53	16.20	15.63	15.12	0.88	-0.45
17	GC-3 × IC 202872	13.47	13.37	13.43	13.42	-0.021*	-1.07
18	V-118 × IC 249141	12.80	13.63	14.30	13.58	0.50	-1.00
19	C-152 × IC 202825	13.60	15.00	13.30	13.97	0.09*	0.54
20	V-118 × IC 27502	12.00	14.29	15.30	13.86	1.15	-1.01
21	V-118 × IC 249132	13.43	15.13	12.23	13.60	-0.11*	3.13 *
22	IC 202778 × IC 214836	11.43	15.80	14.80	14.01	1.43	0.72
23	IC 202778 × IC 202787	12.77	14.17	15.40	14.11	0.87	-0.80
24	V-118 × IC 249140-1	11.87	16.40	16.73	15.00	1.85	-0.76
25	V-118 × IC 68786	12.67	14.77	14.43	13.96	0.73	-0.76
26	C-152 × IC 97767	12.60	14.80	15.50	14.30	1.04	-1.07
27	V-118 × IC 249140 -2	11.73	15.67	13.77	13.72	1.02	2.22
28	DC -15 × DCS-47-1	12.47	15.23	15.10	14.27	1.04	-0.78
29	C-152 × IC 202710	12.07	14.73	15.87	14.22	1.33	-1.01
30	C-152 × IC 249140	11.20	16.89	14.07	14.05	1.46	6.04*
31	Check 1-C-152	12.09	12.09	15.47	13.22	0.89	3.16 *
32	Check 2-DC-15	14.20	15.60	15.1	15.07	1.15	0.89
33	Check 3-DCS-47-1	12.34	12.34	16.27	13.65	1.04	4.64 *
34	Check 4-DC-16	11.90	11.90	15.67	13.16	0.99	4.18 *
	Mean	12.49	14.67	15.26			
	S. Em. ±	0.92	0.63	2.22			
	C.D. (5 %)	1.84	1.27	4.44			
	C. V. (%)	9.03	5.31	17.86			

Population Mean - 14.10

* - Significant at 5 % level of significance

bi - Regression coefficient

** -Significant at 1 % level of significance

S²di - Mean square deviation from regression

Table 13: Stability parameters for number of pods per plant across three locations in cowpea

Sl. No.	F ₆ Stabilized progenies	Dharwad K-2015	Bailhongal K-2015	Malgi S-2016	Genotypic mean	b _i	S ² di
1	GC-3 × IC 198333	10.00	6.87	7.80	8.22	0.93	-0.95
2	DC -15 × JOB-129	8.33	10.40	10.70	9.81	-0.64	-0.10
3	C-152 × IC 202790	11.27	6.50	12.23	10.00	1.32	7.59 **
4	DCS-47-1 × GC-3	9.00	11.87	13.13	11.33	-0.90	3.19 *
5	IC 202730	11.50	10.40	32.07	17.99	-0.14*	296.68**
6	IC 202779	13.33	11.33	14.50	13.06	0.54	2.36
7	IC 249141	16.17	11.27	21.00	16.14	1.28	36.83**
8	DC -15 × NBC -1	9.33	8.27	12.37	9.99	0.24	7.64**
9	C-152 × DCS-5-3-20	17.67	16.39	9.63	14.56	0.54	34.53**
10	DCS-47-1 × DC-15	16.83	14.33	8.50	13.22	0.89	30.91**
11	DC -15 × Subhra	10.67	16.50	8.80	11.99	-1.61	16.24**
12	C-152 × CP-206	14.67	15.20	12.83	14.23	-0.11*	1.92
13	GC-3 × C-152	15.33	8.50	13.33	12.39	1.97	1.06
14	V-118 × GL	15.67	13.33	13.90	14.30	0.70	-0.94
15	C-152 × IC 198701	19.33	15.53	15.10	16.66	1.17	1.90
16	C-152 × IC 201079	17.17	17.67	15.20	16.68	-0.10*	2.26
17	GC-3 × IC 202872	21.63	12.67	8.00	14.10	2.83	48.57**
18	V-118 × IC 249141	20.67	13.47	8.60	14.24	2.30	42.08**
19	C-152 × IC 202825	10.07	7.87	7.43	8.46	0.68	0.23
20	V-118 × IC 27502	23.43	7.73	9.80	13.66	4.73*	14.88**
21	V-118 × IC 249132	15.20	9.95	13.40	12.85	1.52	-0.26
22	IC 202778 × IC 214836	24.20	8.22	12.50	14.97	4.77*	4.17 *
23	IC 202778 × IC 202787	11.70	13.10	7.30	10.70	-0.30	16.71 **
24	V-118 × IC 249140-1	18.87	5.60	11.70	12.06	3.90*	-1.06
25	V-118 × IC 68786	11.17	10.80	31.83	17.93	-0.35	288.09**
26	C-152 × IC 97767	14.63	8.13	16.80	13.19	1.79	21.11**
27	V-118 × IC 249140 -2	16.50	7.44	11.13	11.69	2.67*	-1.02
28	DC -15 × DCS-47-1	29.67	25.47	10.57	21.90	1.60	185.36**
29	C-152 × IC 202710	11.20	13.73	10.02	11.65	-0.69	3.369*
30	C-152 × IC 249140	16.03	7.20	30.50	17.91	2.18	248.23 **
31	Check 1-C-152	15.78	15.78	16.13	15.90	-0.01*	-1.00
32	Check 2-DC-15	16.44	16.44	12.07	14.98	0.10*	11.62**
33	Check 3-DCS-47-1	22.00	22.00	18.53	20.84	0.08*	6.88**
34	Check 4-DC-16	20.78	20.78	14.60	18.72	0.14*	24.23 **
	Mean	15.77	12.37	13.88			
	S. Em. ±	1.17	1.41	1.62			
	C.D. (5 %)	2.33	2.83	3.23			
	C. V. (%)	9.09	14.04	14.30			

Population Mean - 14.00

* - Significant at 5 % level of significance

b_i - Regression coefficient

** - Significant at 1 % level of significance

S²di - Mean square deviation from regression

Table 14: Stability parameters for 100 seed weight (g) across three locations in cowpea

Sl. No.	F ₆ Stabilized progenies	Dharwad K-2015	Bailhongal K-2015	Malgi S-2016	Genotypic mean	b _i	S ² di
1	GC-3 × IC 198333	14.51	13.20	17.40	15.04	1.48	0.57 *
2	DC -15 × JOB-129	10.70	10.85	12.70	11.42	0.79	0.10
3	C-152 × IC 202790	11.87	11.21	13.27	12.12	0.72	0.05
4	DCS-47-1 × GC-3	11.26	11.79	13.80	12.28	0.93	0.05
5	IC 202730	11.30	9.91	13.10	11.44	1.05	0.72*
6	IC 202779	10.45	10.25	13.63	11.44	1.36	0.12
7	IC 249141	11.30	11.78	12.50	11.86	0.39*	0.00
8	DC -15 × NBC -1	11.57	9.77	13.40	11.58	1.15	1.34**
9	C-152 × DCS-5-3-20	12.43	11.35	14.53	12.77	1.10	0.36
10	DCS-47-1 × DC-15	10.80	9.87	16.40	12.36	2.51*	0.14
11	DC -15 × Subhra	10.00	10.38	12.57	10.98	0.98	0.02
12	C-152 × CP-206	10.65	11.39	12.23	11.43	0.49	0.17
13	GC-3 × C-152	9.65	9.51	13.07	10.74	1.44*	0.13
14	V-118 × GL	13.63	14.37	17.03	15.01	1.15	0.23
15	C-152 × IC 198701	10.65	10.76	11.53	10.98	0.34*	0.12
16	C-152 × IC 201079	10.08	10.83	12.03	10.98	0.64	0.19
17	GC-3 × IC 202872	10.25	11.14	11.87	11.09	0.47	0.31
18	V-118 × IC 249141	9.95	9.79	11.63	10.46	0.73	0.12
19	C-152 × IC 202825	9.98	10.61	13.20	11.26	1.19	0.14
20	V-118 × IC 27502	11.03	11.08	13.20	11.77	0.89	0.12
21	V-118 × IC 249132	10.52	8.38	13.60	10.83	1.74	1.86**
22	IC 202778 × IC 214836	10.37	10.55	13.00	11.31	1.05	0.09
23	IC 202778 × IC 202787	10.57	8.95	13.87	11.13	1.71	0.97**
24	V-118 × IC 249140-1	11.71	14.05	12.57	12.77	0.15*	2.57**
25	V-118 × IC 68786	12.13	11.91	12.63	12.23	0.26*	0.11
26	C-152 × IC 97767	11.45	9.99	12.67	11.37	0.82	0.84**
27	V-118 × IC 249140 -2	12.17	13.75	14.30	13.41	0.54	1.19 **
28	DC -15 × DCS-47-1	11.04	9.92	13.70	11.55	1.34	0.38 *
29	C-152 × IC 202710	9.55	10.91	12.40	10.95	0.88	0.90**
30	C-152 × IC 249140	10.34	10.85	14.33	11.84	1.54	0.08
31	Check 1-C-152	10.88	10.88	12.47	11.41	0.65*	0.13
32	Check 2-DC-15	10.47	10.47	14.93	11.96	1.84*	0.12
33	Check 3-DCS-47-1	9.57	9.57	13.07	10.74	1.44	0.12
34	Check 4-DC-16	10.66	10.66	11.73	11.02	0.44*	0.13
	Mean	10.98	10.90	13.36			
	S. Em. ±	0.43	0.32	0.64			
	C.D. (5 %)	0.86	0.65	1.28			
	C. V. (%)	4.82	3.66	5.87			

Population Mean - 11.75

* - Significant at 5 % level of significance

b_i - Regression coefficient

** - Significant at 1 % level of significance

S²di - Mean square deviation from regression

The regression coefficient (b_i) was found significantly different unity at 5 per cent level for F_6 genotypes DCS-47-1 × DC-15, GC-3 × C 152, C-152 × IC 198701, V-118 × IC 249140-1, V-118 × IC 68786, IC 249141, C 152 (check 1), DC-15 (check 2) and DC-16 (check 4). The F_6 genotypes DCS-47-1 × DC-15, GC-3 × C 152 and DC-15 (check 2) recorded b_i value significantly more than unity, while remaining genotypes recorded b_i value significantly less than unity. The deviation from regression (S^2_{di}) was found significantly different from zero at 1 per cent level in F_6 lines DC-15 × NBC-1, V-118 × IC 249132, IC 202778 × IC 202787, V-118 × IC 249140-1, C-152 × IC 97767, V-118 × IC 249140-2, C-152 × IC 202710 genotypes, while 5 per cent significant difference was observed in F_6 lines GC-3 × IC 198333, DC-15 × DCS-47-1 and IC 202730. The remaining genotypes showed non-significance.

The F_6 genotypes namely C-152 × IC 202790, DCS-47-1 × GC-3, C-152 × DCS-5-3-20, V-118 × GL, V-118 × IC 27502, C-152 × IC 249140 and IC 202778 × IC 214836 showed 100 seed weight more than population mean, non-significant b_i value and non-significant S^2_{di} value.

4.6.7 Seed yield

The stability parameters for seed yield are summarized in the Table 15. It was clear from the environmental indices (-251.41 to 253.72) that locations were highly distinct from one another in affecting seed yield. The F_6 genotype DC-15 × DCS-47-1 was the highest yielder (1,450.41 kg ha⁻¹) while, the F_6 line C-152 × IC 249140 was the lowest (622.87 kg ha⁻¹) among all the genotypes. The overall mean recorded was 1,021.50 kg ha⁻¹.

Among the 34 genotypes 17 genotypes recorded *per se* mean value higher than population mean viz., the F_6 progenies of DC-15 × DCS-47-1 (1,450.41 kg ha⁻¹), C-152 × CP-206 (1,259.83 kg ha⁻¹), DC-15 × Subhra (1,251.16 kg ha⁻¹), check 3-DC 47-1 (1,245.22 kg ha⁻¹), check 2 - DC-15 (1,205.94 kg ha⁻¹), C-152 × IC 198701 (1,198.42 kg ha⁻¹), C-152 × IC 97767 (1,189.39 kg ha⁻¹), DC-15 × JOB-129 (1,177.88 kg ha⁻¹), C-152 × IC 201079 (1,170.48 kg ha⁻¹), check 4- DC-16 (1,126.38 kg ha⁻¹), C-152 × DCS-5-3-20 (1,108.04 kg ha⁻¹), C-152 × IC 202710 (1,084.52 kg ha⁻¹), IC 202730 (1,083.41 kg ha⁻¹), check 1-C 152 (1,081.09 kg ha⁻¹), GC-3 × IC 202872 (1,070.38 kg ha⁻¹), IC 249141 (1,051.45 kg ha⁻¹) and V-118 × IC 249141 (1,022.63 kg ha⁻¹).

The regression coefficient (b_i) was found non- significantly different from unity for all the genotypes except F_6 line V-118 × IC 27502, where it is significantly more than one at 5 per cent level. The deviation from regression (S^2_{di}) was found significantly different from zero at 1 per cent level in F_6 progenies GC-3 × IC 198333, DC-15 × JOB-129, C-152 × IC 202790, DCS-47-1 × GC-3, DC-15 × NBC -1, C-152 × DCS-5-3-20, DCS-47-1 × DC-15, DC-15 × Subhra, C-152 × CP-206, GC-3 × C-152, C-152 × IC 202825, V-118 × IC 249132, IC 202778 × IC 214836, IC 202778 × IC 202787, C-152 × IC 97767, V-118 × IC 249140-2, DC-15 × DCS-47-1, C-152 (Check 1), DC-15 (Check 2), DCS-47-1 (Check 3), DC-16 (Check 4) and germplasm lines IC 202730, IC 202779, IC 249141 and it was found significantly different from zero at 5 per cent level in F_6 line V-118 × IC 27502. The remaining genotypes showed non-significant S^2_{di} .

Table 15: Stability parameters for seed yield (kg ha⁻¹) across three locations in cowpea

Sl. No.	F ₆ Stabilized progenies	Dharwad K-2015	Bailhongal K-2015	Malgi S-2016	Genotypic mean	b _i	S ² di
1	GC-3 × IC 198333	950.57	497.50	1,037.47	828.51	1.35	15,735.72**
2	DC -15 × JOB-129	1,082.25	716.83	1,734.56	1,177.88	2.48	20,820.18**
3	C-152 × IC 202790	946.45	1,236.06	513.31	898.61	-1.77	5,055.56**
4	DCS-47-1 × GC-3	1,008.18	1,246.11	601.61	951.96	-1.57	6,377.29**
5	IC 202730	1,230.39	1,305.48	714.36	1,083.41	-1.43	37,920.57**
6	IC 202779	423.85	743.91	1,366.61	844.79	1.45	2,84,725.82**
7	IC 249141	1,209.81	612.11	1,332.44	1,051.45	1.80	27,401.20**
8	DC -15 × NBC -1	1,045.21	488.79	1,066.36	866.79	1.46	38,195.50**
9	C-152 × DCS-5-3-20	1,270.30	1,368.69	685.14	1,108.04	-1.65	47,019.58**
10	DCS-47-1 × DC-15	1,214.49	1,077.35	458.41	916.75	-1.46	1,46,021.33**
11	DC -15 × Subhra	1,078.80	930.82	1,743.86	1,251.16	1.97	54,595.28**
12	C-152 × CP-206	1,238.80	670.88	1,869.79	1,259.83	2.95	2,505.48**
13	GC-3 × C-152	913.53	563.76	1,499.84	992.37	2.29	14,407.44**
14	V-118 × GL	938.19	957.17	1,074.40	989.92	0.28	2,847.30
15	C-152 × IC 198701	1,156.32	919.93	1,519.01	1,198.42	1.47	3,371.69
16	C-152 × IC 201079	1,148.09	892.96	1,470.41	1,170.48	1.42	470.20
17	GC-3 × IC 202872	1,061.67	797.46	1,352.02	1,070.38	1.36	-835.33
18	V-118 × IC 249141	995.83	842.09	1,223.97	1,022.63	0.93	169.56
19	C-152 × IC 202825	1,271.54	436.19	629.97	779.23	0.57	3,53,624.84**
20	V-118 × IC 27502	1,049.33	584.00	1,422.47	1,018.60	2.07*	-1542.98*
21	V-118 × IC 249132	1,109.81	518.49	941.68	856.66	1.09	85,987.46**
22	IC 202778 × IC 214836	950.57	613.14	1,002.13	855.28	0.98	9,164.39**
23	IC 202778 × IC 202787	1,000.10	493.80	1,104.18	866.02	1.53	19,168.18**
24	V-118 × IC 249140-1	991.72	536.72	1,198.29	908.91	1.64	4,734.73
25	V-118 × IC 68786	946.45	646.52	1,073.36	888.77	1.06	1,569.23
26	C-152 × IC 97767	1,065.79	957.60	1,544.77	1,189.39	1.42	27,317.56**
27	V-118 × IC 249140 -2	1,012.29	555.77	1,041.92	869.99	1.22	23,430.11**
28	DC -15 × DCS-47-1	1,226.25	1,457.31	1,667.67	1,450.41	0.47	77,338.44**
29	C-152 × IC 202710	1,065.79	720.13	1,467.66	1,084.52	1.84	565.08
30	C-152 × IC 249140	584.33	472.73	811.56	622.87	0.83	1,724.28
31	Check 1-C-152	776.36	882.32	1,584.59	1,081.09	1.67	1,54,790.64**
32	Check 2-DC-15	1,071.55	960.44	1,585.84	1,205.94	1.51	32,442.84**
33	Check 3-DCS-47-1	1,018.25	1,071.85	1,645.57	1,245.22	1.37	86,109.77**
34	Check 4-DC-16	1,042.47	876.11	1,460.58	1,126.38	1.42	13,126.04**
	Mean	1,031.49	782.39	1,287.53			
	S. Em. ±	58.81	48.16	66.07			
	C.D. (5 %)	245.67	124.91	135.14			
	C. V. (%)	14.61	9.79	6.43			

Population Mean – 1,021.5

* - Significant at 5 % level of significance

b_i - Regression coefficient

** - Significant at 1 % level of significance

S²di - Mean square deviation from regression

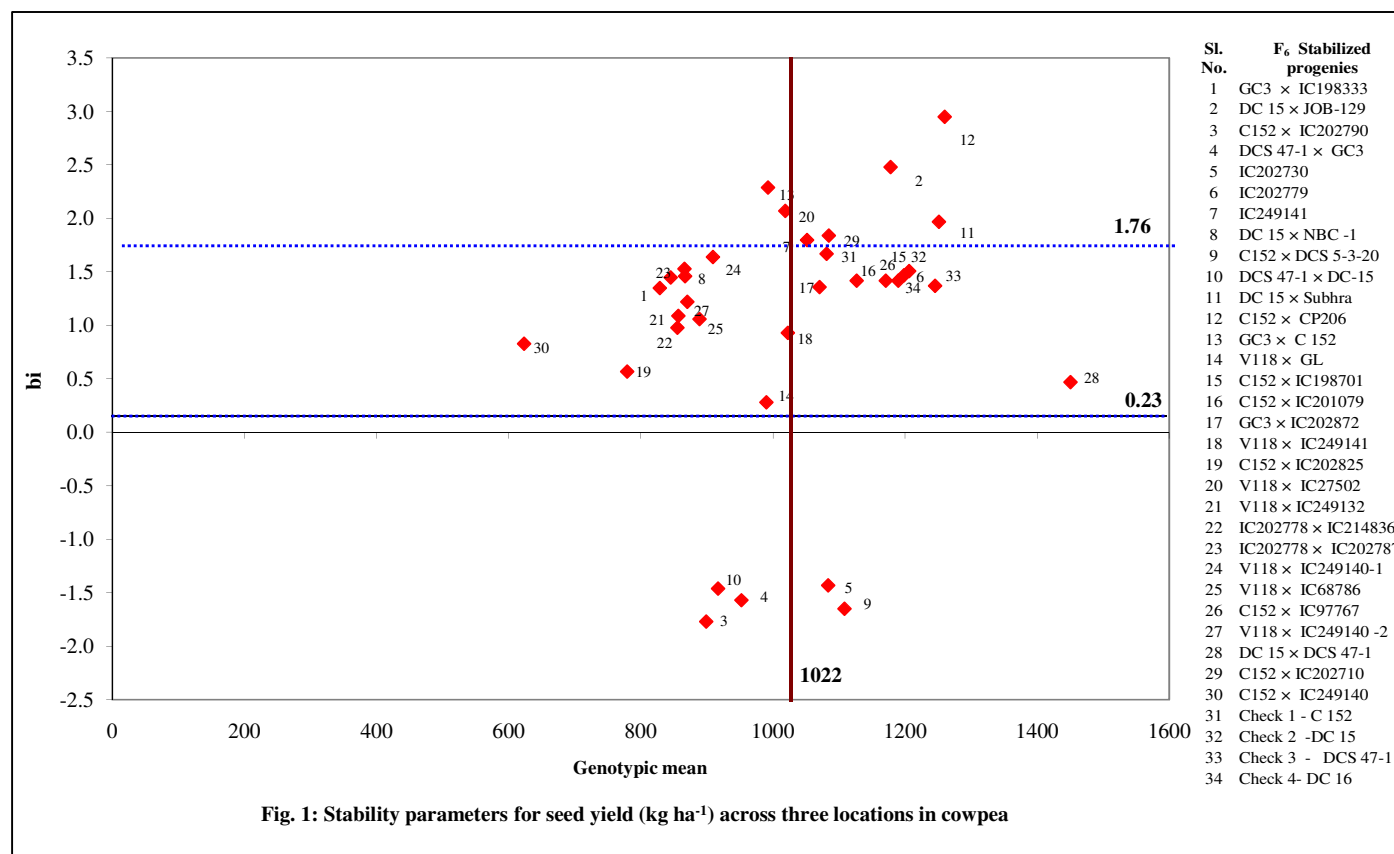


Fig 1: Stability parameters for seed yield (kg ha⁻¹) across three locations in cowpea

The genotypes which showed seed yield higher than population mean, non-significant b_i and non-significant S^2_{di} are F_6 lines namely C-152 $\times$ IC 198701, C-152 $\times$ IC 201079, GC-3 $\times$ IC 202872, V-118 $\times$ IC 249141 and C-152 $\times$ IC 202710.

4.7 Screening for bruchid (*Callosobruchus maculatus*) resistance

250 F_3 segregants of cowpea were screened for resistance to bruchid. The results obtained are explained as follows.

4.7.1 Bruchid infestation

The F_3 segregants were classified as moderately resistant, least susceptible, moderately susceptible and highly susceptible, based on bruchid infestation percentage, as reported in the Table 16.

Accordingly, top 15 moderately resistant F_3 segregants were reported in the Table 17. The results depicted that F_3 segregants F_3 -2 and F_3 -95 recorded the minimum bruchid infestation (24.53 %). Based on the classification of F_3 segregants as reported in the Table 18, moderately resistant (MR) class recorded 30.65 per cent bruchid infestation and least susceptible (LS), moderately susceptible (MS), highly susceptible (HS) classes recorded 45.80 per cent, 63.67 per cent and 82.90 per cent bruchid infestation, respectively.

As illustrated in the Table 19, 47 segregants noticed 21 to 30 per cent bruchid infestation, 24 segregants noticed 31 to 40 per cent bruchid infestation, 145 segregants were noticed 41 to 50 per cent bruchid infestation, 21 segregants noticed 51 to 60 per cent bruchid infestation, 3 segregants noticed the 61 to 70 per cent bruchid infestation. Whereas, only 2 segregants each were noticed 71 to 80 per cent and 81 to 90 per cent bruchid infestation.

4.7.2 Seed moisture

The results pertaining to the seed moisture (%) at physiological maturity of top 15 moderately resistant F_3 segregants are presented in Table 20.

The F_3 -96 contained minimum moisture (8.40 %) followed by F_3 -95 segregant (8.98 %). Based on the classification of F_3 segregants as reported in the Table 21, moderately resistant (MR) class reported 9.13 per cent moisture content while least susceptible (LS), moderately susceptible (MS) and highly susceptible (HS) classes reported 9.20 per cent, 9.53 per cent and 9.60 per cent moisture content, respectively.

4.7.3 Actual weight loss

The results pertaining to the actual weight loss (%) of top 15 moderately resistant F_3 segregants were illustrated in Table 22.

The F_3 -2 segregant reported minimum actual weight loss (4.92 %) followed by F_3 -95 segregant (4.94 %). The moderately resistant (MR) class reported 6.13 per cent actual weight loss, while least susceptible (LS), moderately susceptible (MS) and highly susceptible (HS) classes reported 9.16 per cent, 12.73 per cent and 16.58 per cent actual weight loss respectively as reported in the Table 23.

Table 16: Classification of F₃ segregants of cowpea for resistance to bruchids (*Callosobruchus maculatus*) based on per cent bruchid infestation

Class	Per cent bruchid infestation	Number of segregants
Highly resistant	0-20	0
Moderately resistant	21-40	71
Least susceptible	41-60	172
Moderately susceptible	61-80	5
Highly susceptible	81-100	2

Table 17. Bruchid infestation (%) for top fifteen moderately resistant F₃ segregants in cowpea

Sl. No	F ₃ segregants	Bruchid infestation (%)
1	F ₃ -2	24.53
2	F ₃ -95	24.53
3	F ₃ -221	24.56
4	F ₃ -223	25.00
5	F ₃ -199	25.45
6	F ₃ -7	25.93
7	F ₃ -232	26.42
8	F ₃ -174	26.92
9	F ₃ -4	27.27
10	F ₃ -92	27.29
11	F ₃ -238	27.45
12	F ₃ -96	27.75
13	F ₃ -208	27.77
14	F ₃ -241	27.78
15	F ₃ -172	28.00

Table 18. Variability for bruchid infestation among different classes

Sl. No.	Classes	Bruchid infestation (%)	Number of segregants in each classes
1	Moderately resistant	30.65	71
2	Least susceptible	45.80	172
3	Moderately susceptible	63.67	5
4	Highly susceptible	82.90	2

Table 19: Frequency of F₃ segregants for resistance to bruchids

Class	Per cent seed infestation	Number of segregants
Moderately resistant	21- 30	47
	31- 40	24
Least susceptible	41- 50	145
	51- 60	27
Moderately susceptible	61-70	3
	71-80	2
Highly susceptible	81-90	2

Table 20: Seed moisture (%) at physiological maturity of top fifteen moderately resistant F₃ segregants of cowpea

Sl. No	F ₃ segregants	Seed moisture (%)
1	F ₃ -2	9.67
2	F ₃ -95	8.98
3	F ₃ -221	10.44
4	F ₃ -223	10.37
5	F ₃ -199	10.82
6	F ₃ -7	9.31
7	F ₃ -232	10.75
8	F ₃ -174	10.40
9	F ₃ -4	9.67
10	F ₃ -92	9.20
11	F ₃ -238	10.44
12	F ₃ -96	8.40
13	F ₃ -208	10.20
14	F ₃ -241	10.82
15	F ₃ -172	10.20

Table 21: Variability for seed moisture (%) among different classes

Sl. No.	Classes	Number of segregants in each classes	Seed moisture (%)
1	Moderately resistant	71	9.13
2	Least susceptible	172	9.20
3	Moderately susceptible	5	9.53
4	Highly susceptible	2	9.60

Table 22: Actual weight loss (%), apparent weight loss (%) and number of bruchids emerged for top fifteen moderately resistant F₃ segregants of cowpea

Sl. No.	F ₃ segregants	Actual weight loss (%)	Apparent weight loss (%)	Number of bruchids emerged 30 days after rearing
1	F ₃ -2	4.92	2.60	10
2	F ₃ -95	4.94	2.67	11
3	F ₃ -221	4.95	2.82	8
4	F ₃ -223	5.00	2.83	11
5	F ₃ -199	5.09	2.80	14
6	F ₃ -7	5.19	2.83	10
7	F ₃ -232	5.28	2.85	13
8	F ₃ -174	5.38	2.88	12
9	F ₃ -4	5.45	3.10	12
10	F ₃ -92	5.45	3.30	9
11	F ₃ -238	5.49	2.85	10
12	F ₃ -96	5.54	3.03	13
13	F ₃ -208	5.57	3.07	15
14	F ₃ -241	5.58	3.01	13
15	F ₃ -172	5.60	2.85	10

Table 23: Variability for actual weight loss (%), apparent weight loss (%), number of bruchids emerged among different classes

Sl. No.	Classes	Number of segregants in each classes	Actual weight loss (%)	Apparent weight loss (%)	Number of bruchids emerged 30 days after rearing
1	Moderately resistant	71	6.13	3.20	15.51
2	Least susceptible	172	9.16	4.76	22.88
3	Moderately susceptible	5	12.73	6.60	31.20
4	Highly susceptible	2	16.58	8.70	37.00

4.7.4 Apparent weight loss

The results pertaining to the apparent weight loss (%) of top 15 moderately resistant F_3 segregants were presented in Table 22.

The F_3 -2 segregant reported minimum apparent weight loss (2.60 %) followed by F_3 -95 segregant (2.67 %). Based on the classification of F_3 segregants as reported in the Table 23, moderately resistant (MR) class reported 3.2 per cent apparent weight loss while least susceptible (LS), moderately susceptible (MS) and highly susceptible (HS) classes reported 4.76 per cent, 6.60 per cent and 8.70 per cent apparent weight loss, respectively.

4.7.5 Number of bruchids emerged

The results related to number of bruchids emerged for top 15 moderately resistant F_3 segregants were reported in Table 22.

The F_3 -221 segregant reported minimum number of bruchids emerged (8) followed by F_3 -92 segregant (9). The moderately resistant (MR) class reported 15.51 number of bruchids emerged, while least susceptible (LS), moderately susceptible (MS) and highly susceptible (HS) classes reported 22.88, 31.20 and 37.00 number of bruchids emerged respectively as reported in the Table 23.

4.7.6 Germination percentage

The seed germination (%) was recorded before and after the screening. The results related to germination percentage of top 15 moderately resistant F_3 segregants were presented in Table 24.

Before screening, F_3 -208 and F_3 -241 segregants reported maximum germination (90 %). While after screening, F_3 -241 and F_3 -223 segregants reported maximum germination (84 %). The F_3 -92 (2.7 %) and F_3 -4 segregants (2.78 %) reported minimum per cent reduction in germination over initial values. Per cent reduction in germination was calculated for each classes. The moderately resistant (MR) class reported 8.19 per cent reduction in germination over initial value, while the least susceptible (LS), moderately susceptible (MS) and highly susceptible (HS) classes reported 18.36 per cent, 18.35 per cent and 26.17 per cent reduction in germination over initial value, respectively as reported in the Table 25.

4.7.7 Seedling length

The seedling length was recorded before and after the screening. The results related to seedling length of top 15 moderately resistant F_3 segregants were summarized in Table 24.

Before screening, the F_3 -199 segregant reported maximum seedling length (44.64 cm) followed by F_3 -174 (44.43 cm). While after screening, F_3 -174 segregant reported maximum seedling length (41.30 cm) followed by F_3 -199 (40.23 cm). Per cent reduction in seedling length was calculated for each class. The moderately resistant (MR) class reported 4.13 per cent reduction in seedling length over initial value, while the least susceptible (LS), moderately susceptible (MS) and highly susceptible (HS) classes reported 8.84 per cent, 9.05 per cent and 15.20 per cent reduction in seedling length over initial value respectively as reported in the Table 25.

Table 24: Effect of *Callosobruchus maculatus* on seed germination (%), seedling length (cm) and seedling vigour index of top fifteen moderately resistant F₃ segregants in cowpea

Sl. No.	F ₃ segregants	Germination (%)		Per cent reduction in germination over initial	Seedling length (cm)		Per cent reduction in seedling length	Seedling vigour index		Per cent reduction in vigour index
		Before screening	After screening		Before screening	After screening		Before screening	After screening	
1	F ₃ -2	76	72	5.26	35.30	32.80	7.62	2,682.80	2,361.60	13.60
2	F ₃ -95	80	76	5.00	38.09	32.30	17.93	3,047.20	2,454.80	24.13
3	F ₃ -221	86	78	9.30	30.70	28.70	6.97	2,640.20	2,238.60	17.94
4	F ₃ -223	88	84	4.55	35.00	31.60	10.76	3,080.00	2,654.40	16.03
5	F ₃ -199	82	78	4.88	44.64	40.23	10.96	3,660.48	3,137.94	16.65
6	F ₃ -7	80	72	10.00	31.30	27.90	12.19	2,504.00	2,008.80	24.65
7	F ₃ -232	86	80	6.98	39.51	37.50	5.36	3,397.86	3,000.00	13.26
8	F ₃ -174	78	72	7.69	44.43	41.30	7.58	3,465.54	2,973.60	16.54
9	F ₃ -4	72	70	2.78	39.50	37.00	6.76	2,844.00	2,590.00	9.81
10	F ₃ -92	74	72	2.70	36.93	33.51	10.21	2,732.82	2,412.72	13.27
11	F ₃ -238	88	80	9.09	39.51	36.40	8.54	3,476.88	2,912.00	19.40
12	F ₃ -96	82	78	4.88	33.93	29.60	14.63	2,782.26	2,308.80	20.51
13	F ₃ -208	90	82	8.88	41.97	32.60	28.74	3,777.30	2,738.40	37.94
14	F ₃ -241	90	84	6.67	34.20	32.10	6.54	3,078.00	2,696.40	14.15
15	F ₃ -172	86	80	6.98	35.00	32.50	7.69	3,010.00	2,600.00	15.77

Table 25: Variability for seed germination (%), seedling length (cm) and seedling vigour index of different classes

Sl. No.	Classes	Germination (%)		Per cent reduction in germination over initial	Seedling length (cm)		Per cent reduction in seedling length	Seedling vigour index		Per cent reduction in vigour index
		Before screening	After screening		Before screening	After screening		Before screening	After screening	
1	Moderately resistant	80.31	73.72	8.19	36.72	35.20	4.13	2,948.05	2,448.84	20.70
2	Least susceptible	80.79	65.92	18.36	37.00	33.73	8.84	2,991.47	2,225.37	35.19
3	Moderately susceptible	74.00	60.40	18.35	39.47	35.90	9.05	2,916.04	2,169.00	35.04
4	Highly susceptible	80.00	59.00	26.17	36.60	32.65	15.20	2,918.21	1,989.30	47.53

4.7.8 Seedling vigour index

The seedling vigour index was recorded before and after the screening. The results related to seedling vigour index of top 15 moderately resistant F_3 segregants were presented in Table 24.

Maximum seedling vigour index was reported by F_3 -208 segregant (3777.30) followed by F_3 -199 (3660.48) before screening. While after screening, maximum seedling vigour index noticed by F_3 -199 (3137.94) followed by F_3 -232 (3000.00). The F_3 -4 segregant reported minimum (9.81 %) reduction in seedling vigour index over initial. Per cent reduction in seedling vigour index was calculated for each class. The moderately resistant (MR) class reported 20.70 per cent reduction in seedling vigour index over initial value, while the least susceptible (LS), moderately susceptible (MS) and highly susceptible (HS) classes reported 35.19 per cent, 35.04 per cent and 47.53 per cent reduction in seedling vigour index over initial value respectively as reported in the Table 25.

4.7.9 Seedling dry weight

The seedling dry weight was recorded before and after the screening. The results related to seedling dry weight of top 15 moderately resistant F_3 segregants were presented in Table 26.

The F_3 -2 segregant reported maximum seedling dry weight (0.99 g) followed by F_3 -199 (0.89 g) before screening. After the screening also, the F_3 -2 segregant reported maximum seedling dry weight (0.99 g) followed by F_3 -199 (0.81 g). Per cent reduction in seedling dry weight was calculated for each of the class. The moderately resistant (MR) class reported 31.63 per cent reduction in seedling seedling dry weight, while the least susceptible (LS), moderately susceptible (MS) and highly susceptible (HS) classes reported 35.30 per cent, 39.30 per cent and 42.11 per cent reduction in seedling dry weight, respectively as reported in the Table 27.

4.7.10 Percentage seed damage

The results pertaining to the percentage seed damage of top 15 moderately resistant F_3 segregants were presented in Table 28.

The results depicted that F_3 -221 segregant noticed the minimum percentage seed damage (14.00 %) followed by F_3 -223 (16.00 %). Based on the classification of F_3 segregants as reported in the Table 29, moderately resistant (MR) class noticed 27.52 per cent seed damage and least susceptible (LS), moderately susceptible (MS), highly susceptible (HS) classes noticed 43.52 per cent, 62.40 per cent and 82.00 per cent seed damage, respectively.

4.7.11 Percentage loss in seed viability

The results related to the percentage loss in seed viability of top 15 moderately resistant F_3 segregants were presented in Table 28.

The F_3 -199 segregant recorded minimum loss in seed viability (4.88 %) followed by F_3 -96 segregant (4.83 %). Based on the classification of F_3 segregants as reported in the Table 29, moderately resistant (MR) class noticed 8.19 per cent loss in seed viability and least susceptible (LS), moderately susceptible (MS), highly susceptible (HS) classes noticed 18.36 per cent, 18.35 per cent and 26.17 per cent loss in seed viability, respectively.

Table 26: Effect of *Callosobruchus maculatus* on seedling dry weight (g) of top fifteen moderately resistant F₃ segregants in cowpea

Sl. No.	F ₃ segregants	Seedling dry weight (g)		Per cent decrease in seedling dry weight
		Before screening	After screening	
1	F ₃ -2	0.99	0.89	11.24
2	F ₃ -95	0.68	0.67	2.26
3	F ₃ -221	0.68	0.65	4.62
4	F ₃ -223	0.59	0.56	5.36
5	F ₃ -199	0.89	0.81	9.88
6	F ₃ -7	0.86	0.71	21.13
7	F ₃ -232	0.69	0.54	27.78
8	F ₃ -174	0.63	0.48	31.25
9	F ₃ -4	0.69	0.54	27.78
10	F ₃ -92	0.75	0.60	25.00
11	F ₃ -238	0.68	0.53	28.30
12	F ₃ -96	0.87	0.72	20.83
13	F ₃ -208	0.56	0.41	36.59
14	F ₃ -241	0.69	0.54	27.78
15	F ₃ -172	0.67	0.52	28.85

Table 27: Variability for seed seedling dry weight (g) of different classes

Sl. No.	Classes	Number of F ₃ segregants in each classes	Seedling dry weight (g)		Per cent decrease in seedling dry weight
			Before screening	After screening	
1	Moderately resistant	71	0.69	0.52	31.63
2	Least susceptible	172	0.69	0.51	35.30
3	Moderately susceptible	5	0.64	0.46	39.30
4	Highly susceptible	2	0.90	0.52	42.11

Table 28: Percentage seed damage and percentage loss in seed viability of top fifteen moderately resistant F₃ segregants of cowpea

Sl. No.	F ₃ segregants	Percentage seed damage	percentage loss in seed viability
1	F ₃ -2	20.00	5.26
2	F ₃ -95	20.00	5.00
3	F ₃ -221	14.00	9.30
4	F ₃ -223	16.00	4.55
5	F ₃ -199	18.00	4.88
6	F ₃ -7	20.00	10.00
7	F ₃ -232	22.00	6.98
8	F ₃ -174	24.00	7.69
9	F ₃ -4	20.00	2.78
10	F ₃ -92	20.00	2.70
11	F ₃ -238	26.00	9.09
12	F ₃ -96	22.00	4.83
13	F ₃ -208	22.00	6.67
14	F ₃ -241	22.00	6.50
15	F ₃ -172	28.00	6.98

Table 29: Variability for percentage seed damage and percentage loss in seed viability of different classes

Sl. No.	Classes	Number of F ₃ segregants in each classes	Percentage seed damage	percentage loss in seed viability
1	Moderately resistant	71	27.52	8.19
2	Least susceptible	172	43.52	18.36
3	Moderately susceptible	5	62.40	18.35
4	Highly susceptible	2	82.00	26.17

5. DISCUSSION

Agro-ecological constraint has been one of the major production constraints in pulses in general and cowpea in particular. Hence, a balance between yield stability and productivity is more essential. A pivotal component for enhancing and simultaneously maintaining sustainable production of cowpea is the release of high yielding, stable genotypes for cultivation across different agro-ecological zones. Genotype $\times$ environment interaction pose important problem, whenever new genotypes are developed and selection of genotypes to be grown in an area is to be determined. The term adaptability as related to crop plants applies not only to the ability of plants to survive but also to maintain stability in yield levels under varying environments. The different environments may refer to different locations, seasons and years. Fluctuating yields in different crop growing situations necessitates the use of stable performing genotypes for higher and stable yields. The $G \times E$ interaction thus is of major importance to a plant breeder for developing varieties with wider adaptability or those adapted to specific environmental niche.

The precise information on the nature and degree of genetic variability, heritability among various traits that contribute towards seed yield would help the breeder in identifying the appropriate genotype. If the genotype is also widely adaptable, it is an additional advantage.

A major constraint to the sustainable production and post-harvest preservation of cowpea in the tropics is infestation by the storage pest bruchid, (*Callosobruchus maculatus* F.) a cosmopolitan and most destructive pest of stored pulse grains, which causes severe economic losses to farmers and traders. The control of this pest is crucial to the increased and sustainable production of cowpea. In order to reduce seed loss due to bruchid attack, the search for host plant resistance in cowpea seeds has increasingly become an option of choice in recent years. Hence, it is pertinent that a study on responses of improved cowpea cultivars to bruchid infestation to assess their resistance under storage conditions intended to be released for cultivation.

In the present investigation, an attempt was made to assess the amount of variability, broad sense heritability, genotypic and phenotypic variances, predicted genetic advance, GCV and PCV with respect to yield and yield attributing traits. The $G \times E$ interaction and stability of these characters have been studied. Further, screening of the 250 F_3 segregants was done. The results obtained on stability parameters across three different locations and studies on bruchid resistance screening are discussed below in the light of available literature under following headings.

- 5.1 Analysis of variance.
- 5.2 Analysis of variance for the locations.
- 5.3 Variability studies across locations.
- 5.4 Performance of genotypes in different environments
- 5.5 Genotype $\times$ environmental interaction.
- 5.6 Stability analysis.
- 5.7 Screening for bruchid (*Callosobruchus maculatus* F.) resistance.

5.1 Analysis of variance

Analysis of variance of yield and yield attributing traits showed highly significant differences among the genotypes for the traits *viz.*, plant height, pod length, number of seeds per pod, 100 seed weight and seed yield. This information indicates that sizable variability exists for the characters and considerable improvement can be achieved in these characters by selection. Further, the genotypes under study exhibited sufficient genetic variability, which is the basic requirement of the present experimentation.

5.2 Analysis of variance for the locations

Analysis of variance was performed for all the three locations to test the significant difference among the genotypes for the characters studied. Partitioning the variance into genotypic, phenotypic and environmental components was done as suggested by Fisher and Yates (1963). The significance of mean sum of squares for thirty genotypes along with four checks for all the three environments chosen, suggested existence of adequate variability for the characters *viz.*, days to 50 % flowering, plant height, pod length, number of seeds per pod, number of pods per plant, 100 seed weight and seed yield showing that the choice of these traits will have a significant bearing on crop improvement.

5.3 Variability studies across locations

Plant yield being dependent upon a number of components as it is a very complex character. Many plant characters of economic importance are quantitatively inherited and thus are subjected to the environmental factors. The selections made in the field based on the phenotypic expressions are likely to be less efficient. Studies on the relative amount of heritable (genetic) and non-heritable (non-genetic) variability exhibited for various traits are therefore, likely to be useful in selection. Partitioning the total observed variances into their genotypic, environmental and phenotypic components and subsequent estimation of genetic components of variability by the use of suitable parameters like genotypic coefficient of variability, heritability percentage and expected genetic advance over the mean of each character are considered as a suitable approaches for this purpose.

In the present study, 34 genotypes of cowpea were studied to assess their genetic potential. All the genotypes exhibited substantial amount of differences in their mean performance with respect to all the characters studied, indicating that the genotypes under study were genetically diverse.

The genotypes revealed moderate variation for many of the characters studied. These differences may be attributed to their diverse genetic makeup and the environmental interactions. The characters *viz.*, days to 50 % flowering, plant height, pod length, number of seeds per pod and 100 seed weight showed narrow range of variation. While, characters *viz.*, number of pods per plant and seed yield exhibited high range. The range of values presented in the Table 6 indicated the scope for selection of suitable basic material for breeding for further improvement. The range in the values reflects the extent of phenotypic variability in respect of these characters includes genotypic, environmental and genotype and environmental interaction components.

Therefore, the estimation of heritable (genetic) and non-heritable components of environmental variation is of great value in the choice of suitable breeding procedures. Johansson (1909), East (1916) and Power (1942) separated genetic variance from total variance by using environmental variances. The knowledge of variance alone will not suffice unless the variance is partitioned into phenotypic and genotypic coefficient of variation, which are more reliable for effective selection. Thus the components of variation such as phenotypic and genotypic coefficient of variability, heritability and predicted genetic advance were computed in respect of yield and its component characters.

Higher value of GCV and PCV were obtained for the characters number of pods per plant and seed yield. This indicates that the substantial variability exists for these characters in the material studied and indicates greater scope for selection to increase the expression of these characters. Similar findings were reported by Nehru *et al.* (2009), Ramesh *et al.* (2009), Kiran *et al.* (2014) and Kharde *et al.* (2014). Hence, this indicates the scope for augmenting the genotypes for wider variability which forms a source to improve the yield and yield component characters.

The characters number of pods per plant and seed yield exhibited the larger differences between GCV and PCV reflecting substantial influence of environment. These characters were more sensitive to environmental changes. Selection based on phenotypic observations above may not be very effective for these traits. The characters days to 50 % flowering, plant height, pod length, number of seeds per pod and 100 seed weight exhibited lower differences between GCV and PCV but their values were low to moderate therefore, selection is difficult to practice for these characters because variation among the genotypes is less. Similar findings were reported by Rangaiah (1997) and Sharma (1999).

The effectiveness of selection for any component of yield depends not only on the amount of variability but also how much of it is readily amenable for improvement. Genotypic coefficient of variation together with the heritability estimates would give the best information of the amount of advance to be expected from selection (Burton *et al.*, 1953).

The use of genotypic coefficient of variation would be limited as it is prone to change with fluctuation in environment. So the estimates of heritability have a role to play in determining the effectiveness of selection of character provided they are considered in conjunction with the predicted genetic advance as suggested by Panse and Sukhatme (1967) and Johnson *et al.* (1955).

In the present investigation, moderate heritability and low genetic advance were exhibited by characters viz., days to 50 % flowering, number of seeds per pod and 100 seed weight. Low heritability and low genetic advance were noticed for plant height, pod length and number of pods per plant. Though the large number of genotypes are involved in this investigation the heritability and genetic advance were not high. Seed yield exhibited low heritability but high genetic advance. These results are in accordance with Hanumanthraya (2003). Therefore, selection based on phenotypic observation alone may not be very effective for these traits. Hence to achieve the defined high variability for the selection programme, systematic efforts need to be made to combine hybridization and recombination in cowpea to generate desirable variability. So, approaches like hybridization of

superior diverse parents followed by selection are suggested to generate desired variability to develop transgressive segregants for economically important traits.

5.4 Performance of genotypes in different environments

5.4.1 Mean performance of genotypes

The mean performance of the genotypes varied with environments in response to the changes in environments. Permanent inheritable changes in the genetic material can also be induced by environmental changes. Since the response of the genotypes was not equal or similar, the mean performance of genotypes *i.e.*, population mean or site mean (Eberhart and Russel, 1966) changed in different environments. Eberhart and Russel (1966) introduced one parameter based on site means, the “Environmental index”, which is the deviation of site mean from overall grand mean. This parameter is based on environmental factors.

5.4.1.1 Days to 50 % flowering

The character, days to 50 % flowering expressed well in environment at Malgi as indicated by higher mean value and environmental index. Early flowering was more favoured in Dharwad.

5.4.1.2 Plant height

Plant height was more influenced by the changes in environment as the range of mean values and environmental indices was very wide across all environments. Plant height was more favoured in the environment at Malgi. The luxuriant vegetative growth is attributed to rich soil nutrient status at Malgi.

5.4.1.3 Pod length

The environments at Malgi and Bailhongal were most favourable for pod length as indicated by the high mean values and environmental indices. The character was little influenced by the change in environment as indicated by narrow range of environmental indices, obviously indicating predominant genetic control of the character.

5.4.1.4 Number of seeds per pod

Number of seeds per pod was favored most by environment at Malgi followed by Bailhongal. The narrow range of mean values and environmental indices indicate the little effect of change in environment on the character expression.

5.4.1.5 Number of pods per plant

The environment at Dharwad was most favourable for number of pods per plant as indicated by the high mean value and environmental index. The narrow range of mean values and environmental indices indicate the little effect of change in environment on the character expression. The environment at Bailhongal restricted the expression of this character probably due to agro-ecological factors.

5.4.1.6 100 seed weight

The character, 100 seed weight exhibited superiority in environment at Malgi as indicated by higher mean value and environmental index. The narrow range of mean values and environmental indices indicate the little effect of change in environment on the character expression.

5.4.1.7 Seed yield

Seed yield was greatly affected by the change in environment across different environments. The wide range of mean values and environmental indices across the environments indicate the extent of influence of change in environment on the character expression. The yield was maximum in environment at Malgi and least in Bailhongal. The environment at Malgi was most favourable for seed yield as indicated by the high mean value and environmental index.

5.5 Genotype $\times$ environmental interaction

Pooled analysis of variance was carried out in cowpea for different characters *viz.*, days to 50 % flowering, plant height, pod length, number of seeds per pod, number of pods per plant, 100 seed weight and seed yield.

The pooled analysis of variance (Table 8) revealed that mean sum of squares (MSS) due to genotypes were significant for most of the characters. This obviously indicates the presence of large amount of variability in the material chosen for the study. The MSS due to environments were also significant for all the traits indicating the validity of conduct of experiment in these environments. The genotype $\times$ environment interactions were significant for most of the traits except for number of pods per plant, revealing that genotypes under study were having significant differential response to the changing environment. These results are in conformity with those obtained by Patel and Jain (2012) and El-Shaieny *et al.* (2015).

Component analysis of environment + (genotype $\times$ environment) were significant for all the traits except for number of pods per plant. Partitioning of this variation into linear and non-linear component revealed that the mean square due to linear component of environment were significant for all the characters indicating that environmental effects are additive. The significant mean squares confirm that the environments were random and different. There was influence of environment on the expression of the traits and this variation could have arisen due to the linear response of the regression of the cultivar to the environment. The mean square due to the linear component $G \times E$ was significant for the all characters except for the characters namely number of seeds per pod and number of pods per plant. This revealed that the behavior of the genotypes could be predicted over the environments more precisely and accurately as the $G \times E$ interaction was the outcome of the linear function of the environmental components.

The non-linear component arising due to the heterogeneity measured as mean square due to the pooled deviation was significant for all the traits revealed presence of non-linear response of the genotypes to the changing environment for these traits. The significance of pooled deviation confirms contribution of the non-linear component to the total $G \times E$ interaction. The genotypes differed with

respect to the stability of these traits making its prediction more difficult. However, the magnitude of linear component *i.e.*, environment (linear) and genotype $\times$ environment (linear) was many times higher than the non linear component (pooled deviation) for most of the characters revealed that the prediction of stability could be reliable though it may get affected to some extent. The results obtained in the present study are in agreement with the findings of Akande (2007), Adewale *et al.* (2010), Patel and Jain (2012) and El-Shaieny *et al.* (2015).

5.6 Stability analysis

Once the genotype $\times$ environment interactions were found to be significant, the next task is to identify stable genotypes. The stable genotype is the one, which interact less with the environments giving a near consistent performance across different environments. Many stability models have been developed to identify the stable genotypes. Eberhart and Russell (1966) model is the one which has been used in cowpea and in other crops by several workers. According to Eberhart and Russell (1966), a variety is said to be stable which exhibit high *per se* mean performance, regression coefficient (b_i) is equal to one and deviation from regression (S^2_{di}) as close to zero as possible. Allard and Bradshaw (1964) suggested selection of stable genotypes that interact less with environments in which they are to be grown with a view to reduce the genotype $\times$ environment interaction to a considerable extent.

The above three measures of assessing the stability of genotype *viz.*, mean, regression coefficient (b_i) and the mean square deviation (S^2_{di}) were employed in assessing the stability of genotypes included in the present study. The linear regression (b_i) could simply be regarded as the measure of response of a particular genotype and if it is greater than one then, the genotype is said to be sensitive to environmental changes but adapted to favourable environments. If it is less than one then it indicates above average stability. If this is accompanied by a high mean value then, the genotype is said to be better adapted to unfavourable environments and if the mean value is low, greater $G \times E$ interaction indicated (Finlay and Wilkinson, 1963). On the other hand, deviation around the regression line is considered as a better measure of stability. With respect to the non linear component of the $G \times E$ interaction, the genotype with the lowest standard deviations will be the most stable and *vice-versa*.

Stability analysis was carried out by employing the linear regression model proposed by Eberhart and Russell (1966). Although there are number of models available to characterize the genotypes for their $G \times E$ interactions, this model is widely used for its simplicity and reliability. Many workers have employed this model in cowpea namely Akande (2007), Adewale *et al.* (2010), Patel and Jain (2012), Nelia (2013), Gabriel *et al.* (2015) Olayiwola *et al.* (2015) and El-Shaieny *et al.* (2015).

The results pertaining to these stability parameters are discussed character-wise as suggested by Eberhart and Russell (1966).

5.6.1 Stability analysis for different characters

5.6.1.1 Days to 50 % flowering

Normally, the desirable and stable genotypes have high mean value, $b_i=1$ and $S^2_{di} = 0$ for the concerned character but, for the trait like days to first flower, early flowering will be desirable, so in the context of this character the definition of desirable stable genotype changed to low mean, $b_i=1$, $S^2_{di} = 0$. From the mean performance of genotypes across all the environments it appears that among the thirty four genotypes, fifteen genotypes flowered early. However from the stability point of view, eleven genotypes viz., F_6 lines of cross C-152 $\times$ IC 202790, C-152 $\times$ DCS-5-3-20, DCS-47-1 $\times$ DC-15, IC 202778 $\times$ IC 202787, V-118 $\times$ IC 249140-1, C-152 $\times$ IC 97767, V-118 $\times$ IC 68786, DC-15 $\times$ DCS-47-1, C-152 $\times$ IC 249140, DC-15 (check 2) and DC-16 (check 4) were found to be stable with lower mean values for days to 50 % flowering, regression coefficient (b_i) near to unity and least deviation from regression (S^2_{di}) hence found suitable to all environments with predictable performance. The F_6 lines of cross DCS-47-1 $\times$ GC-3, DC-15 $\times$ NBC-1, V-118 $\times$ IC 249140-2 and C-152 $\times$ IC 249140 possessed lower mean values but the regression coefficient was exceeding unity indicating suitability of these genotypes to favourable environments.

5.6.1.2 Plant height

Difference in plant height among genotypes is by virtue of their indeterminate and determinate growth habit. The present study revealed that the F_6 lines of crosses, C-152 $\times$ DCS-5-3-20, C-152 $\times$ IC 198701, V-118 $\times$ IC 27502, C-152 $\times$ IC 202710, GC-3 $\times$ IC 198333, DC15 $\times$ JOB-129, DC-15 $\times$ Subhra and germplasm lines IC 202779, IC 249141, IC 202730, checks DCS-47-1 (check 3) and DC-16 (check 4) showed better adaptability to all the three locations with predictable performance as far as plant height is concerned, as indicated by higher mean values, regression coefficient (b_i) near to unity and least deviation from regression (S^2_{di}). While the F_6 line of cross C-152 $\times$ IC 201079 exhibited high mean value but regression coefficient (b_i) significantly greater than unity which indicated that this genotype has below average stability and this is well adapted to favorable environment and performance can be predicted.

5.6.1.3 Pod length

From the mean performance of genotypes across all the environments it appears that the F_6 lines namely DCS-47-1 $\times$ GC-3, GC-3 $\times$ C 152, V-118 $\times$ IC 249140-1, V-118 $\times$ IC 249140-2, C-152 $\times$ IC 249140 and germplasm line IC 202730 exhibited better adaptability to all the three locations and performance of these genotypes can be predicted. Whereas the F_6 lines namely DC-15 $\times$ NBC-1, C-152 $\times$ IC 97767 and DC-15 $\times$ DCS-47-1 exhibited high mean value but regression coefficient (b_i) significantly greater than unity which indicated that these genotypes have below average stability and these are well adapted to favourable environment and performance of these can be predicted. Whereas, the DC-15 (check 2) revealed above average stability with suitability to poor environment. The F_6 lines of cross C-152 $\times$ DCS-5-3-20, DC-15 $\times$ Subhra, V-118 $\times$ GL, C-152 $\times$ IC 202825, V-118 $\times$ IC 27502, V-118 $\times$ IC 68786, IC 202778 $\times$ IC 202787 and germplasm line IC 249141 exhibited higher mean values with unpredictable performance.

5.6.1.4 Number of seeds per pod

Among the thirty four genotypes, fifteen genotypes have the higher mean values than population mean for number of seeds per pod. Among these the F_6 progenies of crosses namely, C-152 × IC 97767, C-152 × IC 198701, C-152 × IC 201079, DC-15 × DCS-47-1, GC-3 × IC 198333, DCS-47-1 × GC-3, V-118 × IC 249140-1, GC-3 × C 152, GC-3 × IC 202872, C-152 × IC 202710, germplasm lines IC 202730, IC 249141 and DC-15 (check 2) possessed b_i values near to unity and least non-significant S^2di values coupled with high mean which revealed their average stability across environments with predictable performance. Whereas the F_6 line DC-15 × Subhra reacted with the environment, with the b_i value less than unity along with non significant S^2di value, indicating its stability under poor environment. The F_6 lines C-152 × DCS-5-3-20, DC-15 × NBC-1 possessed high mean accompanied with significant S^2di value and therefore, its performance was unpredictable in nature under changing environment.

5.6.1.5 Number of pods per plant

Among the thirty four genotypes, seventeen genotypes have the higher mean values than population mean for number of pods per plant. However from the stability point of view considering the criteria of desirable and stable genotypes *i.e.*, high mean, $b_i = 1$ and $S^2di = 0$, only two F_6 progenies of crosses namely V-118 × GL and C-152 × IC 198701 exhibited the average stability across the locations with predictable performance.

The F_6 lines which exhibited above average stability and adaptation to poor environment were C-152 × CP-206, C-152 × IC 201079 and C 152 (check 1) as evident from their higher mean, b_i value lower than unity and least non-significant S^2di and performance of these genotypes can be predicted. Whereas F_6 lines of crosses C-152 × DCS-5-3-20, GC-3 × IC 202872, V-118 × IC 249141, IC 202778 × IC 214836, V-118 × IC 68786, DC-15 × DCS-47-1, C-152 × IC 249140, germplasm lines IC 249141, IC 202730 and checks DC-15, DCS-47-1, DC -16 recorded higher mean values than population mean but exhibited significant deviation from the regression coefficient hence their performance could not be predicted under changing environment.

5.6.1.6 100 seed weight

The F_6 lines of the crosses namely DCS-47-1 × GC-3, C-152 × DCS-5-3-20, V-118 × GL, V-118 × IC 27502, C-152 × IC 202790, C-152 × IC 249140 and IC 202778 × IC 214836 were averagely stable across the environments as evident from non significant b_i from unity and S^2di values coupled with high mean. The F_6 progeny of cross namely DCS-47-1 × DC-15 and DC-15 (check 2) reacted with the environment, with the b_i value more than unity along with non significant S^2di value, indicating stability under favourable environment and performance of these genotypes can be predicted. The F_6 line the cross V-118 × IC 68786 and germplasm line IC 249141 exhibited above average stability and adaptation to poor environment. Whereas the performance of F_6 lines the crosses *viz.*, GC-3 × IC 198333, V-118 × IC 249140-1, V-118 × IC 249140-2 cannot be predicted under changing environment as indicated by significant deviation from the regression coefficient even though they exhibited higher mean values.

5.6.1.7 Seed yield

Yield has been described as a complex phenotypic trait in plants because it is a final aggregate product of many interwoven physiological and developmental traits controlled by different arrays of genes. Being final product of complex physiological and development processes from sowing to maturity (Oladejo *et al.*, 2011), seed yield recorded highest variation across the locations. This observation is expected as yield as a trait is more influenced by environment.

Based on *per se* performance the top five genotypes identified for environment at Malgi (rich environment) were F₆ progenies of C-152 × CP-206 (1,869.79 kg ha⁻¹), DC-15 × Subhra (1,743.86 kg ha⁻¹), DC-15 × JOB-129 (1,734.56 kg ha⁻¹), DC-15 × DCS-47-1 (1,667.67 kg ha⁻¹) and check 3-DCS-47-1 (1,645.57 kg ha⁻¹).

Likewise with respect to environment at Dharwad (moderate environment) the top five genotypes identified were F₆ progenies of C-152 × IC 202825 (1,271.54 kg ha⁻¹), C-152 × DCS-5-3-20 (1,270.30 kg ha⁻¹), C-152 × CP-206 (1,238.80 kg ha⁻¹), IC 202730 (1,230.39 kg ha⁻¹) and DC-15 × DCS-47-1 (1,226.25 kg ha⁻¹).

Similarly, with respect to environment at Bailhongal (poor environment) the top five genotypes identified were F₆ progenies of DC-15 × DCS-47-1 (1,457.31 kg ha⁻¹), C-152 × DCS-5-3-20 (1,368.69 kg ha⁻¹), IC 202730 (1,305.48 kg ha⁻¹), DCS-47-1 × GC-3 (1,246.11 kg ha⁻¹) and C-152 × IC 202790 (1,236.06 kg ha⁻¹).

In continuation with it with respect to *per se* performance across the locations the top five genotypes were F₆ progenies of DC-15 × DCS-47-1 (1,450.41 kg ha⁻¹), C-152 × CP-206 (1,259.83 kg ha⁻¹), DC-15 × Subhra (1,251.16 kg ha⁻¹), check 3-DC 47-1 (1,245.22 kg ha⁻¹) and check 2-DC-15 (1,205.94 kg ha⁻¹).

Considering superiority with respect to *per se* mean values and regression co-efficient (non-significantly different from unity) across all three environments, the best ten genotypes among 34 cultivars are F₆ progenies of crosses DC-15 × DCS-47-1 (1,450.41 kg ha⁻¹, $b_i = 0.47$), C-152 × CP-206 (1,259.83 kg ha⁻¹, $b_i = 2.95$), DC-15 × Subhra (1,251.16 kg ha⁻¹, $b_i = 1.97$), check 3-DCS-47-1 (1,245.22 kg ha⁻¹, $b_i = 1.37$), check 2-DC-15 (1,205.94 kg ha⁻¹, $b_i = 1.51$), C-152 × IC 198701 (1,198.42 kg ha⁻¹, $b_i = 1.47$), C-152 × IC 97767 (1,189.39 kg ha⁻¹, $b_i = 1.42$), DC-15 × JOB-129 (1,177.88 kg ha⁻¹, $b_i = 2.48$), C-152 × IC 201079 (1,170.48 kg ha⁻¹, $b_i = 1.42$) and check 4-DC-16 (1,126.38 kg ha⁻¹, $b_i = 1.42$).

However according to stability model considering all the three parameters *per se* mean, regression coefficient (b_i) and standard deviation from regression, the stable genotypes are which have *per se* mean higher than population mean, regression coefficient (b_i) is near or equal to one (non-significantly different) and deviation from regression (S^2_{di}) as close to zero as possible (Eberhart and Russell, 1966). When analysis was made according to above stability model considering all three above genetic parameters the most stable genotypes observed were the F₆ lines of crosses as indicated below:

C-152 × IC 198701 (Mean-1,198.42 kg ha⁻¹, b_i-1.47, S²di-3371.69)

C-152 × IC 201079 (Mean-1,170.48 kg ha⁻¹, b_i-1.42, S²di-470.2)

C-152 × IC 202710 (Mean-1,084.52 kg ha⁻¹, b_i-1.84, S²di-565.08)

GC-3 × IC 202872 (Mean-1,070.38 kg ha⁻¹, b_i-1.36, S²di-835.33)

V-118 × IC 249141 (Mean-1,022.63 kg ha⁻¹, b_i-0.93, S²di-169.56)

However the genotypes DC-15 × JOB-129, IC 202730, IC 249141, C-152 × DCS-5-3-20, DC-15 × Subhra, C-152 × CP-206, C-152 × IC 97767, DC-15 × DCS-47-1, C-152 (check 1), DC-15 (check 2), DCS-47-1(check 3) and DC-16 (check 4) possessed higher mean values and regression coefficient not significantly different from one, but deviation from regression coefficient for these genotypes deviated significantly different from zero indicating their unpredictable performance. Hence, these genotypes are suited for specific environment conditions in order to express their full yield potential. These results appeared to be in harmony with those obtained by Yousaf and Sarwar (2008), Sarvamangala *et al.* (2010), Patel and Jain (2012), Chaudhari *et al.* (2013) and El-Shaieny *et al.* (2015).

Further based on this study the promising genotypes were F₆ lines of crosses DC-15 × DCS-47-1, C-152 × CP-206, DC-15 × Subhra, C-152 × IC 198701, C-152 × IC 97767, DC-15 × JOB-129, C-152 × IC 201079, C-152 × IC 202710, GC-3 × IC 202872, V-118 × IC 249141. Even though they are exhibiting significant standard deviation, the mean values at each environment were very high. These could be promoted to multilocation trials and also coordinated yield trials after one year of evaluation in the station trial.

5.6.2 Stability of genotypes for different characters and frequency of stable genotypes for different traits under different locations

The genotypes exhibiting stability for each character was given a score of 1 and total score obtained by each genotypes across traits were calculated (Table 31). Of the 34 genotypes, the F₆ progenies of crosses DCS-47-1 × GC-3, C-152 × IC 198701, V-118 × IC 249140-1 and C-152 × IC 249140 were found to be stable for three characters each therefore these genotypes deserve a special consideration. The F₆ progenies of crosses C-152 × IC 202790, C-152 × DCS-5-3-20, GC-3 × C 152, V-118 × GL, C-152 × IC 201079, GC-3 × IC 202872, C-152 × IC 97767, DC-15 × DCS-47-1, C-152 × IC 202710, germplasm line IC 202730 and DC-15 (check 2) were stable for two characters each. The F₆ progenies of crosses GC-3 × IC 198333, DCS-47-1 × DC-15, V-118 × IC 249141, V-118 × IC 27502, IC 202778 × IC 214836, IC 202778 × IC 202787, V-118 × IC 68786, C-152 × IC 97767, germplasm line IC 249141 and DC-16 (check 4) were stable for one character each. The C-152 × IC 201079, GC-3 × IC 202872, C-152 × IC 198701, C-152 × IC 202710 and V-118 × IC 249141 exhibited stability for seed yield.

Among the genotypes tested as many as 13 genotypes exhibited stability for number of seeds per pod, 11 genotypes exhibited stability for days to 50 % flowering which indicated that these genotypes did not show environmental effect on flowering time, 7 genotypes exhibited stability for 100 seed weight, 6 genotypes exhibited stability for pod length, 5 genotypes exhibited stability for seed yield, whereas only 2 genotypes recorded stability for number of pods per plant

Table 30: *Per se* performance of promising genotypes at different locations

Sl. No.	Dharwad	Seed yield (kg ha ⁻¹)	Bailhongal	Seed yield (kg ha ⁻¹)	Malgi	Seed yield (kg ha ⁻¹)	Overall locations	Seed yield (kg ha ⁻¹)
1	C-152 × IC 202825	1,271.54	DC -15 × DCS-47-1	1,457.31	C-152 × CP-206	1,869.79	DC -15 × DCS-47-1	1,450.41
2	C-152 × DCS-5-3-20	1,270.3	C-152 × DCS-5-3-20	1,368.69	DC -15 × Subhra	1,743.86	C-152 × CP-206	1,259.83
3	C-152 × CP-206	1,238.8	IC 202730	1,305.48	DC -15 × JOB-129	1,734.56	DC -15 × Subhra	1,251.16
4	IC 202730	1,230.39	DCS-47-1 × GC-3	1,246.11	DC -15 × DCS-47-1	1,667.67	C-152 × IC 198701	1,198.42
5	DC -15 × DCS-47-1	1,226.25	C-152 × IC 202790	1,236.06	C-152 × IC 97767	1,544.77	C-152 × IC 97767	1,189.39
6	DCS-47-1 × DC-15	1,214.49	DCS-47-1 × DC-15	1,077.35	C-152 × IC 198701	1,519.01	DC -15 × JOB-129	1,177.88
7	IC 249141	1,209.81	C-152 × IC 97767	957.6	GC-3 × C-152	1,499.84	C-152 × IC 201079	1,170.48
8	C-152 × IC 198701	1,156.32	V-118 × GL	957.17	C-152 × IC 201079	1,470.41	C-152 × DCS-5-3-20	1,108.04
9	C-152 × IC 201079	1,148.09	DC -15 × Subhra	930.82	C-152 × IC 202710	1,467.66	C-152 × IC 202710	1,084.52
10	V-118 × IC 249132	1,109.81	C-152 × IC 198701	919.93	V-118 × IC 27502	1,422.47	IC 202730	1,083.41
11	C-152 (Check 1)	776.36	C-152 (Check 1)	882.32	C-152 (Check 1)	1,584.59	C-152 (Check 1)	1,081.09
12	DC-15 (Check 2)	1,071.55	DC -15 (Check 2)	960.44	DC-15 (Check 2)	1,585.84	DC-15 (Check 2)	1,205.94
13	DCS-47-1 (Check 3)	1,018.25	DCS-47-1 (Check 3)	1,071.85	DCS-47-1 (Check 3)	1,645.57	DCS-47-1 (Check 3)	1,245.22
14	DC-16 (Check 4)	1,042.47	DC-16 (Check 4)	876.11	DC-16 (Check 4)	1,460.58	DC-16 (Check 4)	1,126.38

Table 31: Pooled score for Stability for yield and yield attributing traits in cowpea

Sl. No.	F ₆ progenies	Days to 50 % flowering	Pod length (cm)	Number of Seeds per pod	Number of Pods per plant	100 Seed weight (g)	Seed yield (kg ha ⁻¹)	Total Score
1	GC-3 × IC 198333	0	0	I	0	0	0	1
2	DC -15 × JOB-129	0	0	0	0	0	0	0
3	C-152 × IC 202790	I	0	0	0	I	0	2
4	DCS-47-1 × GC-3	0	I	I	0	I	0	3
5	IC 202730	0	I	I	0	0	0	2
6	IC 202779	0	0	0	0	0	0	0
7	IC 249141	0	0	I	0	0	0	1
8	DC -15 × NBC -1	0	0	0	0	0	0	0
9	C-152 × DCS-5-3-20	I	0	0	0	I	0	2
10	DCS-47-1 × DC-15	I	0	0	0	0	0	1
11	DC -15 × Subhra	0	0	0	0	0	0	0
12	C-152 × CP-206	0	0	0	0	0	0	0
13	GC-3 × C-152	0	I	I	0	0	0	2
14	V-118 × GL	0	0	0	I	I	0	2
15	C-152 × IC 198701	0	0	I	I	0	I	3
16	C-152 × IC 201079	0	0	I	0	0	I	2
17	GC-3 × IC 202872	0	0	I	0	0	I	2

I- Stable 0- Unstable

Contd.....

Sl. No.	F ₆ progenies	Days to 50 % flowering	Pod length (cm)	Number of Seeds per pod	Number of Pods per plant	100 Seed weight (g)	Seed yield (kg ha ⁻¹)	Total Score
18	V-118 × IC 249141	0	0	0	0	0	I	1
19	C-152 × IC 202825	0	0	0	0	0	0	0
20	V-118 × IC 27502	0	0	0	0	I	0	1
21	V-118 × IC 249132	0	0	0	0	0	0	0
22	IC 202778 × IC 214836	0	0	0	0	I	0	1
23	IC 202778 × IC 202787	I	0	0	0	0	0	1
24	V-118 × IC 249140-1	I	I	I	0	0	0	3
25	V-118 × IC 68786	I	0	0	0	0	0	1
26	C-152 × IC 97767	I	0	I	0	0	0	2
27	V-118 × IC 249140 -2	0	I	0	0	0	0	1
28	DC -15 × DCS-47-1	I	0	I	0	0	0	2
29	C-152 × IC 202710	0	0	I	0	0	I	2
30	C-152 × IC 249140	I	I	0	0	I	0	3
31	Check 1 - C-152	0	0	0	0	0	0	0
32	Check 2 -DC-15	I	0	I	0	0	0	2
33	Check 3 - DCS-47-1	0	0	0	0	0	0	0
34	Check 4- DC-16	I	0	0	0	0	0	1
Total score		11	6	13	2	7	5	

I- Stable 0- Unstable

Table 32: Cowpea genotypes suitable for individual environments for yield and yield attributing traits

Sl. No.	Characters	Dharwad	Bailhongal	Malgi
1	Days to 50 % flowering	C-152 × IC 202790, DCS-47-1 × GC-3, DC -15 × NBC -1.	C-152 × IC 202790, DCS-47-1 × GC-3, DC -15 × DCS-47-1.	DCS-47-1 × GC-3, DC -15 × DCS-47-1, IC 202730.
2	Plant height (cm)	V-118 × GL, DCS-47-1 (Check 3) DCS-47-1 × DC-15.	V-118 × IC 68786, C-152 × IC 198701 C-152 × IC 201079.	IC 202730, GC-3 × IC 198333, C-152 × IC 201079.
3	Pod length (cm)	C-152 × DCS-5-3-20, DC -15 (Check 2), DC -15 × Subhra.	C-152 × DCS-5-3-20, DCS-47-1 × GC-3, IC 249141.	C-152 × IC 97767, DCS-47-1 × GC-3, V-118 × GL.
4	Number of seeds per pod	C-152 × DCS-5-3-20, DC -15 (Check 2), DC -15 × Subhra.	C-152 × DCS-5-3-20, DC -15 × NBC -1, DCS-47-1 × GC-3.	V-118 × IC 249140-1, GC-3 × IC 198333, DCS-47-1 (Check 3).
5	Number of pods per plant	DC -15 × DCS-47-1, IC 202778 × IC 214836, V-118 × IC 27502.	DC -15 × DCS-47-1, DCS-47-1 (Check 3), DC-16 (Check 4).	IC 202730, V-118 × IC 68786, C-152 × IC 249140.
6	100 seed weight (g)	GC-3 × IC 198333, V-118 × GL, C-152 × DCS-5-3-20.	V-118 × GL V-118 × IC 249140 -1, GC-3 × IC 198333.	GC-3 × IC 198333, V-118 × GL, DCS-47-1 × DC-15.
7	Seed yield (kg ha ⁻¹)	C-152 × IC 202825, C-152 × DCS-5-3-20, C-152 × CP-206.	DC -15 × DCS-47-1, C-152 × DCS-5-3-20, IC 202730.	C-152 × CP-206, DC -15 × Subhra. DC -15 × JOB-129.

5.6.3 Superior genotypes in different environments

The differential response of the genotypes to changing environments bring out change in performance of genotypes. Thus the relative ranking of genotypes on the basis of superiority vary from environment to environment. However certain genotypes which have “buffering capacity” can consistently give stable performance over environments.

In the present investigation efforts were made to identify superior genotypes across environments and also specific to each environment for different characters under study. The genotypes that are found superior at each environments are listed in Table 32.

For seed yield (kg ha^{-1}) the F_6 lines of the crosses namely C-152 $\times$ IC 202825, C-152 $\times$ DCS-5-3-20 and C-152 $\times$ CP-206 were found to be stable in Dharwad, F_6 lines of the crosses DC-15 $\times$ DCS-47-1, C-152 $\times$ DCS-5-3-20 and germplasm line IC 202730 were superior and stable at Bailhongal and F_6 lines of the crosses namely C-152 $\times$ CP-206, DC-15 $\times$ Subhra and DC-15 $\times$ JOB-129 were found to be superior at Malgi.

5.6.4 Stable genotypes for the yield and yield attributing traits

Environmental indices for all three locations suggested that Malgi is the rich environment and Dharwad is poor environment for the characters days to 50 % flowering, plant height, pod length and number of seeds per pod. Whereas, for the characters 100 seed weight and seed yield, Malgi is the rich environment and Bailhongal is poor environment. But for number of pods per plant Dharwad is the rich environment and Bailhongal is poor environment. The soil properties of Malgi *i.e.*, sandy loam soil which is highly suitable for cowpea along with rich soil nutrients and less pest and disease incidence make this environment as rich environment whereas, Dharwad and Bailhongal environments with black soil with more pest and disease incidence compared to Malgi, make these environments as poor environments for different characters.

In the present investigation among 34 genotypes of cowpea for days to 50 % flowering 11 genotypes are well adapted to all environments and 4 genotypes were adapted to rich environment. For pod length 6 genotypes are well adapted to all environments, 3 genotypes were adapted to rich environment and 1 genotype adapted to poor environment. For number of seeds per pod 13 genotypes are well adapted to all environments and 1 genotype adapted to poor environment. For number of pods per plant 2 genotypes are well adapted to all environments and 3 genotypes adapted to poor environment. For 100 seed weight 7 genotypes are well adapted to all environments, 2 genotypes adapted to rich environment and 2 genotypes adapted poor environment. For seed yield 5 genotypes are well adapted to all environments as reported in Table 33.

5.7 Screening for bruchid (*Callosobruchus maculatus*) resistance

The resistance of cowpea to bruchid infestation has been a major concern to plant breeders as some elite cowpea varieties become susceptible to the polymorphic nature of this storage insect pest. However, with the increasing polymorphic nature of the *C. maculatus* as reported by Credland (1994), George and Verma (1999), the durability of resistance or tolerance of improved cowpea.

Table 33: Stability of cowpea genotypes for the yield and yield attributing traits for different environments

	Well adapted to all environments *	Adapted to rich environments **	Adapted to poor environments **
Days to 50 % flowering	C-152 × IC 202790, C-152 × DCS-5-3-20, DCS-47-1 × DC-15, IC 202778×IC 202787, V-118 × IC 249140 -1, C-152 × IC 97767, V-118 × IC 68786, DC -15 × DCS-47-1, C-152 × IC 249140 , DC-15 (Check 2) , DC-16 (Check 4)	GC-3 × IC 198333 , DCS-47-1 × GC-3, DC -15 × NBC -1, V-118 × IC 249140-2.	--
Pod length (cm)	DCS-47-1× GC-3, GC-3 × C-152, V-118 × IC 249140 -1, V-118 × IC 249140-2, C-152 × IC 249140, IC 202730	DC -15 × NBC -1, C-152 × IC 97767 , DC -15 × DCS-47-1	DC-15 (Check 2)
Number of seeds per pod	C-152 × IC 97767, C-152 × IC 198701, C-152 × IC 201079, DC -15 × DCS-47-1 ,GC-3 × IC 198333, DCS-47-1 × GC-3, V-118 × IC 249140 -1, GC-3 × C-152, GC-3 × IC 202872, C-152 × IC 202710, IC 202730, IC 249141, DC-15 (Check-2)	--	DC -15 × Subhra
Number of pods per plant	V-118 × GL, C-152 × IC198701	--	C-152 (Check -1), C-152 × CP-206, C-152 × IC 201079
100 seed weight (g)	DCS-47-1 × GC-3, C-152 × DCS-5-3-20, V-118 × GL, V-118 × IC 27502, C-152 × IC 202790, C-152 × IC 249140 , IC 202778 × IC 214836	DCS-47-1 × DC-15, DC-15 (Check 2)	IC 249141, V-118 × IC 68786
Seed yield (kg ha ⁻¹)	C-152 × IC 201079 , GC-3 × IC 202872, C-152 × IC 198701, C-152 × IC 202710, V-118 × IC 249141	--	--

* - Mean higher then population mean, $b_i = 1$, and low (non- significant) s^2_{di}

** - Mean higher then population mean, $b_i > 1$ and low (non- significant) s^2_{di}

*** - Mean higher then population mean, $b_i < 1$ and low (non- significant) s^2_{di}

varieties to this insect pest becomes a major priority. Resistance breeding is a potential option to minimize losses caused by *C. maculatus* during storage because it is easy to utilize, cost effective mainly because cowpea is a crop of low input. The development of resistant cultivars is however still very limited, since few complete resistance sources have been identified (Singh *et al.*, 1985; Dongre *et al.*, 1996).

In the present investigation screening of seeds of 250 F₃ segregants was carried out to identify the resistance of F₃ segregants to *C. maculatus*. The results obtained are discussed as follows.

5.7.1 Bruchid infestation

Discrimination between resistant and susceptible genotypes was apparent with the bruchid infestation percentage. The percentage of bruchid infestation in different F₃ segregants is presented in Table 17. The resistant genotypes were characterized by least bruchid infestation. The minimum percentage of bruchid infestation was noticed for F₃-2 and F₃-95 segregants.

Based on bruchid infestation percentage, the F₃ segregants were classified as moderately resistant, least susceptible, moderately susceptible and highly susceptible. Among 250 F₃ segregants, 71 individual segregants were identified as moderately resistant, 172 segregants were least susceptible, 5 segregants were moderately susceptible and only 2 segregants were identified as highly susceptible (Table 16). This classification is based on the earlier classification as reported by Nagaraj (2006) as highly resistant (0 to 20 %), moderately resistant (21 to 40 %), least susceptible (41 to 60 %), moderately susceptible (61 to 80 %) and highly susceptible (81 to 100 %) in greengram against *Callosobruchus Chinensis* L.

The extent of bruchid infestation varied significantly between different classes. The moderately resistant class noticed minimum bruchid infestation (30.65 %) whereas, highly susceptible class noticed maximum bruchid infestation (82.90 %).

Maximum number of segregants exhibited (145 numbers) 41 to 50 per cent bruchid infestation. Whereas, only 2 segregants each were showed 71 to 80 per cent and 81 to 90 per cent bruchid infestation. 47 segregants noticed the 21 to 30 per cent bruchid infestation.

5.7.2 Seed moisture

The minimum seed moisture was reported for F₃-96 segregant followed by F₃-95 segregant. This trait did not differ between different classes however the moderately resistant class recorded minimum seed moisture, highly susceptible class recorded maximum seed moisture.

5.7.3 Actual weight loss

The F₃-2 segregant reported lowest actual weight loss followed by F₃-95 segregant indicating resistance to *C. maculatus*. Actual weight loss was differed highly among different classes. The data on actual weight loss revealed damaged seeds. The extent of actual weight loss was relatively higher in the susceptible segregants. For example in case of highly susceptible segregants the actual weight

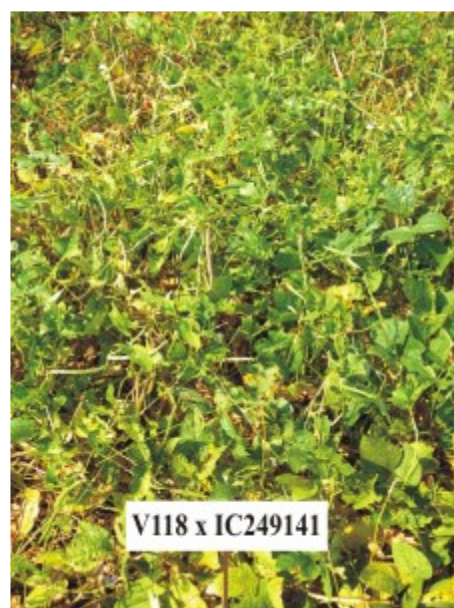
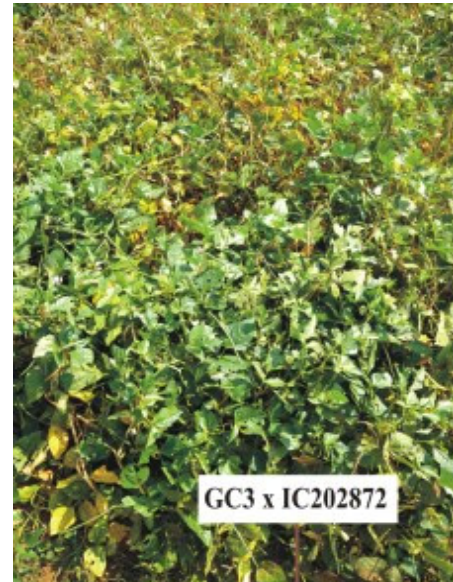
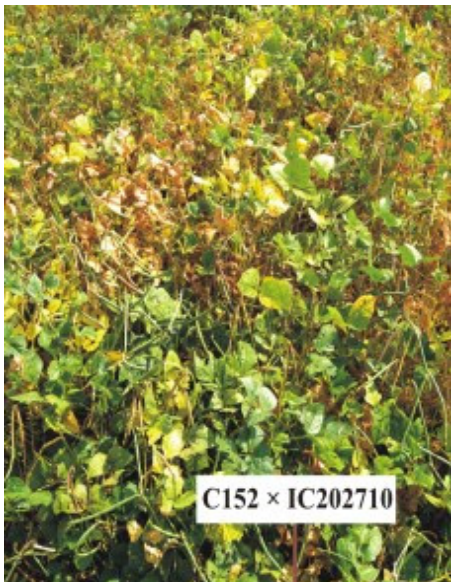
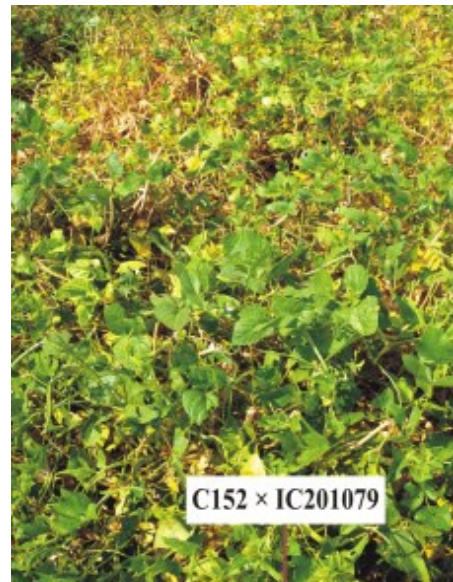
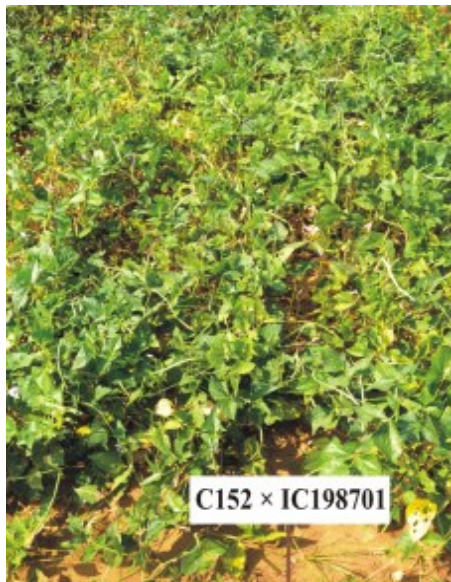


Plate 5: Superior F₆ progenies exhibited stability for yield

loss recorded was maximum (16.58 %). Whereas, for moderately resistant segregants it was minimum (6.13 %). In the present study, the weight loss varied much among different segregants. The larval stage, which is the only feeding stage in case of bruchids where adult is the non-feeding stage, is very sensitive to the differences in the genotypes. It is the most vulnerable stage determining the resistance or susceptibility of the cultivars. It is a measure of both the physiological and usefulness of the food and the total amount of food ingested (Hovanitz and Chang, 1962). Lambrides and Imrie (2000) reported that the tolerant varieties showed the least weight loss against bruchids, which could be attributed to the small size, seed coat thickness, seed coat width and presence of well formed texture layer on the seed. Delay in developmental period of bruchids may lead to a considerable reduction in seed loss during storage (Sulehrie *et al.*, 2003).

5.7.4 Apparent weight loss

The resistance to *C. maculatus* was exhibited by F₃-2 and F₃-95 segregants as they exhibited minimum apparent weight loss of 2.60 per cent and 2.67 per cent, respectively. Apparent weight loss differed less between segregants. For moderately resistant segregants it was minimum and for highly susceptible segregants it was maximum.

5.7.5 Number of bruchids emerged

Number of bruchids emerged was lowest in F₃-221 followed by F₃-92. Indicates these segregants were less preferred for oviposition. These segregants also noticed least bruchid infestation. The number of bruchids emerged differed among different F₃ segregants. For moderately resistant segregants it was minimum (15.51) and for highly susceptible segregants it was maximum (37.00). Their resistance, therefore, appears to be due to antibiosis to the eggs or larvae. Nawanze and Horber (1976) reported that differences in the seed coats of cowpeas affected oviposition and larval development of *C. maculatus*. The testa may be so thick that the newly hatched larva dies before it reaches the cotyledon or the cotyledon may be poisonous. Sometimes the cotyledonous food is unpalatable or of poor nutritive quality (Janzen, 1977). Thus the larval development and adult progeny production is independent of oviposition and is greatly influenced by preferred host of good nutritive value. The oviposition on seeds may be affected by thick and hard testa of convex or wrinkled nature, while adult recovery is hampered by unpalatable physico-chemical characteristics of grains *i.e.*, antibiosis.

5.7.5 Germination percentage

The emergence of seeds is influenced by many abiotic and biotic factors including damages by different insects. The period for which the seeds emerge and germinate has serious consequences on the whole process of plant growth and development. The final effect of seeds with beetle infestation on the germination of host legumes can be unpredictable (Southgate, 1979). In some cases the larva feeding effectively kills the embryo or removes so much endosperm that the seed cannot germinate (El-Atta, 1993; Camargo *et al.*, 2004; Tomaz *et al.*, 2007). Larval feeding may also create openings for pathogenic bacteria and fungi (Cipollini and Stiles, 1991; Mucunguzi, 1995; Chang *et al.*, 2011). Even if germination occurs prior seed infestation after that the infestation may distort the development of cotyledons or prevent the formation of true leaves (Hegazy and Eesa, 1991).

The seed germination (%) was recorded before and after the screening and per cent reduction in germination was determined. The results with regard to the germination index were analogical and indicative. The F₃-92 and F₃-4 segregants reported minimum per cent reduction in germination. The moderately resistant segregants reported 8.19 per cent reduction in germination, while highly susceptible segregants reported 26.17 per cent reduction in germination. As a result of damage from *C. maculatus* and related to that deterioration of seed quality changed the germination of seeds. The least damaged seeds with *C. maculatus* had better potential for growth and development whereas the highly damaged seeds had lower germination, these seeds could not provide the establishment of well garnished stand and stable yields.

5.7.6 Seedling length

Expression of the sowing characteristics of seeds was the growth and strength of primary radicle and plumule within certain genotype. Data from measurements with regard to the length of seedlings (cm) permitted objectively to evaluate the reaction of studied segregants in the initial stages of their development as a result of damage by *C. maculatus*. The seedling length was recorded before and after the screening and per cent reduction in seedling length was determined. The most essential changes with regards to the seedling length were found in the highly susceptible plants as they noticed maximum reduction in seedling length over the initial (15.20 %), whereas moderately resistant segregants reported minimum reduction in seedling length (4.13 %). The depletion of cotyledon reserves due to larval feeding of *C. maculatus* in seeds of highly susceptible plants probably slowed the growth of plant and hence resulted in reduction in the length of seedlings.

5.7.7 Seedling vigour index

The seedling vigour is an important component that can influence crop plant density and yield (Siddique and Wright, 2004). The vigour is related to the germination and seed ability to grow rapidly and jointly. It suggested that the speed and uniformity of emergence are important parameters of seed quality (Copeland and McDonald, 1995). The data on seedling vigour index was recorded before and after the screening and percentage reduction in seedling vigour index was determined. The results revealed that the moderately resistant segregants reported least reduction in seedling vigour index (20.70 %), while the highly susceptible segregants reported higher reduction in seedling vigour index (47.53 %). The F₃-4 segregant reported minimum reduction in seedling vigour index (9.81 %) among different segregants.

5.7.8 Seedling dry weight

The segregant F₃-95 noticed lowest reduction in seedling dry weight (2.26 %). The extent of reduction in seedling dry weight ranges from 31.63 per cent for moderately resistant segregants to 42.11 per cent for highly susceptible segregants, this range is quite high. According to Bonal *et al.* (2007) and Mack (1998) in some plants, part of the cotyledon may serve to buffer the negative impact of bruchid damage whereas any loss of cotyledon tissue in other plants greatly reduces seedling mass. Probably this was the reason for difference in reaction of studied F₃ genotypes to bruchid infestation.

5.7.9 Percentage seed damage

The results depicted that F₃-221 segregant noticed the minimum per cent seed damage (14.00) followed by F₃-223 (16.00). Per cent seed damage was highest for highly susceptible segregants whereas, it was lowest for moderately resistant segregants. Thus, the longer life cycle and smaller population size for multiplication of bruchids in resistant lines were major factors behind the reduced damage of the seeds. The extent of damage depends upon the number of adults emerged during each generation and the duration of life cycle, therefore seeds permitting more rapid and higher rate of adult beetle emergence would be more extensively damaged.

The study further reveals that segregants with highest adult emergence recorded extensive damage. In other words, increasing population of adult emergence causes more extensive damage and *vice versa*. This agrees with the findings of Singh *et al.* (1985) who reported that the number of emerging adult determines the extent of damage and consequently, seeds permitting more rapid and higher levels of adult emergence will be more extensively damaged.

5.7.10 Percentage loss in seed viability

The F₃-199 segregant recorded minimum loss in seed viability (4.88 %) followed by F₃-96 segregant (4.83 %). The results on per cent loss in viability of different cowpea cultivars were highly related with susceptibility. Per cent loss in seed viability ranges from 8.19 per cent for moderately resistant segregants to 26.17 per cent for highly susceptible segregants. Damage inflicted by cowpea bruchids consists of the consumption of seeds, loss or conversion of nutrients, reduced germination of seeds and contamination with filthy materials composed of insect fragments, exuviae, excreta and moulds.

The variation in seed parameters was mainly due to variation in per cent infestation level, adult emergence and reduction in seed weight and also inherent capacity of each genotype response to be attacked by bruchids (*C. maculatus*). Similar results with respect to seed parameters were reported earlier by Nagaraja (2006), Bhaduria and Jakhmola (2006) in cowpea.

The fact that resistance to *C. maculatus* is controlled by two recessive genes (Adjadi *et al.*, 1985) indicates that chemical and physical factors responsible for resistance should be present in all resistant lines and absent in all susceptible. In present study, none of the segregants were found to be highly resistant to *C. maculatus*.

Taking into account, bruchid infestation measured through different damage parameters, comparatively superior segregants for bruchid resistance were F₃-2, F₃-95, F₃-221, F₃-223 and F₃-199 because they exhibited least bruchid infestation, per cent seed damage, minimum actual and apparent weight loss, minimum number of bruchids emerged. For seed and seedling related parameters, the segregants F₃-2, F₃-4, F₃-24, F₃-92, F₃-95, F₃-199, F₃-221, F₃-223, F₃-232 and F₃-241 were found superior, for which the values of parameters related to germination and vigour of seeds were influenced in the lowest degree from the damage by bruchids.



Plate 6: Moderately resistant F₃ segregants

Future line of work

1. Since the F_6 progenies of crosses C-152 × IC 198701, C-152 × IC 201079, GC-3 × IC 202872, V-118 × IC 249141 and C-152 × IC 202710 were well adapted to all environments, they should be further analyzed for stability over seasons, locations and extensively used in breeding programmes.
2. Based on this study, the promising genotypes for mean *per se* performance were F_6 lines of crosses DC-15 × DCS-47-1, C-152 × CP-206, DC-15 × Subhra, C-152 × IC 198701, C-152 × IC 97767, DC-15 × JOB-129, C-152 × IC 201079, C-152 × IC 202710, GC-3 × IC 202872 and V-118 × IC 249141. These promising advanced stabilized lines could be promoted to multilocation trials and also Co-ordinated yield trials after one year of evaluation in the station trials.
3. The F_6 line of cross C-152 × CP-206 was found superior for the paddy fallow situation. Its suitability should be further confirmed by repeated testing and can be recommended to farmers for cultivation in the paddy fallows during *rabi*-summer season.
4. The F_3 segregants *viz.*, F_3 -2, F_3 -95, F_3 -221, F_3 -223 and F_3 -199 which were found moderately resistant to bruchid infestation should be advanced to next generations to stabilize and also need to be evaluated for yield *per se*. Stabilized high yielding lines with enhanced tolerance to bruchids could be further used in resistance breeding programmes in cowpea.
5. The biochemical and molecular basis of resistance in the resistant parent need to be identified.
6. In addition to the present region wise investigation, the studies representing varying latitudes, longitudes and altitudes with large number of genotypes are essential, as cowpea is an important component of farming systems in Arid and Semi-Arid Tropics.

6. SUMMARY AND CONCLUSIONS

The assessment of variability and stability of performance of cowpea genotypes to environmental fluctuations is important for the stabilization of crop production across the locations. Hence in the present investigation, field experiments were conducted at three locations to investigate the presence of genotype $\times$ environment interaction leading to adaptation. Seed yield, yield components of the 34 cowpea genotypes were evaluated in the process. Assessment of genetic variability present in the crop helps in successfully developing suitable varieties with desirable traits. Therefore, in the present study, an attempt at variability assessment in 34 genotypes for productivity traits was made.

Cowpea is seriously damaged by the bruchids [*Callosobruchus maculatus* (F.)] leading to considerable yield loss during storage conditions. In the present investigation an attempt was made to screen the seeds of 250 F₃ segregants of cross DC 615 $\times$ Dharwad local.

The salient findings of the present study are summarized below.

1. Analysis of variance of yield and yield attributing traits during preliminary screening showed highly significant differences among the genotypes for the traits viz., plant height, pod length, number of seeds per pod, 100 seed weight and seed yield.
2. The significance of mean sum of squares for thirty genotypes with four checks for all the three environments chosen suggested the existence of adequate variability for the characters viz., days to 50 % flowering, plant height, pod length, number of seeds per pod, number of pods per plant and seed yield showing that the choice of these traits will have a significant bearing on crop improvement.
3. The genotypes revealed moderate variation for many of the characters studied. These differences may be attributed to their diverse genetic makeup and the environmental interactions, whereas characters viz., days to 50 % flowering, plant height, pod length, number of seeds per pod and 100 seed weight showed narrow range of variation. However the characters number of pods per plant and seed yield exhibited high range.
4. Higher value of GCV and PCV were obtained for the characters number of pods per plant and seed yield and also these traits exhibited the larger differences between GCV and PCV reflecting substantial influence of environment. However the characters, days to 50 % flowering, plant height, pod length, number of seeds per pod and 100 seed weight exhibited low differences between GCV and PCV but their values were low to moderate.
5. In the present investigation, moderate heritability and low genetic advance were exhibited by characters viz., days to 50 % flowering, number of seeds per pod and 100 seed weight. Low heritability and low genetic advance were noticed for plant height, pod length and number of pods per plant whereas, seed yield exhibit low heritability but high genetic advance.
6. Environmental indices for all three locations suggested that Malgi is the favorable environment for the characters days to 50 % flowering, plant height, pod length, number of seeds per pod, 100 seed weight and seed yield. However, for the character number of pods per plant Dharwad is the favorable environment.

7. The pooled analysis of variance revealed that mean sum of squares (MSS) due to genotypes and environment were significant for most of the characters. The genotype $\times$ environment interactions were significant for most of the traits revealed that genotypes under study were having significant differential response to the changing environment.
8. The significance of pooled deviation confirms contribution of the non-linear component to the total $G \times E$ interaction. The genotypes differed with respect to the stability of these traits making its prediction more difficult. However, the magnitude of linear component *i.e.*, environment (linear) and genotype $\times$ environment (linear) was many times higher than the non linear component (pooled deviation) for most of the characters revealed that the prediction of stability could be reliable though it may get affected to some extent.
9. For the character days to 50 per cent flowering, the F_6 lines *viz.*, C-152 $\times$ IC 202790, C-152 $\times$ DCS-5-3-20, DCS-47-1 $\times$ DC-15, IC 202778 $\times$ IC 202787, V-118 $\times$ IC 249140-1, C-152 $\times$ IC 97767, V-118 $\times$ IC 68786, DC-15 $\times$ DCS-47-1, C-152 $\times$ IC 249140, DC-15 (check 2) and DC-16 (check 4) found to be stable across the locations. Whereas the F_6 lines DCS-47-1 $\times$ GC-3, DC-15 $\times$ NBC -1, V-118 $\times$ IC 249140-2 and C-152 $\times$ IC 249140 found to be well adapted to favourable environments.
10. For the plant height, the F_6 lines namely C-152 $\times$ DCS-5-3-20, C-152 $\times$ IC 198701, V-118 $\times$ IC 27502, C-152 $\times$ IC 202710, GC-3 $\times$ IC 198333, DC15 $\times$ JOB-129, DC-15 $\times$ Subhra and germplasm lines IC 202779, IC 249141, IC 202730, checks DCS-47-1(check 3) and DC-16 (check 4) showed better adaptability to all the three locations. While the F_6 line C-152 $\times$ IC 201079 found to be well adapted to favorable environment.
11. The F_6 lines namely DCS-47-1 $\times$ GC-3, GC-3 $\times$ C 152, V-118 $\times$ IC 249140-1, V-118 $\times$ IC 249140-2, C-152 $\times$ IC 249140 and germplasm line IC 202730 exhibited better adaptability to all the three locations for pod length. Whereas the F_6 lines namely DC-15 $\times$ NBC-1, C-152 $\times$ IC 97767 and DC-15 $\times$ DCS-47-1 have below average stability and well adapted to favourable environment. The DC-15 (check 2) revealed above average stability with suitability to poor environment.
12. For the trait number of seeds per pod the F_6 progenies of crosses namely, C-152 $\times$ IC 97767, C-152 $\times$ IC 198701, C-152 $\times$ IC 201079, DC-15 $\times$ DCS-47-1, GC-3 $\times$ IC 198333, DCS-47-1 $\times$ GC-3, V-118 $\times$ IC 249140-1, GC-3 $\times$ C 152, GC-3 $\times$ IC 202872, C-152 $\times$ IC 202710, germplasm lines IC 202730, IC 249141 and DC-15 (check 2) revealed their average stability across environments whereas, the F_6 line DC-15 $\times$ Subhra indicating its stability under poor environment.
13. Only two F_6 progenies of crosses namely V-118 $\times$ GL and C-152 $\times$ IC 198701 exhibited the average stability across the locations for number of pods per plants whereas, the F_6 progenies of crosses C-152 $\times$ CP-206, C-152 $\times$ IC 201079 and C 152 (check 1) have below average stability and well adapted to favourable environment.

14. For 100 seed weight, the F_6 lines namely DCS-47-1 $\times$ GC-3, C-152 $\times$ DCS-5-3-20, V-118 $\times$ GL, V-118 $\times$ IC 27502, C-152 $\times$ IC 202790, C-152 $\times$ IC 249140 and IC 202778 $\times$ IC 214836 were average stable across the environments. The F_6 progenies of crosses namely DCS-47-1 $\times$ DC-15 and DC-15 (Check 2) indicated stability under favourable environment. Whereas the F_6 line V-118 $\times$ IC 68786 and germplasm line IC 249141 exhibit above average stability and adaptation to poor environment.
15. Seed yield being final product of complex physiological and development processes from sowing to maturity, recorded highest variation across the locations. According to stability model considering the three parameters *per se* mean, regression coefficient (bi) and standard deviation from regression, the stable genotypes identified were F_6 progenies of crosses namely, C-152 $\times$ IC 198701, C-152 $\times$ IC 201079, C-152 $\times$ IC 202710, GC-3 $\times$ IC 202872 and V-118 $\times$ IC 249141.
16. Apart from stability point of view, in this study the promising genotypes identified were F_6 lines of crosses DC-15 $\times$ DCS-47-1, C-152 $\times$ CP-206, DC-15 $\times$ Subhra, C-152 $\times$ IC 198701, C-152 $\times$ IC 97767, DC-15 $\times$ JOB-129, C-152 $\times$ IC 201079, C-152 $\times$ IC 202710, GC-3 $\times$ IC 202872 and V-118 $\times$ IC 249141.
17. In the present investigation among 34 genotypes of cowpea, for days to 50 % flowering 11 genotypes are well adapted to all environments and 4 genotypes were adapted to rich environment. For pod length 6 genotypes are well adapted to all environments, 3 genotypes were adapted to rich environment and 1 genotype adapted to poor environment. For number of seeds per pod 13 genotypes are well adapted to all environments and 1 genotype adapted to poor environment. For number of pods per plant 2 genotypes are well adapted to all environments and 3 genotypes adapted to poor environment. For 100 seed weight 7 genotypes are well adapted to all environments, 2 genotypes adapted to rich environment and 2 genotypes adapted poor environment. For seed yield 5 genotypes are well adapted to all environments.
18. Screening of 250 F_3 segregants of cowpea cross DC 615 $\times$ Dharwad Local, indicated maximum variation in regard to the studied parameters for damaged seeds with bruchid infestation.
19. Taking into account of bruchid infestation measured through different damage parameters, comparatively superior F_3 segregants identified bruchid resistance were F_3 -2, F_3 -95, F_3 -221, F_3 -223 and F_3 -199 because they exhibit least bruchid infestation, per cent seed damage, minimum actual and apparent weight loss, minimum number of bruchids emerged. For seed and seedling related parameters, the segregants F_3 -2, F_3 -4, F_3 -24, F_3 -92, F_3 -95, F_3 -199, F_3 -221, F_3 -223, F_3 -232 and F_3 -241 were found superior, for which the values of parameters related to germination and vigour of seeds were influenced in the lowest degree from the damage by bruchids.

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Appendix I: Monthly rainfall data for experiment year (2015) of Main Agricultural Research Station, Dharwad, Agricultural Research Station, Bailhongal and Agricultural Research Station, Malgi (2016)

Sl. No.	Month	MARS, Dharwad		ARS, Bailhongal		ARS, Malagi	
		Rainfall (mm)	Number of rainy days	Rainfall (mm)	Number of rainy days	Rainfall (mm)	Number of rainy days
1	January	0.00	0.00	0	0	0	0
2	February	0.00	0.00	0	0	0	0
3	March	103.40	3.00	40.6	1	0	0
4	April	140.00	2.00	7.9	1	0	0
5	May	90.70	8.00	61.1	7	-	-
6	June	100.00	13.00	145.0	10	-	-
7	July	46.80	7.00	31.0	3	-	-
8	August	39.40	7.00	16.9	3	-	-
9	September	71.40	4.00	62.6	2	-	-
10	October	134.40	5.00	130.0	5	-	-
11	November	15.80	2.00	5.2	1	-	-
12	December	0.00	0.00	0	0	-	-
	Total	741.90	51.00	502.3	35		

Appendix II: Values of different parameters for F₃ segregants for bruchid resistance screening

F ₃ segregants	Bruchid infestation (%)	Seed moisture (%)	Actual weight loss (%)	Apparent weight loss (%)	Number of bruchids emerged 30 days after rearing	Germination (%)			Seedling length (cm)			Seedling vigour index			Seedling dry weight (g)			% seed damage	Per cent loss in seed viability
						Before screening	After screening	Per cent reduction in germination	Before screening	After screening	Per cent reduction in seedling length	Before screening	After screening	Per cent reduction in Seedling vigour	Before screening	After screening	Per cent reduction in seedling dry wt		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F ₃ -1	36.54	9.23	7.31	3.85	17	72.00	64.00	11.11	41.29	38.79	6.44	2972.88	2482.56	19.75	0.85	0.67	26.87	34.00	11.11
F ₃ -2	24.53	9.67	4.92	2.60	10	76.00	72.00	5.26	35.30	32.80	7.62	2682.80	2361.60	13.60	0.99	0.89	11.24	20.00	5.26
F ₃ -3	84.31	9.17	16.86	8.60	29	82.00	58.00	29.27	31.90	29.40	8.50	2615.80	1705.20	53.40	0.96	0.78	23.08	84.00	29.27
F ₃ -4	27.27	9.67	5.45	3.10	12	72.00	70.00	2.78	39.50	37.00	6.76	2844.00	2590.00	9.81	0.69	0.54	27.78	20.00	2.78
F ₃ -5	41.18	8.93	8.24	4.26	22	84.00	68.00	19.05	31.90	29.40	8.50	2679.60	1999.20	34.03	0.77	0.59	30.51	40.00	19.05
F ₃ -6	48.08	8.83	9.62	5.22	26	82.00	70.00	14.63	32.80	29.40	11.56	2689.60	2058.00	30.69	0.75	0.57	31.58	46.00	14.63
F ₃ -7	25.93	9.31	5.19	2.83	10	80.00	72.00	10.00	31.30	27.90	12.19	2504.00	2008.80	24.65	0.86	0.71	21.13	20.00	10.00
F ₃ -8	41.82	9.20	8.36	4.65	24	74.00	64.00	13.51	31.70	28.30	12.01	2345.80	1811.20	29.52	0.65	0.47	38.30	36.00	13.51
F ₃ -9	44.23	8.18	8.85	4.62	20	78.00	62.00	20.51	42.42	39.20	8.41	3220.62	2349.18	37.10	0.78	0.60	30.00	42.00	20.51
F ₃ -10	49.06	8.82	9.81	5.21	27	88.00	66.00	25.00	41.29	37.89	8.97	3633.52	2500.74	45.30	0.89	0.71	25.35	46.00	25.00
F ₃ -11	50.00	9.31	10.00	5.42	27	80.00	64.00	20.00	39.46	36.06	9.43	3156.80	2307.84	36.79	0.75	0.57	31.58	46.00	20.00
F ₃ -12	45.28	9.20	9.06	4.81	20	76.00	62.00	18.42	41.29	37.89	8.97	3138.04	2349.18	33.58	0.85	0.67	26.87	42.00	18.42

Contd.....

Appendix II contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F ₃ -13	81.48	9.21	16.30	8.84	45	78.00	60.00	23.08	41.29	37.89	8.97	3220.62	2273.40	41.67	0.84	0.66	27.27	80.00	23.08
F ₃ -14	41.51	9.65	8.30	4.42	23	70.00	60.00	14.29	33.20	31.20	6.41	2324.00	1872.00	24.15	0.72	0.54	33.33	38.00	14.29
F ₃ -15	44.00	8.93	8.80	4.45	25	70.00	56.00	20.00	36.50	34.50	5.80	2555.00	1932.00	32.25	0.65	0.47	38.30	44.00	20.00
F ₃ -16	49.02	8.80	9.80	5.12	19	78.00	62.00	20.51	32.80	30.80	6.49	2558.40	1909.60	33.98	0.74	0.56	32.14	48.00	20.51
F ₃ -17	38.46	9.31	7.69	4.20	22	68.00	62.00	8.82	39.50	37.50	5.33	2686.00	2325.00	15.53	0.89	0.71	25.35	36.00	8.82
F ₃ -18	39.62	9.20	7.92	4.25	23	78.00	68.00	12.82	32.80	30.80	6.49	2558.40	2094.40	22.15	0.73	0.55	32.73	36.00	12.82
F ₃ -19	40.74	8.18	8.15	4.42	23	78.00	68.00	12.82	38.90	36.90	5.42	3034.20	2509.20	20.92	0.45	0.27	66.67	36.00	12.82
F ₃ -20	46.94	8.86	9.39	4.65	27	78.00	64.00	17.95	39.50	37.50	5.33	3081.00	2400.00	28.38	0.68	0.50	36.00	48.00	17.95
F ₃ -21	48.08	9.31	9.62	5.02	20	74.00	64.00	13.51	31.90	29.90	6.69	2360.60	1913.60	23.36	0.74	0.56	32.14	46.00	13.51
F ₃ -22	54.90	9.21	10.98	5.65	32	90.00	72.00	20.00	38.50	36.50	5.48	3465.00	2628.00	31.85	0.62	0.44	40.91	54.00	20.00
F ₃ -23	47.06	9.33	9.41	4.81	26	78.00	68.00	12.82	35.20	33.20	6.02	2745.60	2257.60	21.62	0.68	0.50	36.00	46.00	12.82
F ₃ -24	44.23	9.22	8.85	4.64	25	88.00	72.00	18.18	33.00	31.00	6.45	2904.00	2232.00	30.11	0.57	0.39	46.15	42.00	18.18
F ₃ -25	30.19	9.07	6.04	3.25	16	80.00	74.00	7.50	41.29	39.29	5.09	3303.20	2907.46	13.61	0.64	0.46	39.13	26.00	7.50
F ₃ -26	42.31	9.32	8.46	4.44	19	76.00	62.00	18.42	33.20	31.20	6.41	2523.20	1934.40	30.44	0.79	0.61	29.51	40.00	18.42
F ₃ -27	43.40	9.02	8.68	4.64	20	78.00	70.00	10.26	36.50	33.50	8.96	2847.00	2345.00	21.41	0.91	0.73	24.66	40.00	10.26
F ₃ -28	34.62	7.85	6.92	3.62	12	74.00	68.00	8.11	41.29	38.29	7.83	3055.46	2603.72	17.35	0.64	0.46	39.13	32.00	8.11
F ₃ -29	43.40	9.12	8.68	4.80	21	80.00	66.00	17.50	41.29	38.29	7.83	3303.20	2527.14	30.71	0.69	0.51	35.29	40.00	17.50
F ₃ -30	30.00	9.16	6.00	3.60	10	76.00	70.00	7.89	33.20	30.20	9.93	2523.20	2114.00	19.36	0.65	0.47	38.30	30.00	7.89
F ₃ -31	46.94	8.96	9.39	4.20	26	78.00	66.00	15.38	36.50	33.50	8.96	2847.00	2211.00	28.77	0.68	0.50	36.00	48.00	15.38
F ₃ -32	28.57	9.67	5.71	2.85	14	74.00	72.00	2.70	32.80	29.80	10.07	2427.20	2145.60	13.12	0.57	0.39	46.15	30.00	2.70
F ₃ -33	30.61	9.31	6.12	3.02	18	76.00	68.00	10.53	41.29	38.29	7.83	3138.04	2603.72	20.52	0.59	0.41	43.90	32.00	10.53
F ₃ -34	36.54	9.20	7.31	3.80	23	74.00	66.00	10.81	33.20	30.20	9.93	2456.80	1993.20	23.26	0.65	0.47	38.30	34.00	10.81
F ₃ -35	34.62	8.80	6.92	3.60	21	78.00	68.00	12.82	36.50	33.50	8.96	2847.00	2278.00	24.98	0.68	0.50	36.00	32.00	12.82

Contd.....

Appendix II contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F ₃ -36	29.41	7.35	5.88	3.00	10	82.00	74.00	9.76	36.80	34.50	6.67	3017.60	2553.00	18.20	0.72	0.54	33.33	28.00	9.76
F ₃ -37	41.51	9.23	8.30	4.45	24	78.00	62.00	20.51	39.50	37.20	6.18	3081.00	2306.40	33.58	0.89	0.71	25.35	38.00	20.51
F ₃ -38	41.18	9.31	8.24	4.20	20	76.00	62.00	18.42	33.90	31.60	7.28	2576.40	1959.20	31.50	0.52	0.34	52.94	40.00	18.42
F ₃ -39	32.69	9.17	6.54	3.44	21	68.00	60.00	11.76	38.50	36.20	6.35	2618.00	2172.00	20.53	0.63	0.45	40.00	30.00	11.76
F ₃ -40	50.00	9.65	10.00	5.21	20	74.00	58.00	21.62	35.20	32.90	6.99	2604.80	1908.20	36.51	0.74	0.56	32.14	48.00	21.62
F ₃ -41	42.59	9.37	8.52	4.62	24	72.00	58.00	19.44	33.00	30.70	7.49	2376.00	1780.60	33.44	0.75	0.57	31.58	38.00	19.44
F ₃ -42	34.62	9.31	6.92	3.64	23	78.00	70.00	10.26	33.20	30.90	7.44	2589.60	2163.00	19.72	0.69	0.51	35.29	32.00	10.26
F ₃ -43	49.06	9.14	9.81	5.21	20	80.00	62.00	22.50	36.50	34.50	5.80	2920.00	2139.00	36.51	0.67	0.49	36.73	46.00	22.50
F ₃ -44	42.59	9.16	8.52	4.60	18	76.00	62.00	18.42	39.50	35.30	11.90	3002.00	2188.60	37.17	0.68	0.50	36.00	38.00	18.42
F ₃ -45	45.28	8.98	9.06	4.8	18	76.00	60.00	21.05	39.50	36.30	8.82	3002.00	2178.00	37.83	0.87	0.69	26.09	42.00	21.05
F ₃ -46	29.63	8.85	5.93	3.26	12	82.00	72.00	12.20	33.90	33.20	2.11	2779.80	2390.40	16.29	0.56	0.38	47.37	24.00	12.20
F ₃ -47	40.74	9.31	8.15	4.40	32	80.00	66.00	17.50	41.29	38.30	7.81	3303.20	2527.80	30.67	0.69	0.51	35.29	36.00	17.50
F ₃ -48	42.00	9.20	8.40	4.41	20	76.00	64.00	15.79	35.30	31.30	12.78	2682.80	2003.20	33.93	0.59	0.41	43.90	42.00	15.79
F ₃ -49	41.18	9.55	8.24	4.20	19	96.00	82.00	14.58	33.20	30.30	9.57	3187.20	2484.60	28.28	0.64	0.46	39.13	40.00	14.58
F ₃ -50	44.23	9.16	8.85	4.64	20	74.00	60.00	18.92	36.50	35.30	3.40	2701.00	2118.00	27.53	0.85	0.67	26.87	42.00	18.92
F ₃ -51	41.51	8.56	8.30	4.41	23	76.00	62.00	18.42	32.80	32.30	1.55	2492.80	2002.60	24.48	0.71	0.53	33.96	38.00	18.42
F ₃ -52	40.74	8.96	8.15	4.80	23	82.00	68.00	17.07	39.50	38.50	2.60	3239.00	2618.00	23.72	0.69	0.51	35.29	36.00	17.07
F ₃ -53	32.65	9.31	6.53	3.24	20	78.00	68.00	12.82	32.80	30.20	8.61	2558.40	2053.60	24.58	0.68	0.50	36.00	34.00	12.82
F ₃ -54	51.92	8.92	10.38	5.40	30	72.00	60.00	16.67	39.90	36.60	9.02	2872.80	2196.00	30.82	0.54	0.36	50.00	50.00	16.67
F ₃ -55	39.22	9.07	7.84	4.04	19	94.00	84.00	10.64	39.46	38.60	2.23	3709.24	3242.40	14.40	0.67	0.49	36.73	38.00	10.64
F ₃ -56	41.18	9.02	8.24	4.20	23	74.00	62.00	16.22	41.29	40.30	2.46	3055.46	2498.60	22.29	0.61	0.43	41.86	40.00	16.22
F ₃ -57	36.54	9.47	7.31	3.87	23	76.00	64.00	15.79	33.20	30.20	9.93	2523.20	1932.80	30.55	0.63	0.45	40.00	34.00	15.79
F ₃ -58	54.72	9.10	10.94	5.84	29	72.00	54.00	25.00	36.50	33.50	8.96	2628.00	1809.00	45.27	0.91	0.73	24.66	52.00	25.00

Contd.....

Appendix II contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F ₃ -59	63.46	9.25	12.69	6.65	32	74.00	60.00	18.92	39.02	36.00	8.39	2887.48	2160.00	33.68	0.64	0.46	39.13	62.00	18.92
F ₃ -60	32.69	9.16	6.54	3.40	16	78.00	72.00	7.69	36.97	33.83	9.28	2883.66	2435.76	18.39	0.69	0.51	35.29	30.00	7.69
F ₃ -61	41.18	8.68	8.24	4.23	23	80.00	62.00	22.50	33.47	30.99	8.00	2677.60	1921.38	39.36	0.65	0.47	38.30	40.00	22.50
F ₃ -62	41.51	9.31	8.30	4.42	23	82.00	70.00	14.63	33.93	31.57	7.48	2782.26	2209.90	25.90	0.68	0.50	36.00	38.00	14.63
F ₃ -63	54.90	9.18	10.98	5.61	31	78.00	60.00	23.08	38.07	35.67	6.73	2969.46	2140.20	38.75	0.57	0.39	46.15	54.00	23.08
F ₃ -64	40.38	9.03	8.08	4.24	23	72.00	60.00	16.67	41.29	38.99	5.90	2972.88	2339.40	27.08	0.59	0.41	43.90	38.00	16.67
F ₃ -65	38.46	9.16	7.69	4.00	22	74.00	68.00	8.11	35.30	33.00	6.97	2612.20	2244.00	16.41	0.65	0.47	38.30	36.00	8.11
F ₃ -66	48.15	7.41	9.63	5.24	16	78.00	66.00	15.38	31.90	29.60	7.77	2488.20	1953.60	27.36	0.68	0.50	36.00	44.00	15.38
F ₃ -67	48.08	9.31	9.62	5.01	27	80.00	62.00	22.50	39.50	37.20	6.18	3160.00	2306.40	37.01	0.72	0.54	33.33	46.00	22.50
F ₃ -68	41.51	9.23	8.30	4.36	23	82.00	68.00	17.07	31.90	29.60	7.77	2615.80	2012.80	29.96	0.89	0.71	25.35	38.00	17.07
F ₃ -69	42.59	9.27	8.52	4.58	20	74.00	58.00	21.62	35.20	34.50	2.03	2604.80	2001.00	30.17	0.52	0.34	52.94	38.00	21.62
F ₃ -70	47.17	9.16	9.43	5.15	20	76.00	62.00	18.42	33.00	30.20	9.27	2508.00	1872.40	33.95	0.63	0.45	40.00	44.00	18.42
F ₃ -71	40.74	8.93	8.15	4.47	18	74.00	64.00	13.51	33.20	31.20	6.41	2456.80	1996.80	23.04	0.74	0.56	32.14	36.00	13.51
F ₃ -72	41.51	9.31	8.30	4.41	23	76.00	62.00	18.42	35.71	31.20	14.46	2713.96	1934.40	40.30	0.75	0.57	31.58	38.00	18.42
F ₃ -73	42.00	9.10	8.40	4.20	19	82.00	66.00	19.51	33.90	31.30	8.31	2779.80	2065.80	34.56	0.69	0.51	35.29	42.00	19.51
F ₃ -74	45.10	9.07	9.02	4.63	19	82.00	66.00	19.51	39.10	30.30	29.04	3206.20	1999.80	60.33	0.67	0.49	36.73	44.00	19.51
F ₃ -75	48.08	9.16	9.62	5.00	27	80.00	58.00	27.50	36.99	35.30	4.79	2959.20	2047.40	44.53	0.68	0.50	36.00	46.00	27.50
F ₃ -76	43.40	8.97	8.68	4.61	21	74.00	58.00	21.62	33.41	32.30	3.44	2472.34	1873.40	31.97	0.87	0.69	26.09	40.00	21.62
F ₃ -77	53.70	9.60	10.74	5.80	20	76.00	58.00	23.68	33.87	29.60	14.43	2574.12	1716.80	49.94	0.56	0.38	47.37	50.00	23.68
F ₃ -78	30.61	9.57	6.12	3.04	15	72.00	64.00	11.11	38.01	30.20	25.86	2736.72	1932.80	41.59	0.91	0.73	24.66	32.00	11.11
F ₃ -79	40.38	7.21	8.08	4.14	19	82.00	74.00	9.76	33.93	32.30	5.05	2782.26	2390.20	16.40	0.64	0.46	39.13	38.00	9.76
F ₃ -80	49.02	9.31	9.80	5.50	27	76.00	58.00	23.68	38.05	33.20	14.61	2891.80	1925.60	50.18	0.69	0.51	35.29	48.00	23.68
F ₃ -81	43.14	9.40	8.63	4.40	24	78.00	64.00	17.95	39.80	29.50	34.92	3104.40	1888.00	64.43	0.65	0.47	38.30	42.00	17.95

Contd.....

Appendix II contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F ₃ -82	40.38	9.17	8.08	4.30	23	72.00	70.00	2.78	40.43	37.93	6.59	2910.96	2655.10	9.64	0.68	0.50	36.00	38.00	2.78
F ₃ -83	41.51	7.35	8.30	4.50	24	82.00	68.00	17.07	39.10	36.52	7.06	3206.20	2483.36	29.11	0.57	0.39	46.15	38.00	17.07
F ₃ -84	40.38	9.67	8.08	4.14	23	78.00	74.00	5.13	36.97	34.47	7.25	2883.66	2550.78	13.05	0.59	0.41	43.90	38.00	5.13
F ₃ -85	48.08	8.83	9.62	5.21	27	80.00	70.00	12.50	33.47	30.87	8.42	2677.60	2160.90	23.91	0.65	0.47	38.30	46.00	12.50
F ₃ -86	41.18	9.31	8.24	4.27	20	76.00	60.00	21.05	33.87	31.15	8.73	2574.12	1869.00	37.73	0.68	0.50	36.00	40.00	21.05
F ₃ -87	33.96	9.20	6.79	3.50	19	74.00	68.00	8.11	38.03	34.57	10.01	2814.22	2350.76	19.72	0.72	0.54	33.33	30.00	8.11
F ₃ -88	49.02	8.80	9.80	5.45	27	86.00	68.00	20.93	38.10	34.70	9.80	3276.60	2359.60	38.86	0.89	0.71	25.35	48.00	20.93
F ₃ -89	50.00	9.23	10.00	5.20	27	80.00	62.00	22.50	39.50	36.10	9.42	3160.00	2238.20	41.18	0.52	0.34	52.94	48.00	22.50
F ₃ -90	46.15	8.98	9.23	4.85	19	76.00	60.00	21.05	33.90	30.50	11.15	2576.40	1830.00	40.79	0.63	0.45	40.00	44.00	21.05
F ₃ -91	40.74	9.17	8.15	4.40	19	68.00	60.00	11.76	38.96	35.54	9.62	2649.28	2132.40	24.24	0.74	0.56	32.14	36.00	11.76
F ₃ -92	27.27	9.20	5.45	3.30	9	74.00	72.00	2.70	36.93	33.51	10.21	2732.82	2412.72	13.27	0.75	0.60	25.00	20.00	2.70
F ₃ -93	35.85	9.37	7.17	3.84	19	72.00	66.00	8.33	33.39	29.89	11.71	2404.08	1972.74	21.87	0.69	0.51	35.29	32.00	8.33
F ₃ -94	29.63	9.16	5.93	3.27	10	78.00	70.00	10.26	33.89	30.29	11.89	2643.42	2120.30	24.67	0.67	0.49	36.73	24.00	10.26
F ₃ -95	24.53	8.98	4.94	2.67	11	80.00	76.00	5.00	38.09	32.30	17.93	3047.20	2454.80	24.13	0.68	0.67	2.26	20.00	5.00
F ₃ -96	27.78	8.40	5.54	3.03	13	82.00	78.00	4.88	33.93	29.60	14.63	2782.26	2308.80	20.51	0.87	0.72	20.83	22.00	4.88
F ₃ -97	41.51	9.22	8.30	4.44	24	76.00	62.00	18.42	38.05	30.20	25.99	2891.80	1872.40	54.44	0.56	0.38	47.37	38.00	18.42
F ₃ -98	42.00	9.07	8.40	4.24	24	78.00	62.00	20.51	39.80	32.30	23.22	3104.40	2002.60	55.02	0.87	0.69	26.09	42.00	20.51
F ₃ -99	60.78	9.16	12.16	6.21	31	72.00	58.00	19.44	40.43	33.20	21.78	2910.96	1925.60	51.17	0.56	0.38	47.37	60.00	19.44
F ₃ -100	55.77	8.91	11.15	5.54	31	82.00	62.00	24.39	39.10	29.50	32.54	3206.20	1829.00	75.30	0.69	0.51	35.29	54.00	24.39
F ₃ -101	45.28	9.17	9.06	4.87	17	78.00	60.00	23.08	36.97	34.27	7.88	2883.66	2056.20	40.24	0.59	0.41	43.90	42.00	23.08
F ₃ -102	44.44	9.77	8.89	4.76	24	82.00	72.00	12.20	33.49	30.89	8.42	2746.18	2224.08	23.47	0.64	0.46	39.13	40.00	12.20
F ₃ -103	28.57	8.93	5.71	2.80	9	76.00	74.00	2.63	33.87	31.25	8.38	2574.12	2312.50	11.31	0.91	0.73	24.66	30.00	2.63
F ₃ -104	40.38	9.24	8.08	4.21	23	78.00	64.00	17.95	38.07	35.41	7.51	2969.46	2266.24	31.03	0.64	0.46	39.13	38.00	17.95

Contd.....

Appendix II contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F ₃ -105	60.78	9.27	12.16	6.15	32	72.00	60.00	16.67	41.29	38.99	5.90	2972.88	2339.40	27.08	0.69	0.51	35.29	60.00	16.67
F ₃ -106	66.67	9.26	13.33	6.87	29	78.00	62.00	20.51	35.30	33.00	6.97	2753.40	2046.00	34.57	0.65	0.47	38.30	66.00	20.51
F ₃ -107	59.62	8.93	11.92	6.22	24	82.00	62.00	24.39	39.10	36.70	6.54	3206.20	2275.40	40.91	0.68	0.50	36.00	58.00	24.39
F ₃ -108	50.94	8.86	10.19	5.41	27	78.00	60.00	23.08	36.97	34.63	6.76	2883.66	2077.80	38.78	0.57	0.39	46.15	48.00	23.08
F ₃ -109	41.51	9.29	8.30	4.46	18	82.00	72.00	12.20	33.49	31.15	7.51	2746.18	2242.80	22.44	0.59	0.41	43.90	38.00	12.20
F ₃ -110	44.00	9.07	8.80	4.36	24	76.00	70.00	7.89	33.87	31.51	7.49	2574.12	2205.70	16.70	0.65	0.47	38.30	44.00	7.89
F ₃ -111	41.18	9.16	8.24	4.21	23	78.00	68.00	12.82	38.07	29.60	28.61	2969.46	2012.80	47.53	0.68	0.50	36.00	40.00	12.82
F ₃ -112	30.00	8.91	6.00	3.10	18	72.00	68.00	5.56	39.80	34.50	15.36	2865.60	2346.00	22.15	0.72	0.54	33.33	30.00	5.56
F ₃ -113	43.40	8.18	8.68	4.61	18	78.00	68.00	12.82	40.49	30.20	34.07	3158.22	2053.60	53.79	0.89	0.71	25.35	40.00	12.82
F ₃ -114	51.85	9.06	10.37	5.60	30	82.00	60.00	26.83	34.37	31.20	10.16	2818.34	1872.00	50.55	0.52	0.34	52.94	48.00	26.83
F ₃ -115	28.57	9.02	5.71	2.84	14	82.00	74.00	9.76	34.25	29.50	16.10	2808.50	2183.00	28.65	0.63	0.45	40.00	30.00	9.76
F ₃ -116	50.00	7.85	10.00	5.20	27	78.00	60.00	23.08	39.80	37.30	6.70	3104.40	2238.00	38.71	0.74	0.56	32.14	48.00	23.08
F ₃ -117	41.18	9.16	8.24	4.24	19	68.00	58.00	14.71	33.79	31.25	8.13	2297.72	1812.50	26.77	0.75	0.57	31.58	40.00	14.71
F ₃ -118	48.08	9.46	9.62	5.07	27	74.00	60.00	18.92	38.03	35.47	7.22	2814.22	2128.20	32.23	0.69	0.51	35.29	46.00	18.92
F ₃ -119	44.23	8.98	8.85	4.60	18	72.00	64.00	11.11	39.80	37.30	6.70	2865.60	2387.20	20.04	0.67	0.49	36.73	42.00	11.11
F ₃ -120	41.18	9.47	8.24	4.27	23	78.00	64.00	17.95	40.49	38.05	6.41	3158.22	2435.20	29.69	0.68	0.50	36.00	40.00	17.95
F ₃ -121	50.94	9.16	10.19	5.40	27	80.00	62.00	22.50	40.00	37.70	6.10	3200.00	2337.40	36.90	0.91	0.73	24.66	48.00	22.50
F ₃ -122	41.18	8.99	8.24	4.15	20	78.00	62.00	20.51	34.98	32.68	7.04	2728.44	2026.16	34.66	0.64	0.46	39.13	40.00	20.51
F ₃ -123	53.85	8.18	10.77	5.60	30	76.00	60.00	21.05	37.90	34.90	8.60	2880.40	2094.00	37.55	0.69	0.51	35.29	52.00	21.05
F ₃ -124	42.31	7.50	8.46	4.45	24	82.00	68.00	17.07	36.60	33.60	8.93	3001.20	2284.80	31.36	0.65	0.47	38.30	40.00	17.07
F ₃ -125	46.30	8.40	9.26	5.10	26	80.00	68.00	15.00	34.70	31.70	9.46	2776.00	2155.60	28.78	0.68	0.50	36.00	42.00	15.00
F ₃ -126	50.00	8.85	10.00	5.24	19	76.00	62.00	18.42	33.80	30.80	9.74	2568.80	1909.60	34.52	0.57	0.39	46.15	48.00	18.42
F ₃ -127	33.96	9.31	6.79	3.65	16	86.00	78.00	9.30	37.80	34.80	8.62	3250.80	2714.40	19.76	0.59	0.41	43.90	30.00	9.30

Contd.....

Appendix II contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F ₃ -128	66.67	9.26	13.33	7.21	32	74.00	62.00	16.22	41.29	38.29	7.83	3055.46	2373.98	28.71	0.65	0.47	38.30	64.00	16.22
F ₃ -129	50.94	9.16	10.19	5.40	27	78.00	58.00	25.64	35.30	33.00	6.97	2753.40	1914.00	43.86	0.68	0.50	36.00	48.00	25.64
F ₃ -130	44.44	8.40	8.89	4.80	24	82.00	64.00	21.95	39.80	37.50	6.13	3263.60	2400.00	35.98	0.72	0.54	33.33	40.00	21.95
F ₃ -131	28.30	8.18	5.66	3.14	13	78.00	74.00	5.13	36.90	32.30	14.24	2878.20	2390.20	20.42	0.89	0.74	20.27	24.00	5.13
F ₃ -132	42.00	8.87	8.40	4.20	20	72.00	62.00	13.89	34.18	29.50	15.86	2460.96	1829.00	34.55	0.52	0.34	52.94	42.00	13.89
F ₃ -133	49.02	9.02	9.80	5.12	20	76.00	62.00	18.42	33.20	29.70	11.78	2523.20	1841.40	37.03	0.63	0.45	40.00	48.00	18.42
F ₃ -134	48.08	7.75	9.62	5.00	20	80.00	68.00	15.00	37.60	34.85	7.89	3008.00	2369.80	26.93	0.74	0.56	32.14	46.00	15.00
F ₃ -135	49.06	9.12	9.81	5.25	27	76.00	58.00	23.68	35.50	34.50	2.90	2698.00	2001.00	34.83	0.75	0.57	31.58	46.00	23.68
F ₃ -136	40.74	9.16	8.15	4.40	20	82.00	72.00	12.20	39.80	34.60	15.03	3263.60	2491.20	31.01	0.69	0.51	35.29	36.00	12.20
F ₃ -137	40.82	8.99	8.16	4.12	23	78.00	68.00	12.82	34.40	33.50	2.69	2683.20	2278.00	17.79	0.67	0.49	36.73	42.00	12.82
F ₃ -138	48.08	8.83	9.62	5.00	27	78.00	64.00	17.95	41.29	32.50	27.05	3220.62	2080.00	54.84	0.91	0.73	24.66	46.00	17.95
F ₃ -139	49.02	9.31	9.80	5.10	19	82.00	66.00	19.51	35.30	34.60	2.02	2894.60	2283.60	26.76	0.64	0.46	39.13	48.00	19.51
F ₃ -140	29.41	9.20	5.88	3.12	13	80.00	74.00	7.50	34.58	29.40	17.62	2766.40	2175.60	27.16	0.69	0.51	35.29	28.00	7.50
F ₃ -141	28.85	9.16	5.77	3.00	16	76.00	70.00	7.89	37.00	32.63	13.39	2812.00	2284.10	23.11	0.65	0.47	38.30	26.00	7.89
F ₃ -142	30.19	7.35	6.04	3.20	14	74.00	72.00	2.70	34.20	32.30	5.88	2530.80	2325.60	8.82	0.68	0.50	36.00	26.00	2.70
F ₃ -143	40.74	9.07	8.15	4.42	18	78.00	66.00	15.38	41.10	39.30	4.58	3205.80	2593.80	23.59	0.57	0.39	46.15	36.00	15.38
F ₃ -144	30.61	9.16	6.12	3.10	16	74.00	70.00	5.41	32.80	25.60	28.13	2427.20	1792.00	35.45	0.59	0.41	43.90	32.00	5.41
F ₃ -145	30.77	8.98	6.15	3.25	17	76.00	70.00	7.89	39.39	38.50	2.31	2993.64	2695.00	11.08	0.65	0.47	38.30	28.00	7.89
F ₃ -146	49.02	8.18	9.80	5.00	27	74.00	58.00	21.62	36.33	35.40	2.63	2688.42	2053.20	30.94	0.68	0.50	36.00	48.00	21.62
F ₃ -147	50.98	9.16	10.20	5.20	21	78.00	56.00	28.21	33.47	28.40	17.85	2610.66	1590.40	64.15	0.72	0.54	33.33	50.00	28.21
F ₃ -148	40.38	8.97	8.08	4.20	23	82.00	70.00	14.63	36.04	31.40	14.78	2955.28	2198.00	34.45	0.89	0.71	25.35	38.00	14.63
F ₃ -149	28.30	9.04	5.66	3.14	13	76.00	72.00	5.26	39.05	31.70	23.19	2967.80	2282.40	30.03	0.52	0.37	40.54	24.00	5.26
F ₃ -150	40.38	10.15	8.08	4.20	23	78.00	62.00	20.51	33.45	32.40	3.24	2609.10	2008.80	29.88	0.63	0.45	40.00	38.00	20.51

Contd.....

Appendix II contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F ₃ -151	30.19	10.20	6.04	3.26	17	78.00	72.00	7.69	44.43	39.60	12.20	3465.54	2851.20	21.55	0.74	0.56	32.14	26.00	7.69
F ₃ -152	30.77	10.44	6.15	3.18	21	82.00	72.00	12.20	39.51	37.80	4.52	3239.82	2721.60	19.04	0.75	0.57	31.58	28.00	12.20
F ₃ -153	54.72	9.67	10.94	5.80	31	84.00	64.00	23.81	34.30	31.60	8.54	2881.20	2022.40	42.46	0.69	0.51	35.29	52.00	23.81
F ₃ -154	60.00	10.37	12.00	6.00	25	86.00	72.00	16.28	34.70	32.80	5.79	2984.20	2361.60	26.36	0.67	0.49	36.73	60.00	16.28
F ₃ -155	28.57	10.24	5.71	2.35	16	80.00	74.00	7.50	39.64	34.60	14.57	3171.20	2560.40	23.86	0.68	0.50	36.00	30.00	7.50
F ₃ -156	55.10	10.75	11.02	5.40	29	82.00	64.00	21.95	44.64	36.90	20.98	3660.48	2361.60	55.00	0.87	0.69	26.09	56.00	21.95
F ₃ -157	30.61	10.21	6.12	3.35	19	78.00	72.00	7.69	30.70	28.63	7.23	2394.60	2061.36	16.17	0.56	0.38	47.37	32.00	7.69
F ₃ -158	32.69	10.04	6.54	3.40	19	80.00	70.00	12.50	39.64	38.50	2.96	3171.20	2695.00	17.67	0.75	0.57	31.58	30.00	12.50
F ₃ -159	44.23	10.17	8.85	4.45	25	82.00	72.00	12.20	35.00	31.20	12.18	2870.00	2246.40	27.76	0.69	0.51	35.29	42.00	12.20
F ₃ -160	41.18	10.38	8.24	4.20	16	84.00	70.00	16.67	39.64	36.50	8.60	3329.76	2555.00	30.32	0.67	0.49	36.73	40.00	16.67
F ₃ -161	49.06	10.10	9.81	5.24	27	82.00	62.00	24.39	30.70	29.40	4.42	2517.40	1822.80	38.11	0.68	0.50	36.00	46.00	24.39
F ₃ -162	41.18	10.34	8.24	4.20	24	82.00	66.00	19.51	34.30	32.63	5.12	2812.60	2153.58	30.60	0.87	0.69	26.09	40.00	19.51
F ₃ -163	42.31	10.14	8.46	4.39	16	82.00	72.00	12.20	34.70	32.30	7.43	2845.40	2325.60	22.35	0.56	0.38	47.37	40.00	12.20
F ₃ -164	44.23	10.27	8.85	4.64	20	84.00	74.00	11.90	44.64	39.30	13.59	3749.76	2908.20	28.94	0.69	0.51	35.29	42.00	11.90
F ₃ -165	42.59	10.25	8.52	4.84	20	80.00	62.00	22.50	30.70	25.60	19.92	2456.00	1587.20	54.74	0.59	0.41	43.90	38.00	22.50
F ₃ -166	50.00	10.54	10.00	5.23	27	82.00	60.00	26.83	39.64	38.50	2.96	3250.48	2310.00	40.71	0.64	0.46	39.13	48.00	26.83
F ₃ -167	49.06	10.14	9.81	5.19	20	86.00	64.00	25.58	30.70	24.60	24.80	2640.20	1574.40	67.70	0.85	0.67	26.87	46.00	25.58
F ₃ -168	53.70	10.37	10.74	5.79	30	84.00	68.00	19.05	44.43	37.10	19.76	3732.12	2522.80	47.94	0.71	0.53	33.96	50.00	19.05
F ₃ -169	52.83	10.54	10.57	5.51	19	82.00	68.00	17.07	39.51	37.40	5.64	3239.82	2543.20	27.39	0.69	0.51	35.29	50.00	17.07
F ₃ -170	29.63	10.65	5.93	3.20	12	82.00	74.00	9.76	34.30	30.20	13.58	2812.60	2234.80	25.85	0.68	0.50	36.00	24.00	9.76
F ₃ -171	45.28	14.12	9.06	4.80	25	84.00	72.00	14.29	34.70	31.90	8.78	2914.80	2296.80	26.91	0.54	0.36	50.00	42.00	14.29
F ₃ -172	28.00	10.20	5.60	2.85	10	86.00	80.00	6.98	35.00	32.50	7.69	3010.00	2600.00	15.77	0.67	0.52	28.85	28.00	6.98
F ₃ -173	41.18	10.14	8.24	4.21	19	82.00	72.00	12.20	39.64	36.50	8.60	3250.48	2628.00	23.69	0.61	0.43	41.86	40.00	12.20

Contd.....

Appendix II contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F ₃ -174	26.92	10.40	5.38	2.88	12	78.00	72.00	7.69	44.43	41.30	7.58	3465.54	2973.60	16.54	0.63	0.48	31.25	24.00	7.69
F ₃ -175	30.19	10.60	6.04	3.21	12	80.00	74.00	7.50	39.51	32.63	21.08	3160.80	2414.62	30.90	0.46	0.28	64.29	26.00	7.50
F ₃ -176	31.48	10.64	6.30	3.47	20	82.00	76.00	7.32	34.30	32.30	6.19	2812.60	2454.80	14.58	0.72	0.54	33.33	26.00	7.32
F ₃ -177	44.90	9.67	8.98	4.44	20	84.00	72.00	14.29	34.70	39.30	-11.70	2914.80	2829.60	3.01	0.89	0.71	25.35	46.00	14.29
F ₃ -178	42.31	10.82	8.46	4.40	22	82.00	70.00	14.63	41.97	37.60	11.62	3441.54	2632.00	30.76	0.52	0.34	52.94	40.00	14.63
F ₃ -179	41.18	10.38	8.24	4.25	23	90.00	76.00	15.56	41.97	36.30	15.62	3777.30	2758.80	36.92	0.63	0.45	40.00	40.00	15.56
F ₃ -180	50.98	10.20	10.20	5.21	27	88.00	66.00	25.00	39.51	36.50	8.25	3476.88	2409.00	44.33	0.74	0.56	32.14	50.00	25.00
F ₃ -181	42.31	10.44	8.46	4.41	24	86.00	74.00	13.95	34.30	32.63	5.12	2949.80	2414.62	22.16	0.75	0.57	31.58	40.00	13.95
F ₃ -182	43.40	10.24	8.68	4.67	18	82.00	66.00	19.51	34.20	29.60	15.54	2804.40	1953.60	43.55	0.69	0.51	35.29	40.00	19.51
F ₃ -183	48.08	10.72	9.62	5.00	17	84.00	72.00	14.29	41.97	37.60	11.62	3525.48	2707.20	30.23	0.67	0.49	36.73	46.00	14.29
F ₃ -184	42.31	10.30	8.46	4.47	24	72.00	62.00	13.89	29.60	27.10	9.23	2131.20	1680.20	26.84	0.68	0.50	36.00	40.00	13.89
F ₃ -185	41.18	10.50	8.24	4.20	18	90.00	74.00	17.78	44.64	42.14	5.93	4017.60	3118.36	28.84	0.87	0.69	26.09	40.00	17.78
F ₃ -186	43.40	10.14	8.68	4.61	20	88.00	70.00	20.45	30.70	28.20	8.87	2701.60	1974.00	36.86	0.56	0.38	47.37	40.00	20.45
F ₃ -187	29.41	9.58	5.88	3.01	16	86.00	78.00	9.30	39.64	36.24	9.38	3409.04	2826.72	20.60	0.69	0.51	35.29	28.00	9.30
F ₃ -188	42.31	10.18	8.46	4.40	24	82.00	68.00	17.07	41.97	38.57	8.82	3441.54	2622.76	31.22	0.59	0.41	43.90	40.00	17.07
F ₃ -189	48.08	10.34	9.62	5.00	27	92.00	76.00	17.39	44.43	41.03	8.29	4087.56	3118.28	31.08	0.64	0.46	39.13	46.00	17.39
F ₃ -190	42.59	10.20	8.52	4.61	24	96.00	82.00	14.58	34.20	30.20	13.25	3283.20	2476.40	32.58	0.85	0.67	26.87	38.00	14.58
F ₃ -191	44.23	10.54	8.85	4.20	24	88.00	78.00	11.36	41.97	36.90	13.74	3693.36	2878.20	28.32	0.71	0.53	33.96	42.00	11.36
F ₃ -192	54.72	10.02	10.94	5.81	27	90.00	68.00	24.44	29.60	27.50	7.64	2664.00	1870.00	42.46	0.69	0.51	35.29	52.00	24.44
F ₃ -193	42.59	10.27	8.52	4.64	24	88.00	72.00	18.18	35.00	33.20	5.42	3080.00	2390.40	28.85	0.68	0.50	36.00	38.00	18.18
F ₃ -194	45.28	10.74	9.06	4.86	16	86.00	68.00	20.93	39.64	34.30	15.57	3409.04	2332.40	46.16	0.54	0.36	50.00	42.00	20.93
F ₃ -195	46.30	10.37	9.26	5.02	20	82.00	64.00	21.95	44.43	43.50	2.14	3643.26	2784.00	30.86	0.67	0.49	36.73	42.00	21.95
F ₃ -196	30.19	10.24	6.04	3.20	18	86.00	78.00	9.30	39.51	36.80	7.36	3397.86	2870.40	18.38	0.61	0.43	41.86	26.00	9.30

Contd.....

Appendix II contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F ₃ -197	42.00	10.18	8.40	4.20	18	88.00	72.00	18.18	34.30	31.30	9.58	3018.40	2253.60	33.94	0.63	0.45	40.00	42.00	18.18
F ₃ -198	49.02	10.36	9.80	5.12	27	84.00	58.00	30.95	34.70	30.20	14.90	2914.80	1751.60	66.41	0.72	0.54	33.33	48.00	30.95
F ₃ -199	25.45	10.82	5.09	2.80	14	82.00	78.00	4.88	44.64	40.23	10.96	3660.48	3137.94	16.65	0.89	0.81	9.88	18.00	4.88
F ₃ -200	32.08	10.20	6.42	3.41	18	88.00	80.00	9.09	30.70	28.30	8.48	2701.60	2264.00	19.33	0.52	0.34	52.94	28.00	9.09
F ₃ -201	50.00	10.94	10.00	5.40	20	92.00	72.00	21.74	39.64	36.80	7.72	3646.88	2649.60	37.64	0.63	0.45	40.00	46.00	21.74
F ₃ -202	48.98	10.64	9.80	4.81	26	88.00	70.00	20.45	34.20	31.40	8.92	3009.60	2198.00	36.92	0.74	0.56	32.14	50.00	20.45
F ₃ -203	48.08	10.37	9.62	5.06	27	82.00	70.00	14.63	41.97	40.20	4.40	3441.54	2814.00	22.30	0.75	0.57	31.58	46.00	14.63
F ₃ -204	50.98	10.24	10.20	5.20	17	84.00	64.00	23.81	29.60	25.60	15.63	2486.40	1638.40	51.76	0.69	0.51	35.29	50.00	23.81
F ₃ -205	47.06	10.75	9.41	4.83	23	82.00	68.00	17.07	39.51	35.60	10.98	3239.82	2420.80	33.83	0.67	0.49	36.73	46.00	17.07
F ₃ -206	55.77	10.34	11.15	5.80	30	86.00	64.00	25.58	34.30	33.50	2.39	2949.80	2144.00	37.58	0.68	0.50	36.00	54.00	25.58
F ₃ -207	49.06	10.75	9.81	5.27	27	88.00	66.00	25.00	34.70	29.80	16.44	3053.60	1966.80	55.26	0.87	0.69	26.09	46.00	25.00
F ₃ -208	27.78	10.20	5.57	3.0	15	90.00	84.00	6.67	41.97	32.60	28.74	3777.30	2738.40	37.94	0.56	0.41	36.59	22.00	6.67
F ₃ -209	28.30	10.85	5.66	3.21	15	84.00	78.00	7.14	34.20	31.20	9.62	2872.80	2433.60	18.05	0.69	0.51	35.29	24.00	7.14
F ₃ -210	29.63	10.37	5.93	3.20	15	86.00	78.00	9.30	41.97	35.60	17.89	3609.42	2776.80	29.98	0.59	0.41	43.90	24.00	9.30
F ₃ -211	32.08	10.45	6.42	3.78	18	90.00	82.00	8.89	29.60	25.60	15.63	2664.00	2099.20	26.91	0.64	0.46	39.13	28.00	8.89
F ₃ -212	58.00	10.24	11.60	5.86	31	88.00	66.00	25.00	34.70	32.40	7.10	3053.60	2138.40	42.80	0.85	0.67	26.87	58.00	25.00
F ₃ -213	41.18	10.65	8.24	4.27	18	82.00	68.00	17.07	41.97	39.60	5.98	3441.54	2692.80	27.81	0.71	0.53	33.96	40.00	17.07
F ₃ -214	42.31	10.18	8.46	4.40	24	66.00	58.00	12.12	35.00	31.20	12.18	2310.00	1809.60	27.65	0.69	0.51	35.29	40.00	12.12
F ₃ -215	54.72	10.64	10.94	5.86	31	78.00	60.00	23.08	39.64	31.60	25.44	3091.92	1896.00	63.08	0.68	0.50	36.00	52.00	23.08
F ₃ -216	40.74	10.20	8.15	4.43	23	80.00	70.00	12.50	44.64	36.30	22.98	3571.20	2541.00	40.54	0.54	0.36	50.00	36.00	12.50
F ₃ -217	28.57	10.14	5.71	2.83	17	80.00	76.00	5.00	30.70	26.90	14.13	2456.00	2044.40	20.13	0.91	0.73	24.66	30.00	5.00
F ₃ -218	32.69	10.36	6.54	3.40	13	82.00	78.00	4.88	39.64	36.90	7.43	3250.48	2878.20	12.93	0.64	0.46	39.13	30.00	4.88
F ₃ -219	56.86	10.25	11.37	5.84	26	82.00	60.00	26.83	41.97	36.20	15.94	3441.54	2172.00	58.45	0.69	0.51	35.29	56.00	26.83

Contd.....

Appendix II contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F ₃ -220	45.10	10.70	9.02	4.59	26	84.00	64.00	23.81	44.64	38.50	15.95	3749.76	2464.00	52.18	0.65	0.47	38.30	44.00	23.81
F ₃ -221	24.56	10.44	4.95	2.82	8	86.00	78.00	9.30	30.70	28.70	6.97	2640.20	2238.60	17.94	0.68	0.65	4.62	14.00	9.30
F ₃ -222	33.96	10.77	6.79	3.54	12	88.00	78.00	11.36	39.64	37.80	4.87	3488.32	2948.40	18.31	0.57	0.39	46.15	30.00	11.36
F ₃ -223	25.00	10.37	5.00	2.83	11	88.00	84.00	4.55	35.00	31.60	10.76	3080.00	2654.40	16.03	0.59	0.56	5.36	16.00	4.55□
F ₃ -224	30.77	10.64	6.15	3.20	20	90.00	80.00	11.11	39.64	32.80	20.85	3567.60	2624.00	35.96	0.65	0.47	38.30	28.00	11.11
F ₃ -225	47.06	10.75	9.41	4.41	20	86.00	74.00	13.95	39.51	34.60	14.19	3397.86	2560.40	32.71	0.68	0.50	36.00	46.00	13.95
F ₃ -226	41.51	10.17	8.30	4.46	24	90.00	68.00	24.44	34.30	28.50	20.35	3087.00	1938.00	59.29	0.72	0.54	33.33	38.00	24.44
F ₃ -227	50.98	10.20	10.20	5.18	20	90.00	68.00	24.44	46.04	36.80	25.11	4143.60	2502.40	65.59	0.89	0.71	25.35	50.00	24.44
F ₃ -228	40.38	10.54	8.08	4.21	20	86.00	74.00	13.95	30.70	31.30	-1.92	2640.20	2316.20	13.99	0.52	0.34	52.94	38.00	13.95
F ₃ -229	30.77	10.45	6.15	3.20	19	88.00	78.00	11.36	35.00	30.20	15.89	3080.00	2355.60	30.75	0.63	0.45	40.00	28.00	11.36
F ₃ -230	31.48	10.94	6.30	3.43	22	90.00	82.00	8.89	39.64	32.50	21.97	3567.60	2665.00	33.87	0.74	0.56	32.14	26.00	8.89
F ₃ -231	48.08	10.24	9.62	5.00	27	88.00	70.00	20.45	44.43	40.30	10.25	3909.84	2821.00	38.60	0.75	0.57	31.58	46.00	20.45
F ₃ -232	26.42	10.75	5.28	2.85	13	86.00	80.00	6.98	39.51	37.50	5.36	3397.86	3000.00	13.26	0.69	0.54	27.78	22.00	6.98
F ₃ -233	29.63	10.18	5.93	3.29	12	88.00	82.00	6.82	34.30	33.50	2.39	3018.40	2747.00	9.88	0.67	0.49	36.73	24.00	6.82
F ₃ -234	43.40	10.40	8.68	4.60	20	82.00	70.00	14.63	34.70	30.10	15.28	2845.40	2107.00	35.05	0.68	0.50	36.00	40.00	14.63
F ₃ -235	44.44	10.60	8.89	4.89	16	84.00	68.00	19.05	44.64	40.20	11.04	3749.76	2733.60	37.17	0.87	0.69	26.09	40.00	19.05
F ₃ -236	41.51	10.86	8.30	4.40	17	86.00	68.00	20.93	30.70	24.60	24.80	2640.20	1672.80	57.83	0.56	0.38	47.37	38.00	20.93
F ₃ -237	46.00	10.20	9.20	4.55	21	86.00	70.00	18.60	39.64	36.90	7.43	3409.04	2583.00	31.98	0.67	0.49	36.73	46.00	18.60
F ₃ -238	27.45	10.44	5.49	2.85	10	88.00	80.00	9.09	39.51	36.40	8.54	3476.88	2912.00	19.40	0.68	0.53	28.30	26.00	9.09
F ₃ -239	32.69	10.18	6.54	3.65	15	90.00	86.00	4.44	34.30	30.70	11.73	3087.00	2640.20	16.92	0.87	0.69	26.09	30.00	4.44
F ₃ -240	41.51	9.36	8.30	4.40	24	86.00	74.00	13.95	34.70	29.50	17.63	2984.20	2183.00	36.70	0.56	0.38	47.37	38.00	13.95
F ₃ -241	27.78	10.82	5.58	3.01	13	90.00	84.00	6.67	34.20	32.10	6.54	3078.00	2696.40	14.15	0.69	0.54	27.78	22.00	6.67
F ₃ -242	42.86	10.20	8.57	4.27	16	90.00	74.00	17.78	41.97	40.70	3.12	3777.30	3011.80	25.42	0.59	0.41	43.90	44.00	17.78

Contd.....

Appendix II contd.....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F ₃ -243	48.08	9.44	9.62	5.12	17	86.00	70.00	18.60	29.60	26.30	12.55	2545.60	1841.00	38.27	0.64	0.46	39.13	46.00	18.60
F ₃ -244	43.14	9.36	8.63	4.46	24	88.00	74.00	15.91	39.51	37.60	5.08	3476.88	2782.40	24.96	0.85	0.67	26.87	42.00	15.91
F ₃ -245	50.98	10.37	10.20	5.27	18	90.00	70.00	22.22	34.30	32.10	6.85	3087.00	2247.00	37.38	0.71	0.53	33.96	50.00	22.22
F ₃ -246	40.38	10.18	8.08	4.23	23	88.00	76.00	13.64	34.70	33.20	4.52	3053.60	2523.20	21.02	0.69	0.51	35.29	38.00	13.64
F ₃ -247	43.40	10.20	8.68	4.64	25	86.00	72.00	16.28	44.43	42.60	4.30	3820.98	3067.20	24.58	0.68	0.50	36.00	40.00	16.28
F ₃ -248	48.08	10.55	9.62	5.00	26	88.00	68.00	22.73	39.51	34.10	15.87	3476.88	2318.80	49.94	0.54	0.36	50.00	46.00	22.73
F ₃ -249	49.06	10.36	9.81	5.21	20	82.00	72.00	12.20	34.30	33.30	3.00	2812.60	2397.60	17.31	0.67	0.49	36.73	46.00	12.20
F ₃ -250	46.15	10.82	9.23	4.80	18	84.00	68.00	19.05	34.70	30.40	14.14	2914.80	2067.20	41.00	0.61	0.43	41.86	44.00	19.05

STABILITY ANALYSIS IN ADVANCED BREEDING LINES AND BRUCHID RESISTANCE STUDIES IN COWPEA [*Vigna unguiculata* (L.) Walp.]

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ABSTRACT

An experiment was carried out involving twenty seven promising advanced breeding lines which were in F₆ generation and three promising germplasm lines of cowpea along with four checks viz., DCS-47-1, DC-15, C-152 and DC-16 at three diverse locations to assess the stability of genotypes.

According to Eberhart and Russel stability model (1966) the stable genotypes identified for seed yield (kg ha⁻¹) were F₆ progenies of crosses namely, C-152 × IC 198701, C-152 × IC 201079, C-152 × IC 202710, GC-3 × IC 202872 and V-118 × IC 249141. The promising genotypes identified for yield *per se* were F₆ lines of crosses viz., DC-15 × DCS-47-1, C-152 × CP-206, DC-15 × Subhra, C-152 × IC 97767 and DC-15 × JOB-129.

In cowpea, bruchid (*Callosobruchus maculatus* F.) is the most serious storage pest due to the fact that cowpea is the primary host in India. It causes 90 to 100 per cent loss in seed quality upon progressive storage. The resistance of cowpea to bruchid infestation has been a major concern to plant breeders as some elite cowpea varieties become susceptible to the bruchids. Keeping this point in view, screening of 250 F₃ segregants of cross between DC-615 × Dharwad local was carried out against bruchids (*Callosobruchus maculatus* F.).

Bruchid infestation (%) measured through different damage parameters revealed that segregants viz., F₃-2, F₃-95, F₃-221, F₃-223, F₃-199, F₃-4, F₃-24, F₃-92, F₃-232 and F₃-241 were found superior for bruchid resistance because they exhibited least bruchid infestation, minimum per cent seed damage, minimum actual and apparent weight loss, minimum number of bruchids emerged. The parameters related to germination and vigour of seeds were influenced to the lowest degree from the damage by bruchids.