YIELD COMPONENTS, NODULATION, ADAPTABILITY AND GENE ACTION IN VEGETABLE COWPEA

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BY

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C E R T I F I C A T E

This is to certify that the work recorded in the thesis entitled " *YIELD COMPONENTS,NODULATION,ADAPTABILITY AND GENE ACTION IN VEGETABLE COWPEA*" submitted by Sri Arup Chattopadhyay, for the award of the Degree of Doctor of Philosophy in Horticulture of the Bidhan Chandra Krishi Viswavidyalaya,is the faithful and bonafide research work carried out under our personal supervision and guidance. The results of the investigation reported in the thesis have not so far been submitted for any other Degree or Diploma.The assistance and help received during the course of investigation have been duly acknowledged.

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CHAPTER-I

INTRODUCTION

INTRODUCTION

The provisional indicative world plan for Agricultural Development (FAO,1970) stressed the vital importance of increasing the output of cheaper sources of quality protein and stated that edible grain legumes provide an immediate potential among food crops for alleviating human malnutrition. Among these legumes, cowpea (*Vigna unguiculata* (L.) walp.) an ancient neolithic African crop ~~are~~ is now grown for dry seed, immature seed, immature green pod, green leaves and even roots throughout the tropics and subtropics. In some areas of semihumid tropics, cowpea provides more than half the plant protein in human diets. It is the key staple for the poorest sector of many poor tropical countries. As a dietary staple it greatly improves an otherwise bland and unbalanced diet. Swaminathan and Jain (1973) discussed the importance of cowpea in the Indian diet. Of the proteins consumed in Indian diet, 60.2% comes from cereals, 25.6% from pulses and nut and only a small portion is derived from animal which lead to an imbalance in essential amino acids especially methionine, lysine and tryptophan (Kale *et al.*,1986). The limiting amino acid of cereals is lysine, good content of which is present in cowpea. On the otherhand, cystine and methionine, the sulfoamino acids are limited in cowpea. So, protein quality is synergistically improved in cereal-cowpea mixture because of the lysine contributed by the cowpea and the methionine contributed

by the cereal (Bressani,1985).

As in other food legumes, it bears nodules in the roots with the symbiotic association of *Rhizobium* that fixes atmospheric nitrogen and thereby restores and improves soil fertility. Effective cowpea *Rhizobium* symbiosis can fix more than 150 kg N per hectare and supply 80-90% of the host plant nitrogen requirement (Eaglesham *et al.*, 1977; Summerfield *et al.*,1977a). Thus, crops grown in association with cowpea or succeeding crops may benefit from the fixed nitrogen. Cowpea is also utilized as a green manure and as a quick growing cover crop and also highly compatible as a companion with a wide range of food and fibre crops. It is tolerant of drought and of most soil stresses, and thus can grow over a wide range of environmental conditions.

Although all the evidence showed to its originating in Africa, but its domestication centre is still uncertain (Ng and Marechal,1985). India is considered as modern centre of diversity of cowpea cultivars (Steele,1976; Pant *et al.*,1982). In the African context, the role of cowpea is predominantly that of a pulse and African use as a pulse continues, but after the introduction of Unguiculata forms to India and south-east Asia, two other cultigroups (cv-gr.) were evolved: cv-gr. Sesquipedalis (vegetable type) and cv-gr. Biflora (fodder type) under the predominant influence of cv-gr. Sesquipedalis in India indicates its recent introduction from south-east Asia (Pant *et al.*, 1982). Steele and

Mehra (1980) concluded that the cultivars grown in India for fodder and seed are integrades of cv-gr. Unguiculata and Biflora, while those grown for green pod as vegetable are integrades of cv-gr. Unguiculata and Sesquipedalis. Hazra *et al.* (1993) also recorded the presence of intermediate types between cv-gr. Unguiculata and Sesquipedalis in the population of vegetable cowpea.

Cowpea is grown extensively in 16 African countries ; Nigeria and Niger together produce almost half of the world production and the other major cowpea producers in Africa include Burkina Faso, Ghana, Kenya,Uganda,Malawi,Tanzania, Togo and Senegal (Rachie, 1985). The second largest cowpea-producing country is Brazil where 26.4% of the world wide total is produced; the other major producers in Latin America are Venezuela, Peru, Panama, El Salvador and Haiti (Watt *et al.*,1985). Asian production includes that of green pod yield, and it is cultivated in India, SriLanka, Bangladesh, Burma, China, Korea, Indonesia, Nepal, Pakistan, the Philippines, Thailand and Malayasia (Mishra *et al.*,1985). Among the Asian countries,India is the largest producer of cowpea where it is cultivated for all the forms - green pod, dry seed, fodder, green manure, and cover crops (Rachie,1985). The only developed country producing large amount of cowpea is the U.S.A., where it is mainly grown for processed dry seed, immature green seed and green tender pods (Fery,1985).

In the Northern drier tracts of India, cowpea is grown primarily for its dry seeds as pulse. Simultaneously, some forms of cowpea are also grown as fodder crops in the semi-arid Western regions of India. In contrast, in humid tropics of Indian subcontinent comprising parts of Bihar, West Bengal, Assam and its adjoining areas and Bangladesh cowpea is by and large grown for vegetable purpose. This clearly demonstrates the preferential use of cowpea which includes three different cultigroups such as Unguiculata, Biflora and Sesquipedalis and their integrades in different parts of India.

The genetic improvement of cowpea becomes increasingly complex as it needs a comprehensive and diversified approach keeping in view of different forms of the cowpea grown. Scanty research work on vegetable types of cowpeas in India stands as a barrier to its improvement. The indigenous vegetable types have got some defects. They are mostly viny,long-duration, and indeterminate types which prevent them to be fitted with proper crop rotation and places them in a disadvantageous position in relay cropping. In fact, cowpeas are mostly cultivated in subsistence farming rather than commercial farming in most parts of Asia because of their growth habit and prolonged period of pod development (Mishra *et al.*,1985). So, development of short duration determinate/semideterminate plant type with synchrony in pod bearing and medium-long succulent pods would be a profitable

proposition (Som and Hazra,1993). For this,restructuring of plant frame i.e. genetic architecture and recombination of different attributes appear to be of paramount importance. Without the proper knowledge of available and existing genetic diversity, thorough understanding of plant frame and its function and genetic make up of the different characters of the plant, a real breakthrough is not possible.

Study on genetic variability,heritability and character association would be of paramount importance in framing the selection indices. Associationship among nodule characters, yield components and yield itself need to be unveiled to explore the possibility of keeping nodule characters as selection indices. Improved genotypes should have wide adaptability so that they can adjust genotypic or phenotypic state in response to transient fluctuations in environment and give high and stable yield for the concerned location and year.

In the present study, several cowpea genotypes were collected and grouped in different cultigroups. Different morpho-physiological, reproductive and nodule characters were examined to identify important green pod yield attributing characters. The genotypes were tested in five different environments accross the locations (New alluvial and Terai Agro-climatic zone of West Bengal) to evaluate their adaptability with a view to identify stable and high-yielding genotypes. Gene action condi-

tioning important green pod yield components were determined to formulate rational breeding programme. At the same time, nature and magnitude of heterosis for green pod yield and its components ~~was~~ were also examined.

CHAPTER-II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Legume vegetable crops are immensely important mainly because of their high protein content and symbiotic association-ship with *Rhizobium* bacteria for the fixation of atmospheric nitrogen. Of these crops, cowpea (*Vigna unguiculata* (L.) Walp.) play unique role in tropical and subtropical agriculture. Cowpea cultivars grown for the immature green pods and used as a vegetable are variously known as asparagus bean, snake bean and yard long bean and when grown for dry or immature seed as pulse, they are variously known as black-eye pea, kaffir pea,china pea and southern bean. It is one of the food legumes which is an important source of nutrients and provides high-quality, inexpensive protein to diets which are mainly based on cereal grains or starchy food. Protein concentration ranges from about 3-4% in green leaf, 4-5% in immature green pods, to 25-30% in mature seeds.

In this review, an attempt has been made to present a comprehensive and up-to-date work done in this crop to understand the yield attributing traits, root and nodule development, adaptability of genotypes, and genetics of quantitative traits.

2.1 Genetic variability and heritability

Burton (1952) suggested that genetic variability along with heritability should be considered for assessing the maximum

and accurate effect of selection. Studies on the variability using genetic parameters like genotypic coefficient of variation, heritability and genetic advance is essential for initiating an efficient breeding programme. The genotypic coefficient of variation helps to measure the range of genetic variability in the character and provides a measure to compare the genetic variability present in various characters, however, with the help of genotypic coefficient of variation alone the heritable variation can not be measured (Singh *et al.*, 1974). The concept of heritability is important to determine whether phenotypic differences observed among various individuals are due to genetic changes or due to the effect of environmental factors. Heritability helps to measure the value of selection for particular characters in various types of progenies and act as an index of transmissibility (Hayes *et al.*,1955). According to Lush (1940), heritability in broad-sense, is the ratio of total genetic variance to phenotypic variance. And in narrow-sense, it is the ratio of additive genetic variances to phenotypic variance(Robinson *et al.*,1949).

According to Dudley and Moll (1969), a plant breeding programme can be divided into three states viz.,(i) building up a pool of variable germplasm (ii) selection of superior individuals from the pool and (iii) utilization of selected individuals to evolve a superior variety. Estimates of genetic variances and heritability may be inevitable in all the three stages. There are

different ways to estimate heritability which include (i) parent off-spring regression (Fisher,1918; Lush,1940; Robinson *et al.*,1949) (ii) use of genetically uniform populations (Lush, 1948), (iii) use of F_2 and back cross progenies (Warner, 1952), (iv) modified parent off-spring regression (Frey and Horner, 1957), (v) constant parent regression (Griffing,1950), (vi) component analysis (Crumpacker and Allard,1962 and Verhalen and Murray,1969 only for F_2 generation) and estimates from combining ability variances (Kempthrone,1956).

Genetic advance or genetic gain is still a more useful estimate. Genetic advance is the improvement in performance of selected lines over the original population. Johnson *et al.* (1955) suggested that heritability estimate in combination with genetic advance would be more reliable than heritability alone for predicting the effect of selection. Genetic advance or genetic gain depends on (i) the amount of genetic variability, (ii) the magnitude of the masking effect of genetic diversity and (iii) the intensity of selection (Comstock and Robinson, 1952). According to Hanson (1961), heritability and genetic gain are complementary aspects, thus values of heritability can also be used for computing the expected genetic progress possible through selection.

Sahoo *et al.* (1971) observed wide genetic variability under three environmental conditions for vine length, pods per

plant and plant weight in cowpea. Aglibut (1956) and Pant *et al.* (1982) reported high heritability for maturity,pods per plant, pod length, seed size and seed shape. From a number of reports, plant height, days to 50% flowering, number of cluster per plant, number of pods per plant, pod length and breadth, number of seeds per pod, and 100-seed weight possessed high estimates of heritability (Thiyagarajan, 1989; Thiyagarajan *et al.*, 1989;Roquib and Patnaik,1990; Hazra, 1991). High genotypic coefficient of variation (G.C.V.) for pods per plants and yield per plant was reported by Singh and Mehndiratta (1969) and Trehan *et al.*(1970). Jana *etal* (1982) reported very high phenotypic coefficient of variation (P.C.V.) and also G.C.V. for pods per plant, pod yield per plant and moderate for pod length. Pandita *et al.*(1982) also reported that days to flower, plant height and yield per plant had high P.C.V. and G.C.V.. Patil and Baviskar (1987) found G.C.V. and P.C.V. were the highest for pod cluster per plant, pods per plant, seed yield per plant, and 100-seed weight but Sharma *et al.* (1988) found the highest G.C.V. for dry matter yield followed by plant height, pods per plant, seed weight and green pod yield. Significant variability in seed protein and some of the essential amino acids has been identified in cowpea acceessions (Bliss *et al.*,1973; Bliss, 1975; Hazra, 1991). Reports on heritability of various economic traits of cowpea have been presented in Table 1.

Table 1: Heritability estimates of various characters of cowpea

Broad-sense, Narrow-sense(N) heritability(%)	Characters	References
(1)	(2)	(3)
	Plant height	
45.3,29.6		Bapna and Joshi,1973
57.9		Veeraswamy *et al.*,1973
97.2		Lakshmi and Goud,1977
66.5		Tikka *et al.*,1977
51.0,13.9,5.9,41.8, 49.8		Erskine and Khan,1978
15.5		Kumar and Mishra,1981
	Branches per plant	
67.8		Thiyagarajan,1989
97.6		Thiyagarajan *et al.*,1989
High		Roquib and Patnaik,1990.
48.8,38.8		Bapna and Joshi,1973
15.0		Kheradnam and Niknejad,1974
40.3		Tikka *et al.*,1977
68.4		Angadi *et al.*,1978
68.8		Jana *et al.*,1982
95.2,93.2		Hazra,1991
50.2		Thaware *et al.*,1992
	Vine length	
82.0,84.9,77.0		Sahoo *et al.*,1971

(1)	(2)	(3)
99.07,98.28		Hazra,1991
	Peduncle length	
22.8		Trehan *et al.*,1970
	Cluster per plant	
98.9		Thyiyagarajan *et al.*,1989
	Days to flowering	
94.3,84.8		Bapna and Joshi,1973
60.5		Bordia *et al.*,1973
38.8,47.1		Tikka *et al.*,1976
95.1		Tikka *et al.*,1977
3.8,14.9,17.0		Erskine and Khan,1978
14.0 (N)		Mak and Yap,1980
44.9		Zaveri *et al.*,1980
88.7		Kumar and Mishra,1981
93.0		Jana *et al.*,1982
52.7(N)		Mishra *et al.*,1987
89.0		Thiyagarajan,1989
High		Roquib and Patnaik,1990
93.9,93.1		Hazra,1991
	Pods per plant	
41.9		Lakshmi and Goud,1977
94.5		Tikka *et al.*,1977
21.4		Trehan *et al.*,1970

(1)	(2)	(3)
44.6,51.5,47.0		Erskine and Khan,1978
13.0 (N)		Mak and Yap,1980
96.7		Jana *et al.*,1982
98.6		Thiyagarajan *et al.*,1989
97.5,97.9		Hazra,1991
	Pod length	
76.9		Bhowal,1976
95.4		Lakshmi and Goud,1977
7.3,20.9,4.8,33.7		Erskine and Khan,1978
70.0 (N)		Mak and Yap,1980
85.4		Jana *et al.*,1982
High		Roquib and Patnaik,1990
99.7,99.5		Hazra,1991
	Seeds per pod	
78.9,52.2		Bapna and Joshi,1973
24.0 (N)		Mak and Yap,1980
78.6		Jana *et al.*,1982
71.2		Thiyagarajan,1989
91.5,95.7		Hazra,1991
	100-seed weight	
98.9		Angadi *et al.*,1978
10.5 (N)		Mak and Yap,1980
97.9		Jana *et al.*,1982

(1)	(2)	(3)
3.3		Thiyagarajan,1989
99.5,99.7		Hazra,1991
	Pod yield per plant	
86.8		Chandrappa *et al.*,1974
80.0(N)		Mak and Yap,1980
94.5		Jana *et al.*,1982
46.9		Sharma *et al.*,1988
99.03,99.55		Hazra,1991

2.2 Character association

Estimation of correlations between various characters is very useful in any breeding programme because information obtained from correlation studies of these characters can be used as a criterion of selection for further improving yield (Liang *et al.*, 1969).

Yield is a complex character which is influenced greatly directly or indirectly by several other characters. Linear correlations between yield and various structural or growth components, because of the inter-relationships among the component themselves, can present a confusing picture. If the cause and effect relationship is well defined it is possible to represent the whole system of variables in the form of a diagram known

as path diagram which affords a much more realistic interpretation of characters involved. From the study of simple correlations, stepwise multiple regression and path coefficient analysis for determining relationship between yield and yield components in cowpea, Ogunbodede (1989) concluded that the path coefficient technique is more useful in establishing the direct and indirect relationships among many variables.

During the past decade there has been considerable interest in developing indirect selection schemes for increasing yield in cowpea. Successful application of such schemes for increasing yield is dependent upon the use of characters or yield components that are highly heritable, strongly correlated with yield and without strong negative correlations with other yield components. Character association in cowpea is reviewed below.

2.2.1 Pod yield and components

Pods per plant, pod length, and pod weight, seeds per pod and seed size emerged as the most important yield components in cowpea (Khan and Stoffella,1985; Hazra,1991).

Correlations between pod yield, protein yield, dry matter yield and their components were established and path analysis indicated that pod number per inflorescence (Ye and Zhang,1987) and pod weight (Hazra,1991) had greatest possitive direct effect on pod yield. Aryeetey and Laing (1973) observed

the correlations of yield per plant was negative with pod length but positive with other components. Pod number per plant was consistently correlated with yield. Gowda (1982) also emphasized the importance of pod per plant as major yield component. Green pod yield is highly and positively correlated with pods per plant, days to flowering, seeds per pod and plant height(Sharma *et al.*,1988). Jana *et al.* (1982) found pods per plant had the highest positive direct effect on pod yield. Oliveira *et al.*(1990) observed a high positive correlations between pod number per plant and seed production. For cowpea as a whole irrespective of the cultigroups, different reproductive characters such as flower weight, length of ovary, pod number per plant, pod weight, and 100-seed weight were important pod yield components (Hazra,1991). Singh *et al.* (1993) found that number of pods per plant and seeds per pod in the presence of phosphorus and number of pods per plant, days to maturity and plant height under phosphorus stress may be used for the selection of high yielding genotypes.

2.2.2 Yield and growth

Tomer and Verma (1989) observed significant and positive phenotypic correlation between seedling dry weight and seed yield per plant. Ogunbodede (1985) found that growth rate between 9 and 13 days after planting was negatively correlated with seeds per pod while growth rate between 21 and 25 days after planting

was positively correlated with yield . Pandey *etal.*(1981) reported the positive correlationship between pods per plant, cummulative growth rate, and relative growth rate. Natarajaratnam and Balakrishnan (1986) found that high yielding genotypes showed higher total dry matter production and had a longer pod filling period than low yielding entries. Hazra *et al.* (1992) recorded area of primary leaves and leaf dry weight were significantly and positively correlated with green pod yield. Their direct effects on yield were also high and positive.

2.2.3 Yield and quality

Mak and Yap (1980) stated that high seed protein content associated with low yielding genoypes. Associationship between yield and percent protein was insignificant and negative (Chauhan and Joshi,1980), significant and negative (Hazra, 1991) in nature and the direct effect of percent protein on yield was also negative (Chauhan and Joshi,1980). Bliss *et al.* (1973) found genotypic and phenotypic correlation of yield with protein and methionine content of seed was strongly negative. They also found out the low heritability for protein, cystine, tryptophan and moderate heritability for methionine. Although a negative correlation generally existed between yield and crude protein percentage, enough variation occured to select plants that combined relatively high yield with relatively high percentage of crude protein. Thus both yield and protein content might be increased

simultaneously . However, Som and Hazra (1993) opined that segregates with high pod yield combined with high seed protein content appeared unlikely.

2.3 Nodulation

Most of legumes are capable of fixing atmospheric nitrogen through the association of bacteria which they harbour in their root nodules. These legumes nevertheless can absorb and assimilate soluble nitrogenous compounds present in the soil or supplied as fertilizers or manures through their root system directly. The successive stages begining from the entry of the bacteria to the host-root, the formation and maturity of nodules and fixation of atmospheric nitrogen constitute a complex system indicating a rather specific relationship, between the host plant and the rhizobial strain. This symbiotic relationship again is an outstanding illustration of the subtle adjustment of the symbiosis with the distinctive and changing environmental factors to which they are constantly expressed.

Biological nitrogen fixation in cowpea is a process whereby *Rhizobium* sp. in association with the host plant, reduce free nitrogen from the soil air to a form usuable by the plant. Not all the nitrogen fixed by the bacteria is made available to the host plant for its use. Nitrogen may pass into soil by excretion, by sloughing off of the roots especially their

nodules, or by the decomposition of the cowpea plant at the end of the season. Thus,crops grown in association with cowpea or succeeding crops may benefit from the fixed nitrogen.

2.3.1 Mechanism of symbiotic nitrogen fixation

The actual site of nitrogen fixation is in the nodules formed on the roots of the legume plant. The accumulation of soil bacteria in the viscinity of plant roots is a common observance. This most likely because of the secretion of certain growth factors into the soil by the plant roots. The bacteria, then either penetrate the relatively soft root hair tip or invade damaged or broken root hairs and progress in an infection thread through the cortex tissue. Cell division commence in this area and the nodule grows rapidly.

During infection the most important aspect is the process of binding of *Rhizobium* cells at the tips of the root hair. One of the most important hypothesis to explain this binding has been formulated by Dazzo and Hubbell (1975) in which a possible role of lectins was postulated. Lectins or phyto haemagglutinins are proteins with sugar binding properties which can bind to surface polysaccharides of erythrosides and other cells that they are agglutinated. The observation by Pweppke *et al.* (1982) that corn mutant which have lost the property to form lectins still are normally infected by *Rhizobium* certainly con-

tradict the general validity of the lectin hypothesis. But Quispel and Leiden (1982) has indicated that not only the plant but bacteria as well may synthesize lectin like molecules. So no definite conclusion can be made about the mechanism of *Rhizobium* bindings to the root hairs.

The binding of *Rhizobium* to the root hairs is of no importance if this binding does not stimulate the next step in the infection process. These next steps consist of a curling of the root hair tip in such a way that the *Rhizobium* cells are trapped between the root hair cell walls. As a consequence the subsequent invagination of the cell wall originates from this point. In this way an infection thread is formed which grows centripetally down into cortex, consisting of a musilageous centre with multiplying bacterial cells and surrounded by a cell wall deposit from the plant (Quispel,1982).

2.3.2 Nitrogen and nodulation

Nitrogen is generally concentrated in the leaves during vegetative growth, becoming localized in the seed towards the end of the vegetative period (Jacquinot, 1967). It has been reported (Sellschop,1962) that in field situations seed inoculation with *Rhizobium* is seldom necessary, as strain capable of causing infection are indigenous to the soils in cowpea growing areas. However, much more research is needed into cowpea/*Rhizo*-

bium symbiosis since the indigenous strains may not be the most efficient in N fixation (Summerfield *et al.*,1974). Indeed, the introduction of new *Rhizobium* strains into India has increased the seed yield of certain varieties of cowpea by over 100% compared with plants infected by indigenous strains (Anonymous, 1971). Nodule production of cowpeas in Malaya was trebled by mulching and significantly increased by watering, but was decreased by repeated cultivation (Masefield,1957).

The degree and effectiveness of nodulation is influenced by environmental conditions. Nodulation is generally increased as soil moisture availability increases (Doku,1970 and Masefield,1957), by application of P (Tewari, 1965b), by mulching (Masefield,1957 and Terada, 1971)), by low nitrogen during early seedling growth (Dart and Mercer, 1965; Ezedinma,1964; Pate and Dart, 1961) and in totally self-pollinated cultivars (Doku,1970). Nodulation is also influenced by photoperiod and is decreased by photoperiod of 16 hour, even when water is not limiting (Doku, 1970).

An estimate of the amount of N fixed annually by cowpea is given as between 73 and 240 kg/ha (Nutman,1971) and more than 150 kg N/ha and supply 80-90% of the host plant nitrogen requirement. (Eaglesham *et al.*, 1977 and Summerfield *et al.*, 1977a). On low nitrogen soils (<15 kg/ha), the benefits in seed yield derived from *Rhizobium* inoculation compared with non inoculation

were equivalent to atleast 100 kg/ha of fertilizer nitrogen (Miller and Fernandez,1985).

2.3.3 Crop growth and nodulation

Pulse crops are generally examined for nodulation at pre-flowering stage around 40 days in experimental trials (Anonymous,1986), sampling and comparison of nodulation of crops of different stages pose a problem. It was reported that nodulation in green gram was the highest at pre-flowering stage i.e. 10 days before flowering stage (Shanmugam and SreeRangasamy,1981). However, Narayana and Gothwal (1954) reported that nodules close to soil surface degenerated in 32 days in black gram with an increase in their numbers in the secondary and tartiary roots. Most of these pulses are nodulated by the cowpea miscellany group. *Rhizobium* sp, however exists a wide variation in the extent of nodulation in one and the same area.

Under field conditions nodule initiation was observed in all these pulses on 10th day after sowing i.e. within 5 days after emergence. However, detachable nodules (i.e. sizeable nodules) could be observed only after 15 days of sowing in cowpea (AnthoniRaj *et al.*,1989; Pawar and Ghulghule, 1980). In general, both the nodule number and dry weight of nodule increased upto 45-55 days after which they declined (AnthoniRaj *et al.*,1989). They also noticed that plant dry weight on the otherhand in-

creased very slowly in the initial stages and gained a momentum at peak nodulation stage suggesting the favourable effect due to nodulation. Patil and Shinde (1980) reported that the decrease in nodule number was more pronounced towards maturity in all varieties of gram. Shanmugam and SreeRangasamy (1981) also reported maximum number of nodules at pre-flowering stage followed by peak flowering stage with a minimum in the pod initiation stage in green gram. However, this may be subjected to variation due to environmental factors as these influence nodulation greatly.

Significant response of leguminous crops to *Rhizobium* inoculation has been reported by many workers (Bajpai *et al.*, 1975; Patil and Gita Nilakantan, 1977). Nodule number recorded for different strains under field conditions did not show significant correlation with grain yield (Schiffmann and Lobel,1973; Bagyaraj and Hegde,1978; Sivaprasad and Shivappashetty,1980). Similarly, there was no significant correlation between nodule number and nitrogen content in cowpea by *Rhizobium* inoculation (Shivaprasad and Shivappashetty, 1980; Beena *et al.*, 1990). On the otherhand, there was a significant correlation between nodule weight per plant and nodule number, shoot weight, shoot and root dry weight (Thompson and Dennis,1976; Pandey *et al.*, 1981). In a field trial of diallel cross of 5 varieties , Miller *et al.* (1986) reported that there were positive and significant correlations between nitrogenase activity and both nodule weight and

nodule number.

Shivaprasad and Shivappashetty (1980) opined that the leghaemoglobin content of nodules, plant dry weight and grain yield of inoculated plant can alone be taken as reliable indices for comparing the effectiveness of *Rhizobium* culture.

2.4 Adaptability analysis

It has long been known that some varieties of the crop are widely adapted whereas others are not so well. Adaptation is the property of a genotype that permits its survival under selection while adaptability is the property of a genotype or a population of genotypes which permit subsequent alteration of the norms of adaptation in response to changed selection pressure (Simmonds,1962). Wild populations of plants and animals, therefore, display a series of compromises depending upon the present ecological circumstances and past evolutionary history (Mather, 1943). These compromises essentially depend upon the adjustment of recombination so that the advantages of close adaptation and disadvantages of the concomitant restriction of variability are balanced.

2.4.1 Measures of adaptation

The phenotype has been conveniently defined as a linear function of the genotype, environment and interaction

between the two. Interaction will be absent when all genotypes behave consistently in all environments or in other words, their ranking does not change when subjected to varying environments. These interactions are usually present whether the materials are pure lines or crosses and present an intractable problem to the plant breeder (Warren,1955) as these interaction reduce progress from selection (Comstock and Moll,1963).

Plant breeders have been aware of genetic differences in adaptability among different varieties but were unable to exploit them fully largely due to lack of precise techniques to quantify the adaptability itself or the complexities of natural environment (Finlay and Wilkinson,1963).

The works of various scientists namely Immer and Powers (1934); Salmon (1951); Horner and Frey (1957) and Sandison and Bartlett (1958) reflected that variety x location and variety x season interactions were the basic estimate of adaptability. But they failed to give an adequate account of the dynamic response of the varieties to various environments. The technique also lack accuracy, and hard to employ as large number of genotypes were being tested.

Plaisted and Paterson (1959) described a procedure to characterise the stability of performance of several varieties. A combined ANOVA over all locations was fitted for each pair of

genotypes and an estimate (mean of σ^2_{ve}) obtained for each variety. The variety with smallest mean of (σ^2_{ve}) was considered as most suitable. The technique becomes most cumbersome with increase in number of varieties calling for n(n-1)/2 analyses.

Yates and Cochran (1938) subdivided the genotype x environment interaction into linear and non-linear partitions. In an attempt to bridge the afore-mentioned gap, Finlay and Wilkinson (1963) described a technique for measuring adaptation in variable environments and used it to identify and describe the environmental response of a range of different barley genotypes. For each variety a linear regression of yield on the mean yield of all varieties for each site and season was computed to measure varietal adaptation.

Stability does not imply general constancy of phenotype in varying environments. It implies stability in those aspects of phenotype,especially yield and quality, that are important economically. A variety which can adjust its genotypic or phenotypic state in response to transient fluctuations in environment in such ways that it gives high and stable economic return for the place and year can be termed "well-buffered"(Allard and Bradshaw, 1964).

Morishima and Oka (1975) predicted the general adaptability of crop plants under varying environments from the mean

performance in yield.

Eberhart and Russell (1966) described a model for stability parameters which may be used to describe the performance of a variety over a wide range of environments. The model was $Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$ where, Y_{ij} is the variety mean of the ith variety at the jth environment (i = 1,2,....,v; j = 1, 2, ...,n), μ_i is the mean of the ith variety over all environments, β_i is the regression coefficient that measures the response of the ith variety to varying environments, δ_{ij} is the deviation from regression of the ith variety at the jth environment and I_j is the environmental index obtained as the mean of all varieties at the jth environment minus the grand mean. They reported that varieties with b_i <1.0 usually had below average yields and therefore defined $b_i = 1.0$ and $S^2_{di} = 0$ to be the desirable criteria for stability. This method for comparing adaptability of different varieties has been used by Gupta (1969) in tobacco, Matsuo, *et al.*(1972) in rice, Joppa *et al.* (1971) in wheat; Singh and Meigo (1981), kandalkar and Sanghi (1982), Sanghi and kandalkar (1983), Ranganatha (1983), Kandaswamy *et al*(1985), Jindal and SatyaVir (1985),Okafor (1986), Sulochana and Peter (1987), Thiyagarajan and Rajasekharan (1989), Nandanwar and Patil (1990), and Birari *et al.* (1993) in cowpea.

2.4.2 Adaptability studies in cowpea

Information on the genotype x environment interaction and stability parameters in vegetable cowpea *Vigna unguiculata* (L.) Walp. subsp. *sesquipedalis* is very limited. Adaptation of cowpea to different environments was associated with several differences in developmental processes (Lush *et al.*,1980). They investigated that the timing of all developmental stages depended on environmental conditions: temperature and soil water status influenced the softening of hard seeds and their rates of germination; day length determined the time of flowering; the vapour pressure deficit in the atmosphere surrounding mature pods controlled the release of seeds.

Miranda *et al.* (1979) examined 50 varieties grown at four locations in Pernam Buco State of N.E.Brazil. They concluded that the bushy varieties, in general, were the most stable than the trailing one and the genetic variability for phenotypic stability among cultivars varied directly with yield with a correlation coefficient of r= 0.83.

Singh and Meigo (1981) evaluated twelve promising varieties at several locations in Tanzania with an object of indentifying potential genotyps with stability for seed yield and component characters.

From a number of reports, stability of pods per plant, 100-seed weight, cluster per plant contributed significantly to stability of yield (Ranganatha,1983; Sanghi and Kandalkar, 1983; Kandaswamy *et al.*,1985). The suitability of regression and genotype grouping methods to evaluate yield stability in segregating population of cowpea was determined by Ntare and Akenova (1985) in F_3 and F_5 lines and bulks from 18 crosses grown in four different environments in Nigeria and Upper Volta. They reported that the genotype grouping method would be most useful when a large number of genotypes are evaluated. The yields of F_3 lines and F_5 lines were well correlated (r=0.64) but the mean yield of F_3 bulks and F_5 lines and bulks were not. They concluded that the selection for adaptability in early generations in cowpea was possible.

Brolmann and Stoffella (1986) reported that the cultivar with a regression coefficient <1.0 for seed yield, biological yield and seed weight per plant was considered stable and adaptable to both favourable and unfavourable environments.

Similarly, an attempt was made by Sulochana and Peter (1987) to identify vegetable types suited for high and low yielding environments. They defined an average stable variety as one with high mean, regression tending to 1.0 and deviation from regression tending to 0 and the variety could be recommended for all round cultivation under varying fertility levels whereas, the

variety with high mean and regression value more than 1.0 could be recommended for high-fertility locations and for cultivation among progressive farmers with access to inputs.

The information on the stability of yield and its components for the hybrids and parents in cowpea, for the development of stable genotypes was reported by Thiyagarajan and Rajasekharan (1989). They concluded that the hybrid and parents which were stable for all the characters, could effectively be exploited directly for evolving high yielding stable lines in cowpea.

Birari *et al.* (1993) opined that the significant linear component of genotype x environment interaction for flower initiation and maturity in genotypes indicated that predictability of crop duration was related to earliness in flowering and maturity. Absence of genotype x environment interaction and minimum yield performance of a genotype indicated that wider adaptability was associated with low grain yield. They also defined a stable genotype as one which showed good predictability for pods per plant, pod length, harvest index, and plant height.

2.5 Analysis of genetic architecture of green pod yield and its components

Recent development in quantitative genetics have led to formulation of a number of biometrical models for systematic

genetic analysis of metric traits. Application of statistics to biological problems was primarily initiated by Galton (1989) and continued by Pearson and Lee (1903). The study of quantitative characters in plants had it begining in the works of Johannsen (1909), Nilsson-Ehle (1909) and East (1916). The theoretical basis of quantitative genetic was established by Fisher (1918), Wright (1912) and Haldane (1932).

Extensive studies in biometrical genetics gained momentum as a result of concepts developed by Sprague and Tatum (1942), Comstock and Robinson (1948), Comstock *et al.* (1949) and Mather (1949). Various models, depending upon the various assumptions and material used have been formulated to estimate the genetic parameters. Among them 'diallel' (Jinks and Hayman,1953; Hayman,1954; Griffing,1956; Eberhart,1964; Gardner and Eberhart, 1966) technique has received considerable attention by geneticists and plant breeders as it enabled them to determine the genetic architecture of metric traits for exploitation in breeding programme.

2.5.1 Diallel analysis

Hull (1945), for the first time, considered some aspect of the method of analysing the data from diallel crosses of homozygous lines using regression technique and utilized the method for the estimation of dominance in maize. Yates (1947) defined

diallel crossing as a set of all possible matings among 'n' genotypes. The genotypes of diallel cross may be homozygous lines, varieties alone and so on. Generally, reciprocals are not included, assuming the maternal inheritance plays a minor role in the inheritance.

To develop the genetical properties of a group of homozygous lines, Jinks and Hayman (1953) and Jinks (1954, 1955 and 1956) developed an approach in the diallel methods following the idea of Mather (1949). Hayman (1954) further improved the method, suggested by Yates (1947) and constructed the analysis of variance table in diallel analysis to test additive and dominance variances, in absence of multiple alleles and reciprocal differences. Hayman and Mather (1955), Anderson and Kempthrone (1954), Hayman(1957,1958) Jinks and Jones (1958), Gardner and Eberhart (1966) and Cowghtry and Mather (1970) developed more refined models accounting for non-allelic gene interactions. Baker (1978) discussed the use of diallel analysis and the range of different assumptions. These methods are based on either first or second degree statistics.

2.5.2 Combining ability analysis

The fact that certain lines gave more desirable hybrids than others was established by East, Shull and Jones in the early part of this century. Sprague and Tatum (1942) and Henderson

(1952) have defined and applied the notations of general and specific combining ability to plant and animal experimental materials using various diallel crossing systems but without a precise and appreciably generalized genetic interpretation of combining ability effects and variances. Eisenhart (1947) with critical evaluation of certain assumptions underlying the analysis of variances has suggested two models depending upon the nature of problems and kind of population under investigation and those are: Model 1 (fixed effects) and Model 2 (random effects). The application of the fixed effect model is felt only when the treatment or variety comparisons are involved and the varieties are deliberately chosen on the basis of their promising performance from a random mating population and are deemed to be a fixed sample behaving itself as a whole population about which the valid inferences can be drawn. On the otherhand, the application of the random effect model is thought worthwhile when the experimental material is a random sample from a random mating population where all effects to be estimated are random variables except the population mean and the valid inference to be drawn not merely describe the sample but reflect the whole population from which the sample has been drawn. Griffing (1956a) has clearly defined the general and specific combining ability effects and variances and has elucidated this relationship to additive and non-additive genetic effects and variance. The general combining ability (gca) refers to average performance of

a line or lines in a series of hybrid combinations while specific combining ability (sca) is designated to cover those cases in which certain combinations do relatively better or worse as expected on the basis of average performance of the lines involved. General combining ability is basically due to additive effect of genes while specific combining abiliy is a consequence of intra-allelic interactions. Generally, in the breeding schemes what are most needed are additive and non-additive genetic effects of individual lines and crosses derived from them to ascertain the genetic potential with respect to kinds of genes assembled in them for further exploitation. Griffing's combining ability analysis is quite an efficient approach in fulfilling these requirements in orienting any breeding programme. A great advantage of this method is that it is not encumbered with fulfilment of many assumptions.

2.5.3 Inheritance of quantitative characters

Information on the inheritance of a character would indicate the ease or difficulty with which the character could be introduced into breeding lines (Ojomo,1971). Review on the inheritance of different characters of cowpea is presented below.

2.5.3.1 Growth habit

It was reported that a single gene designated as T determines climbing characteristic (Brittingham,1950; Krutman *et*

al., 1975; Premsekar and Raman,1972). Norton (1961) and Kolhe (1970) concluded that vining characteristic is governed by two duplicated genes, but Singh and Jindla (1971) observed that the trailing growth habit is conditioned by two complementary genes and one independent gene. The gene symbols they proposed T-1 and T-2 for the complementary dominant factor and T-3 for the independent factor.

2.5.3.2 Flowering and maturity

Earliness is measured by such criteria as days to flowering or days to maturity. Early maturity is dominant or partially dominant over late maturity (Mak and Yap, 1977; Ojomo,1971). Several authors concluded the main genetic variation was due to additive gene action (Kheradnam and Niknejad, 1971; Mak and Yap,1977), but Singh and Dabas (1986) reported that non-additive gene action played major part in the inheritance.

2.5.3.3 Pod number per plant

Aryeetey and Laing (1973) speculated that gene action for the trait of pod number per plant was primarily additive but Singh and Dabas (1986) and Hazra (1991) concluded that non-additive gene action played a major role in the inheritance of this trait. Significant effects of both the additive and non-additive components were observed by Singh and Dabas (1992).

2.5.3.4 Pod length

Long pod is usually dominant or partially dominant over short pod (Aryeetey and Laing, 1973; Jindal and Singh,1970). On the otherhand there are reports of short pod being partially dominant over long pod (Bhowal,1976; Hazra,1991; Leliji,1975). Both additive and non-additive gene action are important for the trait (Hazra,1991; Patil and Shete,1986; Singh and Jain,1972). The extreme parental short and long pods were not recovered in the F_2 of a Biflora x Sesquipedalis cross, but parental short pods were recovered in the F_2 of an Unguiculata x Sesquipedalis cross (Hazra *et al.*,1993).

2.5.3.5 Pod weight

Light pod is partially dominant over heavy pod and additive gene action is predominant for this trait (Hazra *et al.*,1994).

2.5.3.6 Seed weight

Partial dominance for small seeds and predominance of additive gene action played a major role in the inheritance of seed weight (Mak and Yap,1980; Patil and Bhapkar, 1986; Singh and Dabas,1986).

2.5.3.7 Seed number per pod

Higher seed number per pod is partially dominant over small number per pod (Roy and Richharia,1948; Aryeetey and Laing, 1973). On the otherhand, Leliji (1975) concluded that a small seed number per pod is partially dominant over a larger amount. Singh and Jain (1972) and Imrie and Bray (1983) reported that sca and not gca is important. On the otherhand, Kheradnam and Niknejad (1971), concluded that both gca and sca were important. Similarly, Mak and Yap (1980) suggested that both additive and dominance effects were responsible for the variation in this trait. Drabo *et al.* (1984) reported that additive, dominance and epistatic effects were important and were of similar magnitude. Ogunbodede and Fatunla (1986) reported that the involvement of trigenic epistasis, linkage or both in the inheritance in one cross and importance of epistasis and additive effects than dominance in other cross.

2.5.3.8 Yield

The yields of both reproductive and vegetative portion are moderately heritable under most environmental condition (Fery,1985). Singh and Dabas (1986) concluded that non-additive gene effect played a major part, but Hazra (1991) reported that additive gene effect played a major role in the inheritance of pod yield. Mak and Yap (1980) speculated that there was a general

trend that low-yielding parents carried more recessive genes and high-yielding parents carried more dominant genes.

2.5.3.9 Nitrogen fixation

Nitrogen fixation in cowpea controlled by several quantitatively inherited genes (Zary,1980). Nitrogenase activity, secondary root nodule weight, and number are predominantly under the control of additive gene action (Dayap and Rasco,1988). Miller *et al.* (1986) indicated that breeding for enhanced biological nitrogen fixation can be accomplished by improving nodule number and nitrogenase activity.

2.5.4 Hybridization and technique

Cowpea is highly self-pollinated except for limited outcrossing observed occassionally in humid climates (Rachie and Silvestre,1977). Only 10 per cent outcrossing may occur when the activity of pollinating insects is high (Rachie and Roberts, 1974). All four cultigroups of the subspecies *unguiculata* and the varieties of the subspecies *dekindtiana* are interfertile, although hybridization between var.*protracta* and the cultivated subspecies has not been attempted (Evans,1976; Rachie and Rawal,1976). The cowpea could not be hybridized with any other *Vigna* or *Phaseolous* species (Singh *et al.*, 1964; Ballon and York,1959). However, Hazra (1991) noted conspicuous differences in crossability between the cultigroups. Whenever Sesquipedalis

genotypes were involved in the cross either with Unguiculata or Biflora genotypes, the crossing success was less, and the influence of genotype on crossing success was pronounced.

Roy and Richharia (1948) faced great difficulty in a hybridization programme between *V. sinensis* (cv-gr. Unguiculata) and *V. sinensis* subsp. *sesquipedalis* (cv-gr. Sesquipedalis) and in the cross with cv-gr. Sesquipedalis as female parent only one succeeded following cross pollinating 250 flowers. Mishra *et al.* (1985) reported 0-30% crossing success and inferred the significance of male parent in hybrid pod set. A very low percentage of crossing success (6-12%) and simultaneous production of more undeveloped seeds was also observed by Capinpin and Irabagon (1950).

Crossability in cowpea is, in general poor (Hazra,1991; Lush,1979; Rawal,1975), and many reasons for poor crossing success are proposed from the histological and cytological points of view (Ojomo, 1971; Smartt, 1985). Sensitivity of cowpea flowers and their disturbance or injury was also reported by Krishnaswamy *et al.*(1945). High pollen fertility was recorded in the cultigroups, but pollen germination was generally poor, indicating some restrictions at pre-fertilization stage which may be one of the major cause of poor crossing success (Hazra *et al.*,1990).

Cowpea flowers open only once, generally before dawn

(4.30-5.00 a.m.), and most of them shut by noon, with sporadic flower opening to a minor extent in the afternoon (Hazra *et al.*,1990). Anthers do not dehisce simultaneously with the anthesis, rather anther dehiscence occurs between 8 p.m. and 10 p.m. The highest successful hybridization was achieved by emasculating flower buds of 11-13 mm long 12-15 hours before flower opening (Ebong,1972) and the most suitable pollination time was upto 7 a.m. (Hazra *et al.*,1990).

In self pollination of *Vigna sesquipedalis* (cv-gr. Sesquipedalis) it takes 6 hours time to effect fertilization through the style of 11mm length (Ballon and York,1959). So desication of stigmatic surface and style in this time of fertilization process may cause great harm to pod set. Krishnaswamy *et al.*(1945) suggested protection of the emasculated and the next day pollinated bud from desication with the help of a folded leaf let. Sen and Bhowal (1961) recommended an oil paper bag (2" x 2" size) suitable for bagging the flowers.

2.5.5 Heterosis

Heterosis breeding is here to stay as a potent genetic tool for exploiting the predominantly non-additive gene action. Hybrid vigour in artificial plant hybrids was first studied by Kolreuter in 1763 (cited by East and Hays, 1912). Since that time it has continued to be a problem of interest to the student of

fundamental genetics and to plant and animal breeders who utilize hybrid vigour in a planned programme of plant and animal improvement. Jinks (1955) suggested that non-allelic interaction might be a cause of heterosis rather than the special relation between genes at the same locus. Mather (1955) considered heterosis as an expression of genetic balance which might vary with the breeding behaviour of species. Jinks and Jones (1958) opined that heterosis was a complex genetical phenomenon depending upon the balance of additive action, dominance and interaction of homozygous/heterozygous components as well as on the distribution of the genes in the parental lines. Daskalov (1963) concluded that heterosis of F_1 was the combined expression of genetical cytoplasmic and physiological factors and might be attributed to stimulation resulting from the interaction of different heritable factors of the parents in the F_1. Several investigations (Allard, 1956; Hayman,1963; Jinks and Jones,1958; Kempthrone, 1956; Eberhart, 1964) have related heterosis with epistasis.

Hybrid vigour in cowpea, as in other crops, is dependent on the specific parents used in hybrid combination. A very limited work has been done in cowpea to study heterosis for pod yield and its components. Some hybrids exhibit marked pod yield increase over the parents (Hazra *et al.*, 1993; Mak and Yap, 1977). Among the pod yield components, manifestation of heterosis for pod number per plant, pod length, and seed weight was

also reported (Agble, 1972; Hazra *et al.*,1993). When actual heterosis was considered against the corresponding genetic divergence was not found owing to balancing or even cancellation of various components of heterosis (Hazra,1991). Hazra *et al.* (1993) suggested that genetic divergence of the parents should be considered along with the specific combining effects of the crosses to get maximum heterosis in cowpea. Mak and Yap (1977) and Hazra (1991) studied seed protein content of the F_1 hybrids but were unable to demonstrate encouraging results. In this situation enhancement of protein yield per plant through the increase in yield should be given priority keeping seed protein content within average limit (Som and Hazra,1993) and heterosis breeding for protein should concentrate on the sulphur-containing amino acids (Boulter,1976).

Heterosis has also been exhibited for a number of other traits in cowpea. Hofman (1926) reported heterosis for plant height and stem diameter. Premsekar and Raman (1972) observed heterosis for branch length and both leaf width and length. Erskine and Khan (1978) and Tikka *et al.* (1976) reported heterosis for earliness. Heterosis for stomatal frequency has also been reported (Hazra *et al.*, 1988).

2.5.6 Vegetable cowpea breeding in India

Through selection from exotic collections and hybridi-

zation, some useful cultivars have been developed in India. Work on selection from exotic accessions and further improvement through breeding for vegetable cowpeas was initiated during the 1940s by Late Dr.H.B.Singh and his colleagues, at the I.A.R.I. , New Delhi (cited by Patel and Singh, 1984). Singh (1950) reported the trial of cowpea variety EC-455 which was introduced from Philippines where it was used extensively for fresh vegetable purpose. Through planned hybridization (diallel selective mating, multiple crossing, back crosses and convergent backcrosses) and selection from the segregating generations in epiphytotic conditions, breeding lines such as C-152, C-20, C-288, C-30, C-28, EC-42716, UPC-5286 have been developed in India (Mishra *et al.*,1985). The cultivar Pusa Phalguni was selected from the Canadian cultivar Dolique Do Tonkin, whereas the cultivar Pusa Barsati, was selected from a collection from the Philippines (Singh and Sikka,1955). Later Pusa Dofasli, a photoperiod insensitive variety, was developed from a cross Pusa Phalguni x Philippines selection at I.A.R.I., New Delhi (Singh *et al.*,1968). Besides this, several photoinsensitive vegetable cowpea breeding lines like Red Seeded,Brown Seeded (Rituraj), Aseem,P460-1-1 and P85-2/9E(A) have been developed (Singh *et al.*,1974; Mitalet *al.*,1980). Mital *et al.*(1980) indicated that EC-42712(K632),EC-30040 (Mesocarpa),EC-43128(K642) and EC-26410(SE 1436) offered a combination of three desirable characteristics-photoinsensitivity, long pods and earliness. Photoinsensitivity is desirable to

fit the new varieties in multiple cropping patterns and varieties such as C-152, Pusa Phalguni, Pusa Dofasli, Rituraj and Cherodi fit well into such systems and can be successfully cultivated during summer-spring as a catch crop (Jain, 1981). Photosensitive and bacterial blight resistant vegetable cowpea variety, Pusa Komal has also been developed by Patel and Singh (1984) and later Patel and Hall (1986) reported that these breeding lines originally developed for growing under hot and long day condition of North India performed well in the U.S.A. and yielded to the tune of 25-28 tonnes of green pods per hectare. A high yielding vegetable type IIHR-61B has also been developed by Neema *et al.* (1991). Very recently, Lal and Singh (1993) developed a cultivar Cowpea 263 which is a selection from Bangalore local, suitable for growing in both spring and the rainy seasons and a built-in ability to overcome the incidence of mosaic virus and anthracnose to a greater extent than the existing cultivars. Trials have also been conducted on newly developed vegetable cowpea varieties,like Sel-2-1,VS-389, BCS-1,IIHR Sel-11 and IIHR Sel-16 at different centres namely, P.D.V.R., Hesserghatta, Sabour,Ambajogai, Bhubaneswar, Faizabad, Vellanikkara and Dapoli under the All India Co-ordinated Vegetable Improvement Project (Anonymous,1993-1994).

Vegetable cowpea breeding in West Bengal has been started in the Department of Horticulture, B.C.K.V.,by Prof.M.G.Som and his associates in 1986. Combination of determi-

nate growth habit and synchronous pod bearing of cultigroup Biflora and Unguiculata with the pod length and succulence of cultigroup Sesquipedalis has been proposed (Hazra *et al.*,1993). A modified backcross-pedigree method has also been proposed for developing such ideotypes (erect/semierect plant having synchrony in pod bearing and medium-long succulent pod) by combining genotypes of cultigroup Biflora/ Unguiculata and Sesquipedalis (Som and Hazra,1993). At present some of the promising lines and segregates are at the final stage of selection.

CHAPTER-III

MATERIALS AND METHODS

MATERIALS AND METHODS

Four different experimental approaches were followed under the present research programme. The field trials were carried out at District Seed Farm (A & B Block), Kalyani, B.C.K.V. and at Regional Research Station, Terai zone, B.C.K.V., N.B. Campus, Pundibari, Coochbehar over a period of 3 years. All related laboratory works like estimation of protein were done at the vegetable laboratory, Department of Horticulture, B.C.K.V., Mohanpur. However, estimation of leghaemoglobin in the nodules were carried out at Nodule Research Laboratory, B.C.K.V.,Mohanpur.

Twenty five diverse genotypes of cowpea belonging to three cultigroups were assembled from different parts of India and abroad. These materials were used to execute different experimental approaches. First, the study was conducted to determine the extent of genetic variability of the materials, heritability of the important pod yield components and associationship among the yield components. The second was involved in the study of different root and nodule characters. The third approach was based on testing the phenotypic stability of the genotypes in different sets of environments and across locations. The fourth approach aimed at understanding the gene action for pod yield and its important components. Finally, the extent and magnitude of heterosis for different pod yield components was examined.

3.1 Study on genetic variability and character associationship

3.1.1 Materials

Twenty genotypes of cowpea belonging to two cultigroups namely, Unguiculata and Sesquipedalis were employed in this study. A brief description is given in Table 2.

Table 2. Characteristic features of cowpea genotypes used as experimental material in all environments

GENOTYPES/ VARIETIES (1)	SOURCE (2)	CHARACTERISTIC FEATURES (3)
Pusa Barsati	I.A.R.I., New Delhi	Plants are viny, pigmentation present between stipel, at the base of leaf stalk and at the base of primary branches.Flower colour-standard is white and wing is light purple, pods are medium-sized,tender,non fleshy, semi-pendant and light (yellow-ish) green coloured. Seeds are elongated, reniform and seed coat is creamy white with brown blotch.
Pusa Dofasli	I.A.R.I., New Delhi	Plants are semierect and bushy, pigmentation present between stipel,at the base of primary branches and at the base of midribs of leaflet. Flower co-lour - both standard and wing are purple. Pods are medium-sized,tender,non fleshy semipe-ndant and light(yellowish)green coloured. Seeds are small,flat and seed coat is dark tan.
Sel-Tml	Department of Horticulture, B.C.K.V., Mohanpur,Nadia.	Plants are viny, pigmentation present between stipel and at the base of primary branches. Flower colour-both standard and wing are light purple. Pods are

(1)	(2)	(3)
		medium-long,tender,fleshy,pendant and light green coloured with red beak, elongated reniform seeds and seed coat is black coloured.
Sel-Tm2	Department of Horticulture, B.C.K.V., Mohanpur,Nadia.	Plants are viny, pigmentation present between stipel, at the base of leaf stalk, at the base of primary branches and at the base of midribs of leaflets. Flower colour-both standard and wing are deep purple. Pods are medium-long,tender,fleshy,pendant and light green coloured. Seeds are elongated, reniform with dark tan seed coat.
Sel-Tm3	-do-	Plants are viny, pigmentation present between stipel and at the base of primary branches. Flower colour-both standard and wing are deep purple. Pods are long,tender,fleshy, pendant and light green coloured with red beak.Seeds are elongated, reniform with dark black seed coat.
Arka Garima	I.I.H.R., Bangalore.	Plants are semierect and bushy, pigmentation present between stipel and at the base of primary branches. Flower colour-standard is light purple and wing is deep purple. Pods are medium-sized, fleshy, nonpendant and creamy (yellowish) white.Seeds are elongated,reniform with biscuit coloured seed coat.
Sel-Tm4	Department of Horticulture, B.C.K.V., Mohanpur,Nadia	Plants are semierect and bushy. Pigmentation present only at the base of primary branches. Flower colour-both standard and wing are light purple. Pods are medium-sized, fleshy,nonpendant fade brown seed coat.

(1)	(2)	(3)
EC-305827	N.B.P.G.R.; New Delhi	Plants are viny, pigmentation present between stipel, at the base of primary branches,and at the base of midribs of leaflet. Flower colour-both standard and wing are light purple. Pods are very long,tender,fleshy,pendant and deep green coloured with red beak. Seeds are elongated, reniform with reddish brown seed coat.
EC-243954	N.B.P.G.R.; New Delhi.	Plants are semierect, dwarf, and bushy, pigmentation present between stipel and at the base of primary branches. Flower colour-standard is creamy white and wing is white. Pods are medium-sized, somewhat tough, inflated,fleshy,non pendant,and creamy white coloured.Seeds are somewhat bold and seed coat is creamy white with biscuit eye.
5269	Pulse and Oil-seed Research Station, Baharampur,W.B.	Plants are somewhat erect. Pigmentation present between stipel, at the base of leaf stalk and at the base of primary branches. Flower colour-standard is creamy white and wing is light purple. Pods are medium-sized, tender,nonfleshy, nonpendant and deep green coloured. Seeds are somewhat bold and seed coat is creamy white with dark tan blotch.
1-101	-do-	Plants are somewhat erect,pigmentation present between stipel, at the base of primary branches and at the base of midribs of leaflet.Flower colour-both standard and wing are light purple. Pods are short- medium, tender, nonfleshy, nonpendant and light green coloured. Seeds are some-

(1)	(2)	(3)
		what bold with chocolate coloured seed coat.
T-2	Department of Horticulture, B.C.K.V., Mohanpur,Nadia.	Plants are somewhat viny, pigmentation present between stipel, at the base of leaf stalk, at the base of primary branches and at the base of midribs of leaflet.Flower colour-both standard and wing are deep purple. Pods are medium -sized, tender, non fleshy, non pendant and green coloured. Seeds are somewhat elongated, reniform and deep brown seed coat.
T-4	-do-	Plants are viny, pigmentation present between stipel, at the base of leaf stalk, at the base of primary branches and at the base of midribs of leaflet. Flower colour-both standard and wing are deep purple. Pods are medium-sized,tender,fleshy,non-pendant and fade green coloured with black suture. Seeds are somewhat elongated, reniform with fade brown coloured seed coat.
T-6	-do-	Plants are viny, pigmentation present between stipel, at the base of primary branches and at the base of midribs of leaflet.Flower colour-both standard and wing are light purple. Pods are medium-sized, tender, non fleshy, nonpendant, and light green coloured. Seeds are somewhat bold with chocolate coloured seed coat.
Local-1	-do-	Plants are viny, pigmentation present between stipel and at the base of primary branches.

(1)	(2)	(3)
		Flower colour-both standard and wing are deep purple. Pods are medium-long,tender,fleshy, pendant, and ligt green coloured with red beak.Seeds are elongated, reniform with deep black seed coat.
Local-4	Department of Horticulture, B.C.K.V., Mohanpur,Nadia.	Plants are somewhat viny, pigmentation present between stipel and at the base of primary branches.Flower colour-standard is white and wing is light purple. Pods are medium-sized,tender,non fleshy, non pendant,and creamy(yellowish)white coloured Seeds are elongated, reniform and seed coat is creamy white with brown blotch.
Local-9	-do-	Plants are viny, pigmentation present between stipel and at the base of primary branches. Flower colour-both standard and wing are light purple.Pods are medium-long,tender,fleshy,pendant and light green coloured with red beak. Seeds are elongated,reniform and seed coat is deep black.
Local-10	Sheorafully seed market, Hooghly,W.B.	Plants are viny, pigmentation present between stipel, at the base of leaf stalk,primary branches,midribs of leaflet and at internodal region.Flower colour-both standard and wing are light purple.Pods are medium-long,tender, fleshy, pendant and deep marrow coloured. Seeds are elongated, reniform with deep chocolate coloured seed coat.
Local-10A	Sheorafully seed market, Hooghly,W.B.	Plants are viny, pigmentation present between stipel, at the base of primary branches and

(1)	(2)	(3)
		midribs of leaflet. Flower colout-both standard and wing are deep purple. Pods are medium-long,tender,fleshy, pendant and light green coloured. Seeds are elongated, reniform with dark tan coloured seed coat.
Local-16	Madanpur seed market, Nadia,W.B.	Plants are viny, pigmentation present between stipel, at the base of primary branches and midribs of leaflet. Flower colour-both standard and wing are deep purple. Pods are long, tender,succulent,fleshy,pendant and yellowish white with red beak.Seeds are elongated, reniform with black coloured seed coat.
T-5	Department of Horticulture, B.C.K.V., Mohanpur, Nadia.	Plants are viny, pigmentation present between stipel and at the base of leaf stalk, primary branches,and midribs of leaflet Flower colour-standard and wing are deep purple.Pods are medium-sized,tender,fleshy,non-pendant and light green coloured. Seeds are somewhat elongated,reniform with dark tan seed coat.

3.1.2 Methods

The genotypes were grown following Randomized Block Design with three replications in two different environments as described below.

Environment	Sowing date	Location
E_1	17.04.1993	District Seed Farm (A & B Block),kalyani, B.C.K.V.
E_2	16.06.1993	-do-

Physico-chemical features of District Seed Farm (A & B Block) Kalyani, B.C.K.V. and meteorological data of the experimental periods were presented in Appendix I and II, respectively. A single row plot of 6 m length was alloted to each genotypes. The spacing between rows and plants were kept between 60 cm and 30 cm, respectively. Fertilizers were applied as basal at the rate of 20 kg N, 60 kg P_2O_5 and 40 kg K_2O in the form of urea, single super phosphate, and muriate of potash, respectively. The other cultural practices were followed in time as scheduled for its cultivation. The following observations were recorded from five randomly selected plants in each replication except the border plants.

i) Plant height (cm): Measurements were taken in centimeter at maturity from ground level to the tip of the main stem.

ii) Primary branches per plant: Total primary branches were counted in five plants and then averaged.

iii) Peduncle length (cm): Ten peduncles randomly selected from each randomly selected five plants were measured in centimeter and averaged.

iv) Days to flowering: It was the time span from date of sowing to date of first flowering.

v) Pod length (cm): Some pods were tagged at random in the five plants from the date of first pod setting. Ten pods each were taken per replication at random. Their length were measured in

centimeter and averaged.

vi) Green pod weight (g): The pods which were used for measuring pod length were also used to take pod weight in gram.

vii) Dry pod weight (g): Collected green pods were dried in electric oven at 45°C temperature for 48 hours and weights were taken in gram.

viii) Number of pods per plant: Total number of pods from the same five plants were counted and averaged.

ix) Number of seeds per pod: Total number of seeds from the same ten pods in each replication were counted and averaged.

x) 100-seed weight(g): Dry,well developed 100 seeds from five plants were taken at random and their weight were recorded in gram.

xi) Green pod yield per plant (g): Pod weight of the periodical harvest from five plants were taken and then averaged.

3.2 Study on the different root and nodule characters

3.2.1 Materials

Ten genotypes of cowpea namely,T-2,T-5,Sel-Tm3,Local-4,H.G-22,1-101,13-31B,Cherodi,Pusa Dofasli and EC-305827 comprising three cultigroups namely, Biflora,Unguiculata, and Sesquipedalis were selected on the basis of evaluation study with a view to include high-yielding genotypes under all the three cultigroups. A brief description of the genotypes has been given in Table 2 and 3.

3.2.2 Methods

The genotypes were grown following Randomized Block Design with three replications in two different environments as described below.

Environment	Sowing date	Location
E_1	2.03.1993.	Distric Seed Farm (A & B Block),kalyani, B.C.K.V.
E_2	9.11.1993	-do-

Physico-chemical features of District Seed Farm (A&B Block),Kalyani,B.C.K.V. and meteorological data of the experimental periods were presented in Appendix I and II, respectively. A triple row plot of 6 m length was alloted to each genotype. The spacing between rows and plants were kept between 100 cm and 30 cm, respectively. No fertilizers were applied. Irrigation and plant protection measures were provided as and when necessary. Observations were recorded at four stages i.e. pre-flowering stage (30DAS), flowering stage (40-50 DAS),post-flowering stage (60-70 DAS) and early pod setting stage (70-80 DAS). Days in different stages varied with the genotypes belonging to the three cultigroups. At each stage five plants were selected at random for each of the ten genotypes in each replication and uprooted carefully to study the following characters.

i) Fresh shoot weight (g): In each stage, the shoot weight was taken excluding the root portion from the collar region and were weighed in gram.

ii) Dry shoot weight (g): Fresh shoots were dried in electric oven at 45°C temperature for 48 hours and weights were taken in gram at all four stages.

iii) Root length (cm): It was the length of tap root from the collar region and were measured in centimeter at all the stages.

iv) Fresh root weight (g): The roots which were used for measuring root length were also used to take root weight in gram.

v) Nodule number per plant: Total number of nodules collected from tap roots and lateral roots were counted and averaged at all four stages.

vi) Fresh nodule weight (g): All the nodules per plant were weighed in gram with the help of electrical balance.

vii) Leghaemoglobin content of nodule (mg/g): It was carried out following the method of Bergersen (1980) in two stages,pre-flowering and early pod setting stage. Detail procedure are here under given.

Apparatus and reagents used:

Test tubes, mortar and pastle, electronic balance, marker pen,spectrophotometer,phosphate buffer solution (P.H.4) and a coloured reagent which was prepared by mixing 100 mg Benzidine and 0.5 ml H_2O_2 together and the volume was made upto 50 ml

by absolute alcohol.

Procedure:

a) Fresh nodules were collected from the sample plant. The nodules were washed with running tap water and after drying the water film on the nodules, 100 mg lots were weighed by electronic balance.

b) The 100 mg lots were then taken in the test tube filled with 4 ml of phosphate buffer. If crushing of the nodules could not be done immediately in test tubes containing the nodules in the phosphate buffer were kept in the refrigerator for next day's utilization.

c) The nodules and phosphate buffers were transferred in a mortar and pastle for thorough crushing and after doing so the materials were again returned to the test tube for keeping undisturbed upto 30 minutes.

d) The optical density (O.D.) of the material in the test tube was measured only by utilizing the clear liquid of the upper portion of the test tube. About 2 ml of the upper clear liquid was decanted to the measuring vial of the spectrophotometer and 2 ml of Benzidine colour reagent was mixed to it. After gentle shaking for thorough mixing, O.D. was recorded by using 660 μm wave length. Here the O.D. reading was directly expressed as mg leghaemoglobin content per 100 g of nodules.

viii) Protein content of the pod: Green immature pods of marketable maturity (12-15 days after anthesis) were utilized for the

estimation of protein following Micro-Kjeldahl distillation method (Jackson,1967b) at early pod setting stage (70-80 DAS).

Five green tender pods of 12 to 15 days maturity from each of the five sampled plant (twenty five pods per replication) were harvested from the early flushes. Then the samples were oven dried at 45°C for 48 hours. The dried material were grinded finely by grinding machine and were utilized for the estimation of protein.

The protein was obtained by analysing the total nitrogen content from oven dried sample and multiplying the percentage figures obtained with a factor of 6.25. Data were subjected to angular transformation and the transformed data are used for further calculations.

Regeants used:

1) Conc.H_2SO_4.

2) Digestion salt mixture containing 250 g Na_2SO_4, 50 g $CuSo_4$ and 5 g metallic selenium.

3) 4% boric acid solution-prepared by dissolving 40 g of boric acid in 1 litre of distilled water.

4) Mixed indicator solution-prepared by dissolving 0.3 g bromo-cresol green and 0.2 g methyl red in 410 ml of 90% ethanol.

5) 40% NaOH solution.

6) Standard 0.1 (N) HCL solution.

Instruments and glass goods used:

i) Micro-Kjeldahl distillation apparatus

ii) Kjeldahl flask (100 ml volume)

iii) Micro-Kjeldahl flask

iv) Eanlyenmeyer flask

v) Pipette

vi) Burette

vii) Beaker

viii) Glass rod

ix) Grinding machine

x) Electrical balance

Procedure:

Known wt. of the dry powdered preparation was taken in a 100 ml kjeldahl flask. Approximately same amount of salt mixture and 3 ml of conc. H_2SO_4 were added to it.The contents of the flask were then digested until a clear solution was obtained. The contents were cooled. To the cooled solution 10 ml of distilled water was added, mixed thoroughly and allowed to cool again.

The Kjeldahl flask containing the digested sample was then emptied into the micro-kjeldahl distillation apparatus quantitatively by repeated washing with distilled water. The 10 ml of 40% NaOH were added to the distillation apparatus by means of a quick delivery pipette. A 200 ml Eanlyenmeyer flask containing 10

ml of 4% boric acid reagent and 3 drops of the mixed indicator solution was placed under condenser of the distillation apparatus,so that the tip of the condenser outlet tips into the content of the flask. The mixture of the digest sample and Sodium hydroxide was then distilled by passing steam from the boiler and the ammonia distilled off from the cotaining mixture is absorbed into the mixture.

The distillation was continued for about 20 minutes. Then the tip was washed with distilled water into the mixture of boric acid and mixed indicator which was then titrated with standard HCL solution.

$$\%N = \frac{\text{Sample Titer-Blank titer X (N) of HCL X 14 X 100}}{\text{weight of sample (g) X 100}}$$

T= Titrate value with sample in ml.

B= Blank value determined using all the reagents except the sample.

Sample wt. = 100 mg.

(N) of Hcl = 0.1 (N)

Crude protein content of the sample can be estimated by multiplying the nitrogen content of 100 mg sample by a constant of 6.25. Crude protein content in per cent weight = Nitrogen x 6.25.

The average crude protein content of the samples of

each genotypes was considered as the crude protein content for each genotype.

ix> Green pod yield per plant (g): Total green pod weight of the periodical harvests from five randomly selected plants were taken and then averaged.

3.3 Study on the stability of the genotypes

3.3.1 Materials

. Twenty genotypes (same as employed for 3.1) were utilized for the study.

3.3.2 Methods

The genotypes were grown following Randomized Block Design with three replications under five different environments in two locations.

Environment	Sowing date	Location
E_1	25.10.1992	District Seed Farm (A&B Block), Kalyani,B.C.K.V.
E_2	17.4.1993	-do-
E_3	16.6.1993	-do-
E_4	17.3.1994	R.R.S.,Terai zone,N.B.Campus, Coochbehar,B.C.K.V.
E_5	4.5.1994	District Seed Farm, (A&B Block), Kalyani,B.C.K.V.

Physico-chemical features of District Seed Farm (A&B Block),Kalyani,B.C.K.V. and Regional Research Station,Terai zone,

B.C.K.V., N.B. Campus, Pundibari, Coochbehar and meteorological data of the experimental periods were presented in Appendix I and II,respectively. Cultural practices were the same as described for 3.1. Observations were recorded on the five randomly selected plants in each replication for the following characters.

i> Days to flowering

ii> Pod length (cm)

iii> Green pod weight (g)

iv> Dry pod weight (g)

v> Number of pods per plant

vi> Green pod yield per plant (g)

3.4 Gene action for pod yield and its components

Gene action of different characters were studied by combining ability analysis.

3.4.1 Materials

Eight genotypes belonging to three cultigroups were crossed in all possible combinations excluding reciprocals to raise the diallel population. Characteristic features of the parents were given in Table 3.

3.4.2 Methods

3.4.2.1 Hybridization technique for raising the F_1 hybrids

The cowpea has perfect flowers of which has ten stamens

and one pistil enclosed in one floral envelope. The flowers open only once, generally before dawn (4.30-5.00 a.m) and most of them shut by noon,with sporadic flower opening to a minor extent in the afternoon. Cowpea flowers were found very sensitive and liable to drop off with the slightest mechanical injury. For this, the flowers were handled with utmost care. Mature and swollen buds due to open in the next morning were selected for emasculation. Emasculations were performed from 4:00 to 6:00 o'clock in the afternoon when there was no dehiscence. To emasculate, the bud was held between the thumb and forefinger, with the keel side uppermost. A sterilized forcep was run along the ridge where the two edges of the petals unite. One side of the petal was brought down, securing its position by exposing the keel. A slit was made from three millimeters below the bend of the keel to about one and one-half millimeters from the stigma. The ten stamens were pulled out with a pair of pointed forceps; they were counted as they removed to make certain that none was left.

Table 3. Characteristic features of the parents involved in the diallel cross

Genotypes/ varieties (1)	Source (2)	Characteristic features (3)
1. V-70	Pulse and Oil-seed Research Station, Baharampur,W.B	Plants are erect, pigmentation present between stipel, at the base of leaf stalk and primary branches. Flower colour - both standard and wing are deep purple;pod colour green,erect pod

(1)	(2)	(3)
		orientation,small,tough,leathery ;pod texture smooth; seeds are bold, small and seed coat is buff coloured with black eye.
2. Cherodi	Pulse and Oilseed Research Station, Baharampur,W.B	Plants are somewhat erect, pigmentation present between stipel and primary branches. Flower colour-both standard and wing are purple coloured. Pods are green, erect, small, tough, leathery with smooth textured. Seeds are bold,small and seed coat is buff coloured with brownish eye.
3. Covu-62A	-do-	Plants are semi-erect,dwarf and bushy. Pigmentation present between stipel and at the base of primary branches. Flower colour-Both standard and wing are deep purple. Pod colour deep green, semierect pod orientation,small,leathery, tough; pod texture-smooth;seeds are square shaped; seed coat colour buff with reddish brown eye.
4. 13-31B	-do-	Plants are semierect,dwarf, and bushy. Pigmentation present between stipel,at the base of leaf stalk and primary branches. Flower colour-Standard is light purple and wing is deep purple;pods are medium -sized, succulent, nonpendant, and deep green coloured. Pod texture smooth;seeds are somewhat elongated with chocolate coloured seed coat.
5. 5269	-do-	Same as mentioned earlier.

(1)	(2)	(3)
6.Pusa Dofasli	I.A.R.I., New Delhi	Same as mentioned earlier.
7.EC-305827	N.B.P.G.R., New Delhi	Same as mentioned earlier.
8.Sel-Tm3	Department of Horticulture, B.C.K.V., Mohanpur,Nadia.	Same as mentioned earlier.

The disturbed parts of the keel, wings, and standard were placed in their original positions. All other buds of the same inflorescence were removed. The emasculated flower buds were then enveloped with thin cotton wad to protect from pollen contamination. The most suitable pollination time was upto 7 a.m of the next morning. The cotton wad was removed and the emasculated flower bud was pollinated by gently touching its stigma with the pollen laden style of the protected flowers of the desired male parent. The glossy, green appearance of the stigma head and its stickiness are two important signs of the receptivity of the stigma, and appearance of a dull-brown colour of the stigma head indicates decline in receptivity. The pollinated flowers were again covered with fresh cotton wad and were properly labelled indicating the specific parents and date of pollination. Then the mature pods from each cross combination were collected seperately.

3.4.2.2 Growing F_1 hybrids for getting F_2 seeds

Half the quantity of the twenty eight F_1 hybrids were seeded on 16th July, 1993 at District Seed Farm (A & B block), Kalyani,B.C.K.V. to obtain seeds for F_2 generations. Rest half quantity of F_1 seeds were stored for combined trial of F_1, F_2 and parents in the next year. Normal cultural practices were followed. The mature pods from each hybrids were collected separately.

3.4.2.3 Combined trial of F_1,F_2 and parents

This trial was also conducted at District Seed Farm (A & B Block), Kalyani,B.C.K.V., with twenty eight F_1's 28 F_2 families and 8 parents following Randomized Block Design with three replications. Sowing was done on 16th June,1994. Row to row spacing was 60 cm while the seeds were spaced 30 cm apart within the rows. Each replication consisted of one row for each of the parents and F_1's and three rows for F_2's. Cultural practices were the same as described earlier. Observations were recorded from ten plants for each of 8 parents and 28 F_1's and twenty randomly selected plants for each F_2 family of the hybrid combination for the following characters.

i) Days to flowering

ii) Pod length (cm)

iii) Green pod weight (g)

iv) Dry pod weight (g)

v) Pod number per plant

vi) Seed number per pod

vii) Green pod yield per plant (g)

3.5 Statistical and Biometrical analysis

3.5.1 Yield component analysis

The observations recorded on the various characters for the morphophysiological study were subjected to following statistical analysis for two environments viz.E_1 and E_2 as stated earlier.

3.5.1.1 Analysis of variance

Differences between genotypes for different characters were tested for significance using analysis of variance. Analysis of variance was done on the basis of the following model:

$$Y_{ij} = m + g_i + r_j + e_{ij}$$

where, Y_{ij} = Phenotypic observation in ith genotype and jth replication

m = general mean

g_i = effect of ith genotype

r_j = effect of jth replication

e_{ij} = random error associated with ith genotype and jth replication.

The structure of the analysis of variance was as follows:

ANOVA

Source	d.f	M.S.	Expected M.S.	F
Genotypes	(t-1)	Mt_{11}	$\sigma^2e_{11} + r\sigma^2g_{11}$	Mt_{11}/M_{11}
Replication	(r-1)	Mr_{11}	-	
Error	(r-1) (t-1)	Me_{11}	σe^2_{11}	

Where r = number of replications

t = number of genotypes

Mr_{11}, Mt_{11} and Me_{11} stand for mean sum of squares due to replication, genotypes and error,respectively.

Error variance = $\sigma^2e_{11} = Me_{11}$

Genotypic variance = $\sigma^2g_{11} = \dfrac{Mt_{11} - Me_{11}}{r}$ and

Phenotypic variance= $\sigma^2p_{11} = \sigma^2g_{11} + \sigma^2e_{11}$

3.5.1.2 Analysis of covariance

Analysis of covariance table was made for all the characters in their all possible combinations taking two variables at a time. The structure of analysis of covariance was as follows:

ANOVA

Source	d.f	M.P.	Expected M.P.	F
Genotype	(t-1)	Mt_{12}	$\sigma e_{12} + r\sigma g_{12}$	Mt_{12}/Me_{12}
Replication	(r-1)	Mr_{12}		
Error	(t-1) (r-1)	Me_{12}	σe_{12}	

where, r and t = number of replication and genotypes, respectively,

Genotypic covariance = $\sigma g_{12} = (Mt_{12} - Me_{12}) / r$

Phenotypic covariance = $\sigma p_{12} = \sigma g_{12} + \sigma e_{12}$

3.5.1.3 Estimation of standard error, critical difference, G.C.V.,P.C.V.,heritability and Genetic advance

Standard error of mean (S.E.) and critical difference (C.D.) were calculated as follows:

$$S.E. = \sqrt{\frac{EMS\ (Sem)}{r}}$$

C.D. at 5% = S.E. x t at error d.f. at 5% level of significance

where r = number of replication and

EMS = Error mean square

The genotypic (G.C.V.) and phenotypic (P.C.V.) coefficients of variation were calculated by the formulae given by Burton (1952).

$$G.C.V.\ (\%) = \frac{\text{Genotypic standard deviation}}{\text{Grand mean}} \times 100$$

$$\text{P.C.V. (\%)} = \frac{\text{Phenotypic standard deviation}}{\text{Grand mean}} \times 100$$

The heritability (in broad-sense) was estimated according to Hanson *et al.* (1956).

$$\text{Where } H(\%) = \frac{\text{Genotypic variance}}{\text{Phenotypic variance}} \times 100$$

The genetic advance (G.A.) was calculated following Lush (1949).

$$\text{Where G.A.} = \frac{\text{Genotypic variance}}{\text{Phenotypic variance}} \times K\sigma_p$$

in which σ_p = phenotypic standard deviation

K = selection differential,a constant, 2.06 for 5% selection intensity.

3.5.1.4 Estimation of correlations

Phenotypic and genotypic correlation coefficients for all possible combinations were computed using the general formula for correlation coefficients from the phenotypic and genotypic variance and covariance components. Thus,correlation coefficients were calculated as follows:

$$r_{xy} = \frac{\text{Cov.xy}}{\sqrt{\text{Var (x). Var (y)}}}$$

Where, Cov.xy = covariance of characters x and y

Var(x) = variance of character x

Var(y) = variance of character y

To test the significance of correlation coefficient at phenotypic level, the estimated values were compared with the table values (Fisher and Yates, 1967) at (t-2) degrees of freedom at 5% and 1% level of significance.

3.5.1.5 Path coefficient analysis

The path coefficient analysis was done to estimate direct and indirect contribution of eleven characters and described as true by Dewey and Lu (1959) at the phenotypic level.

The following set of simultaneous equations was formed and solved for estimating various direct and indirect effects:

$$r_1y = P_1y + r_{12}P_2y + r_{13}P_3y \quad +\ldots+ r_{1I}P_Iy$$

$$r_2y = r_{21}P_1y + P_2y + r_{23}P_2y \quad +\ldots+ r_{2I}P_Iy$$

$$\vdots \qquad\qquad\qquad\qquad\qquad\qquad \vdots$$

$$r_Iy = r_{I1}P_1y + r_{12}P_2y + r_{13}P_3y +\ldots+P_Iy$$

where,

r_1y to r_Iy = Coefficients of correlation between causal factors 1 to I and dependent character y

r_{12} to $r_{I-1,I}$= Coefficients of correlation among causal factors

P_1y to p_Iy= Direct effects of characters 1 to I on character y

The above equations were written in a matrix form as

$$\underset{A}{\begin{bmatrix} r_1y \\ r_2y \\ r_3y \\ \vdots \\ r_Iy \end{bmatrix}} = \underset{C}{\begin{bmatrix} 1 & r_{12} & r_{13}\cdots r_{1I} \\ r_{21} & 1 & r_{23}\cdots r_{2I} \\ r_{31} & r_{32} & 1\cdots r_{3I} \\ \vdots & \vdots & \vdots \\ r_{I1} & r_{I2} & r_{I3} \quad 1 \end{bmatrix}} \times \underset{B}{\begin{bmatrix} p_1y \\ p_2y \\ p_3y \\ \vdots \\ p_Iy \end{bmatrix}}$$

Then $B = C^{-1}A$

$$C^{-1} = \begin{bmatrix} c_{11} & c_{12} & c_{13}\cdots c_{1I} \\ c_{21} & c_{22} & c_{23} \quad c_{2I} \\ \vdots & \vdots & \vdots \\ c_{I1} & c_{I2} & c_{I3} \quad c_{II} \end{bmatrix}$$

Then,direct effects were calculated as follows;

$$P_1y = \sum_{i=1}^{I} c_{1i}r_iy$$

$$P_2y = \sum_{i=1}^{I} c_{2i}r_iy$$

$$P_Iy = \sum_{i=1}^{I} c_{Ii}r_iy$$

Residual effect which measures the contribution of the characters not considered in the causal scheme was obtained as Residual

effect $(P_{Ry}) = \sqrt{1 - R^2}$

Where, $R^2 = P^2_{iy} + 2 \sum_{i \neq j} \sum P_{iy} P_{jy} r_{ij}$

3.5.2 Study on root and nodule characters

The statistical analyses were same as described in 3.5.1

3.5.3 Stability analysis

The stability analysis was done according to the method described by Eberhart and Russell (1966). For each genotype a function was fitted for the regression of its individual genotype,at the five different environments, on the mean performance of all the twenty genotypes at the respective environments. The regression coefficient b_i and the mean square of the deviations from regression S^2_{di} provide two stability parameters for each genotype. These parameters are defined by the model:

$$Y_{ij} = \mu_i + b_i I_j + \delta_{ij}$$

Where, Y_{ij} is the mean for ith genotype at the jth environment; μ_i is the ith genotype's mean over all environments; I_j is the mean of all genotypes at the jth environment minus the grand mean

$$I_j = (\sum_i Y_{ij}/v) - (\sum_i \sum_j Y_{ij}/vn); \sum_j I_j = 0$$

b_i is the above mentioned regression coefficient;

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

δ_{ij} is the deviation from regression of the ith genotype at the jth environment

S^2_{di} was computed as follows:

Where $S^2_{di} = [\sum_j \hat{\delta}^2_{ij}/(n-2)] - Se^2/r$

where Se^2/r is the estimate of the pooled error.

Testing of δ^2_i's

The deviation from regression for each variety was tested by the formula

$$F = \sum_j \delta^2_{ij} \; / \; (n-2) \; / \; \text{pooled error}$$

Testing of b_i's

$$t = \frac{b_i}{SE\ (b_i)}$$

$$\text{Where } SE(b_i) = \frac{\text{MS due to pooled deviation of the ith variety}}{\Sigma I^2_j}$$

Calculated t is tested against table value of t at pooled error d.f.

3.5.4 Gene action and heterosis

3.5.4.1 Combining ability analysis

Following the analysis of variance to test the signifi-

cance for each characters, the combining ability analyses were carried out as per the procedure given by Griffing (1956a).Method 2 and Model 1 was considered most appropriate for the materials under study. Method 2 was applicable to the present study as parents and one set of non-reciprocal F_1's and F_2's were included. Model 1 assumes that variety and block effects are constant but environmental effect is variable and the experimental material is the population about which inferences are to be made. The method helps to compare combining ability of parents when parents themselves are used as testars. Error is independently distributed with mean zero and variance σ^2_e. The mathematical model for the combining ability analysis was assumed to be

$$X_{ij} = u + g_i + g_j + s_{ij} + 1 / bc \sum_k \sum_l e_{ijkl}$$

$$i,j = 1,.....,p$$

$$k = 1,.....,b$$

$$l = 1,.....,c$$

Where ,p = number of parents

b = number of blocks

c = number of observations for each of the plots

u = population mean

g_i= general combining ability effect of ith parent

g_j= general combining ability effect of jth parent

s_{ij}= specific combining ability effect such that

$$s_{ij} = s_{ji} \text{ and}$$

e_{ijkl}= environmental effect pertaining to the ijklth observation.

The restrictions imposed to this model are ;

$$\Sigma g_i = 0 \text{ and } \sum_j S_{ij} + S_{ii} = 0 \text{ (for each i).}$$

The following summation notation was used in this analysis

$$X_{i\cdot} = \sum_j X_{ij} \text{ (array sum)}$$

where, $X_{ij} = X_{ji}$; X.j need not be considered

$$X_{\cdot\cdot} = \sum_{i \neq j} \sum X_{ij} \text{ (sum of all entries in the diallel table)}$$

(a) Estimation of sum of squares

S.S. due to general combining ability (g.c.a.)

$$= \frac{1}{p+2} \left[\sum_i (X_{i\cdot} + X_{ii})^2 - \frac{4X^2_{\cdot\cdot}}{p} \right]$$

S.S.due to specific combining ability (s.c.a.)

$$= \sum_{i \neq j} \sum X^2_{ij} - \frac{1}{p+2} \sum_i (X_{i\cdot} + X_{ii})^2 + \frac{2}{(p+1)(p+2)} X^2_{\cdot\cdot}$$

Analysis of variance table for combining ability with expectation of mean square was set up as follows:

Source	d.f.	M.S.	Expectation of mean square
General combining ability	(p-1)	M_g	$\sigma^2_e + (p+2)\left(\frac{1}{p-1}\right) \Sigma g^2_i$
Specific combining ability	p(p-1)/2	M_s	$\sigma^2_e + \frac{2}{p(p-1)} \Sigma \Sigma s^2_{ij}$
Error	m	M'_e	σ^2_e

The error mean square (M'_e) for combining ability analysis was obtained by dividing error mean square obtained from

simple RBD analysis of variance by the number of replications. For 'F' test,each mean square was tested against M'_e.

(b) Estimation of effects

$$\hat{u} = \frac{2}{p\ (p+1)}\ x..$$

$$\hat{g}_i = \frac{1}{p+2}\ (x_i\ .+\ x_{ii} - \frac{2}{p}\ X..)$$

$$\hat{s}_{ij} = X_{ij} - \frac{1}{p+2}\ (X_i. + X_{ii} + X_j. + X_{jj}) +. \frac{2X..}{(p+1)\ (p+2)}$$

The s_{ij} was the estimate of s.c.a. effect of F_1 resulting from crossing ith and jth parents.

The variance of any parent or F_1 mean values was

$$\text{Var}\ (X_{ij}) = \hat{\sigma}^2 = M'e$$

and the variance of the difference between any two mean values was

$$\text{Var}(X_{ij} - X_{kl}) = 2\hat{\sigma}^2$$

Variances of effects and of differences between effects were estimated as follows:

$$\text{Var}(\hat{u}) = \frac{2}{p(p+1)}\ \sigma^2$$

$$\text{Var}(\hat{g}_i) = \frac{p-1}{p(p+2)}\ \sigma^2$$

$$\text{Var}(\hat{s}_{ij}) = \frac{p^2+p+2}{(p+1)(p+2)}\ \sigma^2\ \ldots\ldots.(i \neq j)$$

$$\text{Var}(\hat{g}_i - \hat{g}_j) = \frac{2}{p+2}\sigma^2 \quad \ldots\ldots\ldots (i \neq j)$$

$$\text{Var}(\hat{s}_{ij} - \hat{s}_{kl}) = \frac{2p}{p+2}\sigma^2 \quad \ldots\ldots\ldots (i \neq j,k,l;\ j \neq k,l;\ k \neq l)$$

The standard errors were computed from these variances by taking their square roots for the respective 't' values in the test of significance.

(c) Estimation of genetic components and heritability

The additive and non-additive genetic variances were estimated from the combining ability components as follows:

$$\hat{\sigma}^2_a \text{ (additive)} = 2\hat{\sigma}^2_g$$

where

$$\hat{\sigma}^2_g = \frac{1}{(p-1)} \sum_i \hat{g}^2_i = \frac{M_g - M'_e}{p+2}$$

$$\hat{\sigma}^2_{na} \text{ (non-additive)} = \hat{\sigma}^2_s$$

where

$$\hat{\sigma}^2_s = \frac{2}{p(p-1)} \sum_i \sum_j \hat{s}^2_{ij} = M_s - M'_e$$

and $M'_e = \hat{\sigma}^2_e$

Phenotypic variance = σ^2_p

$$\hat{\sigma}^2_p = 2\hat{\sigma}^2_g + \hat{\sigma}^2_s + \hat{\sigma}^2_e = \hat{\sigma}^2_a + \hat{\sigma}^2_{na} + \hat{\sigma}^2_e$$

Heritability in narrow sense = $\hat{h}^2_n$

$$\hat{h}^2_n = \frac{\hat{\sigma}^2_a}{\hat{\sigma}^2_p}$$

and this heritability was expressed in percent.

3.5.4.2 Estimation of heterosis

The magnitude of heterosis was estimated in relation to mid-parent as well as better-parent values. Both were calculated as percentage increase or decrease of F'_1s over the mid-parent (MP) and better-parent (BP) values.

(a) Heterosis over mid-parent (H_1)

$$H_1\ (\%) = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

$$S.E.(H_1) = \sqrt{3/2 \times ve/r}\ ;\ \text{'t' value} = H_1 / S.E.(H_1)$$

calculated 't' was tested against table value of 't' at error d.f. for test of significance.

(b) Heterosis over better-parent (H_2)

$$H_2\ (\%) = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

$$S.E.(H_2) = \sqrt{2 \times ve/r}\ ;\ \text{'t' value} = H_2 / S.E.(H_2)$$

calculated t was tested against table value of 't' at error d.f. where. Ve = error mean square obtained from R.B.D. analysis.

$\overline{F_1}$ = mean of F_1 $\overline{BP}$ = mean of the better parents

$\overline{MP}$ = mean of the two parents S.E. = Standard error.

CHAPTER-IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

Cowpea (*Vigna unguiculata* (L.) Walp.) probably a native of Central Africa is cultivated ~~all~~ most all over the India. It is consumed for various purposes like green pod, dry seed or fodder. In many cases cowpea is cultivated as an inter crop with maize,sorghum,millets and cassava. It is also used as a cover in plantations to smother the weeds. In West Bengal and also in Eastern India cowpea is more popular as a vegetable. Being grouped in the family leguminosae, the cowpea is rich in protein and also vitamins especially vit.A and vit.C. Calcium and Phosphorus content of cowpea pod is also high (Chowdhury, 1967). Compared to cereals or any field crops the productivity of cowpea as a vegetable is appreciably high. But the technology of higher productivity is still of immense importance specially in India where productivity is low as compared to Nigeria, Niger, Brazil etc. Moreover, under agro-climatic situation of West Bengal, cowpea is important as a pure crop and the main constraints of higher productivity in intensive cropping system is lack of high yielding varieties with desirable attributes in pod and plant.

To develop rational breeding programme for the genetic improvement of cowpea many basic informations are needed. The present investigation thus aims at

i> to analyse the components of green pod yield

ii> to study the nodulation pattern

iii> to identify phenotypically stable genotypes for vegetable purpose and

iv> to examine the genetic architecture of different morphological characters in cowpea. The results are presented and discussed here with their significant implications.

4.1 Analysis of components of green pod yield

The development of suitable plant type is of great importance in all legumes in general including cowpea through planned designing programme. Attempt has therefore been made by several scientists to analyse different morphological characters to provide meaningful information about the significance of characters in relation to seed yield in cowpea. Such studies would obviously help to improve grain yield in cowpea. But investigation on the components of green pod yield in cowpea is to some extent limited. An ideal plant ideotype would only be defined if the different components of green pod yield are analysed and their relative importance can be assessed. In the present study, genetic diversity of genotypes collected from different parts of India and abroad were examined and yield component analyses were carried out to identify important green pod yield components.

4.1.1 Analysis of genetic diversity and heritability

The vegetable cowpea comprises genotypes of two culti-

groups namely, Unguiculata and Sesquipedalis. Sometimes integrades of both cultigroups are also found in vegetable cowpea. The present study is initiated to examine the nature of variability in different characters under two different environmental conditions.

Analysis of variance for eleven traits revealed that mean squares due to genotypes were highly significant in each of the environment and pooled environment as well (Table 4). The coefficient of variation of all the three analyses namely,analysis in E_1, E_2 and pooled environment were below 11% for all the characters confirming the reliability of the experiment. E_1 and E_2 were Pre-kharif and Kharif season, respectively. In general Kharif season crop showed marginal improvement in green pod yield per plant and also in some of the characters like pods per plant and plant height in comparison to Pre-kharif crop. Estimates of coefficient of phenotypic and genotypic variation (P.C.V. and G.C.V.) and heritability in broad-sense for different characters were computed seperately over two environments and also for the pooled environment and are presented in Table 5. P.C.V. agreed closely with G.C.V. for almost all the characters. The magnitude of P.C.V. was higher as compared to G.C.V. for all the characters. In general, not large difference was found in two environments indicating low genotype X environment interaction in Pre-kharif and Kharif seasons. The character pods per plant followed

Table 4 : Analysis of variance (mean sum of squares) for eleven characters of vegetable cowpea

Source		d.f.	Plant height	Branches/ plant	Peduncle length	Days to flowering	Pod length	Green pod weight	Dry pod weight	Pods/ plant	Seeds/ pod	100-seed weight	Green pod yield/plant
Repli-	E_1	2	118.937	0.052	3.490	8.011*	0.062	0.271	0.003	11.294	1.082	0.565	4382.750**
cation	E_2	2	121.500	0.171	22.636**	1.050	0.845	0.633	0.001	11.898	0.400	0.238	2180.750
	P	2	1.250	0.093	12.402*	7.429**	0.250	0.241	0.0003	13.558	1.242	0.732	3404.500*
Vari-	E_1	19	6788.673**	1.931**	54.511**	46.820**	192.801**	79.134**	0.650**	335.725**	31.922**	9.479**	10253.017**
eties	E_2	19	7485.530**	1.887**	42.863**	63.557**	189.256**	83.033**	0.631**	387.684**	28.306**	9.067**	11062.579**
	P	19	14215.316**	3.724**	94.640**	98.624**	380.140**	161.727**	1.276**	715.460**	59.498**	18.481**	20478.824**
Error	E_1	38	243.051	0.077	3.177	2.455	0.197	0.223	0.004	3.811	0.784	0.149	698.872
	E_2	38	209.366	0.109	3.971	1.365	0.653	0.507	0.002	6.035	0.578	0.113	1024.407
	P	76	226.228	0.093	3.574	1.910	0.426	0.365	0.003	4.923	0.681	0.131	861.636
CV(%)	E_1		8.443	5.262	6.385	3.492	1.561	3.527	4.499	7.856	6.192	3.244	9.107
	E_2		7.478	6.487	7.601	2.769	2.915	5.357	3.815	9.326	5.416	2.872	10.664
	P		7.955	5.884	6.985	3.175	2.322	4.528	4.184	8.669	5.823	3.066	9.943

** Significant at 1 % level ; * Significant at 5% level.

E_1 : Environment one; E_2: Environment two; P : Pooled over two environments.

Table 5 : Mean and estimates of genetic parameters of eleven characters of vegetable cowpea

Parameter		Plant height (cm)	Branches/ plant	Peduncle length (cm)	Days to flowering	Pod length (cm)	Green pod weight (g)	Dry pod weight (g)	Pods/ plant	Seeds/ pod	100-seed weight (g)	Green pod yield/plant (g)
Mean	E1	184.64	5.29	27.91	44.86	28.48	13.41	1.40	24.84	14.30	11.90	290.25
	E2	193.47	5.09	26.21	42.20	27.73	13.30	1.36	26.34	14.04	11.74	300.13
	P	189.06	5.19	27.06	43.53	28.10	13.35	1.38	25.60	14.17	11.82	295.19
Range	E1	259.80to 65.40	7.47to 3.47	34.80to 20.20	52.33to 37.33	44.57to 15.27	20.47to 4.63	2.38to 0.52	48.73to 14.50	20.27to 8.27	14.16to 7.82	436.76to 197.41
	E2	280.97to 72.17	7.00to 3.57	33.00to 18.80	53.33to 35.33	43.93to 17.10	21.50to 4.17	2.42to 0.46	49.40to 16.13	19.50to 7.40	13.84to 7.95	438.26to 195.60
	P	270.27to 68.78	7.23to 3.52	33.90to 19.50	52.83to 36.33	44.25to 16.18	20.95to 4.40	2.40to 0.49	47.97to 15.32	19.88to 7.83	14.00to 7.89	437.51to 204.88
P.C.V. (%)	E1	26.67	15.76	16.13	9.26	28.18	38.41	33.29	43.05	23.36	15.16	21.47
	E2	26.53	16.46	15.70	11.14	28.74	39.81	33.86	43.82	22.31	14.99	22.03
	P	26.90	16.09	16.06	9.30	28.34	39.09	33.50	43.30	22.83	15.13	21.78
G.C.V. (%)	E1	25.30	14.85	14.82	8.57	28.13	38.25	32.98	42.33	22.52	14.81	19.44
	E2	25.45	15.13	13.73	10.79	28.59	39.44	33.64	42.82	21.64	14.71	19.27
	P	25.69	14.98	14.46	8.74	28.25	38.83	33.24	42.43	22.08	14.82	19.38
Herita-bility% in broad sense	E1	90.00	88.80	84.30	85.80	99.70	99.20	98.20	96.70	93.00	95.40	82.00
	E2	92.10	84.50	76.50	93.80	99.00	98.20	98.70	95.50	94.10	96.30	76.60
	P	91.30	86.60	81.10	88.30	99.30	98.70	98.40	96.00	93.50	95.90	79.20
G.A.% of mean	E1	49.43	28.92	28.05	16.36	57.87	78.45	67.86	85.75	44.76	29.83	36.27
	E2	50.31	28.68	24.76	21.52	58.60	80.53	69.12	86.18	43.30	29.73	34.74
	P	50.56	28.71	26.83	16.93	58.01	79.48	68.12	85.63	43.97	29.86	35.53

E_1 : Environment one ; E_2 : Environment two ; P : Pooled over two environments.

by green pod weight, dry pod weight,pod length and plant height showed high P.C.V. and G.C.V. as well in both the environments and also in pooled environment. Broad-sense heritability were consistently very high (more than 76%) for all the characters in both the environments as well as in pooled environment. These broad-sense heritability values were likely to be over estimated as in this calculation it was not possible to exclude variation due to different genetic components and their interactions. The heritability estimates were, therefore, to be considered with this limitations in view. However,genetic advance (G.A.) expressed as percentage of mean was highest for pods per plant followed by dry pod weight, green pod weight and pod length. In other words, pods per plant, pod weight (green and dry) and pod length were characterized by high P.C.V., G.C.V., very high heritability (above 90%) and high G.A. According to Panse (1957), such association was attributed to additive gene effect. High heritability estimates and G.A. for pods per plant was reported by Sahoo *et al.* (1971), Tikka *et al.*(1977),Jana *et al.*(1982) and Hazra (1991). Similarly, Sahoo *et al.* (1971),Tikka *et al.*(1977),and Hazra (1991) observed high heritability coupled with high G.A. percentage of mean for pod length. On the otherhand, Trehan *et al.* (1970) reported low heritability and G.A. percentage of mean for pod length and pods per plant. Differences in experimental materials and environments would like to generate different expression of characters. Plant height and seeds per pod exhibit-

PLATE NO.1 :

C1 : Pusa Barsati	C11 : 5269
C2 : Pusa Dofasli	C12 : T-2
C3 : Sel-Tm1	C13 : T-4
C4 : Sel-Tm2	C14 : T-6
C5 : Sel-Tm3	C15 : Local-1
C6 : Arka Garima	C16 : Local-4
C7 : Sel-Tm4	C17 : Local-9
C8 : EC-305827	C18 : Local-10
C9 : EC-243954	C19 : Local-10A
C10: 1-101	C20 : Local-16

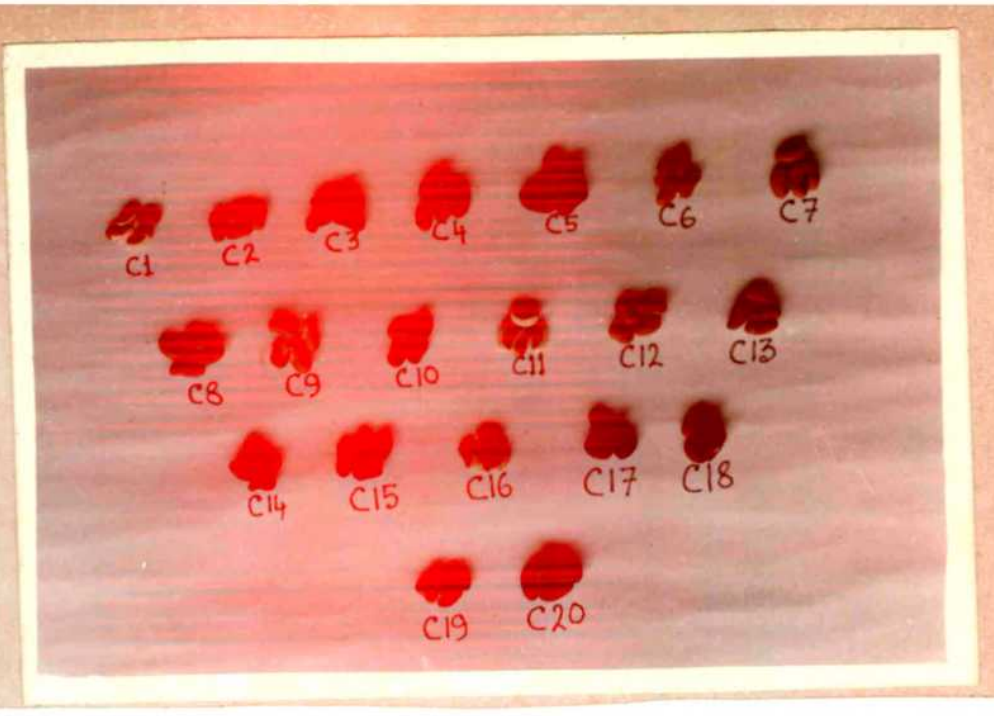
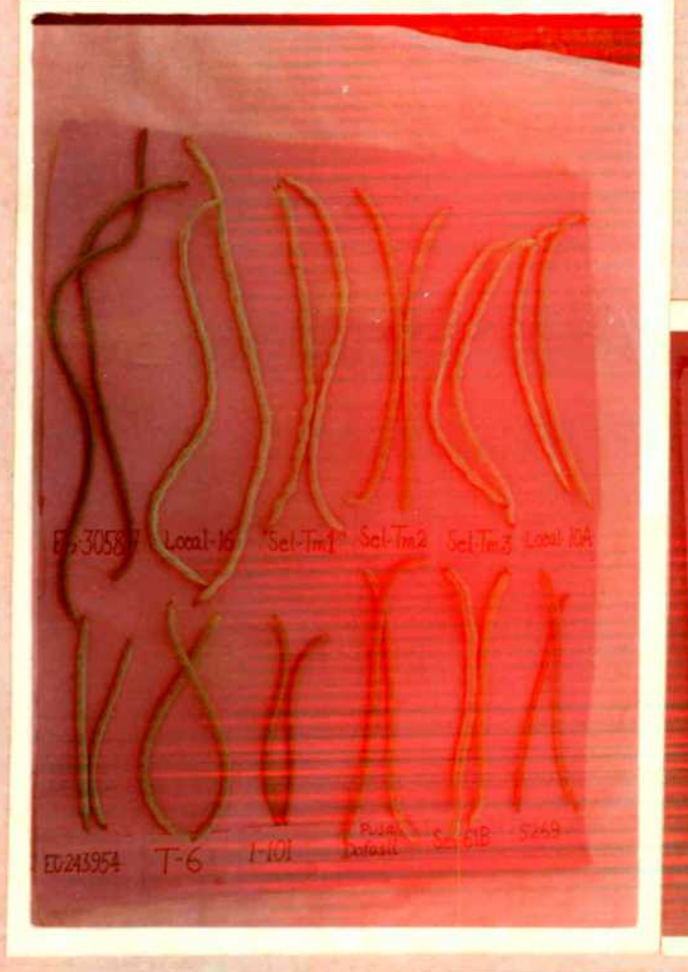


Plate no 1. Variability in seed size and colour of different cowpea genotypes



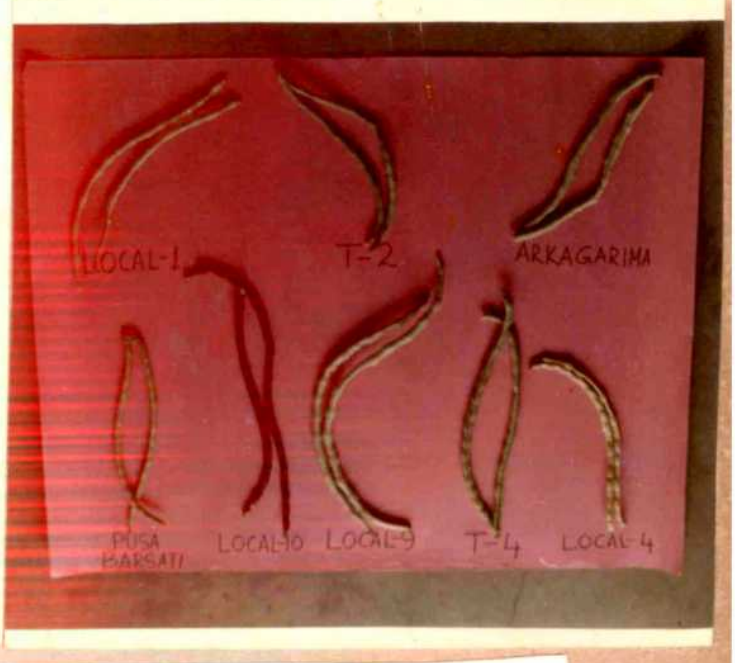


Plate no 2. Variability in pod size and colour of different cowpea genotypes

ed moderately high G.C.V. and P.C.V., high heritability estimates and moderate G.A. percentage of mean which support the early observations of Tikka *et al.*(1977) and Lakshmi and Goud (1977).

4.1.2 Correlation coefficients

Association analyses of different morphological characters with green pod yield and their inter-relationships were investigated through the study of both phenotypic and genotypic correlation coefficients. The concept of component approach enables the breeder to simplify a complex trait like green pod yield into its subdivisions. Grafius (1964) visualized a complex trait such as yield in small grains as a geometrical model in the format of a parallelepiped, designating the volume as yield (W), with the edges, X, Y, and Z as three yield components. The three dimensional model elucidates how W could be altered by changes in X,Y and Z and consequently, how yield could be engineered to suit a given environment by manipulating the individual yield components.

In the present study, eleven morphological characters including growth and reproductive characters namely, plant height, branches per plant, peduncle length, days to flowering, pod length, green pod weight, dry pod weight, pods per plant, seeds per pod, 100-seed weight and green pod yield per plant were

recorded and their genotypic and phenotypic correlation coefficients were analysed in each of the environments and pooled environment as well. The results were presented in Tables 6,7 and 8. Phenotypic and genotypic correlation coefficients, in general, agreed very closely. However, the genotypic correlations were higher than phenotypic correlations in most of the cases. This could occur when the genes governing two traits were similar and environmental factors played a small part in the expression of these traits. Out of the eleven characters studied, five characters namely, pod length, green pod weight, dry pod weight, 100-seed weight and seeds per pod exhibited significantly positive phenotypic correlation coefficient in E_1. These characters showed highly positive genotypic correlation coefficient with green pod yield per plant. However, days to flowering exhibited a significant negative correlation with green pod yield per plant (Table 6). This indicated that early flowering helped in improving yield. This was a desirable situation as early flowering would help to minimise the crop duration and ultimately cowpea could be adjusted profitably in crop rotations. In Kharif season (E_2), almost similar results were found (Table 7). Thus considering two environments and also pooled analyses,five characters namely 100-seed weight, pod length, green pod weight, dry pod weight and seeds per pod registered high correlation coefficients with green pod yield per plant both at phenotypic and genotypic level. Interestingly, pods per plant did not exhibit any significant

Table 6 : Phenotypic (P) and genotypic (G) correlation coefficients of eleven characters for environment one (E_1)

Characters		Branches/ plant	Peduncle length	Days to flowering	Pod length	Green pod weight	Dry pod weight	Pods/ plant	Seeds/ pod	100-seed weight	Green pod yield/plant
Plant height	P	-0.171	-0.064	0.267	0.402	0.346	0.293	-0.256	0.304	0.249	0.061
	G	-0.192	-0.124	0.295	0.424	0.362	0.308	-0.278	0.310	0.271	0.063
Branches/Plant	P		0.378	0.053	-0.268	-0.168	-0.368	0.107	0.004	-0.016	-0.018
	G		0.472	0.041	-0.281	-0.174	-0.383	0.130	-0.023	-0.024	0.024
Peduncle length	P			0.139	-0.008	0.140	0.108	-0.145	0.119	0.242	0.111
	G			0.166	-0.007	0.146	0.123	-0.162	0.133	0.253	0.124
Days to flowering	P				-0.298	-0.133	-0.107	-0.172	-0.187	-0.243	-0.448
	G				-0.318	-0.153	-0.105	-0.175	-0.213	-0.266	-0.499
Pod length	P					0.913*	0.659*	-0.655	0.696*	0.702*	0.610*
	G					0.919	0.666	-0.671	0.724	0.717	0.666
Green pod weight	P						0.590*	-0.827	0.575*	0.693*	0.562*
	G						0.600	-0.845	0.595	0.709	0.615
Dry pod weight	P							-0.414	0.585*	0.456	0.534*
	G							-0.424	0.613	0.473	0.594
Pods/Plant	P								-0.339	-0.365	-0.128
	G								-0.362	-0.381	-0.222
Seeds/Pod	P									0.623*	0.582*
	G									0.653	0.656
100-seed weight	P										0.653*
	G										0.734

* The correlation coefficients must exceed 0.433 and 0.549 to be significant at the 5% and 1% levels, respectively.

Table 7 : Phenotypic (P) and genotypic (G) correlation coefficients of eleven characters for environment two (E_2)

Characters		Branches/ plant	Peduncle length	Days to flowering	Pod length	Green pod weight	Dry pod weight	Pods/ plant	Seeds/ pod	100-seed weight	Green pod yield/plant
Plant height	P	-0.087	-0.122	0.214	0.393	0.294	0.254	-0.221	0.291	0.218	-0.019
	G	-0.116	-0.174	0.239	0.411	0.303	0.277	-0.221	0.297	0.241	-0.014
Branches/Plant	P		0.380	0.375	-0.323	-0.250	-0.304	0.215	0.032	-0.063	0.061
	G		0.515	0.437	-0.354	-0.283	-0.313	0.239	0.028	-0.050	0.072
Peduncle length	P			0.114	-0.035	0.036	0.117	0.055	0.006	0.190	0.308
	G			0.157	-0.054	0.050	0.120	0.050	-0.005	0.227	0.377
Days to flowering	P				-0.249	-0.140	-0.089	-0.222	-0.030	-0.252	-0.439
	G				-0.258	-0.150	-0.093	-0.225	-0.044	-0.274	-0.506
Pod length	P					0.886*	0.697*	-0.678	0.666*	0.676*	0.486*
	G					0.902	0.707	-0.695	0.692	0.695	0.559
Green pod weight	P						0.614*	-0.835	0.491*	0.671*	0.514*
	G						0.623	-0.859	0.502	0.689	0.561
Dry pod weight	P							-0.419	0.530*	0.424	0.560*
	G							-0.433	0.553	0.431	0.639
Pods/Plant	P								-0.258	-0.392	-0.084
	G								-0.287	-0.407	-0.172
Seeds/Pod	P									0.627*	0.476*
	G									0.656	0.501
100-seed weight	P										0.574*
	G										0.673

* The correlation coefficients must exceed 0.433 and 0.549 to be significant at the 5% and 1% levels, respectively.

association with green pod yield per plant in E_1,E_2 and pooled analysis. The correlation studies by and large support observations by sharma *et al.*(1988), Tewari and Goutam (1989) and Hazra (1991) who observed the importance of pod length, pod weight, seeds per pod and 100-seed weight on green pod yield of cowpea. On the otherhand, Jana *et al.* (1983) and Aggarwal (1987) found pods per plant to be the main component of green pod yield. In the present study, the experimental materials comprises of twenty genotypes belonging to cultigroups Unguiculata, Sesquipedalis, and integrades of both cultigroups. Interestingly, Hazra(1991) also observed similar situation of non significant correlation of pods per plant with green pod yield in the combined analyses of the genotypes belonging to different cultigroups. On the contrary, significantly positive correlation between pods per plant and green pod yield was found when analyses were carried out seperately for each of the cultigroup (Hazra,1991). Thus differences in genotypes of different cultigroups might be responsible for the complexity of the situation.

The inter-relationships among the characters exhibited that nine correlation coefficients were significantly positive at both the environments as well as pooled analysis. They showed high genotypic correlations as well (Tables 6,7 and 8). These important inter-relationships were between pod length and green pod weight, pod length and dry pod weight, pod length and seeds

Table 8 : Phenotypic (P) and genotypic (G) correlation coefficients of eleven characters over two environments pooled

Characters		Branches/ plant	Peduncle length	Days to flowering	Pod length	Green pod weight	Dry pod weight	Pods/ plant	Seeds/ pod	100-seed weight	Green pod yield/plant
Plant height	P	-0.126	-0.077	0.256	0.389	0.321	0.269	-0.242	0.295	0.227	0.019
	G	-0.151	-0.129	0.286	0.408	0.332	0.288	-0.252	0.301	0.249	0.023
Branches/Plant	P		0.371	0.212	-0.299	-0.213	-0.342	0.172	0.023	-0.046	0.032
	G		0.481	0.242	-0.321	-0.232	-0.354	0.196	0.007	-0.044	0.059
Peduncle length	P			0.144	-0.016	0.087	0.116	-0.048	0.062	0.223	0.202
	G			0.185	-0.022	0.098	0.125	-0.062	0.065	0.246	0.235
Days to flowering	P				-0.301	-0.151	-0.118	-0.222	-0.106	-0.291	-0.485
	G				-0.319	-0.168	-0.121	-0.228	-0.125	-0.320	-0.555
Pod length	P					0.903*	0.678*	-0.674	0.678*	0.686*	0.547*
	G					0.914	0.687	-0.690	0.705	0.704	0.613
Green pod weight	P						0.602*	-0.832	0.537*	0.679*	0.543*
	G						0.611	-0.853	0.553	0.696	0.594
Dry pod weight	P							-0.420	0.558*	0.436	0.543*
	G							-0.432	0.584	0.447	0.612
Pods/Plant	P								-0.292	-0.375	-0.113
	G								-0.318	-0.391	-0.206
Seeds/Pod	P									0.621*	0.551*
	G									0.650	0.606
100-seed weight	P										0.614*
	G										0.705

* The correlation coefficients must exceed 0.433 and 0.549 to be significant at the 5% and 1% levels, respectively.

per pod, pod length and 100-seed weight, green pod weight and dry pod weight, green pod weight and seeds per pod, green pod weight and 100-seed weight, dry pod weight and seeds per pod, and seeds per pod and 100-seed weight. On the otherhand, pods per plant showed significantly negative inter-relationship at phenotypic and genotypic level with pod length and green pod weight in both the environments as well as in pooled environment.

The correlation analyses of individual environment and pooled environment as well thus indicated the complex nature of relationships of the plant characters as for example,pod length, green pod weight, dry pod weight, seeds per pod and 100-seed weight not only exhibited highly significant positive correlation coefficients with green pod yield but they were also positively and significantly interrelated with each other in both the environments as well as in pooled environment (Tables 6,7 and 8). Days to flowering showed significantly negative correlations at genotypic and phenotypic level in both the environments suggesting early flowering may lead to the production of more pods. Similarly, pods per plant was significantly and negatively correlated with green pod weight and pod length at both phenotypic and genotypic level indicating more number of pods may lead to short pod length and consequently less green pod weight. In vegetable cowpea long pod, earliness and photoinsensitivity are three main desirable criteria to fit the crop in multiple crop-

ping system (Mishra *et al.*,1985). The traits and characters can exhibit significant correlations between each other by chance as well as by the occurence of genetic linkage, pleiotropy or developmental balance (Adams,1967). In the present study, it was not possible to draw conclusions about pleiotropy, linkage and developmental balance because seperation of these factors require study of variances and covariances among individuals within generations. However, chance is very unlikely to have caused such strong correlations between the characters as in the present study, fairly large samples were drawn at random in the two environments. Hazra (1991) observed significantly positive interrelationship between pod length and pod weight, pod length and seeds per pod, pod length and 100-seed weight, pod weight and seeds per pod and pod weight and 100-seed weight. Sharma *et al.* (1988) also observed more or less similar findings. The selection on the basis of any of the interrelated characters was expected to give a desired correlated response in other characters.

4.1.3 Path coefficient analysis

The complexity of character relationship among themselves and with green pod yield becomes evident from the discussion alone did not provide a comprehensive picture of relative importance of direct and indirect influences of each of the characters to the green pod yield as this trait was resultant product of combined effects of various factors complementing or

counteracting. The path coefficient analyses developed by Wright (1921) provides an effective means of untangling direct and indirect causes of association and permits a critical examination of the specific forces acting to produce a given correlation. Therefore to understand the relationship between green pod yield and other related characters, path analyses were worked out in two environments as well as pooled environment.

4.1.3.1 Components of green pod yield

The path analysis in different environments would help to identify those important components of green pod yield which would show consistency in their contribution to green pod yield without being influenced by change in environment. The results were given in Tables 9,10 and 11.

In environment one (E_1) though five characters exhibited significantly positive correlation coefficients with green pod yield per plant, only three characters such as green pod weight, pods per plant and dry pod weight registered high and positive direct effects on green pod yield per plant. Among these three characters, green pod weight exhibited highly positive direct effect on green pod yield per plant. Seeds per pod and branches per plant also showed positive direct effect on green pod yield per plant but to a negligible magnitude. Surprisingly, pod length showed high and negative direct effects on green pod

yield per plant. Days to flowering also exhibited negative direct effect but to smaller extent. The highly positive and significant correlation between pod length and green pod yield per plant was possible due to very high indirect positive effects of green pod weight. Interestingly, pods per plant although exhibited non-significant and low negative correlation with green pod yield per plant but through path analyses it was found that the effect of pods per plant on green pod yield per plant was highly positive. The high negative indirect effects of green pod weight was responsible for the low and negative correlation of pods per plant with green pod yield per plant (Table 9). The indirect effects of green pod weight and dry pod weight were positive in majority of the yield components. Seeds per pod and 100-seed weight although exhibited positive indirect effects in majority of the yield components but the magnitude was small. On the contrary, pods per plant exhibited highly negative indirect effects in majority of the yield components.

The environment two (E_2) and also pooled environment more or less exhibited a similar trend where green pod weight followed by pods per plant and dry pod weight registered very high positive direct effects on green pod yield per plant. The indirect effects of green pod weight and dry pod weight were high and positive through most of the yield components (Tables 10 and 11). Seeds per pod also showed positive direct effects on

Table 9 : Path-coefficient analysis of the components of green pod yield at phenotypic level for environment one (E_1)

Components	Direct and indirect effect via										Correlation with Green pod yield/plant
	Plant height	Branches/ plant	Peduncle length	Days to flowering	Pod length	Green pod weight	Dry pod weight	Pods/ plant	Seeds/ pod	100-seed weight	
Plant height	-0.169	-0.024	0.004	-0.017	-0.129	0.508	0.082	-0.251	0.046	0.010	0.061
Branches/Plant	0.029	0.141	-0.026	-0.003	0.086	-0.247	-0.103	0.105	0.001	-0.001	-0.018
Peduncle length	0.011	0.053	-0.068	-0.009	0.003	0.205	0.030	-0.142	0.018	0.010	0.111
Days to flowering	-0.045	0.007	-0.009	-0.064	0.095	-0.196	-0.030	-0.168	-0.028	-0.010	-0.448
Pod length	-0.068	-0.038	0.001	0.019	-0.320	1.339	0.184	-0.641	0.105	0.030	0.610
Green pod weight	-0.058	-0.024	-0.010	0.009	-0.293	1.467	0.165	-0.810	0.087	0.029	0.562
Dry pod weight	-0.049	-0.052	-0.007	0.007	-0.211	0.866	0.279	-0.405	0.089	0.019	0.534
Pods/Plant	0.043	0.015	0.010	0.011	0.210	-1.213	-0.116	0.978	-0.051	-0.015	-0.128
Seeds/Pod	-0.051	0.001	-0.008	0.012	-0.223	0.843	0.163	-0.332	0.151	0.026	0.582
100-seed weight	-0.042	-0.002	-0.017	0.016	-0.225	1.017	0.127	-0.357	0.094	0.042	0.653

Figures underlined indicate direct effects ; Residual effect is 0.2230.

Table 10: Path-coefficient analysis of the components of green pod yield at phenotypic level for environment two (E_2)

Components	Direct and indirect effect via										Correlation with Green pod yield/plant
	Plant height	Branches/ plant	Peduncle length	Days to flowering	Pod length	Green pod weight	Dry pod weight	Pods/ plant	Seeds/ pod	100-seed weight	
Plant height	-0.121	-0.021	-0.009	-0.048	-0.166	0.366	0.101	-0.166	0.034	0.010	-0.020
Branches/Plant	0.011	0.241	0.027	-0.084	0.136	-0.310	-0.121	0.162	0.004	-0.003	0.061
Peduncle length	0.015	0.091	0.070	-0.026	0.015	0.044	0.047	0.041	0.001	0.009	0.308
Days to flowering	-0.026	0.090	0.008	-0.224	0.105	-0.174	-0.035	-0.167	-0.004	-0.012	-0.439
Pod length	-0.048	-0.078	-0.002	0.056	-0.421	1.101	0.278	-0.510	0.079	0.032	0.486
Green pod weight	-0.036	-0.060	0.003	0.031	-0.373	1.243	0.245	-0.628	0.058	0.032	0.514
Dry pod weight	-0.031	-0.073	0.008	0.020	-0.293	0.763	0.398	-0.316	0.063	0.020	0.560
Pods/Plant	0.027	0.052	0.004	0.050	0.286	-1.038	-0.167	0.752	-0.031	-0.019	-0.084
Seeds/Pod	-0.035	0.008	0.001	0.007	-0.280	0.611	0.211	-0.194	0.118	0.030	0.476
100-seed weight	-0.026	-0.015	0.013	0.057	-0.285	0.834	0.169	-0.295	0.074	0.047	0.574

Figures underlined indicate direct effects ; Residual effect is 0.1846.

Table 11: Path-coefficient analysis of the components of green pod yield at phenotypic level over two environments pooled

Components	Direct and indirect effect via										Correlation with Green pod yield/plant
	Plant height	Branches/ plant	Peduncle length	Days to flowering	Pod length	Green pod weight	Dry pod weight	Pods/ plant	Seeds/ pod	100-seed weight	
Plant height	-0.143	-0.022	0.001	-0.035	-0.158	0.451	0.088	-0.214	0.044	0.008	0.019
Branches/Plant	0.018	0.178	0.001	-0.029	0.121	-0.300	-0.112	0.152	0.003	-0.002	0.032
Peduncle length	0.011	0.066	0.004	-0.020	0.006	0.122	0.038	-0.043	0.009	0.008	0.202
Days to flowering	-0.037	0.038	0.001	-0.135	0.122	-0.213	-0.039	-0.196	-0.016	-0.010	-0.485
Pod length	-0.056	-0.053	0.001	0.041	-0.405	1.270	0.222	-0.595	0.101	0.023	0.547
Green pod weight	-0.046	-0.038	0.001	0.020	-0.366	1.470	0.197	-0.735	0.080	0.023	0.543
Dry pod weight	-0.038	-0.061	0.001	0.016	-0.275	0.846	0.327	-0.371	0.083	0.015	0.543
Pods/Plant	0.035	0.031	0.001	0.030	0.273	-1.171	-0.137	0.883	-0.043	-0.013	-0.113
Seeds/Pod	-0.042	0.004	0.001	0.014	-0.274	0.756	0.182	-0.258	0.148	0.021	0.551
100-seed weight	-0.032	-0.008	0.001	0.039	-0.278	0.956	0.142	-0.332	0.092	0.034	0.614

Figures underlined indicate direct effects ; Residual effect is 0.2084.

green pod yield per plant to a small extent and its indirect effect was also positive through majority of the yield components in E_2 and pooled environment. So the importance of seeds per pod as yield component cannot be over looked. Days to flowering ,on the otherhand, exhibited negative direct effects on green pod yield per plant though the magnitude was not very high in E_2 as well as in pooled environment. This suggested that medium duration variety would probably be more meaningful for higher productivity in vegetable cowpea.

The results described above indicated that green pod weight and dry pod weight not only exhibited very high positive correlation with the green pod yield per plant but their direct as well as indirect positive contribution to green pod yield per plant were remarkably high in both the environments as well as pooled environment. Pods per plant although exhibited nonsignificant correlation with green pod yield per plant but the direct effect was highly positive indicating the importance of pods per plant as a criteria for improving green pod yield. This has reflected a real complex situation for improving yield because pods per plant and green pod weight were significantly and negatively correlated with each other. Seeds per pod although exhibited low direct and indirect positive effect on green pod yield per plant but the result was consistent in both the environments as well as pooled environment which suggest to include seeds per

pod as an important yield component. Not many reports were available in vegetable cowpea on path coefficient analysis. Hazra (1991) however, reported green pod weight and pod number per plant to be the main components of yield in the analysis pooled over three cultigroups while, Jana *et al.* (1983) observed pods per plant to be the main yield component. The present finding of negative direct effects of pod length and days to flowering on green pod yield per plant find support from Tewari and Goutam(1989),Jindal and Gupta (1984) and Padhey *et al.* (1984). The importance of seeds per pod as one of the major yield components as observed in the present findings was reported by Jindal and Gupta (1984), Padhey *et al.* (1984) and Tewari and Goutam (1989).

4.1.3.2 Components of green pod weight and pod length

The analysis of green pod yield components exhibited that green pod weight, dry pod weight and pods per plant were three major yield attributes in vegetable cowpea. In fact it appeared from the present analyses that green pod weight was the most important yield attributes. Out of these four characters, green pod weight was significantly and positively correlated with dry pod weight while negatively correlated with pods per plant. Therefore,selection in green pod weight would like to improve dry pod weight. Pod length though negatively correlated with green pod yield per plant and its direct and indirect effects were also

negative but in vegetable cowpea, pod length is one of the major selection criteria from the consumers' point of view. Within this scenario it was felt urgent to further analyse green pod weight and pod length to understand how these characters were being influenced by others. With this view in mind, two path coefficient analyses were carried out from the data pooled over two environments (Tables 12 and 13). The path analysis of green pod weight revealed that pod length was the most significant contributor for green pod weight as pod length showed high direct and indirect positive effects on green pod weight. It is to be mentioned that in inter-relationship between attributes also pod length and green pod weight were highly correlated. Thus it was suggested that selection for higher green pod weight would like to result in longer pod. Similar finding was also observed from the path analysis of pod length where green pod weight showed highest positive direct effects followed by seeds per pod. It therefore, indicated that to increase the pod length in vegetable cowpea, green pod weight and seeds per pod were the most important components (Tables 12 and 13). Pods per plant, on the otherhand, exhibited high negative direct effects on green pod weight as well as on pod length. Thus a genetic linkage in the negative direction appeared to exist between green pod weight and pods per plant. This is not encouraging for improving green pod yield in vegetable cowpea as improvement in green pod weight and pod length would decrease the pod number in plant. Thus a compro-

Table 12: Path-coefficient analysis of the components of green pod weight at phenotypic level over two environments pooled

Components	Direct and indirect effect via										Correlation with Green pod weight
	Plant height	Branches/ plant	Peduncle length	Days to flowering	Pod length	Dry pod weight	Pods/ plant	Seeds/ pod	100-seed weight	Green pod yield/plant	
Plant height	0.066	0.003	-0.001	-0.010	0.134	-0.015	0.136	-0.019	0.022	0.005	0.321
Branches/Plant	-0.008	-0.026	0.007	-0.008	-0.103	0.019	-0.097	-0.001	-0.004	0.009	-0.213
Peduncle length	-0.005	-0.010	0.019	-0.006	-0.005	-0.007	0.027	-0.004	0.021	0.055	0.087
Days to flowering	0.017	-0.005	0.003	-0.039	-0.014	0.007	0.125	0.007	-0.028	-0.133	-0.151
Pod length	0.026	0.008	0.001	0.012	0.344	-0.038	0.380	-0.044	0.065	0.150	0.903
Dry pod weight	0.018	0.009	0.002	0.005	0.233	-0.057	0.236	-0.036	0.042	0.149	0.602
Pods/Plant	-0.016	-0.004	-0.001	0.009	-0.232	0.024	-0.563	0.019	-0.036	-0.031	-0.832
Seeds/Pod	0.020	-0.001	0.001	0.004	0.233	-0.032	0.165	-0.064	0.059	0.152	0.537
100-seed weight	0.015	0.001	0.004	0.011	0.236	-0.025	0.211	-0.040	0.095	0.169	0.679
Green pod yield/plant	0.001	-0.001	0.004	0.019	0.188	-0.031	0.064	-0.035	0.059	0.275	0.543

Figures underlined indicate direct effects ; Residual effect is 0.0408.

Table 13: Path-coefficient analysis of the components of pod length at phenotypic level over two environments pooled

Components	Direct and indirect effect via										Correlation with Pod length
	Plant height	Branches/ plant	Peduncle length	Days to flowering	Green pod weight	Dry pod weight	Pods/ plant	Seeds/ pod	100-seed weight	Green pod yield/plant	
Plant height	0.137	0.005	0.001	-0.073	0.177	0.035	0.028	0.080	0.002	-0.002	0.389
Branches/Plant	-0.017	-0.037	-0.004	-0.060	-0.118	-0.044	-0.020	0.006	0.001	-0.004	0.299
Peduncle length	-0.011	-0.014	-0.012	-0.041	0.048	0.015	0.006	0.017	0.002	-0.026	-0.016
Days to flowering	0.035	-0.008	-0.002	-0.285	-0.084	-0.015	0.026	-0.029	-0.002	0.062	-0.301
Green pod weight	0.044	0.008	-0.001	0.043	0.552	0.078	0.097	0.145	0.006	-0.069	0.903
Dry pod weight	0.037	0.013	-0.001	0.034	0.332	0.130	0.049	0.151	0.004	-0.069	0.678
Pods/Plant	-0.033	-0.006	0.001	0.063	-0.460	-0.054	-0.117	-0.079	-0.003	0.014	-0.674
Seeds/Pod	0.041	-0.001	-0.001	0.030	0.267	0.072	0.034	0.270	0.005	-0.070	0.678
100-seed weight	0.031	0.002	-0.003	0.083	0.375	0.056	0.044	0.168	0.008	-0.078	0.686
Green pod yield/plant	0.003	-0.001	-0.002	0.138	0.300	0.070	0.013	0.149	0.005	-0.127	0.547

Figures underlined indicate direct effects ; Residual effect is 0.0654.

mise would be required between green pod weight and pods per plant.

From the foregoing correlation and path analyses,the following characters were identified which showed significant influences on green pod yield per plant -

i> pod weight

ii> pods per plant

iii> seeds per pod

iv> days to flowering

It was thus necessary to reconstruct the cowpea plant specially for vegetable purpose for moderately higher number of pods per plant having high pod weight coupled with increased number of seeds per pod through plant breeding programme. The developed ideotype should be of medium duration with higher green pod weight would hopefully help in improving pod length through correlated response.

4.2 Study on different root and nodule characters

In the foregoing section yield components were discussed with an objective of developing suitable plant type in vegetable cowpea. This knowledge of structural framework of cowpea will not throw light in its root and nodule characters. Cowpea which is considered to be drought tolerant as well as soil fertility improving crop, needs emphasis on improved rooting and

nodulation to evolve suitable plant type (Hall and Patel,1985).

A factor unique to the legumes is the symbiotic relationship that exist between them and certain bacteria that are capable of fixing atmospheric nitrogen, the legume can utilize. This property of adding nitrogen to the soil makes legumes an invaluable component in agriculture. This biological nitrogen fixation is mostly provided by the symbiotic association between many leguminous plants with bacteria of the genus *Rhizobium* and these di-nitrogen fixing symbiosis are easily recognised by the appearance of root nodules which harbour the nitrogen fixing micro-symbionts. Such symbiotic association in many legumes is known to influence yield and protein content. The role played by the plant in the symbiosis is to furnish carbohydrates that supply energy to the nitrogen fixing bacteria are used by the plant for their growth. Obviously, only a small, but sometimes significant, portion of the carbohydrates produced by the host plant is used to supply the energy requirements of the bacteria. All nitrogen fixed by the bacteria may not be available to the host plant for its use. Nitrogen may pass into the soil by the decomposition of cowpea plant after harvest, by excretion or by sloughing off of the roots, especially their nodules. Thus crop grown after cowpea or in association with cowpea may benefit from the fixed nitrogen. Effective cowpea *Rhizobium* symbiosis fix more than 150 kg N per hectare and supply 80-90% of host plant nitrogen requirement (Eaglesham *et al.*, 1977 and Summerfield *et*

al.,1977a).

Considering the importance of nodules as well as roots, attempts were made to study root and nodule development of cowpea at four different stages of crop growth i.e., pre-flowering, flowering, post-flowering and early pod setting stage over two years. Ten cowpea genotypes belonging to three cultigroups viz. Biflora, Unguiculata, Sesquipedalis with diverse characters were sown in the field where cowpea was grown successively for 3 seasons. The development of nodules and root was examined under the condition of native *Rhizobium* build up in the soil. The primary object was to analyse the varietal interaction to native *Rhizobium* in nodule development, influence of growth stages on root and nodule development,and to examine to what extent nodulation as well as root characters influences the growth of the plant and also yield. The results are presented in Tables 15a and 15b.

4.2.1 Nodule number per plant

A general picture emerged from Table 14 that number of nodules in the genotypes irrespective of cultigroups were higher in the Pre-kharif season than Rabi season . Cowpea is a typically tropical crop and nodule development was helped by the favourable high soil temperature condition that prevailed during Pre-kharif season. Many workers indicated that the degree and effec-

Table 14 : Mean values of different root and nodule characters over the cultigroups

Cultigroups	Root and Nodule characters																		Growth characters								Protein content of pod	Green pod yield/plant (g)
	Root length(cm)				Root weight(g)				Number of nodules/ plant				Nodule weight (g)/ plant			Leghaemoglobin content of nodules (O.D.)			Fresh shoot weight(g)				Dry shoot weight(g)					
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S4	S1	S2	S3	S4	S1	S2	S3	S4	S4	
Pre-kharif																												
Biflora	9.70	16.57	19.40	22.50	0.88	3.83	8.43	12.03	10.47	18.03	10.63	7.73	0.15	0.66	0.33	0.17	0.83	0.90	16.57	87.73	176.10	278.70	0.94	6.17	18.42	40.73	4.13	108.06
Unguiculata	12.90	16.00	20.12	22.60	1.12	4.68	17.30	20.36	7.98	21.33	17.54	11.90	0.20	1.06	0.78	0.42	0.75	0.86	18.34	116.85	393.34	580.60	1.11	9.52	46.30	93.40	3.94	293.65
Sesquipedalis	11.85	14.50	17.90	19.80	0.93	4.25	14.41	17.30	10.63	24.70	20.73	15.43	0.21	0.96	0.74	0.43	0.71	0.78	15.26	70.50	412.98	580.81	1.17	8.17	49.43	93.68	3.92	419.29
Rabi																												
Biflora	11.10	20.27	21.63	23.00	0.65	3.07	7.73	11.70	6.37	13.83	8.77	5.87	0.11	0.71	0.27	0.12	0.75	0.85	11.40	81.00	151.03	251.53	0.65	5.63	16.11	36.01	3.78	101.59
Unguiculata	13.65	18.76	21.80	23.21	0.92	4.54	18.00	21.70	7.87	17.53	13.16	9.56	0.18	0.94	0.76	0.35	0.67	0.78	14.55	112.96	354.90	472.40	0.89	8.74	40.55	72.80	3.69	207.02
Sesquipedalis	13.23	18.31	22.55	23.95	0.80	4.96	14.41	18.35	7.41	18.30	13.76	10.37	0.18	0.99	0.73	0.35	0.64	0.72	12.48	63.21	388.15	513.46	1.03	20.26	46.05	79.72	3.64	258.93

tiveness of nodulation is influenced by the environmental condition (Doku,1970; Terada,1971; Tewari,1965b; Pate and Dart,1961). Irrespective of genotypes and cropping season, nodule number was highest in the flowering stage and then gradually declined significantly in the two subsequent stages i.e.post-flowering and early pod setting stage. Similar observation was recorded in cowpea by AnthoniRaj *et al.*(1989). Patil and Shinde (1980) also reported that the decrease in nodule number was more pronounced towards maturity in all varieties of gram. However,in other pulse crop like green gram nodule number was highest at pre-flowering stage i.e. 10 days before flowering (Shanmugam and SreeRangasamy, 1981). In cowpea, nodulation should therefore be examined at flowering stage. Nodule number in the pre-flowering stage were low in all the genotypes which was almost doubled and in some cases tripled in the flowering stage of the plant. This finding indicated that nodule number in the plant was not static, rather it degenerates with the advanced growth stages. From the overview of the nodule number among the cultigroups it emerged that nodule number was highest in the cv-gr. Sesquipedalis followed by in the cv-gr.Unguiculata and cv-gr. Biflora. It is to be mentioned here that the Sesquipedalis genotypes are very high-yielders.

All the genotypes showed significant differences in nodule number in both the seasons at all four stages of crop growth (Tables 15a and 15b). The genotype Pusa Dofasli of cv-

Table 15a: Mean values of different root, nodule and other characters at four stages (S1,S2,S3 & S4) of crop growth in Pre-kharif season

Genotypes/ varieties		Growth characters: Fresh shoot weight (g)				Dry shoot weight (g)				Root and Nodule characters: Root length (cm)				Root weight (g)				Number of nodules/ plant				Nodule weight/ plant (g)				Leghaemoglobin content of nodules (O.D.)		Protein content of pod	Green pod yield/ plant (g)
		S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S4	S4	
T-2	U	18.83	61.40	402.50	570.40	1.30	14.49	54.50	99.47	15.27	16.40	18.70	22.03	1.37	2.43	14.10	16.50	10.30	26.47	22.33	13.20	0.09	0.48	0.36	0.13	0.67	0.72	3.80	346.91
T-5	U	16.47	65.73	533.50	770.37	1.03	4.95	60.02	118.33	13.70	14.33	20.53	22.20	0.71	3.84	12.00	13.82	5.40	18.63	15.60	10.47	0.12	0.69	0.63	0.32	0.84	0.90	4.10	233.37
Sel-Tm3	S	15.90	51.27	485.17	669.80	1.04	4.04	59.91	111.37	11.30	15.20	19.53	21.33	0.78	4.24	14.40	16.23	15.73	24.77	19.77	15.97	0.29	1.01	0.81	0.46	0.89	0.95	4.15	362.61
Local-4	U	15.70	59.07	527.00	758.27	0.77	3.70	61.39	125.67	15.17	18.18	20.57	23.73	1.15	3.48	18.40	22.43	6.63	16.13	13.53	10.03	0.25	1.03	0.92	0.42	0.94	1.10	4.30	317.90
H.G-22	U	21.03	164.50	242.63	398.80	1.17	11.28	30.86	68.67	11.87	15.77	21.40	22.60	1.10	5.02	18.57	22.80	10.60	22.53	19.73	12.83	0.34	1.58	0.97	0.55	0.71	0.84	3.94	260.34
1-101	U	19.40	173.63	281.73	410.00	1.27	11.95	30.48	58.43	10.47	14.93	18.60	20.00	1.40	6.26	19.73	20.73	4.87	14.40	10.77	8.13	0.35	1.61	1.10	0.65	0.75	0.87	3.90	253.79
13-31B	U	15.23	136.50	312.40	469.53	0.66	7.72	25.89	63.53	11.67	16.43	19.87	22.70	0.97	6.56	22.20	25.27	10.93	21.77	15.50	12.50	0.17	1.05	0.72	0.46	0.60	0.75	3.84	294.67
Cherodi	B	16.57	87.73	176.10	278.70	0.94	6.17	18.42	40.73	9.70	16.57	19.40	22.57	0.88	3.83	8.43	12.03	10.47	18.03	10.63	7.73	0.15	0.66	0.33	0.17	0.83	0.90	4.13	108.06
Pusa Dofasli	U	21.73	157.17	453.63	686.77	1.60	13.61	61.29	119.93	12.30	15.93	21.23	25.47	1.15	5.18	16.07	20.97	7.17	29.40	25.37	16.20	0.11	1.01	0.77	0.42	0.74	0.85	3.87	348.63
EC-305827	S	14.63	89.73	340.80	491.83	1.30	12.31	38.95	76.00	12.40	13.90	16.37	18.43	1.09	4.27	14.43	18.37	5.53	24.80	21.70	14.90	0.14	0.92	0.67	0.40	0.54	0.62	3.70	475.97
G.M.		17.55	104.67	375.54	550.44	1.109	8.92	44.17	88.21	12.38	15.76	19.62	22.10	1.06	4.51	15.83	18.91	8.76	21.70	17.50	12.19	0.201	1.003	0.73	0.398	0.750	0.852	3.98	300.22
C.D(5%)		2.12	3.61	48.00	68.14	0.29	1.50	6.57	10.73	1.51	1.57	1.78	1.90	0.29	0.75	5.00	4.53	1.73	2.96	3.80	3.00	0.04	0.05	0.07	0.08	0.03	0.03	0.05	46.38

S1 = Pre-flowering stage (30 DAS)
S2 = Flowering stage (40-50 DAS)
S3 = Post-flowering stage (60-70 DAS)
S4 = Early pod setting stage (70-80 DAS)

U = Unguiculata
S = Sesquipedalis
B = Biflora

Table 15b: Mean values of different root, nodule and other characters at four stages (S1,S2,S3 & S4) of crop growth in Rabi season

Genotypes/ varieties		Growth characters: Fresh shoot weight (g)				Growth characters: Dry shoot weight (g)				Root and Nodule characters: Root length (cm)				Root weight (g)				Number of nodules/ plant				Nodule weight/ plant (g)				Leghaemoglobin content of nodules (O.D.)		Protein content of pod	Green pod yield/ plant (g)
		S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S4	S4	
T-2	U	13.47	51.97	358.27	489.30	0.92	10.64	51.45	77.01	14.93	18.90	21.40	23.03	1.35	2.60	12.00	17.87	11.17	20.30	14.67	11.30	0.11	0.49	0.40	0.18	0.60	0.70	3.62	217.67
T-5	U	13.40	55.40	480.07	553.67	0.84	3.75	50.77	92.78	12.71	15.77	19.87	21.23	0.76	3.85	12.00	16.17	8.73	14.57	12.27	9.70	0.13	0.73	0.69	0.37	0.73	0.81	3.73	236.36
Sel-Tm3	S	12.83	53.70	458.67	574.83	0.87	3.86	55.43	92.39	13.10	17.63	20.80	22.67	0.82	4.50	15.70	19.00	11.00	18.80	13.70	10.87	0.25	0.97	0.74	0.38	0.78	0.87	3.84	236.20
Local-4	U	13.57	65.07	468.87	621.93	0.71	4.20	55.18	94.41	16.73	21.77	24.03	24.90	0.83	4.00	20.70	24.60	4.17	12.90	10.67	6.80	0.20	1.10	0.87	0.31	0.85	0.97	4.11	248.05
H.G-22	U	15.47	158.67	225.37	303.07	0.95	10.87	25.71	52.12	14.07	17.70	20.63	22.33	0.89	4.67	21.07	23.53	7.53	16.70	13.60	9.27	0.26	1.07	0.87	0.43	0.63	0.76	3.60	154.53
1-101	U	14.87	170.37	251.63	345.03	0.96	11.42	24.88	49.05	12.40	17.87	21.33	22.73	0.85	5.20	19.17	22.77	6.47	13.67	10.17	7.67	0.33	1.11	1.00	0.51	0.64	0.77	3.65	174.44
13-31B	U	12.37	143.93	273.37	388.70	0.63	8.04	21.78	46.13	12.00	19.67	22.40	23.37	0.77	5.50	25.00	27.13	11.47	21.87	14.77	11.13	0.18	1.02	0.73	0.33	0.56	0.68	3.61	206.58
Cherodi	B	11.47	81.00	151.03	251.53	0.65	5.63	16.11	36.01	11.10	20.27	21.63	23.00	0.65	3.07	7.73	11.70	6.37	13.83	8.77	5.87	0.11	0.71	0.27	0.12	0.75	0.85	3.78	101.59
Pusa Dofasli	U	18.70	145.37	427.10	605.27	1.25	12.32	54.14	98.10	12.77	19.70	23.03	24.93	1.03	5.97	16.10	19.80	5.60	22.73	16.00	11.10	0.11	1.08	0.81	0.36	0.69	0.80	3.57	231.73
EC-305827	S	12.13	72.73	317.63	452.10	1.20	9.26	36.67	67.05	13.37	19.00	24.30	25.23	0.78	5.43	13.13	17.70	3.83	17.80	13.83	9.87	0.11	1.02	0.73	0.33	0.51	0.57	3.45	281.67
G.M.		13.82	99.82	341.20	458.54	0.89	8.00	39.21	70.50	13.31	18.82	21.94	23.34	0.87	4.47	16.26	20.02	7.64	17.31	12.84	9.35	0.17	0.93	0.71	0.33	0.67	0.77	3.70	206.86
C.D.(5%)		1.96	3.21	35.60	34.28	0.19	1.37	6.63	9.72	1.32	0.05	1.02	0.04	0.15	0.93	3.86	3.97	1.83	3.10	2.06	2.08	0.03	0.06	0.08	0.04	0.02	0.03	0.04	24.10

S1 = Pre-flowering stage (30 DAS)
S2 = Flowering stage (40-50 DAS)
S3 = Post-flowering stage (60-70 DAS)
S4 = Early pod setting stage (70-80 DAS)

U = Unguiculata
S = Sesquipedalis
B = Biflora

gr.Unguiculata showed maximum nodule number in the flowering stages in both the seasons. The other Unguiculata genotypes exhibited varied performances. Nodule number at flowering stage in Unguiculata genotypes ranged from 14.40 - 29.40 in Pre-kharif season and from 12.90-22.73 in Rabi season. The two Sesquipedalis genotypes registered almost similar performance in both the seasons where nodule number ranged from 24.77-24.80 in Pre-kharif season and from 17.80-18.80 in Rabi season. Nodule number in the genotype Cherodi, the only Biflora type was 18.03 in Pre-kharif season and 13.83 in Rabi season. This result indicated positive genotype X inherent *Rhizobium* interaction which resulted varied incitation of the symbiosis. Doku (1970) reported that nodulation in cowpea was influenced by the cultivars.

Nodule number is an important character as several workers found positive correlation among nodule number and shoot and root dry weight (Thompson and Dennis,1976; Pandey *et al.*,1981; Miller *et al.*,1986). Wide variability in the nodule number among these genotypes particularly in the peak stage (flowering stage) indicated that this character could be used as a selection index for improving nodulation as well as other related characters in cowpea.

4.2.2 Nodule weight per plant

It is possible that there may be an increase in nodule

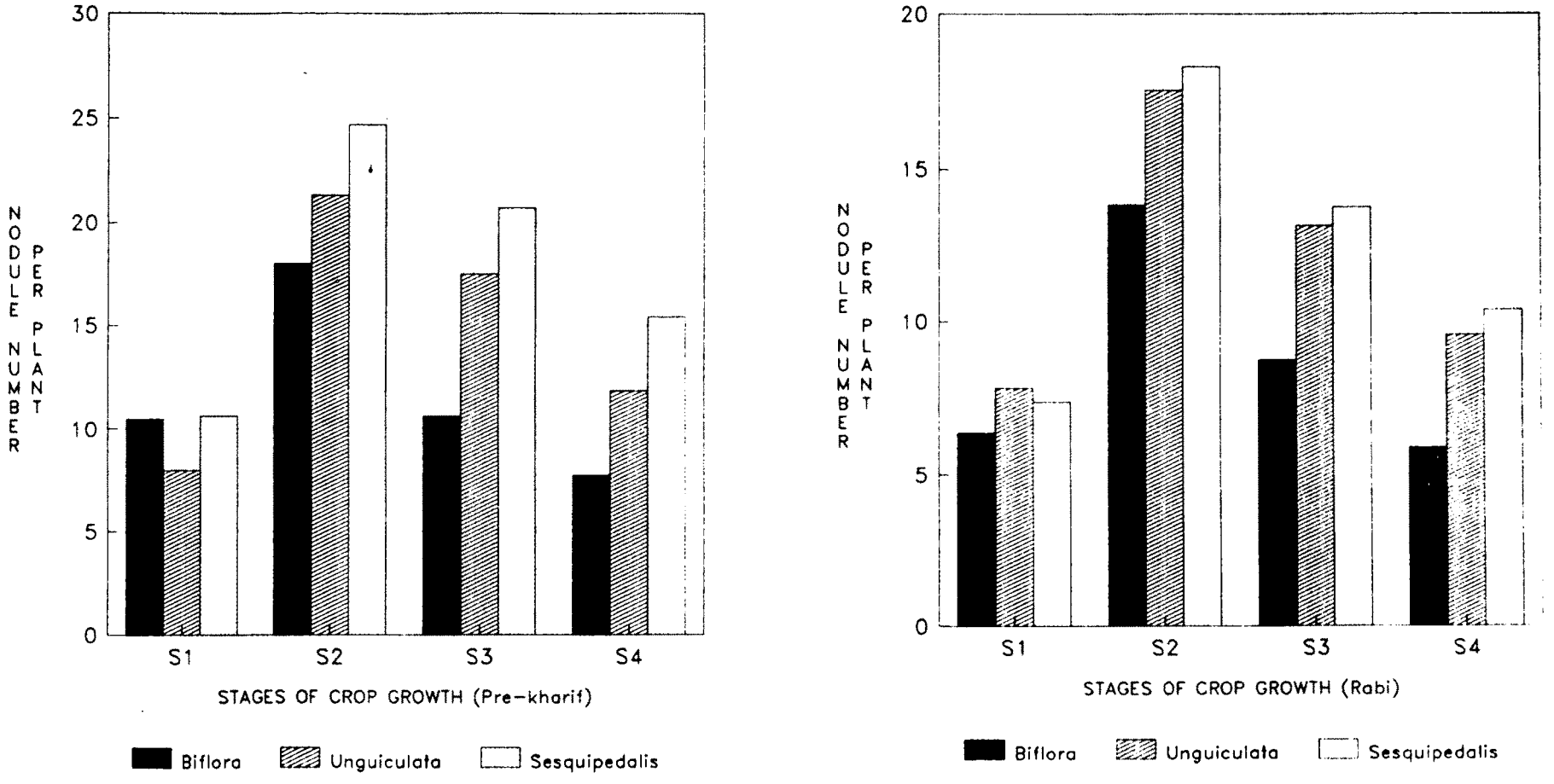


FIG.1: Nodule number of three cultigroups of cowpea in four different growth stages

number without the proper growth and development of nodules. Poorly developed nodules could not be efficient in their activity. It is therefore, desirable that nodulation in plant should be accompanied with proper growth and development of nodules. Nodule size as measured by nodule weight can be considered as the index for nodule growth.

Nodule weight per plant did not show any definite variation with the season of cultivation (Tables 15a and 15b). Hence nodule weight of cv-gr. Unguiculata and Sesquipedalis was higher in Pre-kharif season as compared to Rabi season while that of Biflora registered the reverse. However, there was an apparent trend of increased nodule weight in the Pre-kharif season which might have happened due to increased nodule number in the genotypes grown in Pre-kharif season. Influence of environment on nodulation and nodule dry weight has been reported by several workers (Doku,1970; Terada,1971; Tewari,1965b; Pate and Dart, 1961; AnthoniRaj *et al*,1989). In all the genotypes, irrespective of cropping season, nodule weight per plant at flowering stage was 3-4 times higher than what was in the pre-flowering stage. Nodule weight sharply declined in the 4th stage i.e. 30 days after flowering in all the genotypes. In the 3rd stage i.e. 20 days after flowering, nodule weight slightly declined in most of the genotypes in both the growing seasons.

From the overview of the cultigroups it was clear that

nodule weight was highest in the flowering stage and then gradually declined significantly in two subsequent stages. Deviation of this picture in some of the genotypes (T-5,Local-4, T-2, 1-101 of cv-gr. Unguiculata in Rabi season) might have heppened due to degeneration of small ineffective nodules with subsequent increase in size of the effective nodules. Narayana and Gothwal (1954) reported that nodules close to soil surface degenerated in 32 days in black gram with an increase in their number in the secondary and tartiary roots.

In the present investigation, nodule number sharply declined after flowering stage of the plant and degeneration of nodules might have increased the size of the remaining nodules in the next stage of some of the genotypes as stated before. This finding suggests that nodule weight of cowpea should be considered in both flowering and post-flowering stages.

All the genotypes showed significant differences in nodule weight in both the seasons at all stages of crop growth (Tables 15a and 15b). The two genotypes 1-101 and H.G-22 of cv-gr. Unguiculata registered high nodule weight at the flowering stage consistently in both the seasons. On the otherhand, the genotype T-2 exhibited very low nodule weight at the flowering stages in both the seasons. Nodule weight at flowering stage in Unguiculata genotypes ranged from 0.48 g to 1.61 g in Pre-kharif season and from 0.49 g to 1.11 g in Rabi season. The two Sesqui-

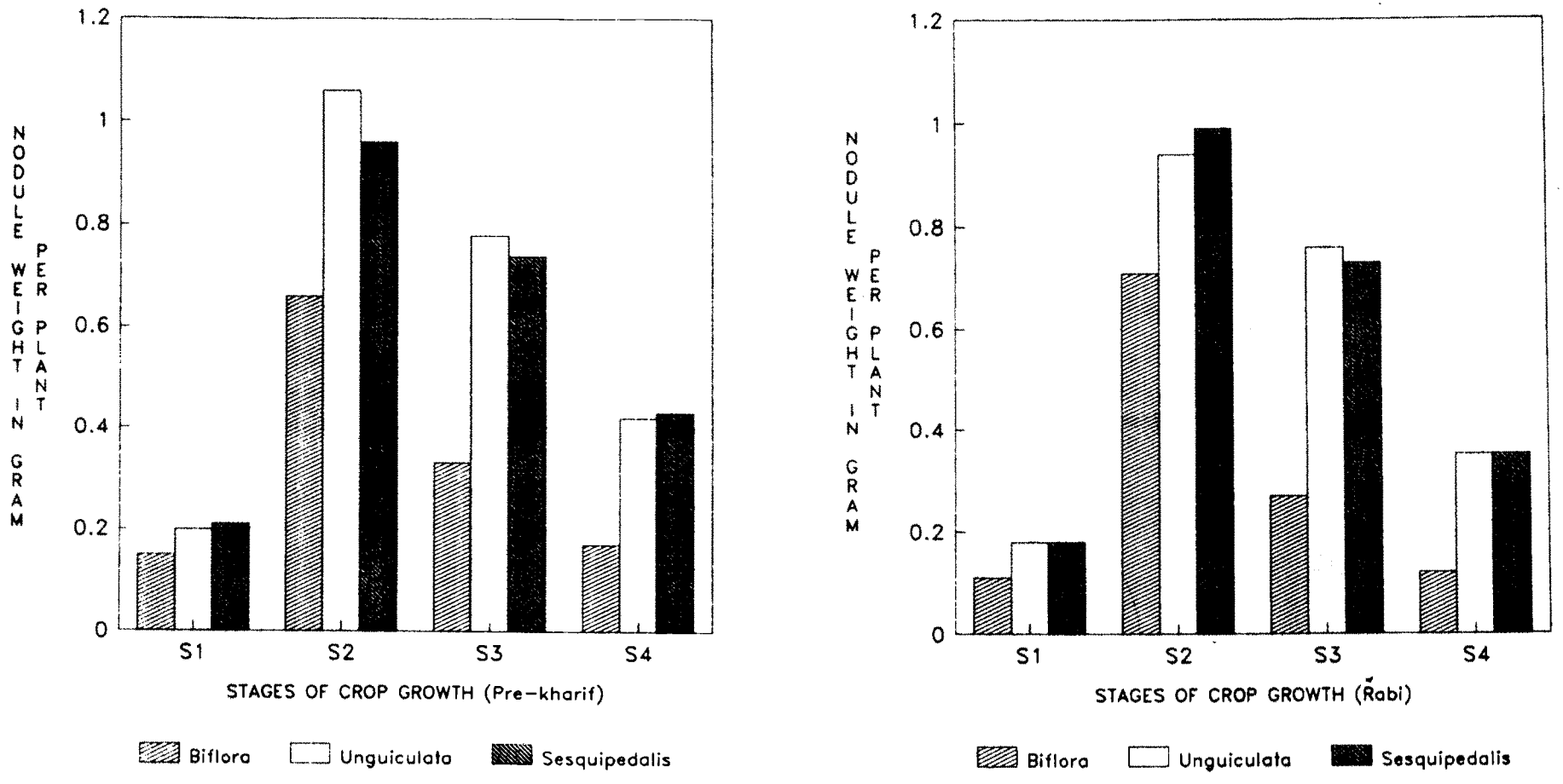


FIG.2: Nodule weight of three cultigroups of cowpea in four different growth stages

pedalis genotypes (Sel-Tm3 and EC-305827) showed almost similar performances in both the seasons where nodule weight ranged from 0.92 g to 1.01 g and from 0.79 g to 1.02 g in Pre-kharif and Rabi seasons, respectively. Nodule weight in the genotype Cherodi of cv-gr. Biflora was 0.66 g in Pre-kharif season and 0.77 g in Rabi season. This significant variation in nodule weight among the genotypes belonging the three cultigroups of cowpea indicated that the genotypes reacted differentially during the infection of the *Rhizobium* strain (s) indigenous to the soils.

Nodule weight is an important character and its positive correlation with nitrogenase activity, nodule number , shoot weight and shoot and root dry weight has also been reported (Miller *et al.*,1986; Thompson and Dennis, 1976; Pandey *et al.*,1981). So this nodule character may be regarded as a selection index during improvement of cowpea for increased nitrogen fixation ability.

4.2.3 Leghaemoglobin content of nodule

Nitrogen fixation is essentially an anaerobic process and have the nodule must have a mechanism to exclude oxygen from the bacteroid which is the site of fixation. Low oxygen is necessary for induction of nitrogenase and the maintenance of high flux of oxygen at low concentration is needed for efficient nodule operation. This is accompanied by the presence of leghae-

moglobin around bacteroids enclosed by membranous envelops of host origin. This pigment limits oxygen supply and helps in providing low oxygen condition near the bacteroids with the result that not only the oxygen sensitive nitrogenase is prevented from damage but also that enough oxygen is available at the site for ATP generation (Appleby,1984). Recent evidence indicate that leghaemoglobin is distributed in the cytoplasm of host cell (SubbaRao,1988). The amount of leghaemoglobin and the extent of bacteroid tissue in nodules have a direct bearing on the amount of nitrogen fixed by the legumes (Bergersen and Briggs, 1958; Chopra and SubbaRao,1967; Verma and Bal,1976).

In both the years leghaemoglobin content increased from the Pre-flowering stage (1st stage) to 30 days after flowering stage (4th stage) in all the genotypes which might have happened due to increase in nodule size in the later stage. A consistent picture appeared in the leghaemoglobin content of nodules of the cultigroups. In both the growing seasons, the leghaemoglobin content was highest in cv-gr. Biflora followed by cv-gr. Unguiculata and cv-gr. Sesquipedalis (Tables 15a and 15b). Irrespective of the cultigroups and individual genotypes,leghaemoglobin content in the nodules was higher in the Pre-kharif season as compared to Rabi season due to increase in nodule weight in the Pre-kharif season which we have discussed earlier.

The genotypes Sel-Tm3 and Local-4 showed high leghae-

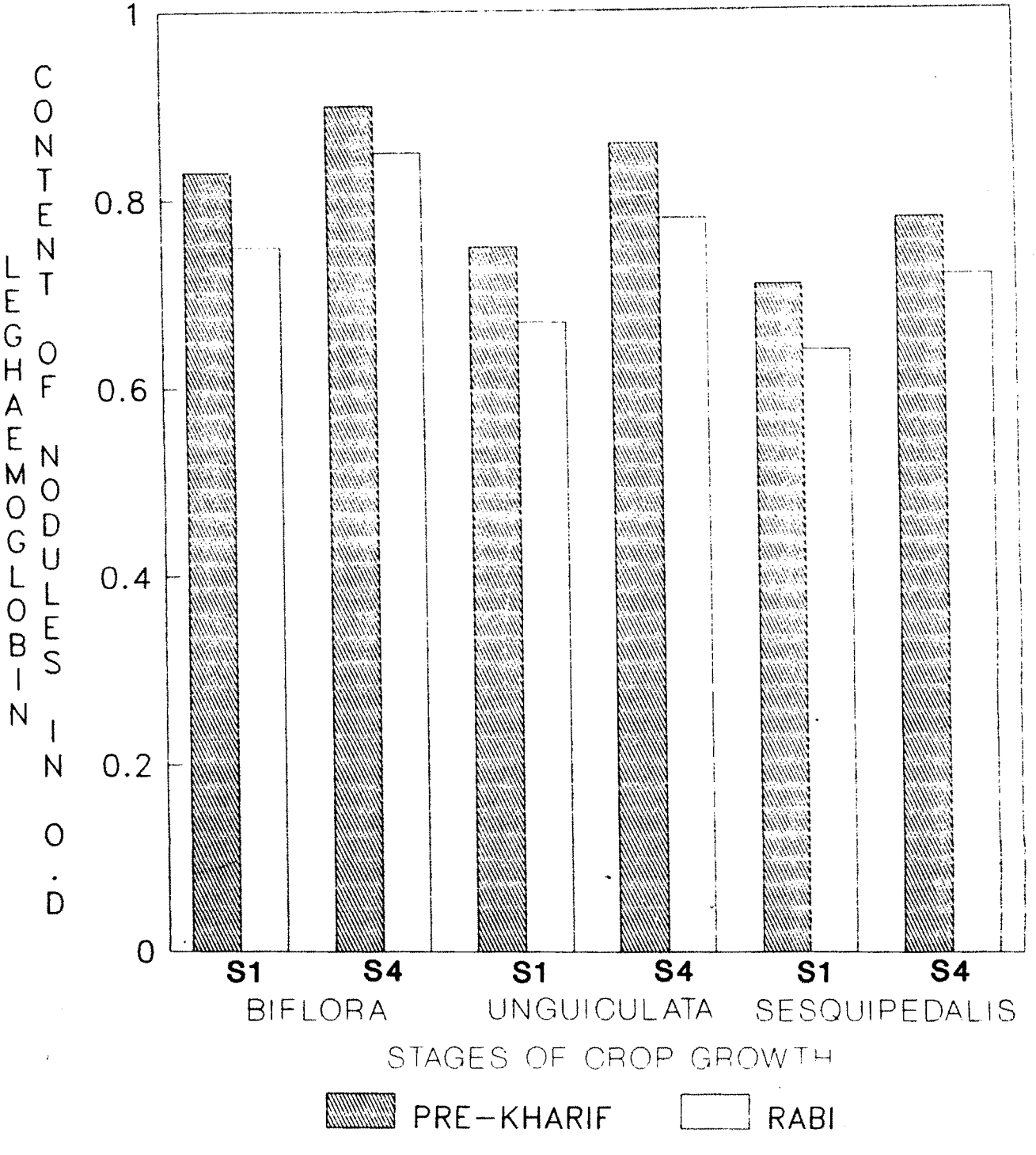


FIG 3 : Leghaemoglobin content of nodules of three cultigroups of cowpea in two different growth stages

moglobin content in both the stages and years. The performance of Cherodi and T-5 were also moderately high consistently in two stages and years. The genotype EC-305827, on the otherhand, exhibited very low leghaemoglobin content at two stages over the years.

Importance of leghaemoglobin content in the study of nodule characters in legume crops has already been discussed by several workers. Seeing the significant variation in the leghaemoglobin content in the different genotypes of cowpea it is suggested that this character may be regarded as selection index for improving cowpea with enhance nitrogen fixing ability.

4.2.4 Associationship among nodule and plant growth characters

There emerged highly significant associationship between fresh weight and dry weight of shoot irrespective of stages of crop growth (Tables 16,17,18 and 19). Correlation with root length and shoot weight (both fresh and dry) was not significant in all the stages of crop growth indicating less variation in root length in the genotypes of cowpea. Root weight registered significantly positive correlation with fresh shoot weight only in the flowering stage (Stage 2). However, correlation between nodule number and dry shoot weight was highly positive in Stage 2,Stage 3 and Stage 4. Such associationship between nodule number and shoot dry weight was previously reported by Thompson and

Table 16: Phenotypic (P) and genotypic (G) correlation coefficients of seven characters in Stage 1 over two environments pooled

Characters		Dry shoot weight	Root length	Root weight	Nodule number/ plant	Nodule weight/ plant	Leghaemoglobin content of Nodule
Fresh shoot Weight	P	0.721*	-0.003	0.418	-0.067	0.109	-0.021
	G	0.650	0.058	0.624	-0.198	0.163	-0.012
Dry shoot Weight	P		-0.004	0.504	-0.293	-0.119	-0.311
	G		0.002	0.598	-0.391	-0.140	-0.361
Root Length	P			0.365	-0.097	-0.104	0.143
	G			0.669	-0.054	-0.090	0.186
Root Weight	P				-0.085	-0.026	-0.324
	G				-0.127	-0.042	-0.375
Nodule number/ plant	P					0.053	0.035
	G					0.019	0.048
Nodule weight/ plant	P						0.216
	G						0.229

Table 17: Phenotypic (P) and genotypic (G) correlation coefficient of six characters in Stage 2 over two environments pooled

Characters		Dry shoot weight	Root length	Root weight	Nodule number/ plant	Nodule weight/ plant
Fresh shoot Weight	P	0.618*	-0.020	0.773*	0.047	0.798*
	G	0.622	-0.048	0.855	0.038	0.818
Dry shoot Weight	P		-0.042	0.347	0.423	0.262
	G		-0.101	0.380	0.464	0.271
Root Length	P			-0.035	-0.012	-0.109
	G			-0.242	-0.052	-0.122
Root Weight	P				0.267	0.728
	G				0.253	0.808
Nodule number/ plant	P					-0.139
	G					-0.184

* The correlation coefficients must exceed 0.632 and 0.765 to be significant at the 5% and 1% level, respectively.

Table 18: Phenotypic (P) and genotypic (G) correlation coefficient of six characters in Stage 3 over two environments pooled

Characters		Dry shoot weight	Root length	Root weight	Nodule number/ plant	Nodule weight/ plant
Fresh shoot Weight	P	0.945*	0.127	0.024	0.315	0.178
	G	0.952	0.823	0.012	0.393	0.193
Dry shoot Weight	P		0.107	-0.079	0.436	0.078
	G		0.964	-0.111	0.537	0.095
Root Length	P			0.147	0.256	0.153
	G			0.977	0.795	0.884
Root Weight	P				0.008	0.644
	G				0.046	0.775
Nodule number/plant	P					0.067
	G					0.009

Table 19: Phenotypic (P) genotypic (G) correlation coefficients of nine characters in Stage 4 over two environments pooled

Characters		Dry shoot weight	Root length	Root weight	Nodule number/ plant	Nodule weight/ plant	Leghaemoglobin content of Nodule	Protein content of pod	Green pod yield/ plant
Fresh shoot Weight	P	0.984**	0.249	0.087	0.410	0.061	0.599	0.362	0.356
	G	0.986	0.770	0.088	0.486	0.049	0.643	0.370	0.366
Dry shoot Weight	P		0.264	0.013	0.408	0.018	0.544	0.382	0.356
	G		0.869	0.012	0.491	0.007	0.587	0.392	0.368
Root Length	P			0.307	0.295	-0.120	0.260	0.276	0.097
	G			0.859	0.750	-0.314	0.903	0.843	0.379
Root Weight	P				0.185	0.560	0.260	-0.012	-0.107
	G				0.174	0.669	0.307	-0.015	-0.102
Nodule number/plant	P					0.157	0.568	-0.375	-0.401
	G					0.073	0.726	-0.462	-0.517
Nodule weight/plant	P						0.206	0.030	-0.076
	G						0.208	0.038	-0.086
Leghaemoglobin content of Nodule	P							-0.035	-0.283
	G							-0.374	-0.300
Protein content of pod	P								0.378
	G								0.383

* The correlation coefficients must exceed 0.632 and 0.765 to be significant at the 5% and 1% level, respectively.

Dennis (1976) and Pandey *et al.*(1981). Nodule weight registered significantly positive correlation with fresh shoot weight in the flowering stage only (Table 17). From this findings, associationship among nodule number,nodule weight and shoot weight was apparent, although dependent on the stages of crop growth. The importance of flowering stage in nodulation activity as compared to other stages was already mentioned . Interestingly, the associationship among growth and nodule characters was very much pronounced in the flowering stage only indicating the momentum of peak nodulation on the vegetative growth. Similar favourable effect of nodulation on growth of cowpea was recorded by Pawar and Ghulghule (1980) and AnthoniRaj *et al.* (1989). So it is suggested that the associationship among root, nodule and growth characters should be undertaken in the flowering stage of the plant to unveil the intricate relationship.

4.2.5 Associationship among nodule characters,yield and protein content

No significant correlation was recorded between nodule number and nodule weight in any stages of crop growth which was contary to the findings of Thompson and Dennis (1976) and Pandey *et al.* (1981).

The associationship though not significant yet was positive in all the growth stages excepting the flowering stage where the associationship was negative (Table 17). This might

have happened due to mutual balancing of number and weight of nodules.

Leghaemoglobin content of nodule which measures the nodule efficiency for nitrogen fixation registered markedly positive correlation with nodule number in the 30 days after flowering stage (Stage 4), but this correlation in Stage 1 (Pre-flowering stage) was very low in magnitude. In Stage 4, highly positive correlation between leghaemoglobin content and both fresh and dry shoot weight was recorded, which did not exist in stage 1 (Table 16). Positive correlation between leghaemoglobin content and nodule number was quite expected because this lentins (Phytohaemogglutenin) was present around the bacteroids enclosed by membranous envelops of host origin (SubbaRao,1988).

Nodule number, Nodule weight, leghaemoglobin content of nodule and protein content of pod did not show any significant correlation with green pod yield per plant (Table 19). Yield is a very complex character and very much influenced by genotype X environment interaction. The formation and maturity of nodules and fixation of atmospheric nitrogen constitute a complex system indicating a rather specific relationship, between the host plant and the rhizobial strain. So more information on symbiotic nitrogen fixation is required to establish the complex relationship between nodule characters and yield. Similar to our findings, nodule number recorded for different strains under field condi-

tions did not show significant correlation with grain yield of cowpea (Schiffmann and Lobel,1973; Bagyaraj and Hedge,1978; Sivaprasad and ShivappaShetty,1980).

There was no significant correlation between protein content of the pod (15 days maturity) and both nodule number and weight which was in confirmity to the pevious report of Sivaprasad and SivappaShetty (1980). Miller *et al.*(1986), however, reported that there were positive and significant correlations between nitrogenase activity and both nodule number and weight. In the present investigation protein content (indicative to nitrogen content) was estimated in the pods of 15 days harvest when deposition of protein to the sink (seed) was not completed. Nitrogen is generally concentrated in the leaves during vegetative growth, becoming localized in the seed towards the end of the vegetative period (Jacquinot,1967). For this reason influence of nitrogen fixation interms of channelization of protein to the sink could not be unveiled properly. The nodule is merely a protective structures since it is now well established that becteroids are the seats of nitrogen fixation. The enzyme nitrogenase mediates the reduction of Nitrogen to Ammonia. Leghaemoglobin around the bacteroids not only prevent the oxygen sensitive nitrogenase from damage but also makes enough oxygen available at the site for ATP generation. In our investigation,leghaemoglobin content of nodules which indirectly measures nitrogen fixation

did not register any significant correlation with protein content of the immature pods (15 days harvest). Several workers reported that the amount of leghaemoglobin and the extent of bacteroid tissues in nodules have a direct bearing on the amount of nitrogen fixed by the legumes (Bergersen and Briggs, 1958; Chopra and SubbaRao, 1967; Verma and Bal,1976). It may be mentioned that in the present investigation no associationship between leghaemoglobin content and total protein content might be due to the fact that the protein content of the immature pods were estimated, where deposition of protein was not completed. This associationship needs more critical analysis so that seed protein and left over protein in the plant (Total protein) are estimated separately.

From the study of the root and nodule characters it emerged that

a) Nodule development largely depends on stages of crop growth and flowering stage is the most important stage of cowpea for the proper development of nodule characters.

b) Vegetative growth was markedly influenced by the nodule characters.

c) Along with nodule numbers,nodule weight and leghaemoglobin content of nodules, shoot dry weight of the plant should be considered as selection index in the improvement programme of cowpea.

4.3 Adaptability analysis

Most plant scientists would agree that a primary objective of applied biological research is the improvement of plant adaptation. However, there would probably be substantial disagreement as to the precise meaning of adaptation. The terms adaptation has been applied to both a process and a condition. On one hand it is used to refer to the action or process of becoming modified to suit new circumstances on the other it may be used to refer to the state or condition of adaptedness; that is to the performance of a genetic population in an environment or a range of environments, or in narrow-sense, even to the possession of a specific trait which has an effect on performance. Whatever,the term clearly implies genetic change as the basic principle and environmental pressure are the driving forces of such change.

The importance of genotype X environment interactions in most investigations of quantitative genetics has been widely discussed (Comstock and Moll,1963). Even though the importance of genotype X environment interactions has been recognised well and these are known to be heritable (Jinks and Mather,1955). The significance of linear regression analysis of G X E interactions in crop breeding programme has been understood not much ago (Wright, 1976). Moreover,in vegetable cowpea, the investigation of G X E interactions has been rarely addressed (Sulochana and Peter,1987). Under this scenario, it becomes important to study

the nature and extent of G X E interactions and its impact on the stability.

In the present study, an attempt has been made to examine the adaptability of twenty cowpea genotypes in two different locations and different years comprising altogether five different environments through an analysis of G X E interactions adapting the approach of regression analysis of Eberhart and Russell (1966). The results of regression analysis in twenty genotypes are presented in table 20 and discussed below.

The perusal of summary table (Table 21) for individual characters over the environments revealed that green pod yield per plant ranged from 186 to 394 g with an average of 264 g. Pods per plant varied from 15.20 to 47.60 g with an average of 24.20 g over the environments. Days to flowering indicated a variation from 42 to 57 days with a mean of 51 days. Pod length ranged from 42.50 to 16.10 cm with an average of 26.80 cm. Green pod weight varied from 19.80 to 4.50 g with a mean of 12.40 g. Dry pod weight exhibited a variation from 2.42 to 0.49 g with an average of 1.42 g. Best performing environment for green pod yield per plant and pods per plant was found to be environment one (E_1). While for pod length, green pod weight and dry pod weight, E_4 was the best environment.

The environmental index has been worked out according

Table 20 : Genotype x Environment and regression analysis for six characters in 20 genotypes of vegetable cowpea

Source	D.F.	Green pod yield /plant M.S.	Pods/ plant M.S.	Days to flowering M.S.	Pod length M.S.	Green pod weight M.S.	Dry pod weight M.S.
Genotype(G)	19	14083.08** ++	553.13** ++	66.11** ++	278.63** ++	110.33** ++	0.99 ** ++
Environment(E)	4	61049.87** ++	211.66** ++	2640.72** ++	49.85** ++	32.87** ++	0.130** ++
G X E interaction	76	788.05** +	4.46** +	12.34** ++	4.05** ++	1.41**	0.012**
Environment + (G X E)	80	3801.14** ++	14.82** ++	143.75** ++	6.34** ++	2.98** ++	0.018** ++
Environment (linear)	1	244201.48** ++	846.66** ++	10562.88** ++	199.41** ++	131.48** ++	0.521** ++
G X E (linear)	19	1728.63** ++	8.96** ++	33.80** ++	4.69**	2.38** ++	0.022** ++
Pooled deviations	60	450.76**	2.82**	4.92**	3.64**	1.03**	0.009**
Pooled error	190	227.16	1.45	1.728	1.279	0.361	0.0032
Linear component(%)		73.31	76.06	87.30	56.30	69.80	70.97
Nonlinear component(%)		20.69	23.94	12.70	43.70	30.20	29.03

** significant at 1% level against pooled error.
+ and ++ significant at 5% and 1% level respectively against pooled deviation.

to Eberhart and Russell (1966). This involved calculating an index for each environment, based on the mean performance of all populations under comparison, measured as deviation from general mean over the environments for that trait. Environment one (E_1) exhibited highest environmental index for green pod yield per plant, pods per plant, and also considerably high positive value for pod length and green pod weight (Table 22). On the contrary, E_5 showed highly negative value for all the traits except days to flowering. Inspite of many objections to this environmental index (Tai,1974; Hardwick and Wood,1972), it has been shown that generally that interpretation of a set of data dependent little on whether independent or dependent values were used for the index in calculating the regression slopes (Parkins and Jinks,1973; Fripp and Caten,1973). The analysis of variance indicated that differences between the genotypes and environments were highly significant for all the characters (Table 20). G X E interaction was also found highly significant for green pod yield per plant and its components indicating that genotypes showed differential response in different environments with respect to these characters. The magnitude of G X E interaction variance was smaller as compared to genotype and environmental vaiances for these characters. Similar observations were reported by Kandalkar and Sanghi (1982) and Sanghi and Kandalkar (1983) in forage cowpea; Kandasamy *et al.* (1985) in pulse cowpea and Sulochana and Peter (1987) in vegetable cowpea. Both the environment (linear) and G X E

Table 21 : Summary of individual characters over the environments for 20 genotyes of vegetable cowpea

	Green pod yield/plant (g)	Pods /plant	Days to flowering	Pod length (cm)	Green pod weight (g)	Dry pod weight (g)
Average value	263.58	24.24	50.58	26.81	12.36	1.42
Range	393.89-185.79	47.64-15.17	57.33-41.93	42.45-16.13	19.81-4.48	2.42-0.49
Environment						
with highest mean	E_1	E_1	E_3	E_4	E_4	E_4
With poorest mean	E_5	E_2	E_1	E_5	E_5	E_5

Table 22 : Estimates of environmental additive effects (I_g) for 5 environments for six characters of vegetable cowpea.

Locations	Green pod yield/plant	Pods /plant	Days to flowering	Pod length	Green pod weight	Dry pod weight
E_1	60.01	4.47	-20.13	1.25	0.48	-0.12
E_2	-26.66	-0.59	5.72	-1.66	-1.05	0.02
E_3	-36.55	-2.09	8.38	-0.911	-0.93	0.06
E_4	58.88	1.95	2.15	2.069	2.03	0.09
E_5	-55.63	-3.72	3.90	-0.741	-0.52	-0.03

(linear) components of variance were highly significant for all the traits. This indicated that the genotypes responded differently in varying environments. Deviation from regression i.e. pooled deviation were also found to be highly significant for all the traits. However,linear component was relatively greater than non linear component for all the traits indicating that the performance of genotypes could be predicted. Sulochana and Peter (1987) also observed similar finding in vegetable cowpea. The relative performance of individual genotypes are discussed below trait wise.

4.3.1 Green pod yield per plant

There was considerable variation between the environments (Table 23). ANOVA has shown that mean and slopes of different genotypes differed among themselves. The proportion of genotypes showing predictable behaviour across the location was 79.3%. Based on the estimates of mean,b_i and S^2_{di} values, twenty genotypes could be classified into different groups adapted to different environments of adaptability . Of all the genotypes, highest mean was exhibited by EC-305827 followed by EC-243954. Altogether seven genotypes namely,EC-305827, EC-243954, Sel-Tm1, Sel-Tm3, Pusa Dofasli, T-2,Local-9, Local-16, and Local-4 showed mean performance above the general mean. Out of these nine genotypes, Sel-Tm1, Sel-Tm3 and EC-243954 exhibited b_i value close to 1 with low S^2_{di} value. Eberhart and Russell (1966) classified

Table 23 : Estimates of stability parameters according to Eberhart and Russell (1966) model for six characters of vegetable cowpea

Variety	Green pod yield /plant			Pods / plant			Days to flowering			Pod length			Green pod weight			Dry pod weight		
	u_i	b_i	S^2d_i	u_i	b_i	S^2d_i	u_i	b_i	S^2d_i	u_i	b_i	S^2d_i	u_i	b_i	S^2d_i	u_i	b_i	S^2d_i
Pusa Barsati	190.63	0.83	864.10	26.82	1.94**	9.04	57.33	0.60**	24.00**	16.13	-0.06	2.17	7.15	0.29	1.76	1.39	0.93	0.001
Pusa Dofasli	304.39	1.26	993.99	30.99	1.61*	12.52*	50.67	0.88	8.96	22.49	1.61	2.93	9.76	0.66	0.96	1.30	1.16	0.011
Sel-Tm1	282.26	1.00	388.64	16.02	0.74	1.00	47.73	0.96	18.26*	31.60	-0.04	10.64*	17.55	1.05	0.54	1.62	0.87	0.122**
Sel-Tm2	256.87	0.83	728.03	15.74	0.87	3.80	56.73	0.95	3.21	30.75	0.19	30.32**	16.46	0.91	14.92**	1.44	3.04**	0.077**
Sel-Tm3	306.38	0.88	95.74	17.20	0.84	3.53	52.27	1.27**	6.05	37.53	1.42	9.00	17.93	0.75	10.42**	1.86	2.07	0.022
Arka Garima	185.79	1.43*	164.24	19.41	1.40	6.38	52.27	1.33**	33.18**	19.63	1.67	0.92	9.21	1.40	3.15*	0.85	0.43	0.042**
Sel-Tm4	208.51	1.31	1112.89	19.13	1.15	10.12	50.33	1.28**	2.57	21.26	1.76	9.85	10.59	1.46	0.51	1.01	0.71	0.043**
EC-305827	393.89	1.19	935.71	19.77	0.58	3.86	41.93	0.68**	4.87	42.45	1.70	6.97	19.81	1.24	1.66	2.42	0.92	0.012
EC-243954	328.42	0.87	1277.18	33.79	1.00	8.57	45.93	0.73**	44.97**	22.18	1.19	4.92	9.70	0.50	1.06	1.05	0.97	0.001
5269	233.90	0.61*	705.56	44.18	1.33	8.25	46.80	0.99	16.84**	20.16	-0.01	0.66	5.27	0.18*	0.15	1.01	0.48	0.006
1-101	214.00	0.03**	2294.90*	47.64	0.40*	17.89**	49.13	1.41**	17.46**	17.67	0.41	8.56	4.48	-0.10**	0.26	0.49	-0.32*	0.014
T - 2	302.37	1.64**	2423.74*	24.61	1.42	26.82**	50.53	0.74**	4.19	24.55	1.57	4.01	12.09	1.33	0.35	1.65	0.82	0.002
T - 4	261.39	1.39*	3416.09**	19.89	1.26	8.70	50.07	0.80*	9.13	23.43	1.59	2.68	12.92	1.29	1.29	1.57	0.47	0.001
T - 6	218.22	1.01	726.23	20.89	1.06	10.39	53.80	1.07	1.46	22.63	1.61	9.16	10.32	0.76	0.08	1.54	1.42	0.013
Local - 1	256.95	1.15	2034.71*	15.72	0.71	1.18	52.07	1.11	8.91	31.42	0.86	29.46**	16.51	1.87	0.96	1.23	2.38*	0.016
Local - 4	299.59	0.57*	386.78	45.13	1.64**	3.10	48.80	1.20*	14.27*	21.23	-0.13	6.91	6.67	0.08*	0.40	1.60	0.68	0.051**
Local - 9	308.25	1.37	1318.36	16.61	0.65	1.65	52.40	1.08	8.56	32.45	1.32	15.96**	18.36	2.14*	0.23	1.34	2.54**	0.054**
Local - 10	210.56	0.72	2528.70*	18.06	0.38*	8.42	51.73	0.80*	53.51**	28.67	1.00	20.25**	11.60	1.33	4.51**	1.11	1.23	0.062**
Local - 10A	234.40	0.70	4087.54**	18.17	0.27**	20.43**	53.73	0.74**	5.92	30.71	1.39	22.26**	12.91	1.43	11.81**	2.10	-0.40*	0.043**
Local - 16	274.86	1.21	563.03	15.17	0.77	3.76	47.33	1.39**	9.26	39.44	0.94	21.13**	17.97	1.43	6.80**	1.82	-0.41*	0.041**
Mean	263.60			24.24			50.58			26.80			12.36			1.42		
S.E.	10.61	0.19		0.84	0.25		1.10	0.09		0.95	0.60		0.50	0.39		0.04	0.59	

* and ** significant at 5% and 1% level, respectively.

a variety to be stable which possessed high mean, unit regression coefficient (b_i=1) and the deviation from regression as small as possible (S^2_{di}=0). In the present study, the genotypes Sel-Tm1, Sel-Tm3 and EC-243954 could therefore be considered as stable since these genotypes possessed high mean, with unit regression and low S^2_{di} values. Five genotypes viz.Pusa Dofasli, EC-305827, Local-9,T-2 and Local-16 although showed high mean values but their b_i values were more than 1. Therefore all these genotypes except T-2 were specifically adapted to favourable environment (below average stability) with high mean, b_i vlaues more than 1 and low S^2_{di} values. The genotype T-2 exhibited low predictability because of significantly positive S^2_{di} value. It was interesting to note that Local-4 although possessed high mean (above general mean) with low S^2_{di} value but was specifically adapted to unfavourable environment because its b_i value was significantly low from 1. Hence this genotype showed higher response in favourable environments like E_5,E_3 and E_2.

4.3.2 Pods per plant

The average number of pods per plant over all the environments and genotypes were found to be 24.24 (Table 21). The proportion of genotype showing predictable behaviour across the environment was 76.1%. Seven genotypes viz.1-101,5269, Local-4, EC-243954,Pusa Dofasli, Pusa Barsati, and T-2 showed higher mean performance over the general mean. Among these seven genotypes,

only EC-243954 was found to possess b_i=1 and low S^2_{di} value. Thus EC-243954 could be considered as a stable genotype or genotype well adapted to all environments. Three genotypes namely,1-101,T-2 and Pusa Dofasli exhibited low predictability as their S^2_{di} values were highly significant. On the otherhand, 5269,Local-4 and Pusa Barsati were specifically adapted to favourable environment since their b_i values were significantly greater than 1 and S^2_{di} values were nonsignificant. Thus these three genotypes performed very well in E_2,E_3 and E_5 (Appendix v). Some other genotypes like Sel-Tm1, Sel-Tm3 and T-6 although were widely adapted to all environments having b_i values close to 1 and low S^2_{di} values but their mean less than the general mean (Table 23).

4.3.3 Days to flowering

Lowest environmental index was observed in E_1 (Table 22). All other environments exhibited little variation in environmental index. Early flowering would be desirable in vegetable cowpea as it would enable the crop to fit intensive crop cultivation. Ten genotypes exhibited mean values less than the general mean (Table 23). No genotypes exhibited general adaptability although 5269 and Sel-Tm1 were relatively stable having b_i values close to 1 and mean performances less than general mean but significant S^2_{di} values indicated that their performance were non predictable. However, the estimates of S^2_{di} values if neglected

as suggested by Lin *et al.* (1986), 5269 and Sel-Tm1 could be considered as stable genotypes. Three genotypes viz.EC-305827,T-2 and T-4 were specifically adapted to unfavourable environment as all these genotypes exhibited mean values lower than the general mean and b_i values less than 1 and low S^2_{di} values. While Local-16 and Sel-Tm4 were characterised by b_i values significantly greater than 1, mean values less than general mean and low S^2_{di} values (Table 23). Hence, these two genotypes were specifically adapted to favourable environment. Some genotypes like Local -9, T-6 and Sel-Tm2 although were adapted to all environments (Wide adaptability) because of b_i values close to 1 and low S^2_{di} values but their mean performances were higher than the general mean.

4.3.4 Pod length

The environmental index ranged from 0.911 to 2.069. Environment one (E_1) and E_4 showed positive index while E_2, E_3 and E_5 exhibited negative index. The highest mean was exhibited by EC-305827. No genotype possessed all the criteria of general adaptability as suggested by Eberhart and Russell (1966). The genotypes Local-10, Local-16 and Local-1 although showed high mean values coupled with B_i values close to 1 but S^2_{di} values of these genotypes were highly significant indicating the performances were non predictable. Nevertheless, these genotypes could be considered as stable if S^2_{di} values were neglected. Sel-Tm3 and EC-305827 on the contrary, were specifically adapted to

favourable environments as these genotypes showed mean performances significantly higher than general mean coupled with b_i values more than 1 and low S^2_{di} values.

4.3.5 Green pod weight

Three environments i.e. E_2,E_3 and E_5 showed negative environmental index while E_1 and E_4 exhibited positive environmetal index. The proportion of genotype showing predictable behaviour across the environment was 69.80%. The green pod weight of nine genotypes were higher than the general mean across environments. Among these nine genotypes only Sel-Tm1 was specifically adapted to all environments (general adaptability) having high mean value,b_i value close to 1 and low S^2_{di} value (Table 23). The genotype Sel-Tm2 although was characterised by high mean coupled with b_i value close to 1 but S^2_{di} value was highly significant suggesting that the performance of this genotype was non predictable. On the otherhand, T-4, Local-1 and Local-9 were specifically adapted to favourable evironment. In other words, the performance of these genotypes were very good in E_1 and E_4 as compared to E_2 ,E_3 and E_5 (Appendix v).

4.3.6 Dry pod weight

The proportion of genotypes showing predictable behaviour across the environment was 70.97% . Environment one (E_1) and E_5 showed negative index while E_2,E_3 and E_4 exhibited posi-

tive environmental index (Table 22). Ten genotypes namely,Sel-Tm1, Sel-Tm3, EC-305827, T-2, T-4, T-6, Local-4, Local-9, Local-10A and Local-16 showed mean performances higher than the general mean. Highest mean value was exhibited by genotype EC-305827 followed by Sel-Tm3. Interestingly, these two genotypes ranked 1st and 2nd in mean performance for green pod weight and pod length as well. In vegetable cowpea, where long pod is one of the desirable criteria, could be utilized in breeding programme. Among the ten genotypes, EC-305827 and T-2 possessed the characteristics of average stability having b_i values close to 1 and low S^2_{di} values (Table 23). The genotypes T-6 and Sel-Tm3, on the contrary, were specifically adapted to favourable environment i.e. E_2,E_3 and E_4 (Appendix v). The genotypes EC-243954 and Pusa Barsati although widely adapted to all environments having b_i values close to 1 and low S^2_{di} value but their mean values were less than the general mean. The genotypes Local-10A,Local-16 and Local-4, on the otherhand, were specifically adapted to unfavourable environment (above average stability) but their nonlinear components were significant indicating performance of these genotypes were unpredictable.

An examination of the data on the relative performance of different genotypes suggested that none of the genotypes exhibited uniform stability and responsiveness for all the characters studied. The stability/responsiveness levels appeared to

be specific for individual character with a genotype and were not common for all the characters of that genotype. Similar differences in stability have been reported by Mehra and Ramanujam (1979) in bengal gram, Mehra (1982) in pigeon pea, Kandasamy *et al.* (1985) and Sulochana and Peter (1987) in cowpea. Nevertheless, the genotype EC-243954 showed average stability and high mean performance for green pod yield per plant and pods per plant and this genotype was adapted to all environments for pod length and green pod weight also. So EC-243954 could be considered as one of the outstanding genotypes having average stability in green pod yield per plant and some of the major components.

One of the major causal factors to realize the potentialities of vegetable cowpea has been the lack of adequate understanding of the plant type suited to a particular growing situation (Singh and Rachie,1985). It was heartening that conserted efforts have been made by breeders in the recent years resulting in the development of better genotypes suited to different agroclimatic conditions (Hazra,1991). Breeders would be interested in developing suitable plant type with following characteristics- high mean performance, average response slope (B_i=1) and low non linear interaction measured by S^2_{di}. The knowledge of relationship between these parameters of adaptability for green pod yield and its components would help in building up desirable genotypes. The correlation coefficients revealed that there was no signifi-

cant positive association among these parameters for all the traits except for pod length and hence the results suggested the involvement of different genetic systems in the control of all the characters except pod length (Table 24).

Table 24: Estimates of correlation coefficient within the stability parameters for six characters in vegetable cowpea.

Correlations between	Green pod yield/ plant	Pods/ plant	Days to flowering	Pod length	Green pod weight	Dry pod weight
u_i&b_i	0.248	0.315	-0.030	-0.198	0.023	0.287
u_i&S^2_{di}	-0.140	0.278	-0.091	0.534*	0.383	-0.460*
b_i&S^2_{di}	-0.050	0.056	-0.176	-0.167	0.116	0.178

* The correlation coefficients must exceed 0.444 and 0.561 to be significant at the 5% and 1% level, respectively.

For pod length, mean and non linear components of variance (S^2_{di}) were significantly and positively correlated indicating that mean value alone was sufficient to suggest the performance of the estimate S^2_{di}. No other significant positive correlation was found. In dry pod weight,on the otherhand, significantly negative association was found between mean and non-linear components of variance (S^2_{di}). Similar finding for pod length was reported by Sulochana and Peter (1987) in cowpea. In general non-significant association between mean,b_i and S^2_{di} indicated that all the three stability parameters would be taken into account while breeding for stable varieties of vegetable cowpea. On the contrary, the utility of non-linear variance (S^2_{di}) was questioned

by Lin *et al.* (1986) as S^2_{di} estimate was not independent of b_i. In the present study, Sel-Tm1, Sel-Tm3, and EC-243954 for green pod yield per plant; EC-243954 for pods per plant; 5269 and Sel-Tm1 for days to flowering; Local-10, Local-1 and Local-16 for pod length; Sel-Tm1 and Sel-Tm2 for green pod weight, EC-305827 and T-2 for dry pod weight; EC-305827 and T-2 for dry pod weight were identified as stable genotypes coupled with high mean. Thus EC-243954 and Sel-Tm1 could be selected as genotypes having wide adaptability in green pod yield and some of its components.

The adaptability appeared to be a character of its own right which can originate in various environments and could be transferred to other genotypes by cross breeding. Finlay (1968) has observed in barley and wheat that a high percentage of line with greatly increased yield and adaptability could be obtained by crossing a widely adapted genotype with one which was especially adapted to high yielding environments i.e. one which have high potentiality for yield.

In the present study, EC-305827 was a very outstanding genotype having highest mean for green pod yield per plant coupled with below average stability indicated their specificity to favourable environments. Moreover, this genotype exhibited highest mean pod length which was another desirable criteria in vegetable cowpea. Thus EC-305827 may be crossed with EC-243954 or Sel-Tm1 to develop genotypes with wide adaptability and in-

Plate no 3. The two most stable genotypes found in adaptability analysis

creased green pod yield. In vegetable cowpea, apart from pod length, determinate plant habit was another useful selection criteria which would help to fit this crop in intensive cropping system. Thus the crossing between EC-305827 and EC-243954 would be more meaningful as these two genotypes belong to two different growth habits i.e., indeterminate and determinate, respectively and therefore, would like to generate transgressive segregants having wider adaptability coupled with desirable plant attributes like determinate growth habit, long pod and high yield.

4.4 Gene action for green pod yield and its components

The knowledge of genetic nature of quantitative traits is a basic requirement for purposeful management of genetic variability. Several biometrical approaches are available for estimating gene action. In the present study, data from a 8 x 8 half diallel were analysed in the F_1 as well as F_2 generations for seven quantitatively inherited traits. One of the main advantages of diallel analysis lies in determining the genetic nature of important quantitative traits. If the parents used were a random sample from a broad base population,the results would quickly enable the breeders to choose the most appropriate breeding methods and selection procedures for the genetic improvement of the crop species (Singh *et al*.1992). In the present analysis, eight diverse parents were chosen representing three cultigroups of cowpea namely ,Biflora, Unguiculata and Sesquipedalis. This

would help to know the general nature of the genetic control of important quantitative traits in cowpea. The results obtained from such a diallel analyses has been presented and discussed in this chapter.

4.4.1 Combining ability analysis

The knowledge of gene action governing it and its magnitude is essential for efficient utilization of genetic variability for any character. In self-pollinated crop like cowpea, more attention is to be given to additive gene effect which is fixable. The importance of non-additive gene effect may have to be cautiously considered since they can not be retained as such.

The analysis of variance indicated that mean squares due to genotypes, parents, F_1's and F_2's were significant to all the seven traits namely, days to flowering,pod length, green pod weight, dry pod weight, pods per plant, seeds per pod and green pod yield per plant (Table 25). The analysis of variance thus revealed wide genetic diversity among the parents. The analysis of variance for combining ability based on Griffing's Model 1 and Method 2 exhibited that components of gca and sca mean squares were highly significant for green pod yield per plant in both F_1 and F_2 generations (Table 26). This indicated that the inheritance of green pod yield per plant was controlled by both additive

Table 25 : Analysis of variance (mean square) for seven characters in 8 X 8 half diallel cross

Source		D.F.	Days to flowering	Pod length	Green pod weight	Dry pod weight	Pods/Plant	Seeds/pod	Green pod Yield/plant
Genotypes	F_1	35	40.62**	206.16**	50.75**	0.448**	493.50**	20.18**	18846.16**
	F_2	35	21.74**	233.91**	60.92**	0.488**	478.61**	14.89**	18439.29**
Replication	F_1	2	3.37	7.03	0.316	0.003	2.25	4.05	833.93
	F_2	2	5.67	10.30	0.154	0.005	280.68	8.64	12315.18
Error	F_1	70	2.39	4.67	0.540	0.001	23.68	1.63	1125.01
	F_2	70	2.57	2.83	0.806	0.002	18.84	1.85	984.18

Table 26 : Analysis of variance (mean square) for combining ability (Griffing's Model 1 and Method 2)

Source		D.F.	Days to flowering	Pod length	Green pod weight	Dry pod weight	Pods/Plant	Seeds/pod	Green pod Yield/plant
G C A	F_1	7	31.76**	304.82**	71.77**	0.593**	717.51**	17.91**	19198.50**
	F_2	7	9.35**	358.17**	88.86**	0.685**	722.00**	18.35**	21270.97**
S C A	F_1	28	8.98**	9.69**	3.20**	0.038**	26.24**	3.93**	3053.07**
	F_2	28	6.72**	7.92**	3.17**	0.031**	18.92**	1.61**	2365.28**
Error	(F_1&F_2)	126	0.890	1.43	0.24	0.002	8.29	0.630	398.11
σ^2_a	F_1		6.19	60.64	14.31	0.117	141.92	3.47	3764.60
	F_2		1.69	71.44	17.71	0.136	143.14	3.54	4188.58
σ^2_{na}	F_1		8.18	8.14	3.02	0.037	18.35	3.39	2678.07
	F_2		5.86	6.97	2.90	0.030	12.64	0.99	2037.22
$\frac{\sigma^2_a}{\sigma^2_a+\sigma^2_{na}}$	F_1		0.43	0.88	0.82	0.76	0.88	0.50	0.58
	F_2		0.22	0.91	0.85	0.81	0.92	0.78	0.67

** significant at 1% level.

and non-additive gene action with gca variance being higher than the sca variance. The other traits namly, days to flowering, pod length, green pod weight, dry pod weight and seeds per pod also reflected a similar trend as both mean squares due to gca and sca were highly significant with gca variance greater in magnitude than the sca variance in both F_1 and F_2 generations. Variance due to gca was found to be increased in F_2 generation as compared to F_1 generation for pod length, green pod weight, dry pod weight, pods per plant, seeds per pod and green pod yield per plant. Days to flowering,on the otherhand, exhibited that mean squares due to gca was lower in F_2 as compared to F_1 generation. Interestingly, mean squares due to sca were found to be decreased in F_2 as compared to F_1 generation for all the traits.

The relative magnitude and importance of additive and non-additive variances in the genetic control of various quantitative characters were further revealed by the predictability ratio as suggested by Baker (1978). This reflected the preponderance of additive gene effects for pods per plant,pod length and green pod weight consistently in F_1 and F_2 generations. For dry pod weight, additive genetic control was predominant in F_2 generation while in F_1 generation, the effect appeared to be slightly less. For other characters, both additive and non-additive effects were important as the predictability ratios were

less than 0.80 (Table 26). The predictability ratio was found to be higher in F_2 generation as compared to F_1 generation for six traits namely, pod length, green pod weight, dry pod weight, pods per plant, seeds per pod and green pod yield per plant. Days to flowering, on the otherhand, exhibited a reverse trend. This indicated increase of additive genetic variance in F_2 generation for all the traits except days to flowering. If there was predominance of repulsion phase linkage additive genetic variance could increase as the generation was advanced and on the otherhand, if the linkage phase was predominantly coupling additive genetic variance could decrease (Robinson, 1966). However, the general nature of predictability trend suggested that either F_1 or F_2 generation could be equally effective to estimate the components of genetic variances. Similar findings were also reported by Jordaan and Laubscher (1968), Bhullar *et al.* (1979) and Singh *et al.* (1992 and 1993). Combining ability studies would therefore be much easier with increased seed quantities in the F_2 generation.

Not many findings were available on the genetics of quantitative characters especially in vegetable cowpea. Lal *et al.*(1976), Mak and Yap (1980) and Hazra (1991) reported predominance of additive genetic variance in the genetic control of pod length and pod weight. While Singh and Jain (1972) found equal importance of additive and non-additive genetic variance in pod

length. The present investigation more or less supported the findings of earlier workers for pod length and pod weight. Aryeetey and Laing (1973) reported that pods per plant was predominantly controlled by additive genetic variance which also supported the present findings. Singh and Dabas (1986) and Haza (1991), on the otherhand, concluded that non-additive gene action played a major role in the inheritance of pods per plant while, Singh and Dabas (1986) found both additive and non-additive genetic components to be equally important in the genetic control of pods per plant. The present observation of equal importance of both additive and non-additive genetic control of seeds per pod and green pod yield per plant find supports from Kheradnam and Niknejad (1971) and Hazra (1991). On the otherhand, Singh and Jain (1972), Mak and Yap (1980) and Imrie and Bray (1983) reported that sca and not gca was important in the genetic control of seeds per pod. In case of days to flowering,Singh and Dabas (1986) reported that non-additive gene action played a major part in the inheritance of this trait. Similar observations were also found in the present investigation. Kheradnam and Niknejad (1971) and Mak and Yap (1977), on the otherhand, found additive genetic variance to be predominant in the genetic control of days to flowering.

The disparities in estimation by different workers may arise from differences in the genetic constitution of the paren-

tal materials studied, variation in the environment, the techniques used in analysing the data and the precision of the experiment. Moreover the utility of the diallel mating design for providing valid estimates of genetic parameters remained in question, mainly because of failure of the parental sets to satisfy the assumptions on which most of the methods of analyses were based. Two of these, the independent distribution of genes involved and the absence of epistasis were rarely , if ever, satisfied, as pointd out by Baker (1978). The failure of the former assumption probably lead to over estimation of the average level of dominance. Whether it also biased estimates of general and specific combining ability variances was not clear (Singh *et al.*,1992). The interpretation of the results were restricted to the specific materials used in the experiment as the parents were deliberately chosen and could not be regarded as a random sample from any population. However, consistency of the trend in two generations, F_1 and F_2 and relatively more number of parents involving crosses like the present investigation more or less reflected a general trend of the genetic control of the crop itself as suggested by Singh *et al.* (1992). Another point which has not been addressed in this finding was the effect of genotype X environment interactions on the estimates of genetic variances which could have more meaningful in the estimate of the genetic variances of the crop as a whole (Singh *et al.*,1992).

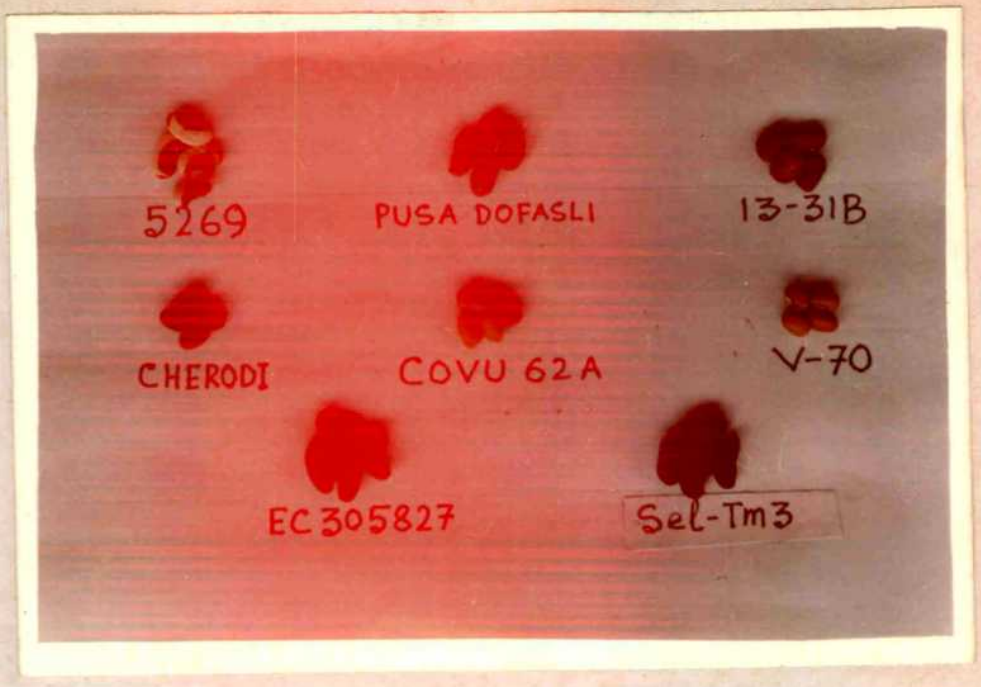


Plate no 4. Variability in seed size and colour of 8 parents used in diallel cross

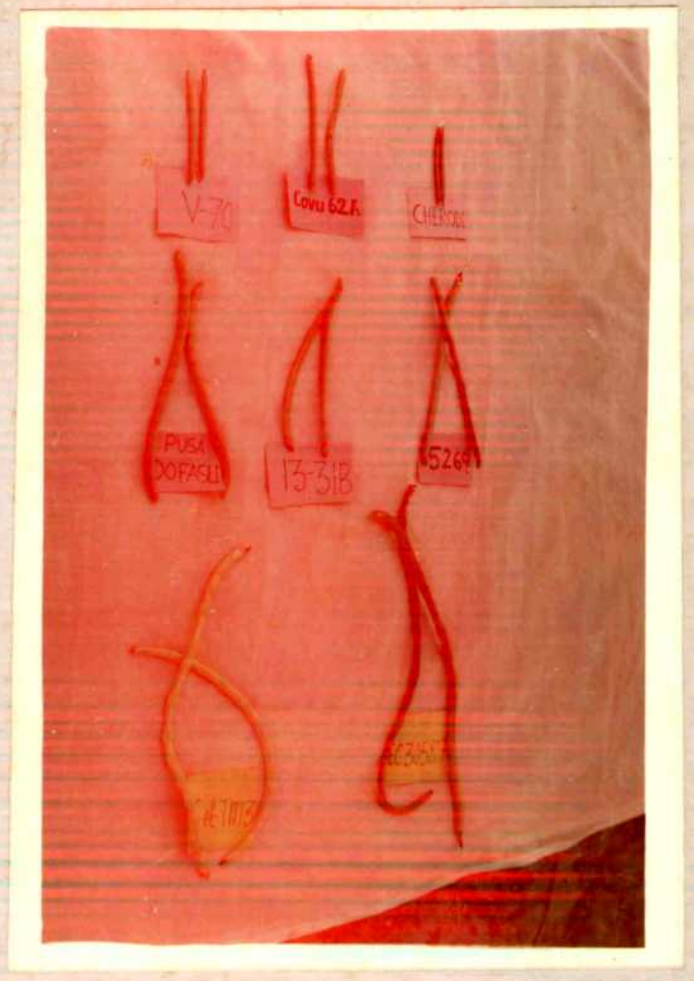


Plate no 5. Variability in pod size and colour of 8 parents used in diallel cross

4.4.2 Combining ability effects

The diallel analysis helped to identify the best combining parents and crosses for the different quantitative traits under study in addition to provide estimates of combining ability variances for the characters to be improved. Thus suitable parents and cross combinations would help to develop desirable segregants in the advanced generation.

4.4.2.1 General combining ability effects

General combining ability effects represented additive and additive x additive component of genetic variation which were fixable in self-pollinated crop like cowpea. The estimates of gca effects of seven characters in F_1 and F_2 generations have been represented in Tables 27 and 28.

4.4.2.1.1 Green pod yield per plant

The parents EC-305827,5269 and Pusa Dofasli exhibited highly significant positive gca effects in both the generations but the parent 13-31B showed non-singificant negative effect in F_1 generation and positive effect in F_2 generation. The parents which showed significant negative effects consistently in F_1 and F_2 generations were Cherodi, V-70 and Covu-62A.

4.4.2.1.2 Pods per plant

The parents Covu-62A, 5269 and Cherodi showed significant positive effects consistently in both the generations. EC-305827 and Sel-Tm3, on the otherhand, showed significantly negative effects in both F_1 and F_2 generations. The parent V-70 showed significantly positive effect in F_1 but its effect in the F_2 generation was also positive but non significant.

4.4.2.1.3 Seeds per pod

Two parents EC-305827 and Pusa Dofasli showed significantly positive gca effect in both the generations. 5269 although recorded significant positive effect in F_1 but its effect was negative in F_2 generation. Cherodi, V-70 and Covu-62A registered significant negative gca effects in both the generations.

4.4.2.1.4 Days to flowering

Highest positive gca effect was exhibited by Sel-Tm3 followed by Pusa Dofasli consistently in both the generations. Cherodi and V-70, on the otherhand, showed significantly negative effects in F_1 as well as F_2 generations. 5269 exhibited non-significant negative effect in F_1 generation but in F_2, the effect was positive. Similarly, 13-31B also showed different trend of effect in both the generations although the effect was non-significant.

4.4.2.1.5 Pod length

Highest positive significant effect was exhibited by the parent EC-305827 followed by Sel-Tm3 consistently in both the generations. The parent Pusa Dofasli also showed positive effect in both the generations but the effect was significant in F_1 and nonsignificant in F_2. Cherodi,V-70,13-31B and Covu-62A exhibited significantly negative effects in both the generations.

4.4.2.1.6 Green pod weight

The parents EC-305827 and Sel-Tm3 showed significantly positive gca effects in F_1 as well as F_2 generations. On the contrary, Cherodi,V-70 and Covu-62A exhibited significantly negative gca effects in both the generations.

4.4.2.1.7 Dry pod weight

Dry pod weight more or less reflected a similar trend like green pod weight. The parents EC-305827 and Sel-Tm3 recorded significantly positive gca effects while Cherodi, V-70, 13-31B and Covu-62A registered significantly negative effects in F_1 as well as F_2 generations.

The ranking of *per se* performance and gca effects obtained from F_1 and F_2 generations for eight parents has been given in Table 29. The rank correlation revealed that all the seven characters studied showed significantly positive correla-

Table 27 : Estimates of general combining ability (g_i) effects in eight parents over 28 F_1s

Parents	Green pod yield/plant	Pods/plant	Seeds/Pod	Days to flowering	Pod length	Green pod weight	Dry pod weight
EC-305827	72.00**	-9.06**	2.38**	-1.98**	8.98**	4.47**	0.45**
Sel-Tm3	7.89	-15.34**	0.21	3.68**	6.99**	3.49**	0.24*
Cherodi	-46.42**	5.11**	-1.17**	-0.82**	-5.34**	-2.21**	-0.21*
V-70	-59.07**	5.34**	-1.80**	-1.75**	-6.00**	-2.66**	-0.23*
13-31B	-7.90	3.35	-0.62**	-0.28	-2.01**	-1.25**	-0.16*
Pusa Dofasli	16.63**	-3.59	1.06**	0.68**	1.21*	0.53	0.07
Covu-62A	-23.71**	8.76**	-0.64*	0.65**	-3.72**	-2.05**	-0.15*
5269	40.59**	5.41*	0.58*	-0.18	-0.10	-0.31	-0.02
SE (g_i)	5.986	0.866	0.244	0.282	0.360	0.141	0.042

Table 28 : Estimates of general combining ability (g_i) effects in eight parents over 28 F_2s

Parents	Green pod yield/plant	Pods/plant	Seeds/Pod	Days to flowering	Pod length	Green pod weight	Dry pod weight
EC-305827	76.06**	-12.97*	2.82*	-0.43	11.10**	5.90**	0.55*
Sel-Tm3	2.39	-13.18*	0.21	1.58**	6.52**	2.73**	0.17*
Cherodi	-50.18**	5.15*	-1.30*	-0.89**	-5.59**	-2.59**	-0.21*
V-70	-60.91**	4.86	-1.15*	-1.56**	-5.61**	-2.74**	-0.24*
13-31B	10.97	4.50	-0.37	0.11	-1.71*	-0.55	-0.11*
Pusa Dofasli	11.85*	-1.52	0.99*	0.74**	0.13	0.07	0.03
Covu-62A	-30.88**	8.04*	-0.63*	0.21	-4.35**	-2.27**	-0.18*
5269	40.71**	5.13*	-0.56	0.24	-0.50	-0.56	-0.02
SE (g_i)	5.986	0.866	0.244	0.282	0.360	0.141	0.042

Table 29 : Ranking of per se (a) performance and gca effects of F_1 (b) and F_2 (c) generations

Parents	Green pod yield/plant			Pods/plant			Seeds/Pod			Days to flowering			Pod length			Green pod weight			Dry pod weight		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
EC-305827	1	1	1	7	7	7	1	1	1	6	8	6	1	1	1	1	1	1	1	1	1
Sel-Tm3	4	4	5	8	8	8	3	4	3	3	1	1	2	2	2	2	2	2	2	2	2
Cherodi	8	7	7	5	4	2	7	7	8	8	6	7	8	7	7	7	7	7	7	7	7
V-70	7	8	8	3	3	4	8	8	7	7	7	8	7	8	8	8	8	8	8	8	8
13-31B	3	5	4	2	5	5	4	5	4	5	5	5	5	5	5	5	5	4	5	6	5
Pusa Dofasli	2	3	3	6	6	6	2	2	2	1	3	2	3	3	3	3	3	3	3	3	3
Covu-62A	6	6	6	1	1	1	6	6	6	2	2	4	6	6	6	6	6	6	6	5	6
5269	5	2	2	4	2	3	5	3	5	4	4	3	4	4	4	4	4	5	4	4	4
Correlation		*	*		*	*		**	**		*	**		**	**		**	**		**	**
with per se & gca ranking		0.80	0.83		0.83	0.76		0.92	0.97		0.80	0.85		0.97	0.97		1.00	0.97		0.97	1.00

* and ** significant at 5% and 1% level,respectively.

tion between *per se* performance and gca effects. Similar observations were recorded in a number of grain legumes including pigeonpea (Mehra,1982) and black gram (Dasgupta and Das,1987). Among the seven traits, pod length, green pod weight and dry pod weight registered high magnitude of correlation consistently in both the generations. Interestingly,pod length, green pod weight, and dry pod weight were predominantly controlled by additive genetic variance.

On the basis of ranking of eight parents in diallel none appeared consistently superior in respect of gca effects and *per se* performance for all the characters. Nevertheless, EC-305827 exhibited significantly positive gca effects consistently in both the generations for green pod yield and other four characters except pods per plant and days to flowering where the effects were significantly negative. Pusa Dofasli and 5269 also showed significantly positive gca effects for green pod yield per plant and its two or three yield components in F_1 and F_2 generations. Covu- 62A, 5269 and Cherodi recorded significantly positive gca effects for pods per plant. The parent V-70 also showed high gca effect. Among these four parents, Covu-62A appeared to be best followed by V-70 because of high gca effects and mean performance.

Considering *per se* performance and gca effects, the parents EC-305827 and Pusa Dofasli appeared to be outstanding as

both parents exhibited high gca effect and *per se* performance in F_1 as well as F_2 generations. On the contrary, both these parents recorded low pod number per plant. These two parents may be crossed either with Covu-62A or V-70 which showed increased pod number per plant and high gca effects of pod number. This would hopefully be expected to produce wide genetic variability of fixable nature in segregating generations and thus would offer a good scope to select desirable segregants having higher number of pods of increased size coupled with less duration and higher green pod yield.

4.4.2.2 Specific combining ability effects

Dominance and epistatic components of genetic variation which are non fixable in self-pollinated crops are represented by specific combining ability (sca) effects. But the crosses having high sca effects could be exploited in a future breeding programme if parents involved in a cross are good general combiners.

In the present investigation, the estimates of sca effects in 28 crosses for F_1 and F_2 generations have been presented in Tables 30 and 31 and described below.

4.4.2.2.1 Green pod yield per plant

Four out of 28 crosses exhibited significantly positive sca effects in F_1 as well as F_2 generations. Out of these four

Table 30: Estimates of specific combining ability (S_{ij}) effects for seven characters in 28 F_1 based on Griffing's Model-1 and Method -2

Crosses	Green pod yield/plant	Pods/plant	Seeds/Pod	Days to flowering	Pod length	Green pod weight	Dry pod weight
EC-305827xSel-Tm3	-115.11**	-0.03	-2.58**	4.61**	-8.94**	-3.06**	-0.45**
EC-305827xCherodi	44.70**	9.45**	-0.88	1.45	-4.01**	-2.33**	-0.23**
EC-305827xV-70	65.85**	11.05**	1.92**	2.38**	-0.58	-2.05**	-0.19**
EC-305827x 13-31B	-87.34**	-9.19**	1.44*	-5.09**	-0.67	-2.02**	-0.18**
EC-305827xPusa Dofasli	7.75	-2.12	1.43*	0.98	5.54**	0.96*	0.01
EC-305827xCovu-62A	83.87**	6.06*	-1.17	-5.39**	1.11	-0.73	-0.01
EC-305827x5269	-8.71	-4.39	-1.79**	-2.85**	0.49	-0.56	-0.07
Sel-Tm3xCherodi	10.71	-6.61**	0.86	-0.55	3.09**	0.38	-0.05
Sel-Tm3xV-70	12.77	-4.54	-1.24	-1.62	1.11	-0.24	-0.03
Sel-Tm3x13-31B	-61.82**	-4.81	0.08	6.58**	2.39*	-1.98*	-0.10**
Sel-Tm3xPusa Dofasli	36.57*	4.76	-1.80**	-1.02	-1.70	-0.06	0.14**
Sel-Tm3xCovu-62A	-38.07*	-3.46	-0.66	4.95**	-2.87**	-2.38**	-0.18**
Sel-Tm3x5269	94.85**	5.93*	-1.82**	0.48	-1.12	1.52**	-0.06
CherodixV-70	46.15**	6.28**	0.96	1.55	1.84	1.07**	0.09**
Cherodix13-31B	5.12	1.94	-0.38	0.08	-1.55	0.42	0.07
CherodixPusa Dofasli	-46.84**	6.27**	0.94	0.15	-3.03**	-1.56**	-0.18**
CherodixCovu-62A	-4.05	0.29	-3.52**	1.11	-0.07	0.55	0.06
Cherodix5269	-13.37	-2.43	1.42	0.31	2.24*	0.29	-0.03
V-70x13-31B	-36.12*	-2.39	-2.75**	-1.99**	-0.83	0.01	0.06
V-70xPusa Dofasli	-78.64**	-5.32*	-3.60**	-2.92**	-5.04**	-1.81**	-0.16**
V-70xCovu-62A	-0.73	-1.37	0.44	0.38	0.45	0.90*	0.09**
V-70x5269	-31.44	1.48	1.55*	0.58	-1.73	-0.70	-0.10**
13-31BxPusa Dofasli	-65.22**	-5.69*	-3.11**	-1.05	-1.77	-0.99*	-0.09**
13-31BxCovu-62A	36.15*	2.89	1.43*	1.91*	-0.64	0.89*	0.08*
13-31Bx5269	41.59*	4.04	0.54	-0.22	-0.02	0.69	0.01
Pusa DofaslixCovu-62A	-12.54	-1.64	0.25	-2.02**	4.51**	-0.26	-0.04
Pusa Dofaslix5269	24.68	5.74*	0.86	1.18	1.33	-0.33	-0.09**
Covu-62Ax5269	-30.98	-0.44	1.40	-0.19	-0.44	-0.21	-0.01
S.E. (S_{ij})	18.071	2.608	0.722	0.842	1.081	0.444	0.040

* and ** significant at 5% and 1% level, respectively.

Table 31: Estimates of specific combining ability (S_{ij}) effects for seven characters in 28 F_2 based on Griffing's Model-1 and Method -2

Crosses	Green pod yield/plant	Pods/plant	Seeds/Pod	Days to flowering	Pod length	Green pod weight	Dry pod weight
EC-305827xSel-Tm3	-97.26**	5.39*	-1.76**	4.75**	-6.95**	-4.01**	-0.48**
EC-305827xCherodi	-12.26	-3.56	0.91	0.88	-0.20	-1.63**	-0.15**
EC-305827xV-70	36.07*	5.18*	-0.23	0.88	2.32*	-0.78	-0.09**
EC-305827x 13-31B	11.01	-8.59**	1.65*	-0.79	1.16	3.87**	0.22**
EC-305827xPusa Dofasli	1.49	-1.50	1.79*	-1.42	6.01**	1.27**	-0.06
EC-305827xCovu-62A	49.98**	-1.09	0.91	-2.55**	1.49	-0.62	-0.05
EC-305827x5269	12.67	-2.55	-0.99	-3.25**	-2.05*	-1.06**	-0.05
Sel-Tm3xCherodi	-11.84	-4.66	-1.31	-0.79	-2.25*	-0.96*	-0.11**
Sel-Tm3xV-70	7.71	-6.07*	0.55	-4.79**	1.20	-0.01	-0.12**
Sel-Tm3x13-31B	-52.68**	-6.34**	1.60*	3.21**	2.97**	-1.26**	-0.07
Sel-Tm3xPusa Dofasli	-38.39*	0.31	-0.76	0.58	-2.47*	-1.42**	0.04
Sel-Tm3xCovu-62A	-44.90**	-4.51	-1.64*	1.11	-3.73**	-2.31**	-0.15**
Sel-Tm3x5269	139.17**	5.46*	-1.05	-2.92**	1.69	2.18**	-0.03
CherodixV-70	42.26*	-1.06	1.39	-2.32**	0.65	1.14**	0.10**
Cherodix13-31B	14.73	4.33	-0.73	-0.32	-0.81	-0.11	0.04
CherodixPusa Dofasli	-19.92	6.78**	-0.42	2.38**	-3.06**	-1.14**	-0.11**
CherodixCovu-62A	1.67	-0.21	0.86	-0.09	-1.06	0.64	0.04
Cherodix5269	-9.34	-1.97	0.96	0.21	2.48*	0.49	-0.02
V-70x13-31B	-38.41*	-0.08	0.30	-1.65	-2.10	-0.96*	0.02
V-70xPusa Dofasli	-63.90**	-1.06	-1.06	-1.29	-4.64**	-1.72**	-0.17**
V-70xCovu-62A	23.48	1.45	1.22	1.25	1.01	0.89*	0.10**
V-70x5269	-52.28**	-1.34	0.48	3.21**	-1.31	-0.59	-0.08*
13-31BxPusa Dofasli	-37.95*	-1.36	-1.84**	-3.29**	-1.84	-1.41**	-0.09**
13-31BxCovu-62A	-2.07	-2.26	0.11	0.91	-0.56	0.94*	0.02
13-31Bx5269	-1.32	-0.62	-0.13	-0.12	-0.37	-0.14	-0.03
Pusa DofaslixCovu-62A	-12.34	-2.00	-1.25	-5.39**	1.73	-0.42	-0.03
Pusa Dofaslix5269	2.11	-0.23	0.34	0.25	0.15	0.03	-0.07
Covu-62Ax5269	-25.45	-0.26	0.79	-0.22	-1.10	-0.12	0.01
S.E. (S_{ij})	18.071	2.608	0.722	0.842	1.081	0.444	0.040

* and ** significant at 5% and 1% level, respectively.

crosses namely, EC-305827 x V-70, EC-305827 x Covu-62A,Cherodi x V-70 and Sel-Tm3 x 5269, the last one ranked first in F_1 as well as F_2 generations. Some of the crosses like EC-305827 x Cherodi, Sel-Tm3 x Pusa Dofasli, 13-31B x Covu-62A and 13-31B x 5269 although showed highly positive significant sca effects in F_1 generation but their effects were negative in F_2 generation. These suggested the effect of generation was predominant in the expression of sca effects specially in some of the crosses. This was not unexpected as heterogygosity declined in F_2 generation as compared to F_1 generation.

4.4.2.2.2 Pods per plant

Only two crosses recorded consistency in their sca effects at both the generations. All these two crosses namely, Sel-Tm3 x 5269 and Cherodi x Pusa Dofasli involved at least one parent with good general combining ability in both F_1 and F_2 generations. In other words, the best general combiners were also involved in best specific combinations. The cross combination of EC-305827 x Cherodi although exhibited very high positive sca effects in F_1 generation but the trend was reversed in F_2 generation.

4.4.2.2.3 Seeds per pod

Only two crosses i.e. EC-305827 x 13-31B and EC-305827 x Pusa Dofasli showed significantly high positive sca effects at

both the generations. A few other crosses showed significant sca effects only in either of the generations, for example, EC-305827 x V-70,13-31B x Covu-62A and V-70 x 5269 showed significantly positive sca efffects only in F_1 generation (Table 30).

4.4.2.2.4 Days to flowering

Two crosses namely, EC-305827 x Sel-Tm3 and Sel-Tm3 x 13-31B showed consistently significant positive sca effects in F_1 as well as F_2 generations. On the otherhand, three crosses i.e. EC-305827 x Covu-62A, EC-305827 x 5269 and Pusa Dofasli x Covu-62A recorded significantly negative sca effects in both the generations.

4.4.2.2.5 Pod length

The cross EC-305827 x Pusa Dofasli registered highest significant positive sca effects consistently in both the generations. Two other crosses namely, Sel-Tm3 x 13-31B and Cherodi X 5269 also exhibited significantly positive sca effects in F_1 as well as F_2 generations. The cross Pusa Dofasli x Covu-62A although showed significantly positive sca effect in F_1 generation but the effect was positively non-significant in F_2 generation.

4.4.2.2.6 Green pod weight

Five crosses i.e. EC-305827 x Pusa Dofasli, Sel-Tm3 x

5269, Cherodi x V-70, V-70 x Covu-62A and 13-31B x Covu-62A showed significantly positive sca effects in both the generations. The cross EC-305827 x 13-31B exhibited significantly positive sca effect in F_2 generation but their effect was significantly negative in F_1 generation. This was unexpected since heterogygosity declined in F_2 generation as compared to F_1 generation. Similar results were reported by Bhullar *et al.* (1979) in wheat and Singh *et al.* (1993) in chickpea. The linkage among the interacting genes and or the effects of competition and heterogenity would be responsible for such an increase in the estimates of sca effects.

4.4.2.2.7. Dry pod weight

Only two crosses i.e. Cherodi x V-70 and V-70 x Covu-62A exhibited consistently significant positive sca effects in both the generations. Some other crosses recorded significant sca effects only in either of the generations. Interestingly, the parents involved in these two crosses were not very good general combiners. Therefore, dominance and epistatic interactions were operative in the expression of high sca effects.

From the foregoing observations, it appeared that different cross combinations exhibited different sca effects in both the generations and only a few cross combinations showed consistently either positive or negative sca effects for few characters.

The perusal of different cross combinations revealed that the crosses involved five types of combinations namely,H X H, H X M or M X H, H X L or L X H, M X L and L X L where H stands for positive, M for non significant and L for negative gca effects of the parents. In the H X H type cross combination i.e. EC-305827 x Pusa Dofasli for seeds per pod, additive as well as additive x additive type of interactions were involved (Table 32). Such cross would be very desirable in a self-pollinated crop as desirable segregants would be fixed in early advance generation. On the otherhand, H X M or M X H and H X L or L X H type of cross combinations involved one parent with high gca effect and low or medium effect in the other parent indicated that predominantly additive effect was present in good combiners and possibly complementary epistatic effect in poor combiners and these two gene actions acted in complementary fashion to maximise the expression. Similar result have been reported by Mehra (1982) in pigeonpea and Hazra (1991) in cowpea. In the cross like Cherodi x V-70 for green pod yield per plant, green pod weight and dry pod weight, belonged to L X L category, sca effect seem to be played a very important role and high performance was due to non-additive gene action.

No cross combinations exhibited significantly positive sca effects for all the characters consistently in both the generations. Nevertheless, four cross combinations viz. EC-305827

Table 32: Best specific combinations in F_1 and F_2 generations

Characters	Cross combinations	Type of combinations	
		F_1	F_2
Green pod yield/ plant	EC-305827xV-70	H x L	H x L
	EC-305827xCovu-62A	H x L	H x L
	CherodixV-70	L x L	L x L
	Sel-Tm3x5269	M x H	M x L
Pods/Plant	Sel-Tm3x5269	M x H	L x H
	CherodixPusa Dofasli	L x H	H x L
Seeds/Pod	EC-305827x13-31B	H x L	H x L
	EC-305827xPusa Dofasli	H x H	H x H
Days to flowering	EC-305827xSel-Tm3	L x H	L x H
	Sel-Tm3x13-31B	H x L	H x M
Pod length	EC-305827xPusa Dofasli	H x H	H x M
	Sel-Tm3x13-31B	H x L	H x L
	Cherodix5269	L x L	L x L
Green pod weight	EC-305827xPusa Dofasli	H x M	H x M
	Sel-Tm3x5269	H x L	H x L
	CherodixV-70	L x L	L x L
	V-70xCovu-62A	L x L	L x L
	13-31BxCovu-62A	L x L	L x L
Dry pod weight	CherodixV-70	L x L	L x L
	V-70xCovu-62A	L x L	L x L

X V-70, EC-305827 X Covu-62A, Cherodi X V-70 and Sel-Tm3 X 5269 showed not only significantly positive sca effects for green pod yield per plant consistently in both the generations but these crosses recorded highly positive sca effects for two or more yield attributes. Among these four cross combinations, EC-305827 x Covu-62A exhibited highest *per se* performance followed by EC-305827 x V-70 and Sel-Tm3 x 5269. Interestingly, all these three crosses involved at least one parent with positively high gca effect. In other words very good general combiner was involved in these three cross combinations, indicating additive and additive x additive type of interaction would be responsible for high sca effect. On the contrary, dominant and epistatic interaction appeared to be important in the cross combination Cherodi X V-70.

4.4.3 Analysis of Heterosis

Heterosis has been a phenomenon of great importance to plant breeders as due to its utilization a considerable yield improvement has been achieved. The classic case of heterosis exploitation was, of course, that of maize but subsequently heterosis breeding has lead to outstanding break through in the productivity of several crops such as sorghum,bajra and cotton. In several legumes including pigeonpea (Green *et al.*, 1979), cowpea (Mak and Yap,1977; Bhaskaraiah *et al.*,1980; and Hazra *et al.*,1993) and blackgram (Dasgupta and Das,1987) attempts were

made to exploit heterosis.

In the present study, heterosis has been calculated over better-parent and mid-parent (Tables 33 and 34). While selecting the cross combinations, besides heterotic vigour, the *per se* performance of the cross would also be given due consideration. There was every possibility of getting a cross with high *per se* performance but with low heterosis, incase when parental performance was high and vice-versa was also true. But at the same time there was no denying the fact that heterosis was measured by mean superiority of F_1 over its better-parent was an important parameter.

The perusal of analyses revealed that the number of crosses with significantly positive heterosis over mid-parent was more as compared to heterosis over better-parent. In general,not many crosses with significantly positive heterosis was obtained for green pod yield and its components. Similar observation was also reported by Hazra *et al.* (1993) in cowpea. Nevertheless, as many as four hybrids for green pod yield per plant, pods per plant and seeds per pod; nine hybrids for days to flowering; two hybrids for green pod weight and one hybrid for dry pod weight recorded significantly positive heterosis over better-parent (Table 33). Maximum heterosis for green pod yield per plant was shown by the hybrid Sel-Tm3 x 5269, followed by Cherodi x V-70, EC-305827 x Covu-62A and EC-305827 X V-70. Interestingly, all

Table 33: Percent heterosis over better-parent in 28 crosses for seven characters

Crosses	Green pod yield/plant	Pods/plant	Seeds/Pod	Days to flowering	Pod length	Green pod weight	Dry pod weight
EC-305827xSel-Tm3	-49.86**	-10.42**	-32.36**	13.82**	-34.28**	-44.22**	-52.51**
EC-305827xCherodi	-21.23	-3.74	-30.53**	1.74**	-51.82**	-68.81**	-62.84**
EC-305827xV-70	34.81*	55.75**	-18.65**	1.76**	-45.26**	-69.64**	-61.69**
EC-305827x 13-31B	-46.61**	-52.16**	-14.99**	-16.81**	-36.02**	-62.54**	-58.39**
EC-305827xPusa Dofasli	-14.14	-23.75**	-9.14**	-9.09**	-13.67**	-38.94**	-40.46**
EC-305827xCovu-62A	36.00*	6.82**	-29.25**	-18.55**	-35.86**	-60.07**	-50.79**
EC-305827x5269	-12.11	-32.69**	-25.96**	-12.40**	-28.75**	-50.66**	-47.20**
Sel-Tm3xCherodi	-28.52	-50.21**	-25.10**	4.07**	-34.28**	-50.61**	-50.98**
Sel-Tm3xV-70	-32.27*	-49.58**	-41.84**	-0.81	-41.09**	-57.17**	-50.98**
Sel-Tm3x13-31B	-45.37**	-55.67**	-26.53**	22.76**	-27.48**	-59.22**	-50.98**
Sel-Tm3xPusa Dofasli	-14.05	-21.99**	-31.79**	-0.76	-29.72**	-36.48**	-23.63**
Sel-Tm3xCovu-62A	-38.04**	-47.13**	-31.22**	20.16**	-45.48**	-66.60**	-55.08**
Sel-Tm3x5269	72.82**	-13.92**	-30.82**	8.13**	-31.61**	-31.97**	-40.23**
CherodixV-70	41.10**	35.00**	0.32	4.42**	0.90	1.32**	-11.70**
Cherodix13-31B	-41.01**	-5.36*	-18.67**	-0.84	-35.28**	-37.89**	-9.73**
CherodixPusa Dofasli	-55.53**	-5.20*	-23.89**	-8.33**	-41.67**	-66.90**	-55.56**
CherodixCovu-62A	-7.28	-5.50*	-41.50**	0.04	-5.45**	-8.05**	-4.09**
Cherodix5269	-23.61	0.48	6.18**	-1.65**	-13.08**	-23.46**	-39.80**
V-70x13-31B	-59.62**	-12.95**	-42.67**	-8.40**	-34.92**	-54.04**	-15.14**
V-70xPusa Dofasli	-69.31**	-28.51**	-53.76**	-17.42**	-53.16**	-74.30**	-55.83**
V-70xCovu-62A	-13.21	-7.97**	-13.65**	-4.03**	-6.54**	-11.49**	-6.47**
V-70x5269	-35.30*	1.86	2.15**	-3.31**	-36.09**	-50.00**	-48.49**
13-31BxPusa Dofasli	-49.28**	-35.57**	-44.12**	-9.85**	-21.84**	-50.70**	-43.61**
13-31BxCovu-62A	-23.48	-4.07	0.02	3.23**	-21.39**	-26.09**	1.08**
13-31Bx5269	1.65	-0.92	2.67**	-1.65**	-7.78**	1.85**	-30.43**
Pusa DofaslixCovu-62A	-37.84*	-23.80**	-24.86**	-9.85**	-2.16**	-51.41**	-38.89**
Pusa Dofaslix5269	18.72	25.58**	-14.26**	-4.55**	-0.29	-33.80**	-32.22**
Covu-62Ax5269	-21.67	-6.25**	10.22**	-1.61**	-18.38**	-29.63**	-32.44**
S.E. (B.P.)	18.29	2.351	0.648	0.667	0.845	0.346	0.036

* and ** significant at 5% and 1% level, respectively.

these four crosses exhibited significantly positive sca effects. Among these four crosses, the *per se* performance of the hybrid EC-30527 X Covu-62A was highest followed by EC-305827 x V-70 and Sel-Tm3 x 5269 (Appendix VII). There was a reasonable ground to suggest that the heterotic expression for green pod yield per plant in all these three cross combinations were due to additive and additive x additive type of gene effects as the cross involved parents with best general combining ability. On the other-hand, the expression of heterosis in the cross combination Cherodi x V-70 was due to both dominant and epistatic gene effects. Interestingly, except Sel-Tm3 x 5269 other three cross combinations which showed maximum heterosis for green pod yield also exhibited heterosis over better-parent for pods per plant. Therefore, it appeared that heterosis for green pod yield per plant could be ascribed mainly to heterosis observed for pods per plant. Hazra (1991) also observed similar finding. No hybrid expressed heterotic vigour with respect to better-parent for pod length. While four hybrids exhibited heterotic vigour over mid-parent in case of pod length (Table 34).

4.4.4 Suggestions for breeding strategy

The present study revealed the significance of additive genetic control for pods per plant,pod length, green pod weight, and dry pod weight. Thus these four characters could be improved by simple selection scheme such as pedigree method, since both

Table 34 : Percent heterosis over mid-parent in 28 crosses for seven characters

Crosses	Green pod yield/plant	Pods/plant	Seeds/Pod	Days to flowering	Pod length	Green pod weight	Dry pod weight
EC-305827xSel-Tm3	-41.95**	-5.86**	-28.64**	17.65**	-31.44**	-38.21**	-45.24**
EC-305827xCherodi	18.55	39.57**	-11.21**	4.00**	-23.22**	-44.57**	-40.32**
EC-305827xV-70	20.37	36.91**	4.71**	2.63**	-13.32**	-45.88**	-37.69**
EC-305827x 13-31B	-40.20**	-28.45**	0.87	-15.38**	-10.65**	-40.81**	-34.24**
EC-305827xPusa Dofasli	-8.41	-0.64	-6.75**	-2.83**	11.42**	-16.85**	-21.48**
EC-305827xCovu-62A	33.96**	16.63**	-14.57**	-15.48**	-0.55	-30.16**	-20.88**
EC-305827x5269	2.60	-2.09	-11.86**	-10.17**	-3.53**	-22.14**	-26.10**
Sel-Tm3xCherodi	-1.55	-25.83**	-8.14**	9.87**	2.83	-14.54**	-26.50**
Sel-Tm3xV-70	-8.30	-23.41**	-28.12**	3.39**	-8.43**	-25.62**	-25.30**
Sel-Tm3x13-31B	-43.27**	-32.04**	-16.76**	24.79**	-1.41	-38.67**	-27.98**
Sel-Tm3xPusa Dofasli	-6.15	5.21**	-29.83**	2.75**	-12.12**	-19.69**	-10.32**
Sel-Tm3xCovu-62A	-21.90	-17.61**	-20.61**	20.65**	-17.15**	-43.30**	-32.55**
Sel-Tm3x5269	36.86**	0.67	-21.35**	9.02**	-10.03**	2.15**	-24.54**
CherodixV-70	4.87	2.23	1.31*	5.83**	2.44	2.67**	-8.76**
Cherodix13-31B	-16.84	0.20	-10.82**	3.06**	-18.62**	-15.61**	-6.18**
CherodixPusa Dofasli	-35.36**	10.91**	-4.59**	0.04	-20.31**	-47.78**	-39.74**
CherodixCovu-62A	4.72	3.45	-37.13**	5.98**	0.58	-1.84**	-3.81**
Cherodix5269	4.56	1.07	16.01**	3.03**	13.27**	4.20**	-23.40**
V-70x13-31B	-43.99**	-11.28**	-36.58**	-6.03**	-19.09**	-37.02**	-8.99**
V-70xPusa Dofasli	-56.07**	-13.62**	-41.61**	-11.02**	-36.64**	-59.22**	-38.85**
V-70xCovu-62A	-4.29	-2.87	-6.34**	0.42	-2.00	-4.35**	-3.64**
V-70x5269	-12.96	5.30**	12.59**	0.06	-17.61**	-31.36**	-32.90**
13-31BxPusa Dofasli	-46.56**	-20.98**	-35.12**	-5.18**	-12.47**	-37.08**	-25.50**
13-31BxCovu-62A	-0.83	-0.59	2.18**	5.35**	-5.91**	-4.03**	5.35**
13-31Bx5269	6.55	4.32*	3.08**	-0.83	-3.21*	2.17**	-14.05**
Pusa DofaslixCovu-62A	-16.45	-3.94	-11.16**	-7.03**	28.13**	-25.61**	-16.98**
Pusa Dofaslix5269	3.17	16.84**	-0.11	-0.40	6.77**	-15.70**	-25.95**
Covu-62Ax5269	-1.98	2.09	12.18**	-0.41	1.54	-8.43**	-13.86**
S.E. (M.P.)	14.10	2.035	0.561	1.157	1.466	0.60	0.031

* and ** significant at 5% and 1% level, respectively.

additive and additive x additive genetic effects which were prominent for these characters could be easily fixable in the early generations. Green pod weight which was highly heritable and important yield component in cowpea, could be used effectively as an indirect selection criteria for improving green pod yield. Interestingly, such attempt would also help ~~to~~ increase the pod length through correlated response.

Both additive and non-additive genetic effects were important in the genetic control of days to flowering, seeds per pod and green pod yield per plant. Improvement of such characters would therefore be based on simultaneous exploitation of both the components of variance. Population improvement with some modification as suggested by Reddan and Jensen (1974) in self-fertilizing species could be effective in such situation. Recurrent selection scheme designated for self-pollinated crop which have been proposed by Comton (1970) would also be tried to utilize both additive and non-additive genetic variance.

The availability of two parents namely, EC-305827 and Pusa Dofasli which combined high gca effects for more than four characters including green pod yield per plant indicated the possibility of simultaneous improvement of the traits. However, these two parents were inferior to parents Covu-62A and V-70 for pods per plant as high gca and high mean performances for pods per plant were exhibited by Covu-62A and V-70. The cowpea ideo-

type having semierect and non-viny plant habit with synchronous maturity with higher number of medium-long, fleshy, succulent pods have been described as ideal for vegetable cultivation (Singh and Ntare, 1985 and Hazra, 1991). Interestingly, Covu-62A and V-70 were characterized by semierect/erect growth habit having higher number of small pods while the parent EC-305827 showed very high green pod yield having long, succulent pod and viny growth habit. Pusa Dofasli was also characterized by high green pod yield with bushy growth habit. Biparental mating between EC-305827 and Covu-62A or V-70 and or between Pusa Dofasli and Covu-62A or V-70 would be expected to offer maximum promise in breeding for high green pod yield with desirable attributes of pod as well as plant. In this case, the use of Jensen's(1970) method of diallel selective mating appeared to be appropriate. With this method all possible biparental combinations could be made among the four desirable combiners.

In the present study, four cross combinations namely, EC-305827 x V-70,EC-305827 x Covu-62A, Sel-Tm3 x 5269 and Cherodi X V-70 showed high sca effects for green pod yield, while sca effects of Pusa Dofasli with either of V-70 or Covu-62A were encouraging. Among these four hybrids, EC-305827 x Covu-62A , EC-305827 x V-70 and Sel-Tm3 x 5269 recorded very high *per se* performance. In these three cross combinations, additive gene effects and additive x additive interactions were predominant

indicating simple pedigree method would help to obtain desirable segregants for the development of promising materials. While in the cross combination Cherodi x V-70 both dominant and non-additive interaction effects were important. In such a situation the selection could be deferred to later generations in order to exploit both additive and non-additive effects as suggested by Singh *et al.* (1992).

CHAPTER-V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

The present study was undertaken with the objective of obtaining basic information needed for initiating a rational breeding approach for genetic improvement of vegetable cowpea (*Vigna unguiculata* cv-gr. Sesquipedalis), a highly proteinous and popular vegetable crop of West Bengal as well as Eastern India.

Keeping in view, twenty five genotypes of cowpea belonging to three cultigroups namely, Biflora, Unguiculata and Sesquipedalis were collected from different parts of India and field trials were carried out at District Seed Farm, Kalyani and at Regional Research Station, Terai zone, Pundibari, Coochbehar, B.C.K.V. over a period of three years (1992-94).

The investigations included:

i> Study on genetic variability, heritability and character associationship.

ii> Study on the different root and nodule characters.

iii> Study on the stability of the genotypes.

iv> Gene action for green pod yield and other reproductive characters.

The important findings of the present study and conclusions drawn from the foregoing have been summarised here topic wise:

1. Analysis of components of green pod yield

The analysis was carried out for green pod yield and its components under two different environments (Kharif and Pre-Kharif) and summarised below :

i> **Analysis of genetic variability and heritability**

The study revealed that Kharif season crop showed marginal improvement in green pod yield and also in some of the characters like pods per plant and plant height in comparison to Pre-kharif season.

The magnitude of phenotypic coefficient of variation (P.C.V.) was higher as compared to genotypic coefficient of variation (G.C.V.) for all characters studied. Both P.C.V. and G.C.V. were higher for pods per plant, green pod weight, dry pod weight, pod length and plant height. Estimates of heritability in broad-sense were higher (above 90%) for pods per plant,green pod weight, dry pod weight, and pod length in both the environments. Genetic advance (G.A.) expressed as percentage of mean was highest for pods per plant followed by dry pod weight, green pod weight and pod length.

ii) Correlation coefficients

Inter-relationships of the characters and their association with green pod yield under two different environments

were examined through the study of phenotypic and genotypic correlation coefficients.

a) Phenotypic and genotypic correlation coefficients, in general, agreed very closely.

b) Five characters namely, pod length, green pod weight, dry pod weight, seeds per pod and 100-seed weight not only exhibited highly significant correlation coefficients with green pod yield but they were also positively and significantly interrelated with each other in both the environments.

c) Days to flowering showed significantly negative correlations at phenotypic and genotypic level in both the environments suggesting early flowering may lead to the production of more pods. Similarly,pods per plant was significantly and negatively correlated with green pod weight and pod length at both phenotypic and genotypic levels indicating more number of pods may lead to short pod length and consequently low green pod weight.

d) The inter-relationships among the characters studied exhibited that only nine inter-relationships,namely,pod length and green pod weight, pod length and dry pod weight, pod length and seeds per pod, pod length and 100-seed weight,. green pod weight and dry pod weight, green pod weight and seeds per pod, green pod weight and 100-seed weight, dry pod weight and seeds per pod and seeds per pod and 100-seed weight remained to be highly positive at phenotypic and genotypic level in both Pre-kharif and Kharif seasons. Thus selection on the basis of any of above mentioned

characters is expected to give a desired correlated response.

iii) Path coefficient analysis

The path analyses were carried out for green pod yield over two different environments and for data pooled over two environments. Simultaneously path coefficients were worked out for green pod weight and pod length also.

a) Green pod weight and dry pod weight exhibited very high positive direct effects on green pod yield in both the environments. Pods per plant although exhibited nonsignificant correlation with green pod yield but its direct effects were highly positive indicating the importance of pods per plant as an important pod yield component.

b) Seeds per pod although registered moderately positive direct effects on green pod yield but the result was consistent in both the environments which suggest to include seeds per pod as an important yield component.

c) Analyses of components of green pod weight and pod length showed that green pod weight and pod length were inter-dependent and influenced each other by highly positive direct and indirect effects.

2. Study on different root and nodule characters

Different root and nodule characters namely, root

length , root weight, nodule number per plant, nodule weight and leghaemoglobin content expressed as mg/g of nodules of ten genotypes belonging to cultigroups Unguiculata, Biflora and Sesquipedalis were studied at 4 stages of crop growth i.e., pre-flowering, flowering, post-flowering and early pod setting stage over two growing seasons namely Pre-kharif and Rabi. The inter relationships among different characters including protein content of pod and green pod yield were investigated in two different growing seasons.

a) Nodule number irrespective of cultigroups were higher in the Pre-kharif season as compared to Rabi season. In all genotypes nodule number was highest in the flowering stage of the plant in both seasons. Nodule number was highest in genotypes of cv-gr. Sesquipedalis which were incidentally the highest yielders. Significant differences in the nodule number among the genotypes in both the seasons were observed.

b) There was an apparent trend of increased nodule weight in the Pre-kharif season. However, irrespective of the cropping season, nodule weight per plant was highest in the flowering stage. Nodule weight also varied significantly among the cultigroups.

c) In both the growing seasons, leghaemoglobin content of nodules increased from the pre-flowering stage to the flowering stage in all the genotypes.The genotypes Sel-Tm3 and Local-4 showed high leghaemoglobin content in both the seasons.

d) There emerged a highly significant associationship between fresh weight and dry weight of shoot . The correlation between root length and shoot weight although highly positive but was not significant. Root weight registered significantly positive correlation with fresh shoot weight only at the flowering stage.

e) Correlation between nodule weight and fresh shoot weight was also significantly positive only in the flowering stage. Associationship among growth and nodule characters was very much pronounced at the flowering stage only.

f) No significant correlation was recorded between nodule number and nodule weight. Leghaemoglobin content of the nodule registered highly positive correlation with nodule number at early pod setting stage.

g) Nodule number, nodule weight and leghaemoglobin content of nodule did not show any significant correlation with green pod yield per plant. There was no significant correlation between protein content of the pod and nodule number, nodule weight and leghaemoglobin content of the nodule. It may be mentioneed that protein content was recorded in the immature pods where deposition of protein was not completed.

3. Analysis of adaptability

The parameters of adaptability for 20 vegetable cowpea genotypes were worked out from data collected over two locations

comprising altogether five different environments for green pod yield and five other traits. Salient results obtained from this study have been summarised below:

a) An examination of the data on the relative stability performance of different genotypes suggested that none of the genotypes included in the study exhibited uniform stability and responsiveness for all the characters examined. The stability/responsiveness levels appear to be specific for individual characters with a genotype and were not common for all the characters of that genotype.

b) The genotypes EC-243954 and Sel-Tm1 belonging to determinate and indeterminate growth habit respectively, were identified as the outstanding genotypes having average stability and high mean performance for green pod yield and some of the major components.

c) The correlation coefficients revealed that there was no significant association among the parameters studied except for pod length suggesting the involvement of different genetic systems in the control of all the characters except pod length.

d) The genotype EC-305827 was identified as a genotype having highest mean for green pod yield per plant and very long pod coupled with below average stability indicating their specificity to favourable environments. But this genotype exhibited indeterminate growth habit. In vegetable cowpea determinate growth habit as well as long pod are ideal in intensive cropping system. Thus the hybridization programme between EC-305827 with stable geno-

type like EC-243954 would like to develop desirable segregants and thus new genotypes with attributes like determinate growth habit, long, succulent pod and high phenotypically stable green pod yield.

4. Gene action for green pod yield and its components

Data from a 8 x 8 half diallel for green pod yield per plant and six of its components were analysed in the F_1 as well as F_2 generations and were subjected to combining ability analysis following Model 1 and Method 2 of Griffing (1956).

a) It was found that for all the traits both variances due to general combining ability and specific combining ability were important in the genetic control of characters. Green pod weight, pod length and pods per plant showed pre-ponderance of additive genetic variance. The improvement of these traits should aim at exploitation of additive genetic variance. While in other traits namely, days to flowering, green pod yield, seeds per pod and dry pod weight,exploitation of both additive and non-additive gene effects would be more meaningful.

b) On the basis of gca effect and *per se* performance of green pod yield and its major components, four genotypes namely, EC-305827, Pusa Dofasli, Covu-62A and V-70 have been selected as good combiners consistently in F_1 and F_2 generations.

c) Four cross combinations viz. EC-305827 x Covu-62A, EC-305827 x V-70, Cherodi x V-70, and Sel-Tm3 x 5269 have been

found to exhibit consistently significant positive sca effects in both the generations for green pod yield and its two or more attributes. Out of these four crosses, three crosses viz., EC-305827 x Covu-62A, EC-305827 X V-70 and Sel-Tm3 x 5269 showed very high *per se* performance for green pod yield per plant. These cross combinations could be handled through pedigree method of breeding in the segregating generation as additive and additive X additive gene effects were predominant. In segregating generation of Cherodi X V-70 ,delayed selection would be useful as in this case, dominant gene effect played a major role.

d) Breeding/Selection strategies for improving different traits have been discussed in detail in relation to the type of gene actions.

Analysis of heterosis

a) From the study of heterosis for green yield and its components, it was observed that many F_1 hybrids exhibited significant positive heterosis over mid-parent but very few of them exhibited significant positive heterosis over better-parent.

b) Four hybrids for green pod yield per plant, pods per plant, and seeds per pod; nine hybrids for days to flowering; and two hybrids for green pod weight and one for dry pod weight recorded significant positive heterosis over their better parents. Two hybrids namely, Sel-Tm3 x 5269 and EC-305827 x Covu-62A exhibited very high heterosis over better-parents (72.82% and 36%, respec-

tively) coupled with very high *per se* performance for green pod yield per plant. Specific combining ability of these two crosses were also found to be significantly positive.

c) Heterosis for green pod yield could be ascribed mainly due to heterosis observed for pod number per plant.

CHAPTER-VI

FUTURE SCOPE OF RESEARCH

FUTURE SCOPE OF RESEARCH

Besides broad problems and objectives, some special needs may deserve attention in the years ahead as a focus for secondary objectives. We propose here some of the important line of approaches which are outlined below-

1. More detailed study should be done to understand the genetic architecture of all the major physiological components like biological yield, harvest index, specific leaf weight, leaf area duration, number of leaves per plant etc. Such study will help to develop appropriate breeding/selection methodologies for an overall crop improvement.

2. Nodulation study should be conducted with more genotypes and with application of *Rhizobium* strains. Such study will enable us to understand more critically the host-*Rhizobium* interaction and ultimately for evolution of ideal plant type. Besides this, the improved strains of *Rhizobium* are required to be tested with more number of genotypes to improve nodulation.

3. The segregating generations developed from the present study may thoroughly be screened for selection of lines having high green pod yield, ideal plant characteristics and harvest index on the basis of multilocational trials.

4. Diallel analysis with more number of genotypes and in

different environments will help to understand the general trend of genetic architecture of green pod yield and its components in the cowpea as a whole.

5. Adaptability study in different agro-climatic situations with more number of vegetable cowpea genotypes need to be conducted for identifying genotypes with high green pod yield and wider adaptability.

6. Testing the effect of plant growth regulators for improving hybrid pod set which is the major barrier of hybridization in this crop.

7. A detailed study on the quantity as well as quality of protein in cowpea pod will be required in different genotypes of cowpea. This will help to initiate breeding programme for restructuring cowpea genotypes having erect growth coupled with high green pod yield and long, succulent pods with farely good amount of quality protein.

8. Breeding for high pod yield and good pod quality should be coupled with resistance to biotic stresses. Breeding methodology to incorporate resistant genes against major diseases and insect pests in otherwise high yielding genotypes should be formulated.

9. Efficiency of different methods of selection in segregating generations need to be assessed through critical study.

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* Original not seen

APPENDIX

Appendix I: Physico-chemical features of the soil in the experimental plots

	District Seed Farm (A&B Block),Kalyani	R.R.S.,Teraizone, Coochbehar	Method
Clay %	24.36	11.62	International Pipette method (Piper, 1966)
Silt %	36.42	25.92	-do-
Sand %	41.40	62.46	-do-
Total N%	0.054	0.146	Modified Kjeldahl metohd (Jackson,1967b)
Available P_2O_5 (kg/ha)	34.00	21.93	Olsen's method (Chopra and Kanwar, 1986c)
Available K_2O (kg/ha)	97.00	104.00	Flame Photometric method (Jackson,1967c)
Organic Carbon%	0.49	0.87	Walklay and Black's method (Chopra and Kanwar,1986a)
PH of the soil	6.8	5.7	Potentiometric method with glass electrode (Chopra and Kanwar,1986 b)

Appendix II: Meteorological data of the experimental period

Year	Months	Temperature(°C) Max.	Min.	Total Rainfall (m.m.)	Relative Humidity(%) Max.	Min.
A) KALYANI						
1992	October	33.5	23.32	28.85	90.12	62.40
	November	31.2	16.84	4.25	94.26	49.50
	December	26.5	11.70	0.00	94.14	40.27
1993	January	25.5	10.34	0.00	92.71	50.02
	February	30.7	16.55	0.50	91.35	52.43
	March	32.6	17.31	74.00	83.50	40.52
	April	35.3	20.90	65.65	87.32	55.06
	May	35.6	23.52	112.20	89.06	57.72
	June	33.7	24.33	348.10	87.61	75.64
	July	33.2	26.25	263.80	95.09	79.45
	August	32.4	26.40	316.10	95.45	81.76
	September	32.0	23.62	441.80	96.61	72.43
	October	32.5	23.71	88.00	92.09	67.54
	November	29.5	18.25	5.10	90.90	50.82
	December	27.3	12.73	0.00	93.96	40.37
1994	January	26.11	11.42	10.00	95.20	47.52
	February	26.76	14.35	54.73	95.39	55.71
	March	33.84	18.24	8.00	92.34	43.50
	April	35.02	20.55	106.70	86.59	54.41
	May	36.04	24.21	148.90	90.43	57.50
	June	33.05	24.27	350.40	93.70	80.44
	July	32.31	26.63	213.10	95.13	80.81
	August	32.01	26.16	202.90	96.10	82.90
	September	32.98	25.19	58.60	93.30	69.07
	October	32.82	22.85	41.20	90.68	60.40
B) COOCHBEHAR						
1994	March	28.80	17.32	39.80	88.20	56.17
	April	31.40	20.51	153.82	86.34	54.24
	May	32.34	23.15	513.00	88.41	64.03
	June	31.10	24.65	358.70	93.16	74.63
	July	33.19	25.78	548.60	93.09	69.74

Appendix III : Mean values of 20 genotypes/varieties of vegetable cowpea for environment one (E_1)

Genotypes/ Varieties	Plant height (cm)	Branches/ plant	Peduncle length (cm)	Days to flowering	Pod length (cm)	Green pod weight (g)	Dry pod weight (g)	Pods/ plant	Seeds/ pod	100-seed weight (g)	Green pod yield/plant (g)
Pusa Barsati	183.37	5.97	28.57	52.33	15.27	7.23	1.36	27.27	12.00	7.82	197.41
Pusa Dofasli	189.07	7.47	33.20	44.00	24.67	10.40	1.22	29.90	17.60	12.35	311.28
Sel-Tm1	156.07	4.70	32.80	40.67	32.37	18.63	1.80	17.17	17.20	13.39	319.74
Sel-Tm2	204.90	5.20	30.73	51.67	32.10	16.70	1.32	15.73	16.33	13.26	263.00
Sel-Tm3	259.57	5.23	26.78	46.67	40.13	18.80	1.81	17.57	17.83	14.01	329.39
Arka Garima	172.70	5.30	27.07	46.00	22.73	10.53	0.87	20.30	8.27	9.34	214.06
Sel-Tm4	145.80	5.17	25.37	43.33	23.70	11.87	1.07	19.77	9.00	9.48	234.81
EC-305827	194.37	4.47	23.27	37.33	44.57	20.40	2.38	21.40	20.27	12.88	436.76
EC-243954	65.40	5.13	26.80	40.67	23.63	10.20	1.03	33.43	13.27	12.74	341.35
5269	159.53	5.57	32.67	42.33	20.00	5.17	0.97	45.70	12.07	9.64	236.80
I-101	146.37	5.17	20.63	43.33	17.97	4.63	0.52	48.73	10.07	10.14	225.63
T - 2	151.80	6.00	31.57	46.00	28.20	13.67	1.66	26.87	14.20	12.70	367.00
T - 4	137.50	6.07	34.80	45.00	25.37	14.57	1.57	21.03	12.47	13.21	307.13
T - 6	161.77	4.90	20.20	48.67	24.50	11.17	1.47	22.80	15.50	10.81	254.49
Local - 1	259.80	4.83	23.93	46.00	31.50	17.87	1.15	16.13	11.60	12.15	293.85
Local - 4	256.77	4.57	24.83	44.33	21.10	6.73	1.66	45.03	13.13	12.67	303.53
Local - 9	222.60	6.03	32.20	47.00	34.63	20.47	1.24	17.10	15.67	13.82	349.10
Local - 10	213.40	5.30	26.47	43.00	31.93	13.70	0.97	19.37	18.50	12.30	265.41
Local - 10A	216.33	3.47	30.67	50.00	33.07	15.10	2.17	17.17	14.97	11.88	258.80
Local - 16	195.87	5.33	25.80	39.00	42.17	20.37	1.93	14.50	16.17	14.16	295.63

Appendix IV: Mean values of 20 genotypes/varieties of vegetable cowpea for environment two (E_2)

Genotypes/ Varieties	Plant height (cm)	Branches/ plant	Peduncle length (cm)	Days to flowering	Pod length (cm)	Green pod weight (g)	Dry pod weight (g)	Pods/ plant	Seeds/ pod	100-seed weight (g)	Green pod yield/plant (g)
Pusa Barsati	203.67	6.10	25.10	53.33	17.10	6.83	1.38	31.07	11.73	7.95	212.36
Pusa Dofasli	202.43	7.00	31.90	45.00	24.03	9.73	1.22	37.07	17.33	12.16	360.60
Sel-Tm1	159.63	4.23	28.73	39.00	31.50	18.50	1.71	17.70	16.47	13.15	326.45
Sel-Tm2	219.03	5.37	27.60	47.67	31.83	16.83	1.36	16.70	16.37	13.23	281.35
Sel-Tm3	280.97	4.73	24.83	40.67	40.57	17.23	1.77	19.23	17.47	13.68	332.18
Arka Garima	177.27	5.03	27.47	41.67	20.53	10.37	0.77	23.17	7.40	8.94	239.11
Sel-Tm4	144.63	4.73	24.80	40.67	21.63	11.77	1.05	22.57	8.43	9.29	265.68
EC-305827	197.30	4.33	23.80	35.33	43.93	21.50	2.42	20.40	19.50	12.09	438.26
EC-243954	72.17	4.67	25.27	36.33	22.27	9.50	0.99	36.17	13.17	12.67	342.41
5269	170.47	5.30	32.27	39.67	20.47	5.67	1.02	48.83	12.57	9.81	277.37
1-101	155.53	5.03	20.17	38.33	18.13	4.17	0.46	47.20	12.27	10.00	195.60
T - 2	164.40	5.97	29.30	43.00	26.17	13.60	1.57	25.77	13.70	12.63	350.80
T - 4	146.97	5.93	33.00	45.00	25.07	14.63	1.54	23.83	12.17	13.04	349.10
T - 6	166.47	4.73	18.80	44.33	23.57	11.13	1.43	23.77	14.77	10.29	264.26
Local - 1	274.30	4.27	21.87	43.33	31.50	18.23	1.08	16.63	12.10	12.08	270.63
Local - 4	270.03	4.60	24.23	38.33	19.50	6.53	1.46	49.40	12.73	12.03	320.97
Local - 9	221.10	5.67	28.10	41.00	32.50	20.74	1.24	17.67	14.77	13.65	366.10
Local - 10	218.67	5.57	24.43	48.33	29.57	13.50	0.91	16.90	18.07	12.46	228.96
Local - 10A	222.00	3.57	27.77	46.67	33.60	15.43	2.07	16.60	14.43	11.84	256.77
Local - 16	202.43	4.97	24.90	36.33	41.17	20.03	1.77	16.13	15.50	13.84	323.69

Appendix V : Mean values of 20 genotypes of vegetable cowpea over five environments (E_1, E_2, E_3, E_4 and E_5)

Varieties/ Genotypes	Days to flowering					Pod length (cm)					Green pod weight (g)					Dry pod weight (g)					Pods /plant					Green pod yield/ plant (g)				
	E_1	E_2	E_3	E_4	E_5	E_1	E_2	E_3	E_4	E_5	E_1	E_2	E_3	E_4	E_5	E_1	E_2	E_3	E_4	E_5	E_1	E_2	E_3	E_4	E_5	E_1	E_2	E_3	E_4	E_5
Pusa Barasati	53.00	58.33	69.67	52.33	53.33	15.73	15.87	16.67	15.27	17.10	6.03	7.63	8.00	7.23	6.83	1.30	1.38	1.52	1.36	1.38	25.50	33.57	16.70	27.27	31.07	154.04	255.60	133.72	197.41	212.36
Pusa Dofasli	47.33	48.33	68.67	44.00	45.00	19.83	24.60	19.30	24.67	24.03	8.17	10.70	9.80	10.40	9.73	1.22	1.40	1.42	1.22	1.22	28.03	36.03	23.93	29.90	37.07	228.68	385.85	235.54	311.28	360.60
Sel-Tm1	44.33	47.67	67.00	40.67	39.00	30.33	29.87	33.93	32.37	31.50	15.17	17.80	17.67	18.63	18.50	1.36	1.47	1.74	1.80	1.71	14.70	18.20	12.33	17.17	17.70	223.22	323.92	217.99	319.74	326.45
Sel-Tm2	54.33	54.33	75.67	51.67	47.67	28.23	27.53	34.07	32.10	31.83	13.07	16.30	19.40	16.70	16.83	1.23	1.35	1.93	1.32	1.36	15.47	19.57	11.23	15.73	16.70	202.03	319.59	218.39	263.00	281.35
Sel-Tm3	50.33	46.00	77.67	46.67	40.67	34.37	36.23	36.33	40.13	40.57	15.17	18.23	20.20	18.80	17.23	1.73	1.82	2.18	1.81	1.77	17.00	19.77	12.43	17.57	19.23	257.96	361.41	250.96	329.39	332.18
Arka Garima	52.33	42.33	79.00	46.00	41.67	16.53	21.23	17.13	22.73	20.53	6.83	11.07	7.27	10.53	10.37	0.78	1.02	0.82	0.87	0.77	14.63	24.57	14.40	20.30	23.17	99.67	272.11	104.00	214.06	239.11
Sel-Tm4	46.67	44.67	76.33	43.33	40.67	18.37	24.93	17.67	23.70	21.63	7.63	11.97	9.70	11.87	11.77	0.81	1.06	1.04	1.07	1.05	14.33	23.40	15.60	19.77	22.57	109.58	280.74	151.72	234.81	265.68
EC-305827	42.33	39.33	55.33	37.33	35.33	39.97	45.23	38.57	44.57	43.93	17.50	21.10	18.57	20.40	21.50	2.32	2.41	2.55	2.38	2.42	19.47	21.33	16.27	21.40	20.40	341.57	450.49	302.39	436.76	438.26
EC-243954	44.00	48.67	60.00	40.67	36.33	19.77	24.93	20.30	23.63	22.27	8.57	10.73	9.50	10.20	9.50	0.97	1.11	1.16	1.03	0.99	34.20	37.17	27.97	33.43	36.17	292.69	399.48	266.15	341.35	342.41
5269	45.67	39.33	67.00	42.33	39.67	20.60	20.17	19.57	20.00	20.47	4.87	5.47	5.20	5.17	5.67	0.95	1.04	1.06	0.97	1.02	40.23	47.60	38.53	45.70	48.83	195.46	259.82	200.07	236.80	277.37
1 - 101	45.67	40.33	78.00	43.33	38.33	18.30	19.03	14.90	17.97	18.13	4.83	4.57	4.20	4.63	4.17	0.52	0.51	0.42	0.52	0.46	50.03	48.67	43.57	48.73	47.20	242.08	223.54	183.14	225.63	195.60
T - 2	50.00	48.67	65.00	46.00	43.00	22.07	24.30	22.03	28.20	26.17	9.53	12.33	11.30	13.67	13.60	1.60	1.70	1.74	1.66	1.57	18.20	31.57	20.63	26.87	25.77	173.79	388.03	232.21	367.00	350.80
T - 4	49.33	44.67	66.33	45.00	45.00	19.20	25.07	22.47	25.37	25.07	10.43	12.63	12.33	14.57	14.63	1.53	1.61	1.62	1.57	1.54	15.17	23.97	15.43	21.03	23.83	158.07	301.92	190.71	307.13	349.10
T - 6	51.00	49.67	75.33	48.67	44.33	17.57	24.90	22.63	24.50	23.57	8.90	10.67	9.73	11.17	11.13	1.46	1.63	1.71	1.47	1.43	16.23	24.30	17.33	22.80	23.77	144.25	259.44	168.68	254.49	264.26
Local-1	51.33	45.33	74.33	46.00	43.33	26.43	33.47	34.20	31.50	31.50	12.37	17.90	16.17	17.87	18.23	1.07	1.33	1.53	1.15	1.08	13.83	19.00	13.00	16.13	16.63	170.50	339.81	209.96	293.85	270.63
Local-4	47.00	41.33	73.00	44.33	38.33	20.47	22.33	22.73	21.10	19.50	6.27	6.63	7.17	6.73	6.53	1.65	1.49	1.75	1.66	1.46	41.17	51.43	38.60	45.03	49.40	257.53	339.83	276.10	303.53	320.97
Local-9	51.33	49.00	73.67	47.00	41.00	27.47	33.80	33.87	34.63	32.50	14.07	19.23	17.30	20.47	20.74	1.21	1.28	1.76	1.24	1.24	14.40	19.47	14.40	17.10	17.67	202.41	374.92	248.72	349.10	366.10
Local-10	46.67	52.33	68.33	43.00	48.33	29.27	28.20	24.40	31.93	29.57	9.77	11.60	9.43	13.70	13.50	1.14	1.26	1.24	0.97	0.91	18.80	19.89	15.33	19.37	16.90	183.89	230.31	144.22	265.41	228.96
Local-10A	54.00	49.67	68.33	50.00	46.67	30.43	30.97	25.47	33.07	33.60	11.43	13.13	9.47	15.10	15.43	2.07	2.21	1.96	2.17	2.07	20.90	20.60	15.60	17.17	16.60	238.11	270.90	147.44	258.80	256.77
Local-16	42.00	43.67	75.67	39.00	36.33	40.13	38.57	35.17	42.17	41.17	16.13	18.00	15.33	20.37	20.03	1.81	1.92	1.68	1.93	1.77	13.53	19.30	12.40	14.50	16.13	218.66	346.78	189.52	295.63	323.69

Appendix VI: Mean values of 8 parents used in diallel cross

Parents	Days to flowering	Pod length (cm)	Green pod weight (g)	Dry pod weight (g)	Pods/Plant	Seeds/pod	Green pod Yield/plant (g)
EC-305827	38.33	42.20	20.20	2.32	18.23	18.23	368.50
Sel-Tm3	41.00	38.70	16.27	1.71	16.47	16.33	268.11
Cherodi	36.67	10.77	2.53	0.57	48.07	10.30	121.23
V-70	37.67	11.10	2.47	0.53	52.03	10.10	127.95
13-31B	39.67	18.23	5.37	0.62	54.07	12.50	289.53
Pusa Dofasli	44.00	23.20	9.47	1.20	34.10	17.30	322.39
Covu-62A	41.33	12.23	2.90	0.57	58.13	11.97	157.28
5269	40.33	20.13	5.40	1.00	48.63	12.40	262.87

Appendix VII: Mean values of 28 F_1s

Crosses	Days to flowering	Pod length (cm)	Green pod weight (g)	Dry pod weight (g)	Pods/Plant	Seeds/pod	Green pod Yield/plant (g)
EC-305827xSel-Tm3	46.67	27.73	11.27	1.10	16.33	12.33	184.78
EC-305827xCherodi	39.00	20.33	6.30	0.86	46.27	12.67	290.28
EC-305827xV-70	39.00	23.10	6.13	0.89	81.04	14.83	496.79
EC-305827x 13-31B	33.00	27.00	7.57	0.97	25.87	15.50	196.76
EC-305827xPusa Dofasli	40.00	36.43	12.33	1.38	26.00	16.57	316.39
EC-305827xCovu-62A	33.67	27.07	8.07	1.14	62.10	12.90	501.17
EC-305827x5269	35.33	30.07	9.97	1.23	32.73	13.50	323.89
Sel-Tm3xCherodi	42.67	25.43	8.03	0.84	23.93	12.23	191.65
Sel-Tm3xV-70	40.67	22.80	6.97	0.84	26.23	9.50	181.59
Sel-Tm3x13-31B	50.33	28.07	6.63	0.84	23.97	12.00	158.17
Sel-Tm3xPusa Dofasli	43.67	27.20	10.33	1.30	26.60	11.80	277.09
Sel-Tm3xCovu-62A	49.67	21.10	5.43	0.77	30.73	11.23	166.12
Sel-Tm3x5269	44.33	26.47	11.07	1.02	41.86	11.30	463.34
CherodixV-70	39.33	11.20	2.57	0.50	70.24	10.33	180.54
Cherodix13-31B	39.33	11.80	3.33	0.56	51.17	10.17	170.80
CherodixPusa Dofasli	40.33	13.53	3.13	0.53	45.57	13.17	143.37
CherodixCovu-62A	41.33	11.57	2.67	0.55	54.93	7.00	145.83
Cherodix5269	39.67	17.50	4.13	0.60	48.87	13.17	200.81
V-70x13-31B	36.33	11.87	2.47	0.52	47.07	7.17	116.91
V-70xPusa Dofasli	36.33	10.87	2.43	0.53	37.20	8.00	98.93
V-70xCovu-62A	39.67	11.43	2.57	0.53	53.50	10.33	136.50
V-70x5269	39.00	12.87	2.70	0.51	53.00	12.67	170.09
13-31BxPusa Dofasli	39.67	18.13	4.67	0.68	34.83	9.67	163.51
13-31BxCovu-62A	42.67	14.33	3.97	0.62	55.77	12.50	221.55
13-31Bx5269	39.67	18.57	5.50	0.69	53.57	12.83	294.29
Pusa DofaslixCovu-62A	39.67	22.70	4.60	0.73	44.30	13.00	200.39
Pusa Dofaslix5269	42.00	23.13	6.27	0.81	61.07	14.83	382.91
Covu-62Ax5269	40.67	16.43	3.80	0.67	54.50	13.67	205.91

Appendix VIII : Mean values of 28 F_2s

Crosses	Days to flowering	Pod length (cm)	Green pod weight (g)	Dry pod weight (g)	Pods/Plant	Seeds/pod	Green pod Yield/plant (g)
EC-305827xSel-Tm3	44.33	31.57	11.53	1.14	16.87	15.00	195.43
EC-305827xCherodi	38.00	26.20	8.60	1.08	26.30	16.17	227.85
EC-305827xV-70	37.33	28.70	9.30	1.12	28.27	15.17	259.45
EC-305827x 13-31B	37.33	31.43	16.13	1.55	20.57	17.83	312.27
EC-305827xPusa Dofasli	37.33	38.13	14.17	1.41	21.63	19.33	303.63
EC-305827xCovu-62A	35.67	29.13	9.93	1.22	31.60	16.83	309.39
EC-305827x5269	35.00	29.43	11.20	1.37	27.23	15.00	343.67
Sel-Tm3xCherodi	38.33	19.57	6.10	0.74	24.93	11.33	154.61
Sel-Tm3xV-70	33.67	23.00	6.90	0.71	23.23	13.33	163.42
Sel-Tm3x13-31B	43.33	28.67	7.83	0.89	22.60	15.17	174.91
Sel-Tm3xPusa Dofasli	41.33	25.07	8.30	1.14	23.23	14.17	190.09
Sel-Tm3xCovu-62A	41.33	19.33	5.07	0.74	27.97	11.67	140.85
Sel-Tm3x5269	37.33	28.60	11.27	1.02	35.03	12.33	396.50
CherodixV-70	33.67	10.33	2.73	0.55	46.57	12.67	125.41
Cherodix13-31B	37.33	12.77	3.67	0.62	51.60	11.33	189.76
CherodixPusa Dofasli	40.67	12.37	3.27	0.60	48.03	13.00	155.99
CherodixCovu-62A	37.67	12.00	2.70	0.54	50.60	12.67	134.84
Cherodix5269	38.00	17.27	4.27	0.64	45.93	12.83	195.42
V-70x13-31B	35.33	11.47	2.67	0.57	46.90	12.50	125.88
V-70xPusa Dofasli	36.33	10.77	2.53	0.52	39.90	12.50	101.28
V-70xCovu-62A	38.33	11.93	2.80	0.58	51.97	13.17	145.92
V-70x5269	40.33	13.47	3.03	0.56	46.27	12.50	141.75
13-31BxPusa Dofasli	36.00	17.47	5.03	0.73	39.23	12.50	199.11
13-31BxCovu-62A	39.67	14.27	5.00	0.63	47.90	12.83	192.26
13-31Bx5269	38.67	18.30	5.67	0.73	46.63	12.67	264.59
Pusa DofaslixCovu-62A	34.00	18.40	4.30	0.71	42.13	12.83	182.87
Pusa Dofaslix5269	39.67	20.67	6.47	0.83	41.00	14.50	268.90
Covu-62Ax5269	38.67	14.93	3.97	0.69	50.53	13.33	198.61