POTENTIAL FOR DROUGHT TOLERANCE IN COWPEA [*Vigna unguiculata* (L) Walp]

BY

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Potential For Drought Tolerance in Cowpea (*Vigna unguiculata* (L.) Walp)" is a bonafide record of research work done by me and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

MAGIE MEREENA

Vellayani,
17-7-1989.

CERTIFICATE

Certified that this thesis, entitled "Potential for drought tolerance in cowpea (*Vigna unguiculata* (L.) Walp) is a record of research work done independently by Miss. Magie Mereena under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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INTRODUCTION

INTRODUCTION

Grain legumes constitute an important group among the various food crops of the tropics. Besides being the main source of vegetable protein in the human diet, the value of pulses as nutritious feeds for the cattle and as restorative cover and green manure crops to the soil has long been recorded. India has nearly one third of the global area under pulses (23 million ha.). But due to the present very low level of productivity, the total production (12 million tonnes) is short of country's requirement by about 50 per cent. In order to attain high economic yields, a pulse crop should have high biological yield coupled with high harvest index. Genetic restructuring of the plant types to give higher harvest index may lead to the development of types with high economic yield (Jeswani, 1986). Since a vast majority of people of India depend upon pulses for their protein requirement, increasing the cultivation and production of pulses assume considerable importance in solving the protein malnutrition problem.

Cowpea (<u>Vigna unguiculata</u> (L). Walp) is one of the important pulse crop in Kerala and it occupies nearly 75 per cent of the total area under pulses ie. about 28,500 ha (Anon, 1985). In Kerala, cowpea is grown in uplands during the rainy season and in the rice fallows during the summer months. The yield of rainfed crop is very often significantly reduced due to inadequate and erratic monsoon and the frequent prevalence of long spells of drought in recent years. Drought is usually considered as a deficiency of available soil moisture which produces internal water deficits in plants, severe enough to reduce plant growth and productivity, by a delay or prevention of crop establishment, weakening or destruction of established crops, alteration of physiological and biochemical metabolism and the quality of grain (Larson and Eastin, 1971). Different varieties of cowpea respond differently to the conditions of drought. These differences are attributed to the presence of characters contributing to drought tolerance such as deep wide spread root system, high root/shoot ratio, leaf area index, long grain filling period and high harvest index. In this context, the present investigation in cowpea was taken up with the objectives of

(1) assessing the performance of different cowpea varieties
(2) studying the variability, correlation and the direct and indirect attributes contributing to drought tolerance and grain yield and
(3) identification of drought tolerant varieties.

The study on genetic variability, correlation and path analysis helps to identify an ideal plant type of cowpea with high harvesting efficiency suited to drought prone conditions.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

In India a major part of the cultivated area is under purely rainfed conditions. The erratic rainfall in this area often results in long spells of drought. Hence the identification of drought resistant/tolerant varieties is a must for overcoming this situation. Drought resistance is the result of many, frequently independent morphological and physiological characters, whose interaction has not yet been sufficiently elucidated. Only very little systematic work has been carried out with the specific objective of breeding crop varieties for the development of drought resistant/tolerant varieties. Variability that is observed in the various morphological and physiological characters can be used as the basis for selection of drought tolerant varieties. Selection criteria in breeding for drought tolerance, variability, correlation and path analysis studies on characters contributing to drought tolerance and high yield in crop plants with special reference to pulses are reviewed.

2.1. Selection criteria in breeding for drought tolerance

Drought resistance/tolerance is very difficult to measure because of the presence of large number of adaptations contributing to this mechanism. In the case of stresses to which plants have been exposed only for a short period in their evolutionary history, only one or two adaptations have been developed. In contrast to this, land plants which have been exposed to drought for as long as they have been on land, all conceivable adaptations can be found, some in one species, others in another. When evaluated in this way, resistance is a combination of many things, since yield depend not only on the ability of the plant to survive the drought, but also on its ability to grow and complete its development before, during or after the drought. Some root and shoot characters and physiological characters help the plants to overcome drought and to give good yield.

2.1.1. Root length and root spread

The root system plays a decisive role in plant adaptation to water deficit. The relation of root system to drought resistance has been the subject of considerable research.

Misra (1956) reported that an early and well developed root system enables a plant to withstand early periods of drought more successfully. In latter periods of growth and development, the larger and wider area would be covered by the better developed root system and consequently the plants can tolerate drought conditions. He observed that the different strains of corn which had better root system had greater ability to survive soil drought than others. Rajagopalan (1958) noticed that the root number, total length, thickness and dry weight of roots are greater in drought resistant rice varieties. Kramer (1959) reported that a deep well branched and wide spreading root system is excellent protection against drought injury, because, the more extensive the root system, the larger the reservoir of soil water, the plants can absorb.

The root characters associated with drought resistance in sorghum was studied by Thangavelu et al. (1967a) and found that drought resistance was correlated with the characteristics of root system such as greater length, higher percentage of thin roots and deeper penetration. Hurd (1969) reported that since the yield under semi-arid conditions is related to efficient moisture utilization, the root pattern of varieties is important. He suggested that varieties having a dense root system, capable of penetrating the soil rapidly, along with a larger proportion of roots at lower depths should be selected for making crosses and developing wheat varieties suited for semi-arid conditions. Tiwari et al. (1974) observed that in wheat, varieties with more number of roots capable of deep vertical penetration and a more horizontal spread of seminal roots were drought escaping and high yielding. Sandhu and Horton

(1977) studied the response of oats to water deficit and found that plants growing under soil water stress conditions had deep roots.

Babalola (1980) studied the water relations of three cowpea cultivars and reported that while selecting cowpea cultivars for intercropping purposes characters such as depth of rooting, lateral root spread and root density which affect water extraction at different soil depths should be considered. Thomas (1983) observed that the greater drought resistance exhibited by tepary beans (*Phaseolus acutifolius*) when compared to common beans (*P. vulgaris*) was due to the presence of longer roots in tepary beans.

Pandey *et al*. (1984) studied the drought response of four grain legumes under irrigation gradients and found that cowpea and peanut had higher root densities at 0.4 m to 0.8 m depth than soybean and mungbean and this appeared to be a major adaptative mechanism for their drought tolerance.

2.1.2. Root/Shoot Ratio

A high root/shoot ratio was reported in drought resistant varieties of rice by Rajagopalan (1958) and in sorghum by Thangavelu *et al*. (1967a). Kramer (1969) reported that greater root/shoot ratio is always associated with drought resistance. Parao et al. (1976) found that sorghum and corn which are more drought resistant than rice had much higher root/shoot ratio. O'Toole and Chang (1979) observed that as the root to shoot ratio increases, the visual score in field drought screening shifts towards the resistant rating. O'Toole and Maguling (1981) reported that the dryland cultivars of rice differ from rainfed and irrigated wetland rice cultivars in their greater root-to-shoot ratio. In rice, Cruz et al. (1986) observed that water stress increased the ratio of root drymass to shoot drymass and the leaf area to total root length.

Schulze (1986) reported that water shortage significantly affects root growth and the root-shoot ratio at the whole plant level. Murty (1987) proposed that a well ramified deep root system with greater root/shoot ratio to tap moisture from deeper zones are important for drought tolerance.

2.1.3. Leaf Area Index

Thangavelu et al. (1967b) studied the leaf and panicle characters associated with drought resistance in sorghum and concluded that less number of leaves, narrow leaf characters and reduced fourth leaf area help to withstand the drought by minimising the waterloss by transpiration. Hsiao (1973) observed that moisture stress can reduce the development of leaf surface area. He proposed that the sensitivity of dry matter yield to stress should be greater in a growing crop with a low leaf area index than in a crop with a high leaf area index.

Sammons et al. (1978) reported that a significant reduction in leaf area under drought is related to plant drought susceptibility. They suggested that cultivars which are able to maintain high photosynthesis at or near control level under increasingly severe soil moisture stress are considered drought resistant. Drought adaptation of cowpea studied by Turk (1979) revealed that with increase in levels of drought, leaf area, shoot dry matter, number of leaflets and average leaflet area decreased. Ali (1980) studied the genotypic response to moisture stress in cowpea and found that leaf area index reduced due to moisture stress in all genotypes. He proposed that a genotype suited to rainfed conditions should show a lesser reduction in leaf area index, leaf area duration and photosynthetic efficiency and thus be able to produce high dry matter. Turk and Hall (1980) studied the drought adaptations cowpea and found that drought avoidance by cowpeas were partially due to low transpiration resulting from low leaf area. Garrity et al. (1984) suggested that a reduction in leaf area was an important mechanism for transpiration control under drought stress during the entire reproductive and grain filling periods in grain sorghum. They proposed that the reduction in leaf area which occurred early in the season and the leaf senescence which occurred later proved to be the major mechanism for transpiration control and drought avoidance.

In cowpea, soybean, peanut and mungbean, Pandey et al. (1984) found that increasing moisture stress resulted in progressively less leaf area, leaf area duration, crop growth rate and shoot dry matter and they found that these grain legumes differed in their ability to maintain leaf area index at higher levels of water stress. Shivraj et al. (1987) reported that in ragi, cultivars maintaining high leaf area index under stress produced more grain yield.

2.1.4. Number of stomata

One of the important characteristic which postpone the development of internal water deficit is few stomata or stomata which close promptly when water deficit occurs (Kramer, 1959).

Buican et al. (1964) studied the genetic resistance of maize to drought and reported that in field and lab tests, resistance to drought has been associated with a small number of stomata with long thick walled guard cells. In sorghum, Thangavelu et al. (1969) reported that one of the character which is essential for lowering transpiration is fewer stomata in the leaves. Ravindranath and Ali (1972) reported that less number of stomata must be sought for while breeding for drought resistance.

Setty and Sreeramulu (1972) studied the drought tolerance of sorghum selections based on morphological characters and yield components and reported that selections with good yield have fewer number of stomata/unit area.

Babalola (1980) found that stomatal density, aperture and behaviour to decreased soil water potential differed widely among different cowpea cultivars. Renard and Allurik (1981) studied stomatal and leaf characteristics of cultivars of rice in their response to water stress and reported that the least susceptible cultivars had fewer stomata than other cultivars.

The response of cowpea to atmospheric and soil drought was studied by Nagarajah and Schulz (1983) and they reported that in cowpea stomata is more sensitive to soil drought. Shewesh et al. (1985) suggested that stomatal frequency and distribution are important in determining the drought tolerance or drought susceptibility, because stomata regulates water loss and utilization in crop plants.

2.1.5. Duration upto maturity

In cultivated crops the ability of a cultivar to achieve maturity before the soil dries out is the main adaptation to growth in a dry region. In spring wheat it has been widely demonstrated that earliness leading to drought escape confers an yield advantage under terminal drought (Derera et al., 1969). Chinoy (1960) studied the physiology of drought resistance in wheat and reported that in India, the only wheat varieties that produce good yields are those that complete their growth before the onset of drought.

Ojomo (1971) reported that early flowering has been considered as a desirable character in several breeding programmes with cowpea for drought tolerance. The earliness reduces the number and the time of incidence of the moisture stress periods in relation to the phenology of the plants and therefore is an important characteristic as suggested by Arnon (1975).

Turner (1979, 1986) stated that the greatest advances in breeding for water limited environments have been achieved by shortening of the life cycle, thereby allowing the crop to escape drought. Foster and Weng (1979) suggested that in grain sorghums, the number of days to flowering is a useful selection criteria in developing drought resistant lines.

Hall and Grantz (1981) reported that drought resistance of cowpea can be improved by selecting early appearance of mature pods. They added that earlier partitioning of carbohydrates to reproductive parts would result in more drought resistance in cowpea. Similarly Sangwan and Mehrotra (1982) reported that in mungbean, early maturing genotypes showed promise for high and stable seed yield under rainfed conditions. Norem et al. (1985) studied the characters associated with drought tolerance in sorghum and found that days to anthesis were significantly less for drought tolerant lines than for medium and low drought tolerant lines.

Murty (1987) suggested earliness as an insurance against drought in rice and hence is an important attribute to be considered in selecting the varieties for drought prone areas. In pearl millet, Bidinger et al. (1987) assessed the factors affecting yield under stress and found that the major factor determining grain yield of a genotype under stress conditions is its duration to flowering.

2.1.6. Grain Filling Period

Shorter grain filling period adversely affects yield under drought conditions. Since most of the carbohydrates accumulating in the grains are synthesised during grain filling period, its shortening will have an adverse effect on the yield as suggested by Asana et al. (1968) in wheat. Gregory (1982) reported that in rice, yield under stress can be increased by increasing the quantity of assimilates moved to fill the grains.

The effect of moisture stress on the duration of the seed filling period was studied by Meckal et al. (1984) in soybean and they reported that the duration of the seed filling period ranged from 27 days in the late stress plants to 43 days in the well watered plants. Drought after anthesis hastens maturation and leaf senescence, thereby reduces the length of the filling period. Bruckner (1986) suggested that high rate and short duration of grain filling were associated with post anthesis drought tolerance in spring wheat.

The duration of seed filling is related to yield in many crops. Plancho et al. (1986) suggested that the reduction in seed weight of soybean under late stress was due to poor seed filling. Omara (1987) observed that the response of early selections of barley to the drought treatments in sandy soil was characterised by a reduction in the time to flowering and a corresponding prolongation in the time from flowering to maturity.

Nelson (1987) studied the relationship between seed filling period and seed yield in soybean and found that longer seed filling period leads to higher seed yield.

2.1.7. Plant height

Among the structural characteristics which may be related to drought resistance include plant height along with root and inflorescence characters. Henckel (1964) reported that drought causes a dwarfing effect on plants mainly due to early cell maturation. Day and Intalap (1970) studied the effects of soil moisture stress on the growth of wheat and found that moisture stress, at the critical period of growth resulted in shorter plants.

Hiler et al. (1972) found that plant height was drastically reduced in cowpea when drought was imposed during various growth stages. In mungbean similar results were reported by Ali and Alam (1973). Similarly in oats, Sandhu and Horton (1977) noticed reduction in plant height under conditions of drought.

2.1.8. Proline Accumulation

A major effect of water stress on plant metabolism involves an inhibition of protein synthesis and the modification of aminoacid metabolism leading to a rapid and extensive accumulation of proline (Barnett and Neylor, 1966;

Singh et al., 1973b). Levitt (1972) stated that free proline accumulation in water stressed leaves has been speculated to constitute an attribute of drought resistance or drought hardiness. Singh et al. (1972) observed that the rate and extent of proline accumulation under comparable water stress conditions varies considerably between different genotypes. They found that the potential for proline accumulation appears to vary directly with the ability of the genotype to yield under drought conditions. Singh et al. (1973a) studied the stress metabolism in barley and reported substantial varietal differences in proline accumulation and found that varieties which accumulated larger concentration of free proline tend to have leaves which survived extreme water stress more readily and grow more rapidly following stress relief. They suggested that proline content may be linked in an indirect manner to tissue survival during and after stress.

In soybean, Waldren and Teare (1974) reported that accumulation of proline under water stress could be an indicator of drought resistance or susceptibility. Singh et al. (1974) observed proline accumulation in wheat and barley plants subjected to soil moisture stress and they suggested that this ability can serve as a criterion of drought resistance/tolerance. But Hansen et al. (1977) suggested that proline accumulating potential should not be utilized as a positive index of drought resistance in screening methods for cereal breeding programmes. Similarly Michael and Elmore (1977) suggested that accumulation of proline is not a good indicator of the onset of plant water stress. Hansen et al. (1979) suggested that selecting barley for low proline accumulation might help to identify promising material for drought prone environments.

In sorghum, Sivaramakrishnan et al. (1988) observed high levels of proline accumulation in drought resistant lines and low levels in drought susceptible lines.

2.1.9. Harvest Index

One of the important objective for the rainfed crop production under semiarid condition for high yield is to have high harvest index (Arnon, 1975). Foster and Weng (1979) studied the response of sorghum genotypes to drought induced by differencial irrigation and found that high harvest index under conditions of drought or the change in harvest index due to water stress may be useful selection criteria in developing drought resistant grain sorghum types.

Hall and Grantz (1981) studied the drought resistance aspects in cowpea and reported that an early maturing selection from CB5 variety of cowpea had high harvest index and high yield along with drought resistance.

Pandey *et al.* (1984) studied the drought response of four grain legumes, viz. cowpea, soybean, mungbean and peanut, under irrigation gradient and observed that harvest index decreased linearly with increasing levels of drought for all the four species.

Ibrahim *et al.* (1986) observed in pearl millet that lines with high tolerance to stress had high harvest index as it increases the proportion of harvestable grain.

2.1.10. Yield and yield components

Since the aim of the breeder is to develop varieties capable of maximum yield in arid climates, the most commonly used measure of varietal drought resistance has been the yield in the field under conditions of drought. Asana (1957) suggested that drought tolerance capacity of any crop is best assessed on the basis of yield which was considered as a measure of drought resistance/tolerance.

Levitt (1972) and Parao *et al.* (1976) proposed that yield is the ultimate criterion for measuring drought resistance. Fisher and Turner (1978) defined drought tolerance as the ability of the crops to maintain yield when subjected to drought. Fisher and Maurer (1978) reported that cultivar yield under drought is the function of yield potential (yield without drought), drought susceptibility index and intensity of drought.

Manjunatha (1978) made investigations on the growth and yield of pulses in summer. He compared high yielding varieties of greengram, blackgram, cowpea and soybean and found that soybean variety, Hardee, gave highest grain yield when compared to other pulses, mainly due to more number of pods per plant and 1000 grain weight.

Sammons et al. (1980) suggested that a breeder interested in the development of a high yielding soybean cultivar, tolerant to moisture stress should select for vigorous growth potential and yielding ability under a moisture stress environment.

Water relations of three cowpea cultivars, Adzuki, Ife Brown and Newera, were studied by Babalola (1980) and reported that soil moisture stress significantly reduced the growth and yield (34-46 per cent) of these three cowpea cultivars and the grain yield reduction was highest when stress was imposed at flowering/podding stage. Pandey et al. (1984) observed that in grain legumes, the number of pods per square metre was most affected by water stress followed by number of seeds per pod, while seed weight was least affected. Norem et al. (1985) reported that in sorghum, drought tolerant lines produced significantly more heads.

Upadhyaya and Ruwali (1985) suggested that in breeding wheats for heat and drought tolerance, genetic improvements should be made for characters such as number of ears per plant, grain weight per spike and 1000 grain weight.

Bidinger et al. (1987) reported that in pearl millet individual panicle yield can serve as a selection index in terminal stress. They suggested that a differential ability to maintain normal grain numbers or the grain yield per panicle is an important factor in response to stress.

Aggarwal and Sinha (1987) suggested that in wheat breeding programme for drought environments, it would be useful to select for more spikes, whereas for high yielding irrigated environments selection based on more number of grains per spike and reasonable number of spikes would be more desirable.

2.2. Variability

2.2.1. Genotypic and Phenotypic Coefficients of Variation

Studies on genotypic and phenotypic coefficients of variation for characters contributing to drought resistance/tolerance are very limited. Most of the works are confined to the studies on genotypic and phenotypic coefficients of variation for yield and yield components. The available literature on the above aspects are reviewed here.

Singh and Mehndiratta (1969) studied variability in forty varieties of cowpea and reported that number of pods per plant had the maximum genotypic coefficient of variation (52.52 per cent) followed by number of pod clusters per plant (33.02 per cent) and grain yield per plant (22.43 per cent). The number of days to maturity (5.52 per cent) had the minimum value in their studies.

Veeraswamy et al. (1973) estimated high genotypic coefficient of variation in cowpea for grain yield per plant (34.9 per cent), number of pods per plant (28.7 per cent), number of branches per plant (24.2 per cent) height of the plant (23.4 per cent) and number of pod clusters per plant (20.9 per cent). Ramachandran et al. (1980) studied eight varieties of cowpea and reported that genotypic coefficient of variation was maximum for grain yield per plot (57.12 per cent) followed by number of pods per plant (56.56 per cent) and minimum for length of the pod.

Radhakrishnan and Jebaraj (1982) in cowpea reported that the number of pods per plant had the maximum genotypic coefficient of variation followed by number of pod clusters per plant, and number of branches per plant. The number of days to maturity had the minimum value of 4.7 per cent in their trial. Dharmalingam and Kadambavanasundaram (1984) in their studies on genetic variability on forty varieties of cowpea observed high genotypic coefficient of variation for harvest index (35.69 per cent), number of pods per plant (29.92) and grain yield per plant (24.16) and the minimum value for number of seeds per pod (12.88).

Patil and Baviskar (1987) made variability studies in cowpea and reported high genotypic and phenotypic coefficients of variation for pod clusters per plant, pods per plant, seed yield per plant and hundred seed weight. Philip (1987) in blackgram reported high genotypic coefficient of variation for leaf area index at blooming (35.87) and minimum value for number of seeds per pod (2.79) in partially shaded conditions in coconut gardens.

2.2.2. Heritability and Genetic Advance

Singh and Mehndiratta (1969) studied forty varieties of cowpea and reported high heritability estimates for days to flowering (88.8), length of pod (80.5) and days to maturity (78.3) and low heritability for seed yield per plant. They have estimated high genetic advance for number of pods per plant (31.6) and seed yield per plant (27.6 per cent). Veeraswamy et al. (1973) recorded the maximum heritability for pod length and the minimum for number of seeds per pod. Genetic advance was high for pod length followed by number of pods per plant and grain yield per plant.

Rajendran et al. (1979) recorded high heritability and genetic advance for the characters such as days to flowering (95.2 and 57.1), days to first pod harvest (93.7 and 40.3) and number of seeds per pod (83.5 and 100).

In cowpea, Sreekumar et al. (1979) observed moderate to high heritability estimates for number of days to flowering (69.2), total duration (49.2), number of grains per pod (40.6) and grain yield per plot (43.4). Ramachandran et al. (1980) reported high heritability for number of days to flowering and high genetic advance for seed number per pod. Radhakrishnan and Jebaraj (1982) recorded high heritability coupled with high genetic advance for number of pods per plant, and number of pod clusters per plant. The number of days to maturity and plant height had high heritability and low genetic advance in their studies.

Dharmalingam and Kadambavanasundaram (1984) reported maximum heritability estimates for length of the pod followed by harvest index. Patil and Baviskar (1987) made variability studies in cowpea and observed highest heritability for hundred seed weight followed by days to maturity and pod length.

2.3. Correlation Studies

Coefficients of correlation indicate the intensity and direction of character associations in a crop. Correlation between various characters contributing to drought tolerance and high yield is of considerable importance to the breeder when selection is done based on more number of components.

Derera et al. (1969) observed a strong consistent negative correlation between grain yield and days to first ear emergence in wheat under simulated drought conditions.

Singh and Mehndiratta (1969) reported high positive genotypic correlation between number of pods per plant and number of pod clusters per plant and days to flowering and days to maturity in cowpea. Negative genotypic correlation was reported for length of pod with number of pod clusters per plant and number of pods per plant. Setty and Sreeramulu (1972) reported a high genotypic correlation of grain yield in sorghum with plant height, number of nodes, area of fourth leaf, peduncle thickness, days to fifty per cent blooming, dry matter production, 1000 grain weight, number of long roots and length of the longest roots. Root/shoot ratio and root weight do not show any relationship with yield while number of long roots and length of longest root are correlated with yield.

Singh et al. (1972) found that in barley cultivars, accumulation of proline under severe stress has been positively correlated with their drought resistance. In cowpea, Angadi (1976) reported positive genotypic correlation between number of seeds per pod and height of plant and negative genotypic correlation between number of pods per plant and seeds per pod.

Rajendran et al. (1979) evaluated nineteen varieties of cowpea and reported significant positive genotypic correlation of grain yield with height of the plant, number of days to first flowering, number of pod clusters per plant, number of primary branches per plant and number of seeds per pod. Sreekumar et al. (1979) recorded significant positive genotypic correlation for grain yield in cowpea with number of days to blooming, total duration and number of grains per pod. Vidal and Arnoux (1981) observed a negative correlation between seed weight and seed number in soybean under drought conditions.

Kavitha (1982) reported a positive correlation of root length with yield under moisture stress conditions. Ali and Naidu (1982) observed a significant positive correlation between yield under stress and plant height, leaf area, length and size of the grains and 1000 grain weight in maize. Significant negative correlation was observed between yield and stomata number and they suggested that plant height, stomata number and ear characters are the most reliable characters for screening for drought tolerance.

Sangwan and Mehrotra (1982) found a positive correlation coefficient between root length at the fifth day and root weight at maturity and seed yield per plant in mungbean. Dumbre et al. (1982) studied the genotypic and phenotypic correlations of six quantitative characters in twentyfour cultivars of cowpea and reported that height and pods per plant were significantly correlated with yield.

Mambani and Lal (1983) studied the response of upland rice varieties to drought stress and found that soil moisture potential was negatively correlated with root density. Natarajaratnam et al. (1985) estimated phenotypic correlation of yield and yield components in ten varieties of cowpea and found that grain yield showed positive phenotypic correlation with number of pods per plant, number of pod clusters per plant and height of the plant.

Genetic variability in sunflower cultivars under drought conditions were studied by Gimenez and Fereres (1986) and observed a high positive correlation between grain yield and leaf area. In pearl millet, Ibrahim et al. (1986) observed a positive correlation of grain yield with seed weight and number of seeds, and a negative correlation with plant height under low water level. Edillo et al. (1986) reported that yield in rice was positively correlated with days to flowering, and suggested the selection of medium maturing genotypes of rice for drought prone environment.

Kahn and Stofella (1987), based on studies on root morphological characteristics of field grown cowpea, proposed that seed yield was not correlated strongly with any of the root characters. Patil and Bhapkar (1987) made correlation studies in cowpea and observed that seed yield was positively and significantly correlated with pods per plant and seeds per pod which were negatively correlated with each other.

Genetics of some morphological, biochemical and physiological characters associated with drought resistance in maize was investigated by Sharma (1988). His correlation studies indicated positive correlation of harvest index, plant height, leaf area per plant and grains per cob with grain yield per plant.

2.4. Path Analysis

Patel and Telang (1976) made path analysis of yield components in cowpea and reported that seed number per pod had the largest direct effect on seed yield, followed by hundred seed weight and pod number per plant. Pod length had a marked negative direct effect on yield. In pea, Narasinghani et al. (1978) reported maximum direct effect of number of seeds per plant on yield followed by hundred seed weight, number of days to maturity, height and protein percentage.

In cowpea, Hanchinal et al. (1979) reported that the number of branches per plant had direct effect on yield and that number of seeds per plant had indirect effect acting through number of branches. Rajendran et al. (1979) observed that in cowpea, days to first flowering had positive direct effect on seed yield.

Misra (1985) reported that pods per plant, 1000 seed weight, seeds per pod, reproductive period and cluster per plant contributed directly to seed yield in greengram. In maize, Sharma (1988) reported direct contribution of proline content on grain yield followed by harvest index, 500 grain weight, cob length, plant height and leaf area index.

MATERIALS AND METHODS

MATERIALS AND METHODS

The research programme was carried out at the Department of Plant Breeding, College of Agriculture, Vellayani, Trivandrum during October-December 1988.

3.1. Materials

Sixteen varieties of cowpea (Vigna unguiculata (L). Walp) collected from the Department of Plant Breeding were used for the study.

3.2. Methods

A field experiment was laid out in the Instructional Farm, College of Agriculture, Vellayani during October 1988 adopting a Randomised Block Design with four replications. In each plot of 4 x 2.4 m area, the seeds were dibbled at a spacing of 30 x 20 cm. The cultural and management practices were followed as per the package of practices recommendations of the Kerala Agricultural University, 1986.

Five plants were selected at random from each plot and data on the following characters were recorded from these plants and averaged.

1. Root length

Root length was studied at three growth periods viz.

vegetative, flowering and harvest periods. The sample plants were uprooted carefully and length of the tap root was measured in centimetre.

2. Root spread

Root spread was measured by placing the dry root specimen on a graph paper and measuring the width of the root at its broadest part. Columns more than half were considered as one, and the root spread was expressed in centimetre. This character also was studied at the three growth periods.

3. Root/shoot Ratio

The ratio of root dry weight to shoot dry weight was expressed as root/shoot ratio. From each sample plant, root and shoot portions were taken separately, sundried and then ovendried at 60-70°C for 24 hours and their dry weights were measured and ratio found out. This character was studied at vegetative, flowering and harvest periods.

4. Leaf Area Index

Leaf area was measured at vegetative, flowering and harvest periods using Leaf Area Meter. All the leaves separated from each uprooted sample plants were fed to the Leaf Area Meter separately and the total leaf area of each plant was measured. From the leaf area, leaf area index was calculated by using the following formula suggested by William (1946).

$$\text{Leaf Area Index} = \frac{\text{Total leaf area of the plant}}{\text{Ground area occupied (spacing)}}$$

5. Number of stomata per microscopic field

Fully expanded and mature leaves were selected from the sample plants and leaf impressions were taken by giving a thin coat of nail polish on the lower leaf surface and peeling it of after drying. From these impressions fifteen microscopic fields were scored for number of stomata and the mean number per microscopic field was estimated.

6. Days to 50 per cent flowering

Number of days taken from the date of sowing to fifty per cent flowering in each plot was observed and recorded.

7. Plant height at maturity

Height of the plants were measured in centimetre from the ground level to the tip of the main stem at the time of final harvest and the mean height recorded.

8. Number of pods per plant

Number of pods in each observational plant was counted and averaged.

9. Number of grains per pod

Single pod from each observational plant was threshed separately and the number of seeds in each pod was counted and the average worked out.

10. Grain Filling Period

Five random flowers were tagged in each of the observational plants at the day of flower opening and the mean number of days taken for pod maturity were found out.

11. Duration upto maturity

Mean number of days from sowing to final harvest was recorded.

12. Yield per plant

Yield of grains obtained from each observational plants were measured and averaged and expressed in grams.

13. Size of the grain

Size of the grain was measured as volume of water displaced by hundred grains and the average volume of hundred grains were expressed in cubic centimeter.

14. Hundred grain weight

A random sample of hundred grains were selected from the bulk in each plot, weighed and the mean weight was recorded in grams.

15. Grain Yield per plot

The total yield of grains from each plot was recorded in grams.

16. Haulm yield per plot

The total bhusa yield (parts of the plants other than grains) from each plot was expressed in kilograms.

17. Proline content

Proline content was estimated by the methodology suggested by Bates et al. (1973). Leaves collected from each sample plants were dried and powdered separately. Approximately 0.25 g of the material was homogenized in 10 ml of three per cent aqueous sulfosalicylic acid and the homogenate filtered through Whatman No. 2 filterpaper. Two ml of filtrate was reacted with two ml acid ninhydrin and two ml of glacial acetic acid in a test tube for one hour at 100°C and the reaction terminated in an ice bath. The reaction mixture was extracted with four ml toluene, mixed vigorously with a test tube stirrer for 15-20 sec and warmed to room temperature. The chromophore containing toluene was read in Spectronic 2000 at 520 nm using toluene as a blank.

Purified proline was used to standardise the procedure for quantifying sample values. The proline concentration in the samples were determined from the standard curve and calculated on a dry weight basis as follows.

$$(\mu g \text{ proline/ml} \times \text{ml toluene}) \Big/ 5/\text{weight of sample (g)}$$
$$= \mu g \text{ proline/g of dry weight material}$$

18. Harvest Index

Harvest index for each observational plant was calculated by using the following formula.

$$\text{Harvest Index} = \frac{\text{Economic yield}}{\text{Biological yield}}$$

Total grain yield from each observational plant was recorded as the economic yield and dry weight of all the other plant parts and the grain yield were considered as biological yield.

19. Soil moisture

Soil moisture was determined at weekly intervals by gravimetric method, where a known weight of the fresh soil collected from each plot was oven dried at 105°C until constant dry weight was obtained and the loss in weight was expressed as percentage.

3.2.1. Statistical techniques

1. Analysis of variance and covariance

Analysis of variance and covariance were done

(i) to test whether there was any significant different among the varieties, with respect to various traits

(ii) to estimate the variance components and

(iii) to estimate correlation coefficients (Singh and Choudhary, 1979)

The extent of phenotypic variation for any character is the sum of the genetic and environmental effects and can be determined by the methods given by Kempthorne (1957).

$$V(P) = V(G) + 2\ Cov\ (G.E)$$

where $V(P) = \sigma^2_{p}(x)$ = Variance due to phenotype

$V(G) = \sigma^2_{g}(x)$ = Variance due to genotype

$V(E) = \sigma^2_{e}(x)$ = Variance due to environment

$Cov\ (G,E)$ = Covariance between genotype and environment

If the genotype and the environment are independent Cov (G,E) is equal to zero, so that

$$V(P) = V(G) + V(E)$$

$$\sigma^2_{p(x)} = \sigma^2_{g(x)} + \sigma^2_{e(x)}$$

If there are observations on two characters X and Y on each individual, the extent of covariance between X and Y due to the genotype and environment can be estimated as suggested by Kempthorne (1957) as follows.

$$COV_P(x,y) = COV_G(x,y) + COV_E(x,y)$$

or $\sigma_{p(x,y)} = \sigma_{g(x,y)} + \sigma_{e(x,y)}$

where $\sigma_{p(x,y)}$ = Phenotypic covariance between x and y

$\sigma_{g(x,y)}$ = Genotypic covariance between x and y

$\sigma_{e(x,y)}$ = Environmental covariance between x and y

If the experiment is designed in a Randomised Complete Block Design with 'V' treatments and 'r' replications, the estimates of $\sigma^2_{p(x)}$, $\sigma^2_{p(y)}$, $\sigma^2_{g(x)}$, $\sigma^2_{g(y)}$, $\sigma^2_{e(x)}$, $\sigma^2_{e(y)}$, $\sigma_{p(x,y)}$ $\sigma_{g(x,y)}$ and $\sigma_{e(x,y)}$ can be obtained from the analysis of variance/covariance (table 1).

Variation in crop stand occurred in few plots due to erratic seed germination. Hence the population count in each plot was statistically adjusted by analysis of

Table 1. Analysis of variance/covariance

Source	df	M.S.xx	Expectation of M.S.xx	M.S.P. (x,y)	Expectation of M.S.P.(x,y)	M.S. (y,y)	Expectation of M.S.yy
Block	(r-1)	Bxx		Bxy		Byy	
Treatment	(v-1)	Txx	$\sigma^2 e(x)+r\sigma^2 g(x)$	Txy	$\sigma e(x,y)+r\sigma g(x,y)$	Tyy	$\sigma^2 e(y)+r\sigma^2 g(y)$
Error	(r-1)(v-1)	Exx	$\sigma^2 e(x)$	Exy	$\sigma e(x,y)$	Eyy	$\sigma^2 e(y)$
Total	rv-1	Txx		Txy		Tyy	

Hence we have the following estimates

$$\sigma^2 g(x) = \frac{1}{r}(Txx - Exx) \qquad \sigma^2 e(x) = Exx$$

$$\sigma^2 g(y) = \frac{1}{r}(Tyy - Eyy) \qquad \sigma^2 e(y) = Eyy$$

$$\sigma g(x,y) = \frac{1}{r}(Txy - Exy) \qquad \sigma e(x,y) = Exy$$

covariance for eliminating the variation in plot yields due to the difference in plant population.

2. Coefficient of variation

The coefficient of variation is a unitless measurement and is used for comparing the extent of variation between different characters measured in different scales. Phenotypic coefficient of variation (PCV) for character X

$$= \frac{\sigma_{p(x)}}{\bar{X}} \times 100$$

Genotypic coefficient of variation (GCV) for character X

$$= \frac{\sigma_{g(x)}}{\bar{X}} \times 100$$

where $\sigma_{p}(x)$ and $\sigma_{g}(x)$ are the phenotypic and genotypic standard deviation respectively, and $\bar{X}$ is the mean of the character X.

3. Heritability (H^2)

Heritability in the broad sense is the fraction of the total variance which is heritable and was estimated as a percentage following Jain (1982) as -

$$H^2 = \frac{\sigma^2_{g}}{\sigma^2_{p}} \times 100$$

where σ^2_{g} = Genotypic variance

$\sigma^2 p$ = Phenotypic variance

4. Genetic advance under selection (G.A)

Genetic advance is a measure of the change in the mean phenotypic level of the population produced by the selection and depends upon heritability of the character and selection differential

$$\text{G.A as percentage of mean} = \frac{KH^2 \sigma_p}{\bar{X}} \times 100$$

where $\bar{X}$ is the mean of the character X and K is the selection differential which is 2.06 at 5 per cent intensity of selection in large samples (Allard, 1960).

5. Correlations

The phenotypic correlation coefficient between X and Y was estimated as

$$\gamma_p (x,y) = \frac{\sigma_{p (x,y)}}{\sigma_{p (x)} \sigma_{p (y)}}$$

where p (x,y) is the phenotypic covariance between X and Y, σ_p (x) is the standard deviation of the character X and σ_p (y) is the standard deviation of the character Y.

The genotypic correlation coefficient between X and Y was estimated as

$$r_g(x,y) = \frac{\sigma g\ (x,y)}{\sigma g\ (x)\ \sigma g\ (y)}$$

where $\sigma g(x,y)$ is the genotypic covariance between x and y, $\sigma g(x)$ is the standard deviation of the character x, and $\sigma g(y)$ is the standard deviation of the character y.

Critical value of 'r' corresponding to 62 degrees of freedom at 5 per cent level of significance was used for the test of significance for phenotypic correlation coefficient (Fisher and Yates, 1957).

6. Path Analysis

The method of path analysis developed by Wright (1921) was used to study the cause and effect relationship among a system of correlated variables. The direct influence along each separate path in such a system and the degree to which the variation of a given effect is determined by each particular cause were examined.

Path analysis at genotypic level was carried out using the characters, root/shoot ratio and leaf area index at vegetative period, root length and root spread at harvest period, duration upto maturity, grain filling period and harvest index as causes and grain yield per plot as the effect. The genotypic correlation coefficients of the above component characters with grain yield per plot were partitioned into direct and indirect effects as per the methodology of Dewey and Lu (1959).

The simultaneous equations which give solutions for path coefficients are

$$r_{iy} = r_{i1} p_{1y} + r_{i2} p_{2y} + \ldots p_{iy} + \ldots + r_{ik} p_{ky}$$

where $i = 1,2 \ldots k$

r_{iy} is the genotypic correlation of the i^{th} independent variable (xi) with dependent variable (y). P_{iy} is the direct effect of xi on y and $r_{ik} p_{ky}$ is the indirect effect of xi via xk on y.

RESULTS

RESULT

The results of the experiment are presented below.

4.1. Variability

The mean data collected on twentysix characters were subjected to analysis of variance for testing the significance of the differences among varieties and the ANOVA is presented in Table 2.

The sixteen varieties of cowpea studied, exhibited significant differences for all the characters except for root spread at vegetative period.

Analysis of variance for soil moisture percentages (Table 3) do not show any significant difference among the varieties showing that uniform soil moisture conditions existed in the experimental area. Mean values of soil moisture percentages (Table 4) showed that, in general, during flowering and maturity periods, the crop suffered relatively high moisture stress, when compared to vegetative period.

The mean values for twentysix characters in sixteen varieties of cowpea are presented in Table 5.

Root length at vegetative period ranged from 11.1 cm in Kanakamony to 15.1 cm in UPC-124. The varieties DPLC-224,

Table 2. Analysis of variance for twentysix characters in Cowpea

Sl. No.	Characters	Mean squares			F value
		Replication	Varieties	Error	
1.	Root length at vegetative period	7.132	4.370	1.625	2.69**
2.	Root spread at vegetative period	5.661	2.270	2.054	1.11
3.	Root/shoot ratio at vegetative period	0.009	0.004	0.002	1.83**
4.	Leaf area index at vegetative period	0.023	0.134	0.017	7.79**
5.	Days to 50 per cent flowering	1.641	58.673	1.918	30.59**
6.	Root length at flowering period	7.356	9.366	1.617	5.79**
7.	Root spread at flowering period	0.641	2.863	0.815	3.51**
8.	Root/shoot ratio at flowering period	0.006	0.007	0.002	3.11**
9.	Leaf area index at flowering period	0.118	0.465	0.047	9.83**
10.	Number of stomata per microscopic field	2.047	54.066	12.114	4.46**
11.	Root length at harvest period	7.483	15.650	1.954	8.01**
12.	Root spread at harvest period	9.217	30.416	3.144	9.67**
13.	Root/shoot ratio at harvest period	0.026	0.026	0.006	4.53**

Table 2 (contd.)

Sl. No.	Characters	Mean square			F value
		Replication	Varieties	Error	
14.	Leaf area index at harvest period	0.012	0.048	0.008	5.85**
15.	Number of pods per plant	1.239	17.592	2.001	8.79**
16.	Number of grains per pod	2.709	16.763	1.551	10.81**
17.	Plant height at maturity	10.419	346.226	19.897	17.40**
18.	Grain filling period	0.199	10.988	0.362	30.33**
19.	Duration upto maturity	1.167	53.050	1.611	32.93**
20.	Grain yield per plant	3.286	5.520	1.467	3.76**
21.	Size of the grain	0.828	40.198	0.294	136.81**
22.	Hundred grain weight	4.462	56.110	1.254	44.76**
23.	Grain yield per plot	2201.190	13250.200	2825.750	4.69**
24.	Haulm yield per plot	0.166	1.061	0.171	6.19**
25.	Proline content	1680.330	88831.000	7534.620	11.79**
26.	Harvest index	0.045	0.024	0.004	6.79**

** Significant at 1 per cent probability level

Table 3. Analysis of variance for soil moisture percentage

Sl. No.	Soil moisture percentage	Mean square			F value
		Replication	Varieties	Error	
1.	18 days after sowing	11.523	8.738	5.588	1.56
2.	25 days after sowing	3.987	4.397	2.476	1.78
3.	32 days after sowing	58.620	12.754	10.440	1.22
4.	39 days after sowing	50.537	5.559	3.718	1.49
5.	46 days after sowing	1.591	1.386	0.932	1.49
6.	53 days after sowing	0.665	0.808	0.506	1.60
7.	60 days after sowing	0.634	0.706	0.503	1.53

Table 4. Mean values of soil moisture percentage

Sl. No.	Varieties	Soil moisture percentage						
		18 days after sowing	25 days after sowing	32 days after sowing	39 days after sowing	46 days after sowing	53 days after sowing	60 days after sowing
1.	C-88	11.1	10.2	5.6	5.0	5.0	3.9	3.9
2.	V-240	12.1	10.5	8.5	6.5	4.7	3.6	3.4
3.	C-190	11.8	11.1	7.4	7.9	4.7	3.1	3.1
4.	GC-82-7	10.0	13.0	9.7	7.3	4.7	3.6	3.4
5.	1-26	7.9	8.1	7.3	5.3	3.9	3.1	3.1
6.	UPC-124	7.1	10.5	7.9	5.6	3.6	2.6	2.6
7.	IC-38956	9.0	10.5	9.7	4.8	3.9	3.4	3.2
8.	DPLC-224	9.4	10.5	11.2	5.3	4.2	2.8	2.7
9.	DPLC-198	7.5	9.9	8.0	5.0	3.9	3.1	3.1
10.	DPLC-216	8.1	11.4	10.2	5.6	4.4	3.4	3.4
11.	VCM-8	9.0	9.9	9.2	7.8	4.7	3.6	3.3
12.	DPLC-210	9.9	10.2	12.1	6.2	3.6	2.6	2.6
13.	Kanakamony	10.9	11.1	11.4	8.7	4.7	3.6	3.4
14.	Charodi	9.0	11.1	7.7	5.6	4.2	3.1	3.1
15.	C-152	8.4	11.4	10.5	6.7	5.0	3.4	3.3
16.	V-26	10.2	9.6	10.4	6.7	5.8	4.2	4.1
	General mean	9.47	10.58	9.17	6.25	4.45	3.31	3.28
	CD (0.05)	3.37	2.24	4.61	2.75	1.38	1.01	1.01

Table 5. Mean values of twentysix characters in Cowpea

Sl. No.	Varieties	1	2	3	4	5	6	7	8	9
		At vegetative period					At flowering period			
		Root length (cm)	Root spread (cm)	Root/ shoot ratio	Leaf area index	Days to 50 per cent flowering	Root length (cm)	Root spread (cm)	Root/ shoot ratio	Leaf area index
1.	C-88	13.8	11.6	0.08	0.76	49	18.2	14.8	0.07	1.50
2.	V-240	12.8	12.2	0.04	0.97	50	17.0	13.1	0.06	1.68
3.	C-190	13.8	12.2	0.07	0.35	52	16.4	12.4	0.13	0.65
4.	GC-82-7	11.5	13.7	0.07	0.91	47	18.3	14.9	0.12	1.32
5.	1-26	14.6	12.7	0.05	0.84	41	20.4	15.1	0.19	1.14
6.	UPC-124	15.1	11.8	0.15	0.92	43	21.2	14.2	0.17	1.27
7.	IC-38956	13.5	12.5	0.08	0.62	42	19.0	14.1	0.07	1.14
8.	DPLC-224	14.6	12.1	0.05	0.80	45	19.3	14.5	0.05	1.75
9.	DPLC-198	12.8	12.1	0.05	0.99	44	18.1	14.3	0.08	1.65
10.	DPLC-216	13.1	12.3	0.14	0.88	44	19.1	13.7	0.10	1.38
11.	VCM-8	12.9	11.6	0.09	0.48	40	16.5	13.0	0.12	0.59
12.	DPLC-210	12.7	13.6	0.05	0.66	50	17.6	15.1	0.07	1.63
13.	Kanakamony	11.1	14.1	0.06	1.00	48	15.1	14.2	0.07	1.39
14.	Charodi	13.5	11.8	0.06	0.70	45	18.9	13.5	0.06	1.21
15.	C-152	13.3	12.4	0.08	0.71	50	17.7	13.8	0.10	1.07
16.	V-26	13.7	12.9	0.05	0.82	50	17.4	15.4	0.07	1.53
	General mean	13.30	12.47	0.074	0.776	46	18.13	14.13	0.096	1.31
	CD (0.05)	1.82		0.067	0.187	1.98	1.81	1.29	0.069	0.310

Table 5 (contd.)

Sl. No.	Varieties	10 Number of stomata per microscopic field	11 At harvest period Root length (cm)	12 Root spread (cm)	13 Root/ shoot ratio	14 Leaf area index	15 Number of pods per plant	16 Number of grains per pod	17 Plant height at maturity	18 Grain filling period (days)
1.	C-88	23.7	19.1	19.6	0.17	0.53	2.8	11.0	45.4	17
2.	V-240	25.0	18.2	17.8	0.21	0.40	4.7	14.4	55.5	15
3.	C-190	29.2	17.2	14.0	0.32	0.15	4.6	12.5	31.0	15
4.	GC-82-7	25.8	18.9	17.2	0.19	0.39	5.4	13.5	53.7	15
5.	1-26	15.6	23.7	18.8	0.20	0.27	8.3	13.6	33.3	16
6.	UPC-124	19.5	23.5	21.9	0.34	0.36	7.4	9.6	41.4	18
7.	IC-38956	18.2	19.5	16.3	0.33	0.27	6.8	10.8	32.6	15
8.	DPLC-224	22.0	19.7	23.0	0.18	0.33	10.5	11.0	41.5	17
9.	DPLC-198	21.4	19.6	22.2	0.18	0.34	7.0	8.5	43.0	18
10.	DPLC-216	22.4	20.2	19.4	0.24	0.40	6.0	9.0	36.0	17
11.	VCM-8	17.8	19.5	15.3	0.42	0.22	5.5	12.3	31.2	13
12.	DPLC-210	27.2	18.5	20.3	0.15	0.40	5.8	9.6	49.1	20
13.	Kanakamony	21.5	16.2	15.4	0.16	0.48	3.3	14.7	45.2	16
14.	Charodi	24.0	19.4	15.5	0.29	0.39	8.9	12.0	57.2	15
15.	C-152	23.6	17.8	17.3	0.19	0.51	4.8	14.5	48.8	15
16.	V-26	26.4	17.6	15.5	0.22	0.53	3.5	13.2	57.8	16
	General mean	22.71	19.29	18.10	0.235	0.374	5.98	11.91	43.94	16.2
	CD (0.05)	4.97	1.99	2.53	0.107	0.130	2.02	1.78	6.36	0.86

Table 5 (contd.)

Sl. No.	Varieties	19 Duration upto maturity (days)	20 Yield per plant (g)	21 Size of the grain (cm^3)	22 Hundred grain weight (g)	23 Grain yield per plot (g)	24 Haulm yield per plot (kg)	25 Proline content (g/g)	26 Harvest index
1.	C-88	69.0	3.2	17.1	19.1	109.2	2.32	604.8	0.33
2.	V-240	70.0	4.7	8.9	9.1	229.4	1.85	465.8	0.46
3.	C-190	72.0	2.2	5.3	4.9	53.4	0.55	356.1	0.40
4.	GC-82-7	67.0	4.6	9.5	9.1	151.8	1.69	597.1	0.46
5.	1-26	61.0	5.6	7.2	8.1	110.8	0.50	425.4	0.42
6.	UPC-124	67.0	5.1	14.6	13.5	184.7	1.08	307.1	0.48
7.	IC-38956	62.0	6.0	9.2	10.9	106.3	0.71	672.2	0.55
8.	DPLC-224	68.0	7.3	9.3	9.7	224.4	1.78	308.6	0.45
9.	DPLC-198	68.0	5.2	11.9	11.4	237.7	1.44	255.6	0.42
10.	DPLC-216	68.0	4.3	9.7	10.1	258.0	1.24	311.1	0.43
11.	VCM-8	60.0	4.9	7.0	6.7	155.5	0.82	594.9	0.65
12.	DPLC-210	71.0	5.1	12.1	14.8	144.5	1.36	277.7	0.38
13.	Kanakamony	69.0	4.2	12.2	13.3	199.3	1.79	494.7	0.38
14.	Charodi	65.0	4.1	5.3	4.6	211.2	0.96	296.1	0.43
15.	C-152	70.0	3.8	8.3	7.5	109.2	1.92	206.7	0.41
16.	V-26	70.0	3.6	10.3	11.4	139.6	2.17	275.0	0.33
	General mean	67.0	4.6	9.9	10.28	164.05	1.37	403.07	0.437
	CD (0.05)	1.81	1.73	0.77	1.60	90.77	0.707	123.86	0.086

1-26, C-190, C-88, V-26, IC-38956, Charodi and C-152 were on par with UPC-124.

Root spread at vegetative period varied from 11.6 cm in VCM-8 to 14.1 cm in Kanakamony. Eleven varieties viz. GC-82-7, DPLC-210, V-26, 1-26, IC-38956, C-152, DPLC-216, V-240, C-190, DPLC-198 and DPLC-224 were on par with Kanakamony.

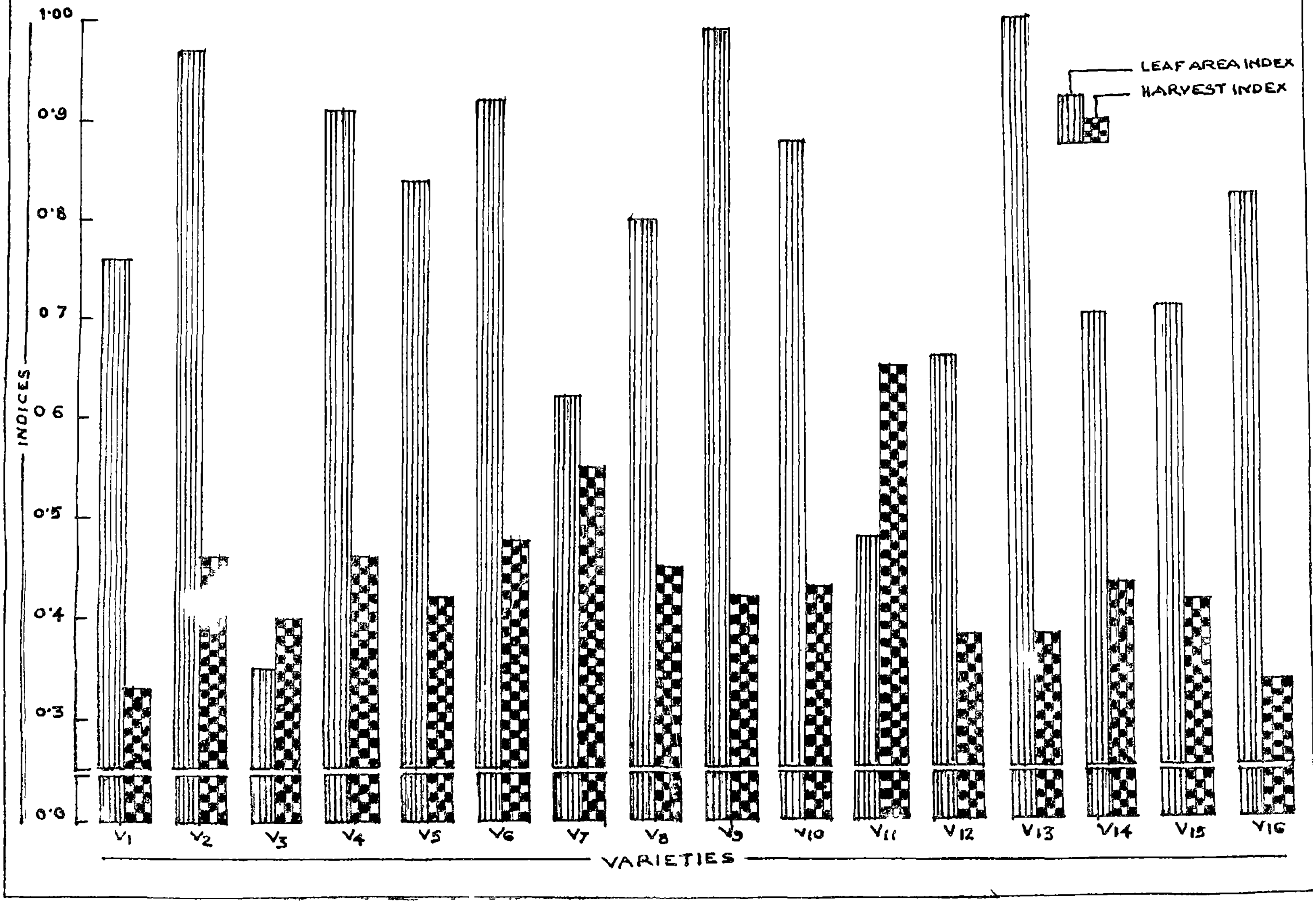
The variety UPC-124 had the highest value for root/shoot ratio at vegetative period (0.15) and V-240 had the lowest value (0.04). The varieties DPLC-216, VCM-8 and C-152 were on par with UPC-124.

Leaf area index at vegetative period ranged from 0.35 (C-190) to 1.00 (Kanakamony). The varieties found to be on par with Kanakamony were DPLC-198, V-240, UPC-124, GC-82-7, DPLC-216, 1-26 and V-26. The leaf area index of different varieties are shown graphically in figure 1.

Days to 50 per cent flowering ranged from 40 in VCM-8 to 52 in C-190. The variety 1-26 was on par with VCM-8.

Root length at flowering period was highest for UPC-124 (21.2 cm) and lowest for Kanakamony (15.1 cm). The only variety on par with UPC-124 was 1-26.

FIG 1 LEAF AREA INDEX AT VEGETATIVE PERIOD AND HARVEST INDEX OF SIXTEEN VARIETIES OF COWPEA



Root spread at flowering period ranged from 12.4 cm (C-190) to 15.4 cm (V-26). Nine varieties were on par with V-26. They were DPLC-210, 1-26, GC-82-7, C-88, DPLC-224, DPLC-198, UPC-124, Kanakamony and IC-38956.

During flowering period root/shoot ratio varied from 0.05 in DPLC-224 to 0.19 in 1-26. UPC-124 and C-190 were on par with 1-26. During this period leaf area index was maximum for DPLC-224 (1.75) and minimum for VCM-8 (0.59). The varieties V-240, DPLC-198, DPLC-216, V-26 and C-88 were on par with DPLC-224.

Number of stomata per microscopic field ranged from 15.6 in 1-26 to 29.2 in C-190. Varieties DPLC-210, V-26, GC-82-7, and V-240 were on par with C-190. The varieties VCM-8, IC-38956, and UPC-124 also had low number of stomata next to 1-26.

The variety 1-26 had the longest root at harvest period (23.7 cm) followed by UPC-124 (23.5 cm). Kanakamony had the least value for root length (16.2 cm) during this period.

Root spread at harvest period ranged from 14 cm in C-190 to 23 cm in DPLC-224. DPLC-198 and UPC-124 were on par with DPLC-224. During this period root/shoot ratio was highest for VCM-8 (0.42) and lowest for DPLC-210 (0.15).

The varieties UPC-124, IC-38956 and C-190 were on par with VCM-8.

Leaf area index at harvest period ranged from 0.15 in C-190 to 0.53 in C-88 and V-26. Varieties C-152, Kanakamony, V-240, DPLC-210 and DPLC-216 were on par with C-88.

Number of pods per plant varied from 2.8 in C-88 to 10.5 in DPLC-224. The variety Charodi was on par with DPLC-224. The other varieties having relatively higher number of pods per plant include 1-26, UPC-124, DPLC-198, IC-38956 and DPLC-216.

Number of grains per pod ranged from 8.5 in DPLC-198 to 14.7 in Kanakamony. The varieties C-152, V-240, 1-26, GC-82-7 and V-26 were on par with Kanakamony.

Plant height at maturity ranged from 31 cm (C-190) to 57.8 cm (V-26). The varieties such as Charodi, V-240 and GC-82-7 were on par with V-26.

Grain filling period varied from 13 days (VCM-8) to 20 days (DPLC-210). No other variety was on par with DPLC-210. The varieties UPC-124, DPLC-198, DPLC-224, and DPLC-216 had relatively longer grain filling periods. Grain filling periods for sixteen varieties of cowpea are presented graphically in figure 2.

Variety VCM-8 took minimum number of days to maturity (60 days) and C-190 took maximum number of days (72 days). 1-26 was the only variety on par with VCM-8. IC-38956 and Charodi were also relatively short duration varieties. Duration upto maturity of different varieties are presented graphically in figure 2.

Yield per plant was maximum in DPLC-224 (7.3 g) and minimum in C-190 (2.2 g). Varieties IC-38956 and 1-26 were on par with DPLC-224.

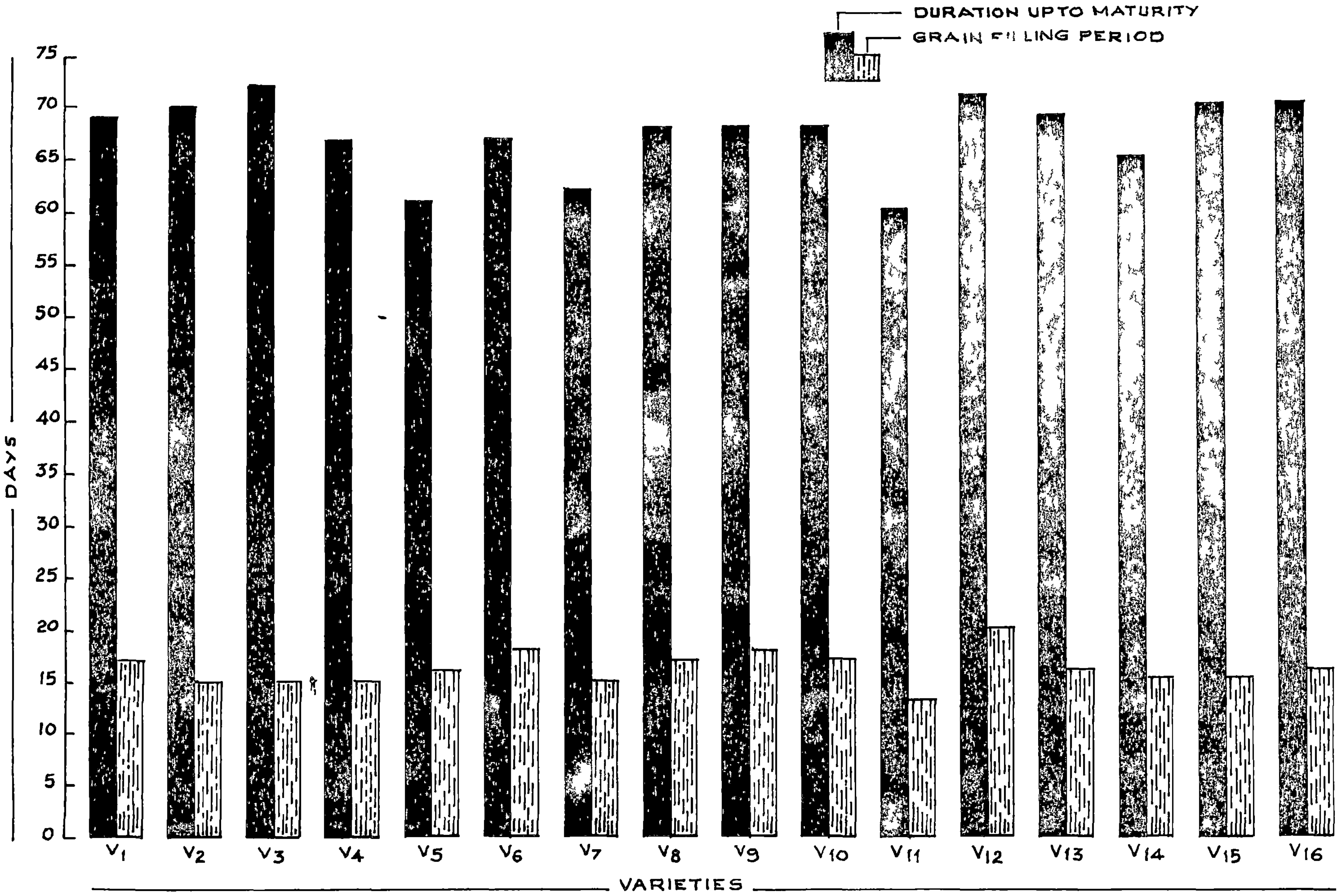
Size of the grain ranged from 5.3 cm^3 in Charodi and C-190 to 17.1 cm^3 in C-88. No variety was on par with C-88 and UPC-124. The varieties Kanakamony, DPLC-210 and DPLC-198 had relatively larger grain size.

Hundred grain weight was lowest in Charodi (4.6 g) and highest in C-88 (19.1 g). No variety was on par with C-88. The varieties DPLC-210, UPC-124 and Kanakamony had relatively higher grain weight.

Grain yield per plot ranged from 53.4 g in C-190 to 258 g in DPLC-216. Six varieties were on par with DPLC-216 viz. DPLC-198, V-240, DPLC-224, Charodi, Kanakamony and UPC-124.

Yield of haulms per plot varied from 0.55 kg in C-190 to 2.32 kg in C-88. Varieties V-26, V-240, Kanakamony,

FIG 2 DURATION UPTO MATURITY AND GRAIN FILLING PERIOD OF SIXTEEN VARIETIES OF COW PEA



DPLC-224 and GC-82-7 were on par with C-88.

Proline content ranged from 206.7 μg/g in C-152 to 672.2 μg/g in IC-38956. The varieties DPLC-198, V-26, DPLC-210, Charodi, UPC-124, DPLC-224 and DPLC-216 were on par with C-152.

Harvest index was lowest for C-88 and V-26 (0.33) and highest for VCM-8 (0.65). No variety was on par with VCM-8. Varieties such as IC-38956, UPC-124 and GC-82-7 had comparatively higher harvest index. Harvest index of different varieties are presented graphically in figure 1.

4.2. Variance and Coefficient of variation

Phenotypic and genotypic variances and coefficients of variation for twentysix characters are presented on table 6.

Root/shoot ratio at vegetative period had the highest phenotypic coefficient of variation (74.01) followed by that at flowering period (65.88), haulam yield per plot (46.68), grain yield per plot (45.20), root/shoot ratio at harvest period (44.63) and proline content (41.41). These characters also showed high genotypic coefficient of variation.

Number of pods per plant, hundred grain weight, yield per plant, size of the grain and leaf area index at

Table 6. Phenotypic and Genotypic variances and coefficient of variation for twentysix characters

Sl. No.	Characters	Variance		Coefficient of variation	
		Phenotypic	Genotypic	Phenotypic	Genotypic
1.	Root length at vegetative period	2.311	0.686	11.43	6.23
2.	Root spread at vegetative period	2.108	0.054	11.64	1.86
3.	Root/shoot ratio at vegetative period	0.003	0.0005	74.01	30.22
4.	Leaf area index at vegetative period	0.046	0.029	27.64	21.95
5.	Days to 50 per cent flowering	16.107	14.189	8.67	8.36
6.	Root length at flowering period	3.554	1.937	10.40	7.68
7.	Root spread at flowering period	1.327	0.512	8.15	5.06
8.	Root/shoot ratio at flowering period	0.004	0.001	65.88	32.94
9.	Leaf area index at flowering period	0.152	0.104	29.76	24.62
10.	Number of stomata per microscopic field	22.602	10.488	20.93	14.26
11.	Root length at harvest period	5.378	3.424	12.02	9.59
12.	Root spread at harvest period	9.962	6.818	17.44	14.43
13.	Root/shoot ratio at harvest period	0.011	0.005	44.63	30.09

Table 6 (contd.)

Sl. No.	Characters	Variance		Coefficient of variation	
		Pheno-typic	Geno-typic	Pheno-typic	Geno-typic
14.	Leaf area index at harvest period	0.018	0.010	35.87	26.74
15.	Number of pods per plant	5.898	3.898	40.61	33.02
16.	Number of grains per pod	5.354	3.803	19.43	16.37
17.	Plant height at maturity	101.479	81.582	22.93	20.56
18.	Grain filling period	3.019	2.656	10.71	10.04
19.	Duration upto maturity	14.471	12.860	5.65	5.32
20.	Yield per plant	2.480	1.013	34.01	21.74
21.	Size of the grain	10.270	9.976	32.37	31.90
22.	Hundred grain weight	14.968	13.714	37.63	36.02
23.	Grain yield per plot	5498.960	2763.380	45.20	32.04
24.	Haulm yield per plot	0.409	0.271	46.68	38.00
25.	Proline content	27858.720	20324.090	41.41	35.37
26.	Harvest index	0.009	0.005	21.71	18.18

all the three growth periods showed relatively high phenotypic and genotypic coefficient of variation. Genotypic coefficient of variation was lowest for root spread at vegetative period (1.86) followed by root spread at flowering period (5.06) and duration upto maturity (5.32).

Days to 50 per cent flowering, grain filling period and duration upto maturity showed very little difference between their genotypic and phenotypic coefficient of variation.

4.3. Heritability and Genetic Advance

Heritability percentages and genetic advance as percentage of mean for twentysix characters in cowpea are presented in table 7 and in figure 3.

Size of the grain had the highest heritability (97.1) followed by hundred grain weight (91.6), duration upto maturity (88.9) days to fifty per cent flowering (88.1) and grain filling period (88.0).

Plant height at maturity, proline content, number of grains per pod, leaf area index at vegetative and flowering periods, root length and root spread at harvest period, haulm yield per plot, number of pods per plant and harvest index had comparatively higher heritability percentages.

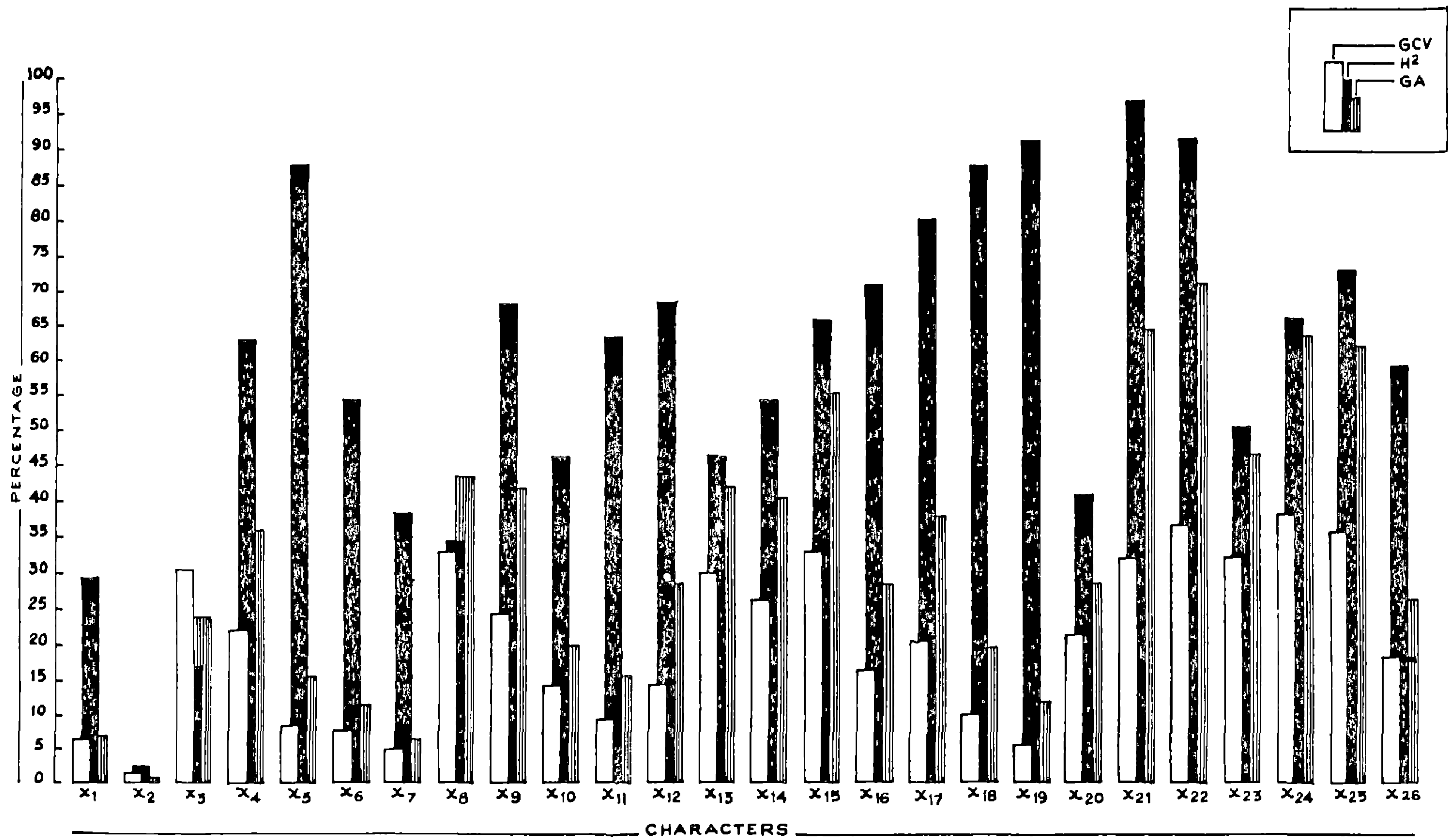
Table 7. Heritability and genetic advance for twentysix characters

Sl. No.	Characters	Heritability percentage (H^2)	Genetic advance as percentage of mean (G.A.)
1.	Root length at vegetative period	29.7	7.00
2.	Root spread at vegetative period	2.6	0.61
3.	Root/shoot ratio at vegetative period	17.2	24.3
4.	Leaf area index at vegetative period	62.9	35.9
5.	Days to 50 per cent flowering	88.1	15.7
6.	Root length at flowering period	54.5	11.7
7.	Root spread at flowering period	38.6	6.5
8.	Root/shoot ratio at flowering period	34.5	43.7
9.	Leaf area index at flowering period	68.8	42.1
10.	Number of stomata per microscopic field	46.4	20.0
11.	Root length at harvest period	63.7	15.8
12.	Root spread at harvest period	68.4	28.6
13.	Root/shoot ratio at harvest period	46.9	42.1

Table 7 (contd.)

Sl. No.	Characters	Heritability percentage	Genetic advance as percentage of mean
14.	Leaf area index at harvest period	54.8	40.6
15.	Number of pods per plant	66.1	55.3
16.	Number of grains per pod	71.0	28.4
17.	Plant height at maturity	80.4	38.0
18.	Grain filling period	88.0	19.4
19.	Duration upto maturity	88.9	11.8
20.	Yield per plant	40.9	28.6
21.	Size of the grain	97.1	64.8
22.	Hundred grain weight	91.6	71.0
23.	Grain yield per plot	50.3	46.8
24.	Haulm yield per plot	66.3	63.7
25.	Proline content	73.0	62.2
26.	Harvest index	59.2	26.1

FIG 3 GENOTYPIC COEFFICIENT OF VARIATION (GCV) HERITABILITY (H^2) AND GENETIC ADVANCE (GA) FOR TWENTY SIX CHARACTERS IN COWPEA



Very low heritability values were shown by characters such as root spread (2.6), root/shoot ratio (17.2) and root length (29.7) at vegetative period.

Very high genetic advance was shown by characters such as hundred grain weight (71.0), size of the grain (64.8), haulm yield per plot (63.7), proline content (62.2) and number of pods per plant (55.3). Root length and root spread during vegetative and flowering periods showed very low values for genetic advance.

High heritability coupled with high genetic advance were exhibited by characters such as size of the grain (97.1 and 64.8), hundred grain weight (91.6 and 71.0), number of pods per plant (66.1 and 55.3), proline content (73.0 and 62.2) and haulm yield per plot (66.3 and 63.7). Leaf area index at vegetative, flowering and harvest periods and grain yield per plot also showed comparatively high heritability together with high genetic advance. Though the characters days to 50 per cent flowering, grain filling period and duration upto maturity exhibited high heritability, they had very low genetic advance. Root length at flowering and harvest periods had comparatively high heritability, but low genetic advance.

4.4. Correlation

The genotypic and phenotypic correlation coefficients of grain yield per plot with twentyfour characters and their interrelationships are shown in table 8. The genotypic correlations between grain yield per plot and other characters are presented graphically in figure 4.

4.4.1. Correlation between grain yield per plot and other characters

Grain yield per plot had maximum positive genotypic correlation with leaf area index at vegetative period (0.778) followed by leaf area index at flowering period (0.626), root spread at harvest period (0.547), number of pods per plant (0.409), root/shoot ratio at vegetative period (0.385), grain filling period (0.330) and plant height at maturity (0.267). Relatively low, but positive genotypic correlation existed between grain yield per plot and characters such as root length and root spread at flowering period, root length and leaf area index at harvest period, duration upto maturity, size of the grain, hundred grain weight, haulm yield per plot and harvest index. Grain yield per plot had high negative genotypic correlation with number of grains per pod (-0.384), root/shoot ratio at flowering period (-0.505) and harvest period (-0.213), proline content (-0.350), days to fifty per cent flowering (-0.258) and number of stomata per microscopic field (-0.132).

Table 8 Phenotypic and Genotypic Correlation Coefficients of yield, yield c

Sl No	Characters	Root length at vegetative period	Root spread at vegetative period	Root/ shoot ratio at vegetative period	Leaf area index at vegetative period	Days to 50 per cent flowering	Root length at flowering period	Root spread at flowering period	Root/ shoot ratio at flowering period	Leaf area index at flowering period	Number of stomata per microscopic field	Root length at harvest period	Root spread at harvest period	Root/ shoot ratio harvest period
1	Root length at vegetative period	-	-0 205	0 065	-0 146	-0 128	0 395**	-0 621	0 133	-0 040	-0 158	0 465**	0 200	0 124
2	Root spread at vegetative period	-2 734	-	-0 113	0 322*	0 102	-0 165	0 144	-0 193	0 154	0 121	0 445**	-0 099	-0 233
3	Root/shoot ratio at vegetative period	0 519	-1 291	-	-0 052	-0 114	0 267*	-0 083	0 299*	-0 218	-0 154	0 199	-0 097	0 184
4	Leaf area index at vegetative period	-0 286	0 591	0 076	-	-0 078	0 184	0 287*	-0 081	0 539**	-0 134	0 134	0 396**	-0 417**
5	Days to 50 per cent flowering	-0 299	1 108	-0 510	-0 058	-	-0 379**	0 016	-0 252*	0 188	0 671**	-0 543**	-0 150	-0 341**
6	Root length at flowering period	0 946	-1 092	0 630	0 247	-0 568	-	0 194	0 299*	0 149	-0 200	0 625**	0 422**	0.062
7	Root spread at flowering period	0 097	1 765	-0 365	0 576	-0 020	0 433	-	0 029	0 419**	-0 175	-0 124	0 215	-0.168
8	Root/shoot ratio at flowering period	0 601	0 227	0 580	-0 135	-0 513	0 564	-0 118	-	-0 369**	-0 304*	0 393**	0 087	0 116
9	Leaf area index at flowering period	-0 086	0 699	-0 363	0 821	0 263	0 170	0 679	-0 681	-	0 116	-0 018	0 459**	-0 456**
10	Number of stomata per microscopic field	0 340	0 782	-0 372	-0 214	0 995	-0 589	-0 048	-0 512	0 224	-	-0 424**	-0.123	-0 255*
11	Root length at harvest period	0 783	-1 342	0 701	0 222	-0 772	1 034	0 301	0 886	-0 038	-0 812	-	0 124	0 183
2	Root spread at harvest period	0 515	-0 653	0 288	0 518	-0 221	0 676	0 535	-0 046	0 720	-0 276	0 562	-	-0 238
13	Root/shoot ratio at harvest period	0 423	-1 871	0 742	-0 651	-0 560	0 099	-0 915	0 471	-0 882	-0 327	0 248	-0.460	-
14	Leaf area index at harvest period	-0 366	0 755	-0 044	0.617	0 543	-0 125	0 696	-0 591	0 634	0 343	-0 413	0 113	-0.774
5	Number of pods per plant	0 643	-1 263	0 038	0 034	-0 626	0 794	0 084	0 246	0 143	-0 493	0 648	0 529	0 209
16	Number of seeds per pod	-0 415	1 320	-0 565	0 021	0 327	-0 566	-0 153	0 038	-0 303	0 086	-0 431	-0 689	-0 206
17	Plant height at maturity	-0 375	0 621	-0 493	0 468	0 570	-0 147	0 364	-0 620	0 583	0 642	-0 397	-0 007	-0 515
18	Grain filling period	0 192	0 641	0 027	0 387	0 244	0 356	0 603	-0 146	0 727	0 281	0 226	0 782	-0 656
19	Duration upto maturity	-0 191	0 912	-0 162	0 139	0 920	-0 397	0 011	-0 508	0 442	0 954	-0 622	0 114	-0 586
20	Size of the grain	-0 021	0 198	0 359	0 514	0 165	0 142	0 637	-0 224	0 565	-0 023	0 105	0 573	-0 438
21	Hundred grain weight	-0 066	0 469	0 160	0 420	0 194	0 087	0 706	-0 322	0 598	0 014	0 027	0 496	-0 516
22	Grain yield per plot	-0 244	-0 107	0 385	0 778	-0.258	0 144	0 023	-0 505	0 626	-0 132	0 105	0 547	-0 213
23	Haulm yield per plot	-0 426	0 664	-0 228	0 554	0 631	-0 331	0 491	-0 765	0 675	0 468	-0 626	0 279	-0 765
24	Proline content	-0 437	0 197	-0 062	-0 119	-0 285	-0 150	-0 013	-0 007	-0 265	-0 364	-0 038	-0 371	0 296
25	Harvest index	0 120	-1 159	0 523	-0 332	-0 749	0 140	-0 616	0 304	-0 569	-0 667	0 331	-0 116	0 849

* Significant at 5 per cent probability level

** Significant at 1 per cent probability level ponents and other characters in cowpea

Leaf area index at harvest period	Number of pods per plant	Number of seeds per pod	Plant height at maturity	Grain filling period	Duration upto maturity	Size of the grain	Hundred grain weight	Grain yield per plot	Haulm yield per plot	Proline content	Harvest index
-0 105	0 285*	-0 184	-0 205	0 067	-0 070	0 021	0 011	-0 132	-0 124	-0 138	-0 147
0 158	-0 004	0 097	0 255*	0 119	0 050	0 040	0 104	-0 060	0 025	0 029	-0 134
-0 015	-0 001	-0.284*	-0 274*	0 141	-0 059	0.133	0 077	-0 082	-0 151	-0 028	0 091
0 420**	0 046	-0 034	0 385**	0 291*	0 057	0 410**	0 341**	0 446**	0 374**	-0 122	-0 262*
0 317*	-0 515**	0 288*	0 415**	0 220	0 901**	0 154	0 191	-0 292*	0 377**	-0 265*	-0 581**
0 077	0 443**	-0 231	-0.115	0 242	-0 279*	0 108	0 016	0 068	-0 151	-0 210	0 017
0.235	-0 051	-0.056	0 266*	0 380**	0 028	0 381**	0 446**	-0 109	0 176	-0 078	-0 211
-0 289*	0 071	0 063	-0.350**	-0 107	-0 269*	-0 097	-0 168	-0 161	-0 363**	0 006	0 143
0 470**	0 042	-0 101	0 522**	0 543**	0 346**	0 469**	0 462**	0 465**	0 580**	-0 233	-0 387**
0 132	-0 278*	0 125	0 325**	0 122	0 629**	-0.047	-0 061	-0 133	0 210	-0 215	-0 351**
-0 080	0 518**	-0.295*	-0 263*	0 131	-0 471**	0 090	0 043	0 094	-0 279*	-0 013	0 198
0 122	0 370**	-0 487**	0 072	0 653**	0 071	0 469**	0 415**	0 287*	0 194	-0 233	-0 101
-0 341**	0 058	-0.018	-0 389**	-0 426**	-0 407**	-0.291*	-0 304*	-0 066	-0 453**	0 158	0 598**
-	-0 287*	0 111	0.570**	0 214	0 296*	0 465**	0 475**	0 267*	0 742**	-0 125	-0 447**
-0 525	-	-0.294*	-0.122	0 147	-0 429**	-0 305*	-0.327**	0 234	-0 280*	-0 179	0 305*
0 218	-0.391	-	0 214	-0 525**	0 039	-0 330**	-0 314*	-0 179	0.123	0 168	-0 038
0 809	-0 218	0 329	-	0 163	0 163	0.152	0 115	0 298*	0 559**	-0 249	-0 394**
0 350	0 164	-0 624	0 199	-	0 425**	0 542**	0 556**	0 146	0 183	-0 415**	-0 403**
0 566	-0 459	0 019	0 489	0 487	-	0 305*	0 281*	-0 053	0 429**	-0 435**	-0 615**
0 613	-0 348	-0 389	0.159	0 601	0 313	-	0.935**	0 104	0 501**	0 098	-0 312*
0 589	-0 381	-0 361	0 133	0 621	0 295	0 974	-	0 030	0 454**	0 179	-0 350**
0 184	0 409	-0.384	0 267	0 330	0 031	0 131	0 042	-	0 288*	-0 122	0 050
0 896	-0 515	0.221	0 684	0 290	0.662	0 612	0 586	0 222	-	-0 023	-0 419**
-0 223	-0 319	0.246	-0 273	-0 511	-0 504	0 110	0 178	-0 350	-0 077	-	0 339**
-0 700	0 349	-0 102	-0.513	-0 560	-0 764	-0.385	-0 428	0 106	-0 547	0 463	-

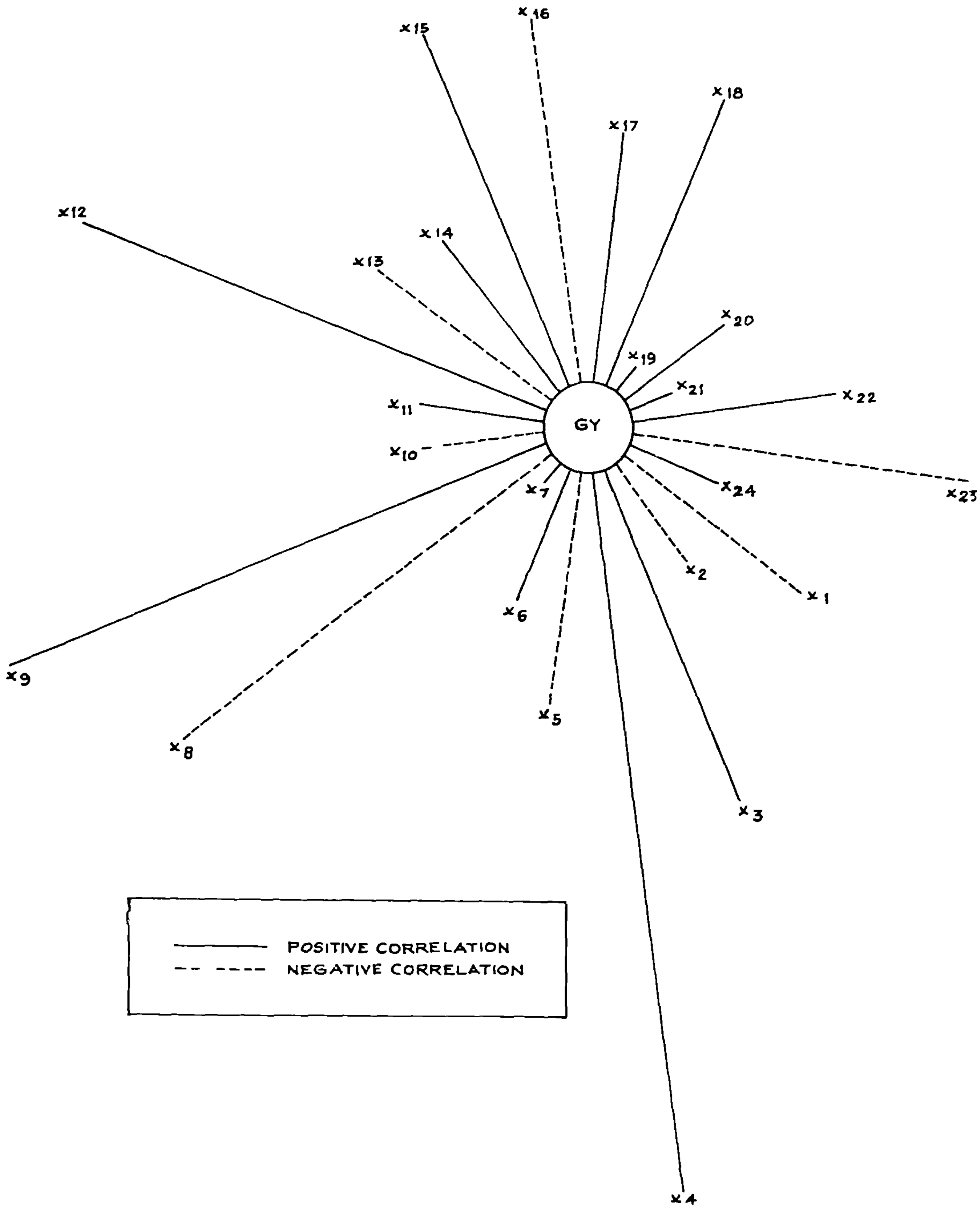
Phenotypic correlations are given as the upper diagonal

Genotypic correlations are given as the lower diagonal

Fig. 4. Genotypic correlation coefficients of grain yield per plot with twentyfour characters.

X_1 - Root length at vegetative period
X_2 - Root spread at vegetative period
X_3 - Root/shoot ratio at vegetative period
X_4 - Leaf area index at vegetative period
X_5 - Days to 50 per cent flowering
X_6 - Root length at flowering period
X_7 - Root spread at flowering period
X_8 - Root/shoot ratio at flowering period
X_9 - Leaf area index at flowering period
X_{10} - Number of stomata per microscopic field
X_{11} - Root length at harvest period
X_{12} - Root spread at harvest period
X_{13} - Root/shoot ratio at harvest period
X_{14} - Leaf area index at harvest period
X_{15} - Number of pods per plant
X_{16} - Number of grains per pod
X_{17} - Plant height at maturity
X_{18} - Grain filling period
X_{19} - Duration up to maturity
X_{20} - Size of the grain
X_{21} - Hundred grain weight
X_{22} - Haulm yield per plot
X_{23} - Proline content
X_{24} - Harvest index
GY - Grain yield per plot

F G 4 GENOTYPIC CORRELATION COEFFICIENTS OF GRAIN YIELD PER PLOT WITH TWENTY FOUR CHARACTERS



Grain yield showed significant positive phenotypic correlation with leaf area index at flowering period (0.465) followed by leaf area index at vegetative period (0.446), plant height at maturity (0.298), haulm yield per plot (0.288), root spread at harvest period (0.287) and leaf area index at harvest period (0.267). Significant negative phenotypic correlation existed between grain yield and days to 50 per cent flowering (-0.292). Non-significant positive phenotypic correlation was recorded between grain yield per plot and characters such as number of pods per plant, grain filling period, size of the grain, root length at flowering and harvest periods, hundred grain weight and harvest index. Non significant and negative phenotypic association was observed between grain yield per plot and characters such as root spread and root/shoot ratio at flowering period, number of stomata per microscopic field, root/shoot ratio at harvest period, number of grains per pod, duration upto maturity and proline content.

4.4.2. Correlation between pairs of characters

Root length at vegetative period had high positive genotypic correlation with root length at flowering period (0.946) followed by root length at harvest period (0.783), number of pods per plant (0.643), root/shoot ratio at flowering period (0.601), root/shoot ratio at vegetative period (0.519), root spread and root/shoot ratio at harvest period. A high negative genotypic correlation existed between root length at vegetative period and characters such as root spread at vegetative period, proline content, haulm yield per plot, number of grains per pod, plant height at maturity, leaf area index at vegetative and harvest periods and number of stomata per microscopic field.

Significant and positive phenotypic correlation was recorded between root length at vegetative period and root length at harvest period (0.465) followed by root length at flowering period (0.395) and number of pods per plant (0.285). A high but non-significant phenotypic association was observed between root length at vegetative period and characters such as root spread at vegetative period, plant height at maturity and number of stomata per microscopic field.

Root spread at vegetative period showed high positive genotypic correlation with root spread at flowering period (1.765) followed by number of grains per pod (1.320) days to 50 per cent flowering (1.108), duration upto maturity (0.912), number of stomata per microscopic field (0.782), leaf area index at vegetative, flowering and harvest periods (0.591, 0.699 and 0.755 respectively), plant height at maturity (0.621) and grain filling period (0.641).

The genotypic correlation between root spread at vegetative period and root/shoot ratio at vegetative period, root length at flowering period and harvest period, root/shoot ratio at harvest period, number of pods per plant and harvest index were high and negative.

Root spread at vegetative period showed significant positive phenotypic correlation with characters such as root length at harvest period (0.445), leaf area index at vegetative period (0.322) and plant height at maturity (0.255) while this character had negative, non-significant phenotypic correlation with root/shoot ratio at vegetative, flowering and harvest periods, root length at flowering and root spread at harvest periods.

Root/shoot ratio at vegetative period had high positive genotypic correlation and significant positive phenotypic correlation with root length at flowering period (0.630 and 0.267 respectively) and root/shoot ratio at flowering period (0.580 and 0.299 respectively). The characters such as root length and root/shoot ratio at harvest period, harvest index, and size of the grain had high positive genotypic correlation and a non-significant positive phenotypic correlation with root/shoot ratio at vegetative period. Number of grains per pod and plant height at maturity showed high negative genotypic correlation and significant negative phenotypic correlation with root/shoot ratio at vegetative period.

Leaf area index at vegetative period had maximum positive genotypic correlation with leaf area index at flowering period (0.821) followed by leaf area index at harvest period (0.617), root spread at flowering period (0.576), haulm yield per plot (0.554), root spread at harvest period (0.518), size of the grain (0.514), plant height at maturity (0.468), hundred grain weight (0.420) and grain filling period (0.387). All these characters had significant positive phenotypic correlation with leaf area index at vegetative period. A significant negative phenotypic correlation was observed between this character and root/shoot ratio at harvest period (-0.417) and harvest index (-0.262). The leaf area index had maximum negative genotypic correlation with root/shoot ratio at harvest period (-0.651), followed by harvest index (-0.332), number of stomata per microscopic field (-0.214), root/shoot ratio at flowering period (-0.135) and proline content (-0.119).

A high positive genotypic correlation was observed between days to fifty per cent flowering and number of stomata per microscopic field (0.995), duration upto maturity (0.920), haulm yield per plot (0.631), plant height at maturity (0.570), leaf area index at harvest period (0.543) while this character had a high negative genotypic correlation with number of pods per plant (-0.626), harvest index (-0.749), root length at flowering and harvest periods, root/shoot ratio at flowering period and proline content.

Days to 50 per cent flowering had maximum positive phenotypic correlation with duration upto maturity (0.901) followed by number of stomata per microscopic field (0.671), plant height at maturity (0.415), haulm yield per plot (0.377), leaf area index at harvest period (0.317) and number of grains per pod (0.288). Days to 50 per cent flowering had significant negative phenotypic correlation with root length and root/shoot ratio at flowering period (-0.379 and -0.252 respectively) and harvest period (-0.543 and -0.341 respectively), number of pods per plant (-0.515) proline content (-0.265) and harvest index (-0.581).

A high positive genotypic correlation was observed between root length at flowering period and at harvest period (1.034), number of pods per plant (0.794), root spread at harvest period (0.676), root/shoot ratio (0.564) and root spread (0.433) at flowering period and grain filling period (0.356). All the above characters exhibited significant positive phenotypic correlation with root length at flowering period. This character showed significant negative phenotypic correlation with duration upto maturity and a high negative genotypic correlation with number of stomata per microscopic field (-0.589), number of grains per pod (-0.566), haulm yield per plot (-0.331) and duration upto maturity (-0.397). The characters such as leaf area index at flowering period, size of the grain and harvest index had relatively low, but positive genotypic correlation with root length at flowering period.

Root spread at flowering period showed a high and positive genotypic association with hundred grain weight (0.706) followed by leaf area index at flowering and harvest periods, size of the grain, grain filling period, root length and root spread at harvest period. A high negative genotypic correlation existed between root spread at flowering period and the characters such as root/shoot ratio at harvest period (-0.915) and harvest index (-0.616). Number of grains per pod, number of stomata per microscopic field and proline content had relatively low, but negative genotypic correlation with root spread at flowering period.

Root spread at flowering period had maximum significant positive phenotypic correlation with hundred grain weight (0.446) followed by leaf area index at flowering period, size of the grain, grain filling period and plant height at maturity, while this character showed negative phenotypic correlation with number of stomata per microscopic field, root length and root/shoot ratio at harvest period, number of pods per plant, number of grains per pod, proline content and harvest index.

A high positive genotypic correlation was observed between root/shoot ratio at flowering period and the characters such as root length (0.886) and root/shoot ratio (0.471) at harvest period and harvest index (0.304). Number of pods per plant and number of grains per pod also showed positive genotypic correlation with this character. Leaf area index at flowering period, number of stomata per microscopic field, leaf area index at harvest period, plant height at maturity duration upto maturity, hundred grain weight and haulm yield per plot showed high negative genotypic correlation with root/shoot ratio at flowering period.

Significant positive phenotypic correlation was observed between root/shoot ratio at flowering period and root length at harvest period (0.393), while this character had significant negative phenotypic correlations with leaf area index at flowering period (-0.369), haulm yield per plot (-0.363), number of stomata per microscopic field (-0.304), plant height at maturity (-0.350), leaf area index at harvest period (-0.289) and duration upto maturity. Root/shoot ratio at flowering period had positive, but non-significant phenotypic association with number of pods per plant, number of grains per pod, proline content and harvest index.

Leaf area index at flowering period had maximum positive genotypic correlation with grain filling period (0.727) followed by the characters such as root spread at harvest period (0.720), haulm yield per plot (0.675), leaf area index at harvest period (0.634), hundred grain weight (0.598), plant height at maturity (0.583), size of the grain (0.565) and duration upto maturity (0.442). A high negative genotypic correlation was observed between leaf area index at flowering period and root/shoot ratio at harvest period (-0.882), harvest index (-0.569), number of grains per pod (-0.303) and proline content (-0.265).

Significant positive phenotypic correlation existed between leaf area index at flowering period and the characters such as root spread (0.459) and leaf area index at harvest period (0.470), plant height at maturity (0.522), grain filling period (0.543), duration upto maturity (0.346), size of the grain (0.469), hundred grain weight (0.462) and haulm yield per plot (0.580). A significant negative phenotypic correlation was shown by this character with root/shoot ratio at harvest period and harvest index.

A high positive genotypic and significant positive phenotypic correlation existed between number of stomata per microscopic field and duration upto maturity (0.954) and plant height at maturity (0.642).

High negative genotypic correlations and significant phenotypic correlations were shown by the characters such as root length at harvest period, root/shoot ratio at harvest period, number of pods per plant and harvest index with number of stomata per microscopic field. Leaf area index at harvest period, number of grains per pod, grain filling period and haulm yield per plot had relatively low positive genotypic and phenotypic correlation with number of stomata per microscopic field.

Root length at harvest period showed high positive genotypic correlation and significant positive phenotypic correlation with number of pods per plant (0.648 and 0.518 respectively). Relatively high positive genotypic correlations and non-significant positive phenotypic correlations existed between root length at harvest period and the characters such as root spread at harvest period, root/shoot ratio at harvest period, grain filling period, size of the grain, hundred grain weight and harvest index. High negative genotypic correlations were observed between root length at harvest period and leaf area index at harvest period (-0.413), number of grains per pod (-0.431), plant height at maturity (-0.397), duration upto maturity (-0.622) and haulm yield per plot (-0.626). Significant negative phenotypic correlation existed between root length at harvest period and the characters such as number of grains per pod, duration upto maturity, and haulm yield per plot.

Root spread at harvest period showed high positive genotypic associations with grain filling period (0.782), size of the grain (0.573), number of pods per plant (0.529) and hundred grain weight (0.496). All the above characters also showed significant and positive phenotypic correlations with root spread at harvest period. High negative genotypic correlations were observed between this character and number of grains per pod (-0.689), root/shoot ratio at harvest period (-0.460) and proline content (-0.371).

Root/shoot ratio at harvest period showed high positive genotypic and significant positive phenotypic correlations with harvest index (0.849 and 0.598 respectively). This character had high negative genotypic correlations and significant negative phenotypic correlations with the characters such as leaf area index at harvest period, plant height at maturity, grain filling period, duration upto maturity, size of the grain, hundred grain weight and haulm yield per plot.

Leaf area index at harvest period showed high positive genotypic correlations with the characters such as plant height at maturity, grain filling period, duration upto maturity, size of the grain, hundred grain weight and haulm yield per plot. High negative genotypic correlations were observed between leaf area index at harvest period and the characters like number of pods per plant (-0.525), harvest index (-0.700) and proline content (-0.223).

The characters such as plant height at maturity, duration upto maturity, size of the grain, hundred grain weight and haulm yield per plot showed significant positive phenotypic correlations with leaf area index at harvest period. This character had significant negative phenotypic correlations with number of pods per plant and harvest index.

Number of pods per plant had high positive genotypic correlation with harvest index (0.349) and high negative genotypic correlations with number of seeds per pod (-0.391), duration upto maturity (-0.459), size of the grain (-0.348), hundred grain weight (-0.381), haulm yield per plot (-0.515) and proline content (-0.319). Number of pods per plant showed significant positive phenotypic correlation with harvest index (0.305) and significant negative phenotypic correlations with number of grains per pod, duration upto maturity, size of the grain, hundred grain weight and haulm yield plot. The grain filling period had positive, but non-significant phenotypic and genotypic correlations with number of pods per plant.

Number of grains per pod had positive genotypic correlations with plant height at maturity (0.329), proline content (0.246), haulm yield per plot (0.221) and duration upto maturity (0.019), while this character showed negative genotypic correlations with grain filling period (-0.624), size of the grain (-0.389), hundred grain weight (-0.361) and harvest index (-0.102). Number of grains per pod showed significant negative phenotypic correlations with grain filling period (-0.525), size of the grain (-0.330) and hundred grain weight (-0.314).

Plant height at maturity had high positive genotypic correlation and significant positive phenotypic correlation with haulm yield per plot, while the characters such as grain filling period, duration upto maturity, size of the grain and hundred grain weight showed positive but relatively low genotypic and phenotypic correlations with this character. Plant height had significant negative phenotypic correlation and high negative genotypic correlation with harvest index.

Grain filling period showed positive genotypic and highly significant positive phenotypic correlations with characters such as duration upto maturity (0.487 and 0.425 respectively), size of the grain (0.601 and 0.542 respectively) and hundred grain weight (0.621 and 0.556 respectively). Grain filling period showed high negative genotypic correlations with proline content (-0.511) and harvest index (-0.560). These two characters also showed significant negative phenotypic correlations with grain filling period.

Duration upto maturity showed positive and high genotypic correlation and significant positive phenotypic correlation with size of the grain (0.313 and 0.305 respectively) while this character showed high negative genotypic and significant negative phenotypic correlations with proline content and harvest index. Duration also had high positive genotypic and phenotypic correlations with hundred grain weight.

Size of the grain showed high positive genotypic and highly significant positive phenotypic correlations with hundred grain weight and haulm yield per plot. This character also showed high negative genotypic correlation with harvest index (-0.385). Significant negative phenotypic correlation existed between size of the grain and harvest index (-0.312).

Genotypic correlation of proline content with hundred grain weight was positive and that with harvest index was high and negative. Significant negative phenotypic correlation was observed between hundred grain weight and harvest index (-0.350) and a non-significant positive phenotypic correlation existed between hundred grain weight and proline content.

Haulm yield per plot showed high negative genotypic correlation (-0.547) and significant negative phenotypic correlation (-0.419) with harvest index. Proline content had high positive genotypic correlation and significant positive phenotypic correlation with harvest index. The genotypic and phenotypic association between proline content and haulm yield per plot was low and negative.

4.5. Path Analysis

The genotypic correlation between grain yield per plot and seven characters viz. leaf area index and root/shoot ratio at vegetative period, root length and root spread at harvest period, grain filling period, duration upto maturity and harvest index were partitioned into their corresponding direct and indirect effects through path coefficient analysis and the results obtained are presented in table 9. Direct effects of these seven characters on grain yield per plot and their interrelationships are shown graphically in figure 5.

The harvest index showed maximum positive direct effect on grain yield (1.387). This component exerted low positive indirect effect on grain yield through root spread at harvest period (0.056) and high negative indirect effects on grain yield through leaf area index (-0.376), grain filling period (-0.461) and duration upto maturity (-0.383), while this character exerts low negative indirect effect on grain yield through root/shoot ratio (-0.085).

Leaf area index at vegetative period was the second component having high direct effect on grain yield (1.132). Leaf area index at vegetative period exerted positive indirect effect on grain yield through grain filling period (0.319) and duration upto maturity (0.069), while this component exerted negative indirect effects on grain yield through harvest index, root spread and root length at harvest period, and root/shoot ratio at vegetative period.

Grain filling period, the third component having high positive direct effect on grain yield (0.825) exerted high positive indirect effects through leaf area index at vegetative period (0.438) and duration upto maturity (0.244) while it exerts high negative indirect effect on grain

Table 9. Direct and Indirect effects of seven characters on yield per plot

Sl. No.	Characters	Leaf area index at vegetative period	Root/shoot ratio at vegetative period	Root length at harvest period	Root spread at harvest period	Grain filling period	Duration upto maturity	Harvest index	Total correlation
1.	Leaf area index at vegetative period	1.132	-0.012	-0.021	-0.249	0.319	0.069	-0.460	0.778
2.	Root/shoot ratio at vegetative period	0.086	-0.163	-0.067	-0.138	0.022	-0.081	0.726	0.385
3.	Root length at harvest period	0.251	-0.114	-0.095	-0.270	0.187	-0.313	0.459	0.105
4.	Root spread at harvest period	0.587	-0.047	-0.053	-0.481	0.645	0.057	-0.161	0.547
5.	Grain filling period	0.438	-0.004	-0.021	-0.376	0.825	0.244	-0.776	0.330
6.	Duration upto maturity	0.158	0.026	0.059	-0.055	0.402	0.501	-1.060	0.031
7.	Harvest index	-0.376	-0.085	-0.032	0.056	-0.461	-0.383	1.387	0.106

Residual effect = 0.149 Direct effects are underlined

Fig. 5. Path diagram showing the direct effects and interrelationships of grain yield per plot with seven component characters in cowpea.

GY - Grain yield per plot

X_1 - Leaf area index at vegetative period

X_2 - Root/shoot ratio at vegetative period

X_3 - Root length at harvest period

X_4 - Root spread at harvest period

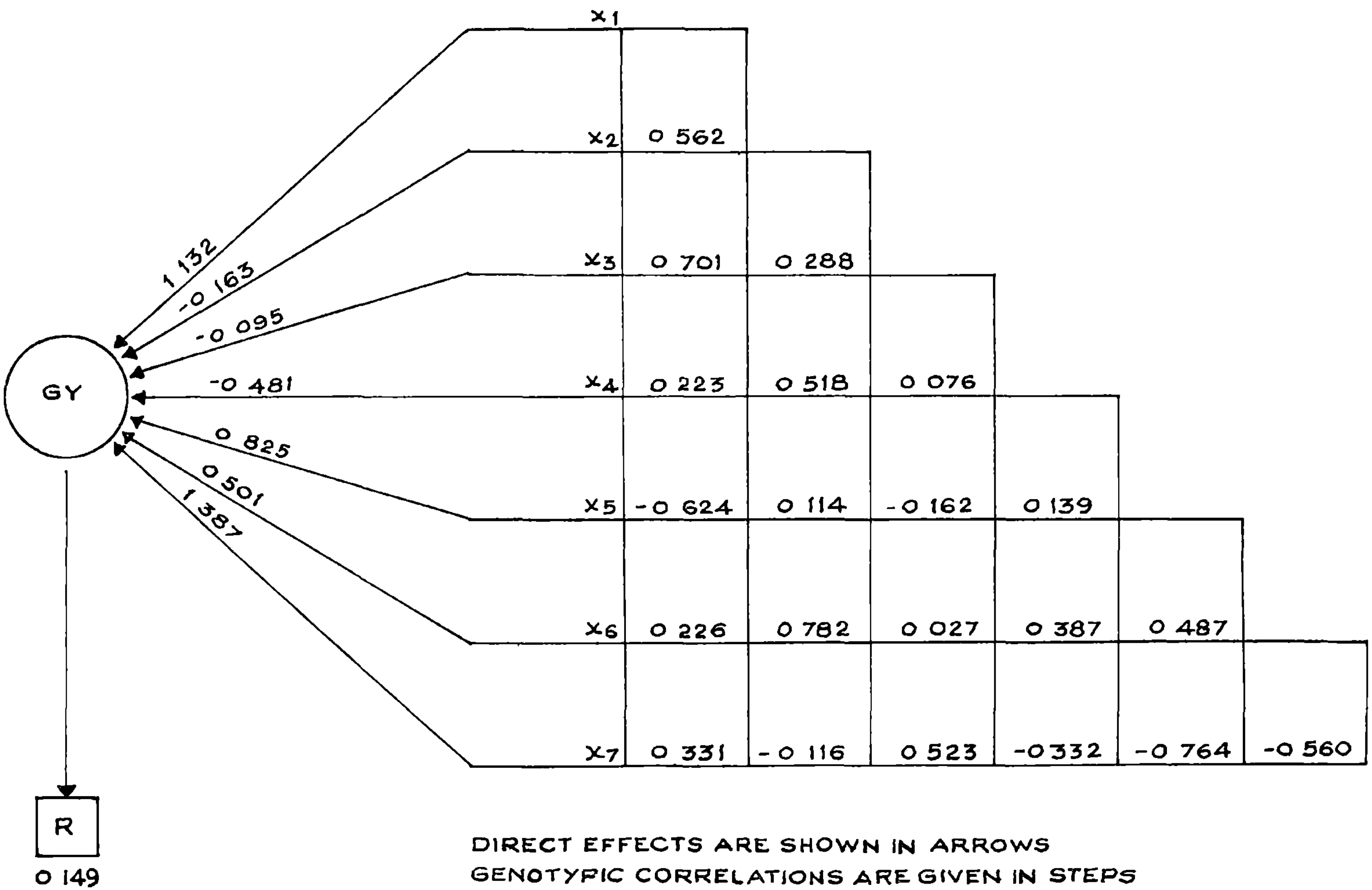
X_5 - Grain filling period

X_6 - Duration up to maturity

X_7 - Harvest index

R - Residual effect

FIG 5 PATH DIAGRAM SHOWING THE DIRECT EFFECTS AND INTERRELATIONSHIPS OF GRAIN YIELD PER PLOT WITH SEVEN COMPONENT CHARACT RS IN COWPEA



DIRECT EFFECTS ARE SHOWN IN ARROWS
GENOTYPIC CORRELATIONS ARE GIVEN IN STEPS

yield through harvest index (-0.776) and root spread at harvest period. The indirect effects exerted by grain filling period on grain yield through root/shoot ratio at vegetative period and root length at harvest periods were low and negative.

Duration upto maturity exerted high and positive direct effect on grain yield (0.501) but its indirect effect through harvest index was very high and negative (-1.060). Duration upto maturity had positive indirect effect on grain yield through leaf area index at vegetative period (0.158), grain filling period (0.402), root length (0.059) and root/shoot ratio (0.026) at vegetative period and negative indirect effect through root spread at harvest period (-0.055).

Root spread at harvest period had negative direct effect (-0.481) on grain yield and high positive indirect effect through leaf area index at vegetative period (0.587) and grain filling period (0.645) and low positive indirect effect through duration upto maturity (0.057). This character had negative indirect effect on grain yield through root/shoot ratio at vegetative period (-0.047), root length at harvest period (-0.053) and harvest index (-0.161).

Root/shoot ratio at vegetative period and root length at harvest period had negative direct effects on grain yield (-0.163 and -0.095 respectively). Both these characters exerted high positive indirect effect on grain yield through harvest index (0.726 and 0.459 respectively). Root/shoot ratio at vegetative period had low positive indirect effect on grain yield through leaf area index (0.086) and grain filling period (0.022) and negative indirect effects through root length at harvest period (-0.067), root spread at harvest period (-0.138) and duration upto maturity (-0.081). Root length at harvest period also had low positive indirect effect on grain yield through leaf area index at vegetative period (0.251) and grain filling period (0.187) and negative indirect effects through duration upto maturity (-0.313), root/shoot ratio (-0.114) and root spread at harvest period (-0.270).

DISCUSSION

DISCUSSION

Successful crop production in regions of frequent drought requires development and cultivation of drought tolerant varieties and methods and practices for providing or maintaining sufficient available water for growth. Varieties within a crop species are found to be differing in their ability to endure drought. Selection of varieties which can evade or endure periods of insufficient moisture lead to efficient crop production. In the present study, sixteen varieties of cowpea were grown under moisture stress conditions to study the varietal differences in response to drought and the various characters contributing to drought tolerance in these varieties. The results obtained in this investigation are discussed below.

5.1. Varietal Evaluation

Detailed evaluation of varieties for assessing the different attributes contributing to drought tolerance and grain yield are essential for identifying and selecting types with potential for drought tolerance. In the present study significant differences among varieties were observed for the characters such as root length, root/shoot ratio and leaf area index at vegetative, flowering and harvest periods, root spread at flowering and harvest periods, days to 50 per cent flowering, number of stomata per micro-scopic field, number of pods per plant, number of grains per pod, plant height at maturity, grain filling period, duration upto maturity, yield per plant, size of the grain, hundred grain weight, grain yield per plot, haulm yield per plot, proline content and harvest index indicating the presence of considerable amount of variability. The variability noticed in the characters such as yield per plant, days to flowering and plant height were in conformity with the results of Pandita et al. (1982) in cowpea under dry farming conditions. The characters such as grain yield per plant, harvest index, stomata number, grain weight, root length, leaf area per plant, proline content and plant height which showed high variability conforms the results obtained by Sharma (1988) in maize under drought conditions.

The greater differences between the genotypic and phenotypic variances observed for the characters such as number of stomata per microscopic field, plant height at maturity, yield per plot and proline content suggests that these characters are highly influenced by the environmental conditions. The smaller differences between the genotypic and phenotypic variances observed for the leaf area index at flowering and harvest periods, grain filling period, yield per plant, size of the grain, and hundred grain weight suggests that variation in these characters are mainly due to genetic factors and the environment had only very little influence in the expression of these characters. The extent of variability noticed for different characters in different varieties of cowpea and their relation to drought tolerance are discussed below.

5.1.1. Root length and Root spread

A well developed root system is very essential for normal growth, development and production of crop plants. Root length and root spread measured at the vegetative, flowering and harvest periods revealed that relatively long and wide spreading root systems were present in the varieties 1-26, UPC-124, DPLC-216, DPLC-224, and DPLC-198. These observations were in agreement to the results of Rajagopalan (1958) in rice and Thangavelu et al. (1967 a) in sorghum that a deep and wide spread root system will be found in drought resistant varieties. Therefore, the above varieties can be considered to have potential for drought tolerance. The varieties UPC-124, DPLC-216, DPLC-224 and DPLC-198 were high yielders in conformity with the reports of Tiwari et al. (1974) in wheat and Kavitha (1982) in blackgram that varieties with deep and wide spread root system were capable of escaping drought and producing high yield.

5.1.2. Root/shoot Ratio

Rajagopalan (1958), Parao et al. (1976) and Murty (1987) in rice reported that drought resistant varieties possessed high root/shoot ratio. The varieties UPC-124, and DPLC-216 showed relatively high root/shoot ratio at all the three growth stages along with high yield and therefore can be considered as drought tolerant in agreement with the results of the above workers. The varieties VCM-8, IC 38956 and C-190 were low yielders eventhough they had high root/shoot ratio at harvest period. According to Fischer and Turner (1978) since root growth under drought conditions may be at the expense of shoot growth and further photosynthetic development, the harvestable yield may be reduced. This may be the reason for the low yield in VCM-8, IC-38956 and C-190.

5.1.3. Leaf area index

Several scientists have reported that cultivars which are capable of maintaining high leaf area index even under conditions of drought were the resistant ones. (Sammons et al., 1978 in soybean; Rajagopalan, 1958 in rice). The varieties Kanakamony, DPLC-198, V-240, UPC-124, DPLC-216 and DPLC-224 had relatively high leaf area index at vegetative and flowering periods and high yield in conformity with the results of Parameshwara (1979) and Setty and Sreeramulu (1972) in sorghum, Ali (1980) in cowpea, and Shivaraj *et al.* (1987) in ragi, that varieties maintaining high leaf area index under stress conditions produce high yield.

5.1.4. Number of stomata

Drought resistance in crop plants is determined by a wide range of physiological characters. The regulation of water loss by the stomata is one important character. Selection for stomatal characters potentially provides great scope for improvements in drought tolerance, because stomata provide the main control of water loss and consequently of plant stress. The varieties such as 1-26, VCM-8, IC-38956, UPC-124, DPLC-198, Kanakamony, DPLC-224 and DPLC-216 which had relatively lower number of stomata per microscopic field can be considered as drought tolerant in conformity to the results of Buican *et al.* (1964) in maize, Ravindranath and Ali (1972) and Renard and Allurik (1981) in rice, and Shewesh *et al.* (1985) in sorghum that drought tolerant varieties will have fewer number of stomata. Varieties UPC-124, DPLC-198, Kanakamony, DPLC-224 and DPLC-216 recorded high yield also in agreement with the reports of Setty and Sreeramulu (1972) in sorghum that under drought conditions, selections with high yield had fewer number of stomata per unit area.

5.1.5. Duration upto maturity

Relatively medium duration varieties like Charodi, UPC-124, DPLC-216, DPLC-198 and DPLC-224 were found to be the high yielders in this study in conformity with the reports of Hall and Grantz (1981) in cowpea that medium duration may be desirable since an extremely precocious plant may be as poorly adapted as a late one. Arnon (1975) also reported an inverse relationship between early maturity and yielding potential and suggested that growing period should not be shortened more than the essential.

5.1.6. Grain Filling Period

Among the sixteen varieties of cowpea, DPLC-210, UPC-124, DPLC-198, DPLC-224, DPLC-216 and C-88 had long grain filling periods. Short grain filling period has been reported to be adversely affecting the yield under drought conditions. The varieties UPC-124, DPLC-198, DPLC-224 and DPLC-216 had longer grain filling period and high yield in agreement with the results of Asana _et al_. (1968) in wheat, Gregory (1982) in rice, Omara (1987) in barley and Nelson (1987) in soybean.

5.1.7. Plant height

Wide variations were observed between varieties with regard to plant height indicating that height is highly affected under conditions of drought, in conformity to the observations of Day and Intalap (1970) in wheat, and Ali and Alam (1973) in greengram. Varieties with medium height such as DPLC-198, DPLC-216, DPLC-224 and UPC-124 were found to be relatively high yielders and drought tolerant.

5.1.8. Proline Accumulation

Varieties IC-38956, C-88 and VCM-8 accumulates more proline in their leaves when compared to other varieties. Varietal differences in proline accumulation under conditions of drought is in agreement with the findings of Singh et al. (1972) and Singh et al. (1973 a) in barley and Blum and Ebercon (1976) in sorghum. High yielding varieties in this study had relatively low amount of proline viz. UPC-124, DPLC-198, DPLC-224 and DPLC-216 suggesting that selecting cowpea varieties for low proline accumulation under drought might help to identify promising material for drought prone environment in agreement with the results of Hansen et al. (1979) in barley.

5.1.9. Harvest index

Varieties VCM-8, IC-38956 and UPC-124 had high harvest indices followed by V-240, GC-82-7, DPLC-224, DPLC-216, Charodi, DPLC-198 and 1-26. Foster and Weng (1979) in sorghum reported that varieties with high harvest index under drought were drought tolerant and therefore these varieties can be considered to have the potential for drought tolerance. Pandey et al. (1984) in grain legumes, Ibrahim et al. (1986) in pearl millet and Lorens et al. (1987) in maize have reported that under drought conditions, varieties with high harvest index also gives high yield.

5.1.10. Yield and yield components

High yielding ability of a crop even under conditions of drought has been considered as a measure of drought resistance (Asana, 1957; Parao et al., 1976 in rice). Varieties DPLC-216, DPLC-198, V-240, DPLC-224, Charodi, Kanakamony and UPC-124 were the high yielding varieties in this study and these varieties can be considered as drought tolerant. These varieties had relatively high number of pods per plant, size of the grain and grain weight suggesting that these three yield components are more important contributing to high yield under drought conditions in consonance with the reports of Manjunatha (1978) in soybean, Upadhyaya and Ruwali (1985) in wheat and Aggarwal and Sinha (1987) in wheat.

5.2. Variability

Variability observed in a plant community is phenotypic variability which is the result of the genetic variability, upon which superimposed is the variability due to the effect of environment in which the individual genotype perpetuate and survives. The variability available in a population could be partitioned into heritable and non-heritable components with the aid of genetic parameters like genotypic coefficient of variation, heritability and genetic advance which serve as useful guidelines for selection.

5.2.1. Genotypic and phenotypic coefficient of variation

Genotypic coefficient of variation measures the range of genetic diversity for quantitative characters in a population and phenotypic coefficient of variation measures the extent of total variability. High genotypic coefficient of variation was shown by characters such as root/shoot ratio at vegetative, flowering and harvest periods, leaf area index at vegetative and flowering periods, number of pods per plant, plant height, yield per plant, size of the grain, 100 grain weight, grain yield per plot, haulm yield per plot and proline content indicating the presence of more genetic variability in these characters. High genotypic coefficient of variation noticed in the case of number of pods per plant and grain yield per plant is in conformity with the results of Singh and Mehndiratta (1969), Veeraswamy _et al_. (1973)

and Radhakrishnan and Jebaraj (1982) in cowpea and Sreekumar and Abraham (1979) in greengram. Contrary to this, Pillai (1980) and Philip (1987) in blackgram reported low genotypic coefficients of variation for number of pods per plant and grain yield per plant. High genotypic and phenotypic coefficients of variation observed in yield per plant is in consonance with the results of Pandita et al. (1982) in cowpea under dry farming conditions.

High genotypic and phenotypic coefficients of variation noticed for height of the plant is in agreement with the results of Veeraswamy et al. (1973) in cowpea; Singh et al. (1975) and Soundarapandian et al. (1975) in blackgram. Philip (1987) in blackgram reported high genotypic coefficient of variation for leaf area index at flowering period in conformity with the present finding. Grain yield per plot showed high genotypic coefficient of variation in agreement with the results of Ramachandran et al. (1980). High genotypic coefficient of variation noticed for 100 grain weight is in consonance with the results of Patil and Baviskar (1987). Harvest index showed relatively high genotypic coefficient of variation in conformity with the findings of Dharmalingam and Kadambavanasundaram (1984). Contrary to this low genotypic coefficient of variation was reported by Sagar et al. (1976) for harvest index in blackgram.

Characters such as number of seeds pod, grain filling period, duration upto maturity and days to 50 per cent flowering had very low phenotypic and genotypic coefficients of variation indicating the low amount of variability in these characters and thereby limiting the scope for their improvement by selection. Low genotypic coefficient of variation noticed for number of seeds per pod is in consonance with the results of Dharmalingam and Kadambavanasundaram (1984) in cowpea and Philip (1987) in blackgram. Duration upto maturity showed low genotypic coefficient of variation in agreement with the results of Singh and Mehndiratta (1969) and Radhakrishnan and Jebaraj (1982). Number of days to fifty per cent flowering showed low genotypic coefficient of variation contrary to the results of Sandhu *et al*. (1978) in blackgram.

5.2.2. Heritability and Genetic Advance

Genotypic coefficient of variation alone cannot estimate the heritable portion of the variation. Burton (1952) had suggested that genotypic coefficient of variation together with heritability estimates would give a better idea regarding the amount of genetic advance to be expected by selection. Allard (1960) suggested that gains from selection for a particular character largely depends on the heritability of the character.

Heritability was high for characters such as size of the grain, hundred grain weight, duration upto maturity, days to fifty per cent flowering and grain filling period. High heritability noticed for hundred grain weight is in agreement with the findings of Patil and Baviskar (1987). Duration upto maturity showed high heritability in conformity with the reports of Singh and Mehndiratta (1969), Sreekumar et al. (1979) and Patil and Baviskar (1987). High heritability observed for days to fifty per cent flowering agrees with the findings of Singh and Mehndiratta (1969), Sreekumar et al. (1979) and Ramachandran et al. (1980). Moderate to high heritability was recorded for characters such as plant height at maturity, proline content, number of grains per pod, leaf area index at vegetative and flowering periods, root length and root spread at harvest period, haulm yield per plot, number of pods per plant and harvest index. High heritability noticed for number of grains per pod agrees with the results of Rajendran et al. (1979), and Sreekumar et al. (1979) but contrary to the reports of Veeraswamy et al. (1973). Harvest index showed high heritability in conformity with the findings of Dharmalingam and Kadambavanasundaram (1984). The high values of heritability estimates indicates the highly heritable nature and the minimum influence of the environment in the expression of these characters.

Johnson *et al*. (1955) suggested that heritability in conjunction with genetic advance is more effective and reliable in predicting the resultant effect of selection than heritability alone. Moderate to high heritability coupled with relatively high genetic advance was shown by the characters size of the grain, hundred grain weight, number of pods per plant, proline content, haulm yield per plot, leaf area index at vegetative, flowering and harvest periods, root spread at harvest period, number of grains per pod, plant height at maturity, grain yield per plot and harvest index. High heritability coupled with high genetic advance noticed for number of pods per plant agrees with the results of Radhakrishnan and Jebaraj (1982) in cowpea; Singh and Melhotra (1970), Ratnaswamy *et al*. (1978) and Sreekumar and Abraham (1979) in greengram. In cowpea, Rajendran *et al*. (1979) reported high heritability together with high genetic advance for number of grains per pod in consonance with the present findings. High heritability and high genetic advance for plant height obtained in this study agrees with the findings of Soundarapandian *et al*. (1975) and Sandhu *et al*. (1978) in blackgram. But Radhakrishnan and Jebaraj (1982) in cowpea and Sreekumar and Abraham (1979) in greengram reported high heritability and low genetic advance for plant height contrary to the present findings.

According to Panse (1957) high values of heritability combined with high genetic advance indicates the additive gene action for the character and selection based on these characters will lead to improvement of the population. High heritability values associated with low genetic advance is attributed to the non-additive gene effects which include epistasis, dominance and genotype x environment interaction (Panse, 1957). Characters such as days to fifty per cent flowering, root length at flowering and harvest periods, grain filling period and duration upto maturity showed high heritability but low genetic advance. High heritability coupled with low genetic advance observed for days to fifty per cent flowering is in consonance with the results of Singh and Melhotra (1970) and Sreekumar and Abraham (1979) in greengram. Contrary to this, Rajendran et al. (1979) in cowpea, and Sandhu et al. (1978) in blackgram reported high heritability and high genetic advance for this character. High heritability and low genetic advance noticed for days to maturity agrees with the findings of Radhakrishnan and Jebaraj (1982) but contrary to this high heritability and high genetic advance was reported by Rajendran et al. (1979) for days to maturity. Yield per plant showed low heritability in consonance with the findings of Singh and Mehndiratta (1969) in cowpea. Contrary to this, Pandita et al. (1982) reported high heritability for this character. High heritability estimated for yield per plot is in agreement with the results of Sreekumar et al. (1979) in cowpea.

5.3. Correlation

Coefficients of correlation indicate the intensity and direction of character associations in a crop. The interrelationships of component characters of yield provide information about the probable consequences of selection for simultaneous improvement in these characters.

The grain yield recorded positive genotypic correlation with leaf area index at all the three growth periods viz. vegetative, flowering and harvest periods, root length and root spread at flowering and harvest periods, root/shoot ratio at vegetative period, grain filling period, number of pods per plant, plant height at maturity, haulm yield per plot, duration upto maturity, size of the grain, hundred grain weight and harvest index indicating that selection based on any one or more of the above components will result in an increase in grain yield.

Positive genotypic correlation between grain yield and leaf area index is in conformity with the results of Setty and Sreeramulu (1972) in sorghum, Ali and Naidu (1982) in maize and Gimenez and Fereres (1986) in sunflower under drought conditions. Root length at harvest period and grain yield showed positive correlation in agreement with the findings of Setty and Sreeramulu (1972) in sorghum and Kavitha (1982) in blackgram. The root/shoot ratio at vegetative period showed positive correlation with grain yield, but Setty and Sreeramulu (1972) reported that root/shoot ratio do not show any relationship with grain yield in sorghum, contrary to the observations of this study. In conformity with the reports of Nelson (1987) in soybean grain filling period showed positive correlation with grain yield. Plant height and grain yield showed positive genotypic correlation in agreement with the results of Rajendran et al. (1979), Dumbre et al. (1982) and Natarajaratnam et al. (1985) in cowpea. Contrary to this, Ibrahim et al. (1986) reported a negative correlation between grain yield and plant height in pearl millet. Positive correlation of grain yield with duration upto maturity is in consonance with the reports of Sreekumar et al. (1979) in cowpea. Number of pods per plant and grain yield showed positive genotypic correlation in agreement to the findings of Rajendran et al. (1979), Dumbre et al. (1982), Natarajaratnam et al. (1985) and Patil and Bhapkar (1987) in cowpea. Ali and Naidu (1982) reported positive genotypic correlation between grain yield and size of the grain in maize in conformity with the present results. Positive correlation of grain yield with hundred grain weight agrees with the results of Patel and Telang (1976), Chikkadyavaiah (1985) and Choulwar and Borikar (1987) in cowpea, Setty and Sreeramulu (1972) in sorghum and Ali and Naidu (1982) in maize under drought conditions. Harvest index and grain yield showed positive genotypic correlation in agreement with the results of Sharma (1988) in maize, under drought conditions.

Grain yield had negative genotypic correlation with number of grains per pod, root/shoot ratio at flowering and harvest periods, proline content, days to fifty per cent flowering and number of stomata per microscopic field. Negative correlation observed between grain yield and number of grains per pod is contrary to the results of Rajendran et al. (1979), Sreekumar et al. (1979) and Patil and Bhapkar (1987). Days to fifty per cent flowering showed negative genotypic correlation with grain yield contrary to the results of Sreekumar et al. (1979) in cowpea, and Setty and Sreeramulu (1972) in sorghum. Grain yield and number of stomata showed negative correlation in conformity with the findings of Ali and Naidu (1982) in maize.

Days to fifty per cent flowering and duration upto maturity showed positive genotypic correlation which agrees with the findings of Singh and Mehndiratta (1969) in cowpea.

Number of pods per plant and number of grains per pod had negative genotypic correlation in agreement with the findings of Patil and Bhapkar (1987) in cowpea. Angadi (1976) in cowpea reported positive correlation with seeds per pod and plant height in agreement to the results of this study. Negative correlation between grain weight and grain number observed agrees with the results of Vidal and Arnoux (1981) in soybean. Number of pods per plant and 100 grain weight showed negative correlation in consonance with the results of Hanchinal et al. (1979) in cowpea.

5.4. Path Analysis

Path analysis is an efficient biometric tool throwing light on the contribution (direct effect) of a character to the yield and also its influence (indirect effect) through other characters. In the present study the genotypic correlation between grain yield per plot and seven characters were partitioned into their corresponding direct and indirect effects through path analysis. Harvest index showed maximum direct effect on yield followed by leaf area index at vegetative period, grain filling period and duration upto maturity suggesting that selection based on these characters may lead to increased yield under conditions of drought. High direct effects of harvest index and leaf area index on yield is in conformity with results of Sharma

(1988) in maize. Direct effect of days to maturity on yield is in agreements with the findings of Narasinghani *et al*. (1978) in pea.

Based on correlation studies and path analysis, it can be concluded that a plant type suited to drought conditions should be early flowering with deep and wide spread root system, high root/shoot ratio and leaf area index at vegetative period, low proline content, few number of stomata, long grain filling period and medium duration resulting in the production of more number of pods per plant and high harvest index. The cowpea varieties UPC-124, DPLC-198 and DPLC-216 which satisfies the above plant type can be selected as drought tolerant.

SUMMARY

SUMMARY

A field experiment was conducted at the College of Agriculture, Vellayani, Trivandrum during October to December 1988 with sixteen varieties of cowpea (Vigna unguiculata (L) Walp) adopting a Randomised Block Design with four replications, to study the potential for drought tolerance. Observations were made on twentysix characters viz. root length, root spread, root/shoot ratio and leaf area index at vegetative, flowering and harvest periods, days to fifty per cent flowering, number of stomata per microscopic field, number of pods per plant, number of grains per pod, plant height at maturity, grain filling period, duration upto maturity, grain yield per plot, proline content and harvest index. Soil moisture content of different plots were assessed at weekly intervals by gravimetric method.

The analysis of variance indicated that significant differences existed among varieties for all the characters except for root spread at vegetative period. Analysis of variance for soil moisture percentage showed no significant differences among experimental plots, indicating uniform soil moisture status in all the plots.

Studies on root characters, root/shoot ratio and leaf area index at different growth periods revealed that

varieties with deep and wide spreading root system at harvest period, high root/shoot ratio at vegetative period, and high leaf area index at vegetative, flowering and harvest periods were relatively high yielders. Studies on the number of stomata per microscopic field indicated that plants with less number of stomata are giving high yield under conditions of drought. Varieties with low proline content, medium duration, long grain filling period and high harvest index were high yielding indicating the importance of the above components for selecting drought tolerant varieties.

More difference was observed between the genotypic and phenotypic variances of number of stomata per microscopic field, plant height at maturity, yield per plot and proline content indicating the high influence of environment in the expression of these characters. Very small difference was observed between the genotypic and phenotypic variances of leaf area index at flowering and harvest periods, grain filling period, yield per plant, size of the grain and hundred grain weight suggesting that variation in these characters are mainly due to genetic factors.

Characters such as root/shoot ratio at the three growth periods, leaf area index at vegetative and flowering periods, number of pods per plant, plant height, yield per plant, size of the grain, hundred grain weight, grain yield per plot, haulm yield per plot and proline content showed high genotypic coefficient of variation indicating the presence of more genetic diversity and scope for utilization by selection. The characters such as number of grains per pod, grain filling period, duration upto maturity and days to fifty per cent flowering showed low genotypic coefficient of variation and low genetic variability.

Moderate to high heritability coupled with high genetic advance were recorded by the characters such as size of the grain, hundred grain weight, number of pods per plant, proline content, haulm yield per plot, leaf area index at vegetative, flowering and harvest periods, root spread at harvest period, number of grains per pod, plant height at maturity, grain yield per plot and harvest index indicating the reliability of these characters during selection programme for the improvement of yield. Characters such as days to fifty per cent flowering, root length at flowering and harvest periods, grain filling period and duration upto maturity showed high heritability and low genetic advance.

Grain yield per plot showed high positive genotypic correlation with leaf area index at vegetative and flowering periods, root spread at harvest period, number of pods per plant, root/shoot ratio at vegetative period, grain filling period and plant height at maturity suggesting that selection based on any one or more of the above characters will result in an increase in grain yield.

The path analysis revealed that maximum direct effect on yield was contributed by harvest index, followed by leaf area index at vegetative period, grain filling period and duration upto maturity suggesting that selection based on these characters can increase the yield.

Based on the variability, correlation and path analysis, it can be concluded that a plant type suited to drought conditions should be early flowering with deep and wide spreading root system, high root/shoot ratio and leaf area index at vegetative period, low proline content, few number of stomata, long grain filling period and medium duration resulting in the production of more number of pods per plant and high harvest index. The cowpea varieties UPC-124, DPLC-198 and DPLC-216 which satisfies the above plant type can be considered as drought tolerant.

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POTENTIAL FOR DROUGHT TOLERANCE IN COWPEA [*Vigna unguiculata* (L) Walp]

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ABSTRACT OF A THESIS
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ABSTRACT

A research programme was carried out at the department of plant breeding, College of Agriculture, Vellayani, Trivandrum during 1988 with sixteen varieties of cowpea for studying the potential for drought tolerance. The data on twentysix characters and soil moisture percentage in different plots were collected and subjected to analysis of variance/covariance. The genetic variability and correlations were estimated for the characters contributing to drought tolerance, yield and its components. The path analysis was conducted using yield as the effect and seven components contributing to drought tolerance as causes. Analysis of variance for twentysix characters revealed that significant differences existed among varieties for all the characters except for root spread at vegetative period. The analysis of variance for soil moisture percentage showed no significant difference among experimental plots indicating uniform soil moisture status in all the plots.

High genotypic coefficient of variation, moderate to high heritability and high genetic advance was shown by characters such as leaf area index at vegetative, flowering and harvest periods, number of pods per plant, hundred grain weight, and proline content. Harvest index also had moderately high heritability and genetic advance. This indicates

the reliability of the above components during selection programmes for the improvement of yield.

Grain yield per plot showed high positive genotypic correlation with leaf area index at vegetative and flowering period, root spread at harvest period, number of pods per plant, root/shoot ratio at vegetative period, grain filling period, and plant height at maturity. Path analysis revealed that harvest index and leaf area index at vegetative period had maximum positive direct effect on yield. Based on the studies on variability, correlation and path analysis it can be concluded that a plant type suited to drought conditions should be early flowering with deep and wide spread root system, high root/shoot ratio and leaf area index at vegetative period, low proline content, few number of stomata, long grain filling period and medium duration resulting in the production of more number of pods per plant and high harvest index. The cowpea varieties UPC-124, DPLC-198 and DPLC-216, satisfying the above plant type can be considered as drought tolerant.