"EVALUATION OF GRAIN AMARANTH [*Amaranthus* spp.] GERMPLASM FOR GENETIC DIVERSITY UNDER DIFFERENT SEASONS"

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Affectionately dedicated to

My beloved Parents and Sister

DEPARTMENT OF GENETICS AND PLANT BREEDING
UNIVERSITY OF AGRICULTURAL SCIENCES
BENGALURU

CERTIFICATE

This is to certify that the thesis entitled "Evaluation of Grain amaranth [*Amaranthus spp.*] Germplasm for Genetic Diversity under different Seasons" submitted by **Mr. YASHWANT KUMAR, M.S.** in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (AGRICULTURE) IN GENETICS AND PLANT BREEDING** from the University of Agricultural Sciences, Bengaluru, is a record of bonafide research work carried out by him during the period of his study in this university under my guidance and supervision and that no part of the thesis has been submitted for the award of any other degree, diploma, associateship, fellowship or other similar titles.

Bengaluru
July 2009

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Evaluation of Grain amaranth [*Amaranthus* spp.] Germplasm for Genetic Diversity under different Seasons

YASHWANT KUMAR, M.S.

ABSTRACT

Grain amaranth (*Amaranthus* spp.) is protein-rich pseudocereal it has been received the attention by many researchers due to its valuable source of protein and amino acids which are deficient in other cereals. The investigation on diversity in Grain amaranth germplasm consisting of 100 lines was carried out during summer and *kharif* 2008. Genotypes in grain amaranth germplasm collection was evaluated in both the seasons with an objective of studying genetic variability, character association, path analysis, and genetic diversity for 12 characters and genotypes evaluated for seed protein content. Genotypic and phenotypic coefficients of variation were high for number of leaves in summer but it was number of branches in *kharif*. Stem girth at collar region recorded high heritability and low heritability by panicle length in summer season whereas, it was plant height which exhibited high heritability and low heritability by number of leaves in *kharif* season. Number of branches exhibited high genetic advance in both the season. Dry weight of the panicle showed a highly significant positive correlation with grain yield in summer and also in *kharif* season. GCV were higher than their respective PCV in both summer and *kharif* experiments. Dry weight of panicle exhibited high positive direct effect on grain yield in summer whereas it was fresh weight of panicle in kharif.

The indirect effect of 1000 seed weight through dry weight of panicle and fresh weight of panicle was more than its direct effect on seed yield at genotypic path in both seasons. Genotypes based on the mean values of characters were grouped into 12 clusters in summer and 14 clusters in *kharif* season indicating better exhibition of diversity in kharif season due to varied response of the genotypes to rain fall pattern. Clustering pattern showed appreciable amount of divergence among the genotypes in both experiments.

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INTRODUCTION

I. INTRODUCTION

In order to feed the burgeoning world population, estimated to reach nine billion by the year 2050, agriculture must respond by tripling its net production of food and fibre from present day levels. So obviously the stress will be on the major cereals where most of them have already reached their yield plateau. At this juncture the pressure on these major crops can only be minimized by laying emphasis on the promising underutilized crop without compromising quality, since it is bestowed with very high nutritive quality which can satisfy the nutritional hunger of the world. Grain amaranth (*Amaranthus* spp.) is protein-rich pseudocereal it has been received the attention by many researchers due to its valuable source of protein and amino acids which are deficient in other cereals (Ahamed *et al.,* 1998). It is also used for the production of healthy food in several world regions (National Research Council, 1989). The amino acid composition of grain amaranth protein corresponds to the FAO standards for human nutrition. Its lysine and phenylalanine amino acids have better profile than other cereals such as wheat, maize and oat. The unsaturated fatty acid compositions and content in grain amaranth seeds are in balanced spectrum. In addition, it is also contains high crude fibre content (Thanapornpoonpong, 2004).

Grain amaranth belongs to the family Amaranthaceae and genus *Amaranthus.* The genus Amaranthus includes 60 species of annual herbs, which are native to Central and South America and are distributed in the tropical and sub tropical countries of the world, some of which occur in India. In India this crop is cultivated in Border States of Himalayan hills and it is grown as minor grain crop in southern hills. It is grown as pure crop under intensive cultivation and irrigation in eastern Gujarat. Four cultivated grain amaranth species are reported *viz., Amaranthus hypochondriacus L.,* (n=16); *A. Caudatus* L.,(n=16) ; *A. Cruentus* (n=17) and *A. edulis spegazzini* (n=16) (William,1959). The pistillate flowers on

the cyme develop early before the staminate flower has opened, while others become receptive following the abscission of the male flower. Self-pollination is more likely than out crossing, although both types of fertilization are possible (Tucker, 1986). Fruit, unlike other cereals, grain amaranths have retained the dehiscent fruits of their wild progenitors, although the majority of seeds remain in densely packed inflorescences, some seeds are lost during the harvest due to grain shattering (Sauer,1993). However, in recent years non-shattering grain amaranth populations have been identified (Brenner, 2002).

The main virtue of the seed lies in its high protein (8-22%) and with 6% lysine content which ranges from 0.73 to 0.84% of amaranth's total protein content (Bressani *et al*., 1987), and sulphur containing amino acids (4.4%) which are deficient in other grain crops, it also contains minerals (3%), vitamins (1.5%) and easily digestible carbohydrates (62%) and is considered as one of the best source of an anti oxidant called squalene.

Before any crop improvement programme, it is necessary to assess the existing genetic variability in parental material. The efficiency of selection depends upon the knowledge on the nature and magnitude of genetic variability for important trait. The extent of the genetic and non-genetic components of variation formulates proper breeding programme to reach the goal. Higher mean accompanied by higher genetic variability affords a scope for selection.

Robinson *et al.,* (1951) emphasized that heritability of the character is the main concern for breeders, since it indicates the possibility and extent to which improvement is possible through selection. It has been suggested that heritability together with genetic advance will bring out the genetic gain expected from selection (Johnson *et al.,* 1955).

Yield is a quantitative character contributed by many characters. Therefore, adequate knowledge about the magnitude and degree of association of yield with its attributing characters is of great significance to the breeders, when they have to exercise selection for simultaneous improvement of more than one character. However, correlation alone does not provide the information on the contribution of related characters, which necessitates the study of cause and effect relationship of different characters among themselves. Therefore, the path analysis depicts the exact relationship of characters, thereby providing more information than correlation.

The D^2 statistic is a tool to evaluate large number of germplasm lines for their genetic diversity and helps to identify genetically divergent parents for their utilization in hybridization programmes as hybrids of divergent lines display a greater magnitude of heterosis than those between closely related strains. Multivariate analysis with Mahalonobis D^2 statistics is a powerful tool to know the clustering pattern to establish the relationship between genetic and geographic divergence and to determine the role of different quantitative characters towards the maximum divergence.

Keeping these points as land marks the present investigation was conducted to accomplish the following objectives.

1. To estimate the magnitude of genetic variability among selected characters.
2. To estimate the phenotypic and genotypic correlation coefficient between different growth and yield parameters.
3. To estimate the direct and indirect effects of different attributes towards yield by path coefficient analysis.
4. Grouping of genotypes into different clusters based on D^2 analysis and evaluation of genotypes for protein.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

Genetic variability is the prerequisite for improvement of any crop. It is important to collect, evaluate and conserve as wide a range of genetic variation within a species as possible. Limited availability/access of the useful grain amaranth germplasm to breeders is the basic reason for its insufficient exploitation in crop breeding at present. The use of crop genetic resources in crop improvement programme should be the ultimate objective of all the activities in the field of germplasm resource management. Among different types of crop genetic resources, released varieties and breeding lines contribute more to crop breeding. Wild relatives and genetic stocks, however, are expected to play a greater role in the future and landraces will remain important in crop improvement.

Amaranth *(Amaranthus* spp.) is a new crop with ancient history. Members of *Amaranthus* spp. have been grown for centuries for vegetable and grain in different parts of the world (NRC, l989). Grain Amaranth attains special importance because of its C_4 pathway of photosynthesis, indicating high productivity, because it is an efficient tapper of solar energy. They imbibe most of the qualities to qualify as a subsidiary food crop to solve the food problem of the hungry world. It is said to be a more nutritious with high protein and lysine content than almost any cereal. The grain amaranths are comparable to the improved cereal in terms of mineral, carbohydrate and fat content.

Improvement in both qualitative and quantitative characters of a crop is the main aim of any breeding programme. The information on genetic architecture of various quantitative traits, contributing to yield and quality is useful in planning the breeding programmes. Various biometrical techniques have been developed for studying the genetics of quantitative traits. This information can be used for developing more sophisticated and efficient approach to select the parents. The

literature available on various aspects of the investigation in grain amaranth is represented in this chapter.

Grain amaranth is one of important under utilized plants of food and has multiple uses. It has potentiality to withstand adverse weather changes, particularly severe moisture stress. Besides, it can be grown in wide ranges of agroclimatic conditions *viz.,* high rainfall area to low rainfall, from seashore to high altitudes and suitable for sustainable agriculture (Joshi, 1986).

Crop improvement depends on the magnitude of genetic variability and extent to which the desired characters are heritable. This has in turn attracted the attention of biometrician to study the genetic aspects of economically important characters such as yield, its components and biochemical estimates like protein.

The logical way to start any breeding programme is to assess the existing genetic variability, which is the basis for any crop improvement programme. Information on the nature and magnitude of genetic variability is of immense value for starting any systematic breeding programme in crops because the presence of considerable genetic variability in the base material ensures better chances of evolving desired plant types and the success of phenotypic selection depends upon the range of genetic diversity available in the population for important economic characters and their inter-relationship which affects one another. The related review of literature is presented under the following heads.

1) Genetic variability, heritability and genetic advance
2) Correlation and path co-efficient analysis
3) Genetic diversity studies
4) Nutritional quality studies

2.1 Studies on variability, heritability and genetic advance

There is more genetic potentiality in the genetically variable population and thus, the chances to achieve desired types are many fold. The estimates of variability and other parameters are helpful to a plant breeder to predict the performance of genotypes in the subsequent generation. So, it is necessary to split the phenotypic variability into heritable and non-heritable components such as genotypic and phenotypic co-efficient, heritability and genetic advance.

Johannsen *et al.* (1909) in his famous 'Pure Line Theory' suggested, both heritable and non-heritable changes affecting somatic variation and that; the variation in a pure line is entirely due to environment. Nelson Ehle (1909) and East (1916) proposed the need to partition the phenotypic variability in to its genetic and non-genetic components because of environmental influence.

Charles and Smith (1939) separated the genetic variance from total variance by using estimates of environmental variance from the non-segregating population. Therefore, genotypic coefficient of variation indicates the relative magnitude of genetic diversity present in the material and helps to compare the genetic variability present for different characters.

Genetic advance is a measure of improvement that can be achieved by practicing selection in a population. The estimation of heritability along with genetic advance is generally more useful in predicting the result and in selecting the best individuals (Johnson *et al.,* 1955a). The estimates of heritability give no indication of the amount of progress expected from the selection. They are most meaningful when accompanied by estimates of genetic advance. Factors influencing genetic advance are intensity of selection, heritability and phenotypic variance. High genetic advance coupled with high heritability is an indication of more additive gene action (Panse and Sukhatme, 1957).

Lush (1949) proposed heritability as the ratio of additive variance to total variance in a narrow sense. The heritability in broad sense was proposed by Hanson *et al.* (1956) as the ratio of genotypic variance to the total variance.

Pushpa Rekha (1986) observed low values of phenotypic and genotypic coefficient of variation for days to maturity, days to 50% flowering and stem girth and recorded high co-efficient of variation for number of leaves per plant and seed yield with respect to both GCV and PCV.

Joshi (1986) reported wide range of variability for plant height, leaves per plant, leaf length, leaf width, panicle length, spikes per plant, days to maturity, 1000 seed weight, popping size, protein content and seed yield per plant in twenty promising genotypes of grain amaranth *(Amaranthus hypochondriacus* L.) and also reported high heritability and expected genetic advance for 1000 seed weight, panicle length and plant height.

Maruthi, (1987) reported low phenotypic and genotypic coefficient of variation for days to maturity and days to 50% flowering in grain amaranth.

Guillen Portal *et al.* (1999), in 'Plainsman' grain amaranth noticed highest heritability for plant height followed by stem diameter, grain yield per plant and panicle length. Zero heritability was observed for 1000-seed weight and relatively high genetic gain for plant height, low genetic gain for yield per plant, stem diameter and no genetic gain for 1000-seed weight.

Verma *et al.* (2001) in *Amaranthus hypochondriacus* noticed wide range of variability for seed yield per plant, plant height, protein content and phosphorus content. Highest heritability and genetic advances were reported for seed yield per plant and plant height.

2.2 Studies on correlation and path coefficient analysis

It is often observed that certain quantitative characters of economic importance are associated with one another. Yield per plant is dependent upon a chain of biologically integrated and interrelated events, which are sequential in time and regulated by gene at critical sites and also subjected to the modifying influence of non-genetic forces. In such cases, knowledge of association between such characters is quite helpful in formulating selection procedures.

Association of characters, which is statistically determined by correlation coefficient, has been quite useful as a basis of selection. Correlation coefficient is a measure of association between two or more variables and not a measure of dependence of one variable over the other. Importance of any crop needs better understanding of association between yield and yield attributes. Galton (1889) developed basic concept of correlation and later elaborated and discussed by Fisher (1918) and Wright (1921) in plant breeding programmes.

Correlation explains the true association existing between the component characters with dependent character. Slight change in any component will ultimately disturb the complex, hence character has to be analyzed for its action which is done through path analysis, where the two types of action namely direct effect of component character on seed yield and the indirect effects through other component characters on seed yield are obtained which cannot be recorded by the correlation studies.

Lerner (1958) stressed the importance of correlation of the various characters with yield. Genotypic correlation coefficient provides a measure of genotypic association between characters and gives an indication of more useful character. The main genetic cause of such correlation is pleotrophic, which refers to manifold effects of gene (Falconer, 1981). Genotypic correlation provides basic

information to breeder in understanding the nature of the species with which they work.

The method of path coefficient analysis provides an efficient means of finding out direct and indirect causes of association and permits critical examination of specific forces acting to produce a given correlation. The concept of path coefficient analysis was developed by Wright (1923) for animal breeding. The application of this method to plant breeding was done for the first time by Dewey and Lu (1959).

Grafius (1964) has pointed out that it would be more meaningful if the structure of yield were provided through its components rather than *per* se performance. For improving yield through breeding, it is necessary to study these yield components, their interrelationship with yield and their direct and indirect contributions.

Pandey (1979) reported that the harvest index of *Amaranthus hypochondriacus* had the strong correlation with the yield followed by pollen fertility. He further noticed negative correlation of number of days to flowering and length of panicle with the yield.

Stepwise multiple regression analysis in grain amaranth for quantitative traits indicated negative correlation of number of days to flowering correlated with plant height but positive correlation of leaf length with yield (Hauptli and Jain, 1984).

Agong and Ayiecho (1992) found high positive association of head weight with seed yield per plant. Plant height also had significant association with seed yield. Head weight and head length had significant correlation with other traits.

Andani Gowda *et al.* (1999) reported positive correlation of yield per hectare was with plant height, dry weight per plant, panicle length and panicle weight and negative correlation with leaf number, days to 50 percent flowering and 1000 seed weight in grain amaranth.

Sudhir Shukla and Singh (2003) reported significant positive association of grain yield per plant with plant height, leaf size, number of inflorescence per plant and number of spikelets per spike during their study on 66 genotypes of grain amaranth *(Amaranthus* spp.).

Genotypic and phenotypic association of grain yield was positive and significant with panicle fresh weight, panicle length, number of spikes per panicle, dry weight of panicle, dry weight of stem and harvest index. Panicle fresh weight had high direct positive effect on seed yield per plant. Positive but indirect effects of panicle fresh weight was exerted through number of spikes per panicle, dry weight of stem and harvest index (Patgar, 2003).

Path analysis in grain amaranth *(Amaranthus* spp.) revealed highest direct effect of leaf size towards grain yield followed by Plant height. Indirect positive effects of plant height via days to flowering, where as inflorescence length, leaf size and number of spikes per panicle showed negative direct effect on seed yield (Sudhir Shukla and Singh, 2003).

2.3 Genetic divergence studies

A meaningful classification of experimental material that enables to distinguish genetically close and divergent type is a prerequisite for both theoretical as well as practical plant breeding. Eco-geographical diversity has been regarded as an index of genetic diversity (Vavilov, 1926). The cultivation from widely separated localities has been included in hybridization programme presuming the presence of genetic divergence and maximum likelihood of

recovering promising segregants. As per the expectation, this has not yielded very satisfactory and consistent results. The D^2 statistic as a measure of genetic divergence was used for the first time in the field of plant breeding by Nair and Mukharjee (1960) in classifying teak.

Genetic diversity was studied by Lohithaswa (1992) in 144 genotypes of grain amaranth using Mahalanobis D^2 statistic. Where in he grouped the genotypes into clusters by using Tocher method. Fresh weight of plant, fresh weight of inflorescence and plant height contributed more towards genetic diversity and there exhibited no perfect relation between genetic diversity and geographic diversity.

Genetic divergence in twenty genotypes of grain amaranth *(Amaranthus hypochondriacus* L.) was studied by Joshi and Rana (1995). The data were subjected to multivariate analysis using Mahalanobis generalized distance D^2. The genotypes were grouped into different clusters according to Tocher method as described by the Rao (1952). The popping size contributed the maximum divergence (65.48%) followed by the protein content (18.62%) grain yield (8.44%), inflorescence length (4.42%), day to maturation (4.42%) and 1000 grain weight (1.52%).

Waghmode *et al.,* (1997) grouped fifty genotypes of grain amaranth, *Amaranthus hypochondriacus* L. into sixteen clusters by applying Mahalanobis D^2 analysis. The clustering pattern revealed that the genetic diversity is not necessarily parallel to the geographical diversity.

Sudhir Shukla and Singh (2002) assessed 66 strains of amaranth *(Amaranthus hypochondriacus* L.) for Mahalanobis D^2 statistic analysis and they grouped these into nine clusters, and reported that genetic diversity among the genotypes may be due to factor like history of selection, heterogeneity, selection

under diverse environment and genetic drift. The intra-cluster values varied from 0.00 to 2.253, days to flower contributed the maximum towards divergence followed by plant height, nodes per plant and leaf size.

Genetic divergences in sixty-eight genotypes of grain amaranth was studied by Verma *et al*., (2002) and were grouped into nine clusters. The clustering pattern revealed that the genetic diversity might not be related to the geographical diversity.

Patgar (2003) grouped 64 grain amaranth genotypes into 11 clusters based on the D^2 values. Panicle fresh weight contributed more (74.70%) toward divergence followed by plant height (8.63%), dry weight of stem (7.94%) and panicle length (2.18%).

Hazra et *al.,* (2004) reported the genetic divergence in 47 genotypes of amaranth (*Amaranthus spp.*) of Indian and exotic origin was determined using the Mahalanobis D^2 statistic. The genotypes were grouped in to 22 clusters. Intracluster distance was highest for cluster VII followed by cluster II which included 13 genotypes from different states in India. The highest intercluster distance was recorded between cluster XII and XIII followed by cluster VI and XVII.

Study of genetic similarity with 141 specimens representing 98 accessions of 8 weedy amaranth species was carried by Wassom *et al*., (2005) using amplified fragment length polymorphism (AFLP) based unweighted pair group method with arithmetic mean (UPGMA) analysis. The analysis grouped the specimens into four principal clusters composed of Palmer amaranth (*Amaranthus palmeri* S. Wats.) and spiny amaranth (*Amaranthus spinosus* L.); Powell amaranth (*Amaranthus powellii* S. Wats.), Redroot Pigweed (*Amaranthus retroflexus* L.), and smooth Pigweed (*Amaranthus hybridus* L.); Waterhemp (*Amaranthus*

tuberculatus (Moq.) and Sandhills amaranth (*Amaranthus arenicola* I.M. Johnst.); and tumble Pigweed (*Amaranthus albus* L.).

Kusuma et *al.,* (2007a) reported genetic divergence among sixty-four grain amaranth genotypes was assessed using Mahalanobis D^2 statistic. The genotypes were grouped into eleven clusters, which revealed wide diversity in the experimental material. Panicle fresh weight contributed maximum towards genetic divergence. The maximum inter cluster distance was observed between cluster III and XI followed by cluster VII and XI, cluster II and III.

Genetic diversity and relationships among 6 Amaranthus species from 8 phytogeographic regions of the Indo-Gangetic plains were analyzed by Tui Ray and Satyesh Chandra Roy (2009) using a random amplified polymorphic DNA (RAPD) marker. The genetic similarity coefficient among all the Amaranthus species ranged from 0.16 to 0.97 with a mean similarity coefficient of 0.56, indicating that variation existed in the genetic diversity of different populations.

2.4 Nutritional Quality Studies

Grain amaranth is a nutritious pseudocereal yielding high amounts of energy. They are rich source of protein and are excellent source of micronutrients.

Downton (1973) 'reported that grain amaranth, *(Amaranthus edulis),* has high protein content (14.5%). Amaranth varieties recorded a protein score of 67 against 58 in barely, 35 in corn and 63 in buckwheat. Leucine was limiting amino acid in amaranth while lysine in wheat, barley and corn.

Schmidt (1977) documented 12.6 to 15.6 per cent crude protein and 4.3-5.4 per cent crude fat in grain amaranth. It was higher in calcium, magnesium and iron content when compared to other cereal grains.

According to Barker *et al.* (1979), amaranth has higher protein (15.5-16.5%), sodium, calcium, iron and manganese when compared to most conventional grains. It also has high biological value (73%) and calorie content (390 kcal).

Pant (1983) found that amaranthus seed of different varieties had 14.5-17.9 per cent protein, 2.5-3.9 per cent minerals and 2.06-2.16 per cent fibre. The iron content was 7.5-12.2 mg/100g.

Crude protein content in different species of grain amaranth ranged between 13.2 to 17.6 per cent, zinc content ranged between 3.6 to 3.9 mg/100g and iron 9.1 to 21.7 mg/100g (Teutonico & and Knorr, 1985).

In a study of the composition of 14 selections of amaranthus species, Bressani *et al.* (1987) observed that protein content varied from 12.5 to 16.0 per cent and fat from 8.25 to 12.85 per cent. They have also reported that 27 species of amaranthus contained 12.8 to 17.4 per cent protein.

Pederson *et al.* (1987) studied the nutritive value, protein and minerals of raw and processed grain. The black grams had a much higher content of dietary fibre (16%) than pale grains (8%) and a higher protein content but lower protein digestibility. The black grains had higher content of calcium and phosphorus than pale grains.

Prakash and Pal (1992) studied the seed protein, fat and fatty acid composition of 41 grain amaranth species. The protein content varied from 103 to 183 g/kg and fat from 8 to 69 g/kg.

The protein content of amaranth grains ranges between 11.8 to 17.6 percent. The variation amongst the different species may be of a genetic nature,

though it may also due to environmental conditions and cultural practices (Bressani, 1993).

Geetha *et al.* (1994) observed that in eleven grain amaranth cultivars, the protein content ranged from 15.2 to 19.6 g per cent, ash content from 2.0 to 2.5 per cent on dry weight basis. Iron content ranged from 6.2 to 13.0 per cent.

Munjal *et al.* (1999) in 12 grain amaranth cultivars revealed that the content of crude protein was in the range of 12.34-16.86 per cent on dry weight basis, while the iron content ranged from 8.58-17.00 mg/100g. The cultivar RGAS-92-1 contained the highest amount of iron (17 mg /100 g) while the cultivar Rasana-2 contained the highest amount of crude protein (16.86%).

Martirosyan *et al*. (2007) reported decreased amount of total cholesterol, triglycerides, low-density cholesterol (LDL) and very low-density cholesterol (VLDL) and in the blood serum significantly by Amaranth oil and reported concentration-dependent cholesterol lowering effect of amaranth oil, amaranth grain and amaranth oil supplements as an antioxidant therapy for correcting hyperglycaemia and Amaranth grain contains tocotrienols and squalene compounds.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

The Grain Amaranth Germplasm material used in the current study comprised of 100 genotypes of three different species of grain amaranths obtained from AICRIP on under utilized crops, Main Agricultural Research Station, Hebbal Bangalore-24. The characteristic features of three species are given in the table 1. The genotypes chosen for study are given in the table 24 and 25. The information regarding the details of the materials used and the techniques adapted in the investigation are presented here as under.

3.1 Site of Experiment

The experiment was laid out at Main Agricultural Research Station, Hebbal, Bangalore-24.

3.2 Details of the experiment

The investigation on diversity in grain amaranth germplasm was carried out during summer and *kharif* 2008. The experiment was laid out in 10 X 10 simple lattice design with two replications. Each genotype was sown in single row leaving a spacing of 60 cm between the rows. In each row plant to plant distance was maintained at 20 cm by thinning. All normal recommended agronomic practices and plant protection measures were followed during the crop growth period in both the seasons to ensure good crop growth.

3.3 Observations recorded

When the crop was 30 days old, five plants were randomly selected leaving the border plants and tagged with label in each line. The observations were recorded in respect of following quantitative characters in each replication on these five plants in both summer and *kharif* seasons. The average values of these five plants were used as treatment mean in all statistical analysis.

The following were the observations recorded:

3.3.1 Days to 50% flowering

Number of days taken from the date of sowing to the day on which 50 per cent of the plants flowered in each line was recorded.

3.3.2 Days to maturity

The number of days taken from the date of sowing to the day on which the plants turned light yellow and leaves began to drop which coincided with free separation of seeds from the inflorescence.

3.3.3 Stem girth at collar region (cm)

Stem girth was measured at the collar region at the time of harvest by using marked thread according to the girth of the stem and measurement was noted in centimeter.

3.3.4 Leaves per plant

Number of fully opened leaves borne on the main stem was recorded at the time of harvest.

3.3.5 Branches per plant

Total number of the branches borne directly on the main stem including small rudimentary ones was counted and recorded.

3.3.6 Plant height (cm)

Height of the main stem from the ground level to the tip of the inflorescence was recorded at the time of harvest.

3.3.7 Panicle fresh weight (g)

Fresh weight of the panicle was weighed and recorded in grams.

3.3.8 Panicle length (cm)

The length of the panicle from the base of the compound spike to the tip was recorded in centimeters.

3.3.9 Stems girth at the ground region (cm)

Girth of the main stem below the first basal node was measured in centimeters using marked threads.

3.3.10 Dry weight of panicle (g)

Panicle of each plant was dried under sunlight and the dry weight of panicle was recorded.

3.3.11 1000 Seed weight (g)

A total of 1000 seeds harvested from each genotype obtained from the dry inflorescence of each selected plant was weighed and expressed in grams.

3.3.12 Seed yield per plant (g)

The total quantity of seeds obtained from the dry inflorescence each selected plant was weighed and expressed in grams.

3.4 Analysis of quality character

Grain amaranth is a nutritious pseudocereal yielding high amounts of energy. They are rich source of protein and are excellent source of micronutrients. The present study was undertaken to estimate crude protein.

3.4.1 Crude protein content in grain amaranth

One representative sample from each genotype in each replication was taken for protein analysis. The total nitrogen was estimated by Micro Kjeldhal Distillation method (A.O.A.C., 1970). The crude protein was computed by

multiplying total nitrogen by the factor 6.25 to arrive at the protein content and expressed in percentage.

$$\text{Nitrogen (\%)} = \frac{\text{TV x N of acid x 0.014 x VI}}{\text{Weight of sample x V2}} \times 100$$

TV - Titre value

N - Normality of acid (HCI)

VI - Volume of digested sample

V2 - Volume taken for distillation

Table 1 : Morphological features of three different species of grain amaranth

Characters	*Amaranthus hypochondiracus* L. (2n=32)	*Amaranthus cruentus* L. (2n=32)	*Amaranthus edulis Speg*. (2n=32)
Origin	Mexico	Southern Mexico and Guatemala	North-Western Argentina
Plant character	Annul herb	Erect annual, generally smaller than *A. hypochondriacus*	Erect and branching type
Inflorescence	Terminal and lateral inflorescence, long pointed inflorescence	Terminal, it forms lax and soft spikes, semi drooping	Terminal and lateral, finger like inflorescence (Compressed spike), erect
Growth habit	Indeterminate type	Indeterminate type	Determinate type
Pigmentation Inflorescence Leaf	Green to reddish Green to reddish	Green or creamy color Green	Golden color Green
Branching habit	Simple to branching	Less branching type	More branching type
Leaf characters	Elliptic or ovate oblong, apex acute or acuminate	Elliptic, rhombic-ovate to ovate-lanceolate, apex acute	Elliptic or ovate oblong, apex acute or acuminate
Leaf size	Medium to larger in size	Larger leaf size than *A. hypochondriacus*	Smaller sized leaf than *A. hypochondriacus*
Seed color	White, gold, brown and black	White, Black and Brown	Golden color

3.5 Statistical analysis

The statistical analysis of the data on individual character was carried out by using the mean values of five plants over two replications. The data was analyzed using statistical software GENERES and SPAR for Agricultural Research developed by Indian Agricultural Statistical Research Institute, New Delhi and the analysis was carried at department of Genetics and Plant Breeding, UAS, GKVK Bangalore. Statistical techniques adopted for analysis of the data followed are given below:

3.5.1 Mean

On the basis of observations recorded on five randomly selected plants, the mean for each character was computed as follows.

$$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} Y_i$$

Where,

y_i = Individual value

$\bar{y}$ = Sample mean

n = Number of observations

3.5.2 Range

The minimum and maximum value for each character recorded on individual plants was used to indicate the range for a given character.

3.5.3 Variance

Variance was computed for all the characters as follows.

$$\text{Variance} = \frac{1}{n-1} \quad [\Sigma (y_i - \bar{y})^2] = s^2$$

Where,

y_i = Individual value

$\bar{y}$ = Sample mean

n = Number of observations

Standard deviation (SD) $s = \sqrt{\text{Variance}}$

Estimated standard error (S_e) $S_e = \frac{SD}{\sqrt{n}} = \frac{s}{\sqrt{n}}$

3.6 Analysis of variance (ANOVA)

The analysis of variance for 1 a characters was done following the simple lattice design as suggested by Cochram and Cox (1957); method of which is presented below.

Model of analysis of variance for simple lattice design

Source of variation	**Degrees of freedom**	**Sum of squares**	**Mean squares**	**'F' ratio**
Replication	(r-1)	SSQr	$\frac{\text{SSQb (adj)}}{r\,(q-1)} = Eb$	Eb/Ee
Genotypes	(q^2-1)	SSQg (unadjusted)		
Blocks	r (q-1)	SSQb		
Error (Intra block)	(q-1) (rq-q-1)	SSQe	$\frac{\text{SSQe}}{(q-1)\,(rq-q-1)} = Ee$	
Total	**$(r \times q^2) - 1$**	**SSQt**		

Where, r = Number of replications

q^2 = Number of treatments (genotypes)

The adjusted variable mean differences were tested for their significance as given below.

Variance

Source of variation	Degree of freedom	Sum of squares	Mean squares	'F' ratio
Genotypes (adjusted)	q^2-1	SSQg	G	G/Ee
Error (intra block)	(q-l) (rq-q-l)	SSQe	Ee	

The computed 'F' value was compared with the critical F value at (q^2-1) and (q-l) (rq-q-l) degrees of freedom at 5 per cent and 1 per cent levels of significance.

$$S.E = \sqrt{\frac{2Ee}{r}\left(1+\frac{rqu}{q+1}\right)}$$

Where, S.E = Standard error of mean

Ee = Mean sum of squares for error (intra block)

r = Number of replications

q = Number of genotypes in each sub-block

u = Weight age factor computed

The average critical difference (C.D) between any two adjusted treatment (genotypes) means was computed using the formula.

C.D = S.E x 't' value at 5% probability level for (q-1) (rq-q-1) degree of freedom.

3.6.1 Estimation of variance components:

Phenotypic and genotypic components of variance were estimated with the help of following formulae:

$$\text{Genotypic variance } (\sigma^2_g) = \frac{MSS_g - MSS_e}{\text{Number of replications}}$$

Phenotypic variance (σ^2_p) = Genotypic variance + MSS_e

3.6.2 Estimation of genetic variability

Both genotypic and phenotypic coefficients of variability for all the characters were computed as per the method given by Burton and De Vane (1953).

3.6.4 Genotypic Coefficient of Variability (GCV)

$$GCV = \frac{\sigma_g}{\overline{X}} \times 100$$

Where;

σ_g = Genotypic standard deviation

$\overline{X}$ = General mean of the character

3.6.5 Phenotypic Co-efficient of Variability (PCV)

$$PCV = \frac{\sigma_p}{\overline{X}} \times 100$$

Where;

σ_p = Phenotypic standard deviation

$\overline{X}$ = General mean of the character

GCV and PCV were classified as follows.

Low = 0 to 10%

Moderate = 10-20%

High = > 20%

3.6.6 Estimation of heritability

Broad sense heritability for all the twelve characters was worked out using the formula given by Hanson *et al.,* (1956).

$$h^2 (\%) = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

Where;

$\sigma^2 g$ - genotypic variance

$\sigma^2 p$ - phenotypic (total) variance

Heritability was classified as,

Low = 0 to 30%

Moderate= 30-60%

High= > 60%

3.6.7 Genetic advance (GA)

Genetic advance as per cent of mean for each character was worked out by adopting the formula given by Johnson *et al.* (1955a).

Genetic advance (GA) = h^2. σp. K

Where;

h^2 - Heritability in broad sense

K - Selection differential, K = 2.06 at 5 per cent intensity of selection (Lush, 1949)

σ_p - Phenotypic standard deviation

Further, genetic advance as per cent of mean (GAM) was worked out by using the formula given below:

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

Where;

GA - Genetic advance

$\overline{X}$ - General mean of the character

Genetic advance as percent mean was classified as follows.

Low = 0 to 10%

Moderate = 10-20%

High = > 20%

3.7 Simple correlation

The correlation co-efficients were calculated to determine the degree of relationship of characters with yield and also among the yield components. Phenotypic and genotypic correlation coefficients were compared against table 'r' values given by Fisher and Yates (1963) at 'n-2' d.f at the probability levels of 0.05 and 0.01 to test their significance. Genotypic and phenotypic correlations were computed by using the formula given by Weber and Moorthy (1952).

$$r_g = \frac{COVxy_g}{\sqrt{\sigma^2 x_g \, \sigma^2 y_g}}$$

Where;

$COV\ xy_g$ = genotypic covariance for xy

$\sigma^2 x_g$ and $\sigma^2 y_g$ = genotypic variance of the characters x and y

r_g = genotypic correlation

$$r_p = \frac{COVxy_p}{\sqrt{\sigma^2 x_p \times \sigma^2 y_p}}$$

Where;

$COV\ xy_p$ = phenotypic covariance for xy

$\sigma^2 x_p$ and $\sigma^2 y_p$ = phenotypic variance of the characters x and y

rp = phenotypic correlation

3.8 Path coefficient analysis

Path coefficient analysis was carried out using the phenotypic correlation coefficients to know the direct and indirect effects of the yield components on yield as suggested by Wright (1921) and as illustrated by Dewey and Lu (1959).

Standard path coefficients which are the standardized partial regression coefficients were obtained by solving the following set of 'P' simultaneous equations through the use of "DOO LITTLE TECHNIQUE" as described by Goulden (1959).

$P_{01} + P_{02}.r_{12}$+---------- $P_{0n}\, r_{1n} = r_{01}$

$P_{01}.r_{12}+P_{12}.r_{02}$+----------$P_{0n}\, r_{2n} = r_{02}$

-

-

-

-

$P_{01}r_{1n} + P_{02}.r_{2n}$+----------$P_{0n} = r_{0n}$

Where, P_{01}, P_{02} ----------P_{0n} are the direct path coefficients of variables 1, 2, ----------n on the dependent variable 0, r_{12}, r_{13} ----------r_{1p}----------rp (p-1) are the possible correlation coefficients between various independent variables and r_{01}, r_{02}, ---------- r_{0p} are the correlations between dependent variable and independent variable.

$P^2_{0x} = 1-(P^2_{01}+2P_{01}\, P_{02}\, r_{12}+2P_{01}P_{03}r_{13}$ + ----------$P^2_{02}+2P_{02}$

$P_{03}\, r_{13}$+ ---------- + P^2_0p)

Residual effect = $\sqrt{P^2_{ox}}$

3.9 Genetic diversity

3.9.1 Mahalanobis D^2 analysis

The formula given by Mahalanobis (1936) was used to compute the distances between different populations. The square of the Mahalanobis generalized distance between any two populations is given by the formula,

$$\delta^2 = \sum \delta i \, \delta j \, rij$$

Where;

δ^2 = Square of generalized distances

r_{ij} = Reciprocal of the common dispersion matrix

$\delta_I = (U_{i1} - U_{i2})$

$\delta_J = (U_{i1} - U_{j2})$

Where;

U = Vector of mean values for all the characters. The formula for the estimation of distance D for the samples

$D^2_p = d^1 s^{-1} d$

Where;

D^2p = Square of the distance considering p variables

D = Vector of observed differences of the mean values of all the Characters $(X_{i1} - X_{i2})$

X^{i1} = Vector of the mean values of all the characters

S^{-1} = Inverse of variance and covariance matrix

Since inversion the matrix is complicated the original correlation variables (Xi) were transformed to non-correlated variables (yi). So the computation of D^2 values reduces to simple summation of the square of the difference between the values of transformed variables of the two populations. This transformation is

done by pivotal condensation method. These newly transformed uncorrelated variables were used to calculate the square of distance using the formula,

$$D^2 = (y_{i1} - y_{i2})^2$$

Where;

y = vector of transformed mean values

The square of these D^2 values gives the general distance between the two populations. The D^2 values were arranged in matrix form.

The significance of D^2 values between any two populations is tested using the following formula,

$$T^2 = \frac{N_1 \times N_2}{N_1 + N_2} \times D^2$$

Using T^2, the F value was calculated using the formula,

$$F = \frac{N_1 + N_2 - P\text{-}1}{(N_1 + N_2 - 2)\, P} \times T^2$$

This computed F value was compared with the table F value at five per cent and one per cent level of significance at P and (N_1+N_2-P-1) degrees of freedom.

3.9.2 Clustering of D^2 values

All the [n (n-1)/2] D^2 values were clustered using Tocher's method as described by Rao (1952).

3.9.3 Intra-cluster distance

The intra-cluster distances were calculated by the formula given by Singh and Chaudhary (1977).

$$\text{Square of intra-cluster distance} = \frac{\sum Di^2}{n}$$

Where;

$\sum D_i^2$ = Sum of distances between all possible combination of the entries Included in a cluster

n = Number of all possible combinations

3.9.4 Inter-cluster distance

The inter-cluster distances were calculated by the formula given by Singh and Chaudhary (1977).

$$\text{Square of inter-cluster distance} = \frac{\sum Di^2}{n_i n_j}$$

Where;

$\sum D_i^2$ = Sum of distances between all possible combination ($n_i n_j$) of the entries included in the cluster study (i and j)

n_i = Number of entries in cluster i

n_j = Number of entries in cluster j

EXPERIMENTAL RESULTS

VI. EXPERIMENTAL RESULTS

The study performed on grain amaranth genotypes grown in summer and *kharif* seasons to evaluate their performance, in terms of genetic variability, genetic divergence, and assessment of the association between yield and yield components through path coefficient analysis and evaluation of genotypes for crude protein through nutritional analysis. The results of this investigation are presented under the following headings.

1. Analysis of variance
2. Genetic variation
3. Inter-character relationship
4. Path co-efficient analysis
5. Study of genetic divergence
6. Nutritional analysis

4.1 Analysis of variance

Mean sum of square due to genotype and error of the experiment carried in summer is presented in table 2 and that of *kharif* season in table 3. The results from the Analysis of variance revealed highly significant differences among genotypes for all the 12 characters studied in both summer and *kharif* season.

4.2 Genetic variation

4.2.1 Seed yield per plant

In the summer experiment grain yield per plant ranged from 8.00 g to 43.5 g with a mean yield of 21.4 g (Table 4). IC-415264 was the highest yielder (43.5g/plant) followed by EC-519544 (40.5g) and IC-519512 (39.5 g). EC-519592 (8.00 g/plant) was the lowest yielder. In case of *kharif* experiment grain yield per plant ranged from 5.25g to 40.0g with a mean yield of 19.36g (Table 5).

Table 2 : Analysis of variance for 12 different characters in Grain amaranth (Summer 2008)

Source of variation	df	Mean sum square											
Treatment (adjusted)		**X_1**	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
	99	79.05**	126.46**	14.80**	3.52**	9456.05**	52.59**	2717.59**	311.19**	7998.90**	1929.05**	0.05**	110.14**
Intra block error	81	0.37	1.30	0.03	0.02	4.36	1.98	8.22	0.65	0.29	0.56	0.002	7.02
S.Em ±		0.07	1.14	0.17	0.13	2.09	1.41	2.87	0.81	0.54	0.75	0.05	2.65
CD at 5%		1.20	2.26	0.33	0.25	4.14	2.79	5.69	1.61	1.71	1.49	0.09	5.53

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

X_1- days to 50 % flowering

X_2- days to maturity

X_3- stem girth at ground level (cm)

X_4- stem girth at crown level (cm)

X_5- number of leaves per plant

X_6 number of branches per plant

X_7 – plant height (cm)

X_8- panicle length (cm)

X_9- fresh weight of the panicle (g)

X_{10}- dry weight of the panicle (g)

X_{11}- 1000 seed weight (g)

X_{12}- grain yield per plant (g)

Table 3 : Analysis of variance for 12 different characters in Grain amaranth (*kharif* 2008)

Source of Variation	df	Mean sum of squares (MSS)											
Treatment (Adjusted)	99	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
		78.44**	123.33**	14.44**	2.83**	9472.37**	52.74**	2528.62**	305.07**	7507.11**	1896.43**	0.034**	113.96**
Intra block error	81	1.12	0.45	0.34	0.02	3.80	1.60	8.07	0.06	12.70	12.27	0.003	3.81
S.Em ±		1.056	0.673	0.581	0.124	1.950	1.265	2.841	0.253	3.563	3.503	0.055	1.952
CD at 5%		2.096	1.335	1.153	0.246	3.870	2.510	5.638	0.502	7.070	6.951	0.109	3.873

* - significance at 5% level

** - significance at 1% level

X_1- days to 50 % flowering

X_2- days to maturity

X_3- stem girth at ground level (cm)

X_4- stem girth at crown level (cm)

X_5- number of leaves per plant

X_6 - number of branches per plant

X_7 -plant height (cm)

X_8- panicle length (cm)

X_9- fresh weight of the panicle (g)

X_{10}- dry weight of the panicle (g)

X_{11}- 1000 seed weight (g)

X_{12}- grain yield per plant (g)

Table 4 : Variability parameters for 12 different characters in Grain amaranth genotypes (Summer 2008)

Sl. No	Characters	Range		Mean	Variance		Coefficient of variation		Heritability	Genetic Advance (%mean)
		Minimum	Maximum		Phenotypic	Genotypic	Phenotypic	Genotypic		
1	Days to 50 % flowering	27.55	58.66	43.91	39.71	39.34	14.85	14.28	0.99	29.28
2	Days to maturity	59.59	95.95	81.44	63.88	62.58	9.81	9.31	0.98	19.79
3	Stem girth at ground level (cm)	3.60	13.65	7.32	7.42	7.39	8.75	7.63	0.96	76.57
4	Stem girth at crown level (cm)	2.40	7.65	4.04	1.77	1.75	6.87	6.00	0.99	67.55
5	number of leaves per plant	75.50	381.79	192.85	4730.21	4725.84	35.90	35.18	0.85	73.67
6	Number of branches per plant	1.14	21.13	10.04	27.28	25.31	52.13	50.20	0.93	99.60
7	Plant height (cm)	49.27	231.98	99.77	1362.91	1354.69	37.91	37.20	0.93	76.39
8	Panicle length (cm)	14.21	60.79	37.59	155.92	151.27	36.00	33.15	0.54	68.15
9	Fresh weight of the panicle (g)	102.81	328.73	190.18	3999.60	3995.31	37.68	33.04	0.84	68.68
10	Dry weight of the panicle (g)	29.11	198.50	74.34	964.81	959.24	45.48	42.22	0.82	86.94
11	1000 seed weight (g)	0.50	1.55	0.79	0.02	0.02	19.53	18.60	0.91	36.49
12	Grain yield per plant (g)	8.00	43.50	21.54	58.58	51.56	35.68	33.47	0.88	64.69

Table 5 : Variability parameters for 12 different characters in Grain amaranth genotypes (*kharif* 2008)

Sl. No	Characters	Range		Mean	Variance		Coefficient of variation		Heritability	GA (%mean)
		Minimum	Maximum		Phenotypic	Genotypic	Phenotypic	Genotypic		
1	Days to 50 % flowering	27.50	57.25	43.30	39.78	38.66	14.57	14.36	0.97	29.16
2	Days to maturity	60.00	94.50	80.94	61.89	61.44	9.72	9.68	0.99	19.88
3	Stem girth at ground level (cm)	3.63	14.00	6.87	7.39	7.05	9.34	9.01	0.95	77.81
4	Stem girth at crown level (cm)	1.91	6.59	3.37	1.43	1.41	7.45	6.34	0.99	72.25
5	number of leaves per plant	73.50	383.31	189.45	1.43	1.40	36.33	36.14	0.76	74.79
6	Number of branches per plant	2.50	21.30	10.57	4738.09	4734.29	49.31	47.84	0.94	95.60
7	Plant height (cm)	44.80	219.07	93.12	27.17	25.57	38.24	38.12	0.98	78.28
8	Panicle length (cm)	15.21	60.79	38.09	1268.34	1260.27	34.66	32.42	0.82	66.78
9	Fresh weight of the panicle (g)	99.81	327.00	184.34	152.57	152.50	35.74	33.21	0.81	68.29
10	Dry weight of the panicle (g)	32.03	209.00	70.79	3759.90	3747.21	44.87	43.36	0.84	88.74
11	1000 seed weight (g)	0.50	1.40	0.78	954.35	942.08	17.49	16.01	0.84	30.20
12	Grain yield per plant (g)	5.25	40.00	19.36	0.02	0.02	39.63	38.33	0.94	76.36

IC-415264 was the highest yielder (40.0 g/ plant) followed by IC-415448 (38.13g) and IC-519512 (37.25 g), while the seed yield per plant was lowest in BGA-14 (5.25 g/plant).

4.2.2 Days to 50% flowering

The overall mean for number of days for 50 % flowering was 43.91 days with a wide range of variation from 27.55 days (BGA-11) to 58.66 days (EC-519549) in summer experiment (Table 2) and 27.5 days (BGA-11) to 57.25 days (IC-423408) with a mean of 43.3 days was noticed in *kharif* experiment (Table 5).

4.2.3 Days to maturity

Wide variation for days to maturity was observed in the genotypes in both the seasons with the mean of 81.44 days and 80.94 in summer and *kharif* experiment respectively.

In both the seasons the genotype BGA-11 was early maturing with 60.0 days, while IC-415297 and GA-1 were late maturing with 95.95 days and 93.43days respectively compared to check Suvarna, which took 90.90 days to mature in summer experiment. Where as in *kharif* experiment IC-415297 (94.5 days) and GA-1(94.18 days) were late maturing.

4.2.4 Stem girth at Ground level (cm)

The stem girth at ground level in the genotypes ranged from 3.6 to 13.65 cm. The stem girth at ground level was maximum in IC-415462 (13.65) followed by BGA-26 (12.85 cm), IC-415264 (12.68 cm) and IC-38127 (12.65 cm), while it was minimum in the genotype IC-415252 (3.60 cm) with an overall mean of 7.32 cm in the summer experiment. In *kharif* experiment the genotypes IC-415462 (14.0 cm) and BGA-26 (13.5 cm) followed by IC-415498(12.7 cm) were recorded

maximum stem girth and the minimum with stem girth of 3.63cm was noticed in BGA-21.

4.2.5 Stem girth at collar region (cm)

The overall mean for stem girth at collar region in the genotypes was 4.04 cm which ranged from 2.40 to 7.65 cm and 3.37 cm which ranged from 1.91 to 6.59 cm in summer and *kharif* experiments respectively. The stem girth at collar region was maximum in the IC-38127 (7.65cm) followed by IC-415462 (7.54 cm) and BGA-26 (7.52 cm), while it was minimum in the genotype IC-415252 (2.40 cm) in summer and in *kharif* season the genotypes IC-415462 (6.59 cm), followed by IC-415498 (6.52) and BGA-26 (6.49 cm) were noticed for maximum stem girth at collar region and the genotype BGA -21 was recorded minimum with (1.91 cm).

4.2.6 Number of leaves per plant

Among the genotypes, IC-415274 (75.5) and IC-41525 (79.5) recorded lowest number of leaves per plant. The genotype IC-403548 had maximum of 381.79 leaves per plant followed by Suvarna (380.5) and EC-519531 (379.28) with an average of 192.85 leaves per plant were observed in summer, while in *kharif* genotypes IC-403548 had maximum of 383.31 leaves per plant followed by EC-519531 (379.0) and Suvarna (376.97) with an average of 189.45 leaves per plant with lowest number of leaves recorded by IC-415274 (73.5) followed by IC-415284 (77.95).

4.2.7 Number of branches per plant

In summer experiment number of branches per plant of IC-415222, IC-423448, and EC-519526 were 21.33, 21.0 and 20.71 respectively. Minimum numbers of branches per plant were recorded in KBGA-1and BGA-18 (1.14 and 2.06 branches respectively). The over all mean of number of branches per plant was 10.04. Where as in *kharif* the minimum number of branches was observed in

GA-2 (2.5) and KBGA-1(2.8) and the genotypes BGA-25 (21.3), BGA-14 (21.0) and IC-423448 (20.5) were showed maximum number of branches per plant.

4.2.8 Plant height (cm)

The plant height varied from 49.27 to 232 cm with an overall mean of 99.77 cm. The genotype IC-415498 (232 cm) and IC-415462 (226 cm) were the tallest genotypes, while BGA-3 (49.27cm) was dwarf genotype in the collection in summer experiment. The average plant height observed was 99.7 cm. The genotypes IC-415462(219.07cm) and IC-415498 (211.02cm) recorded maximum plant height and minimum plant height by BGA-3 (44.80cm) with a mean of 93.12cm in the collection in *kharif* experiment.

4.2.9 Panicle length (cm)

In summer experiment Panicle length of the genotypes varied from 14.21 to 60.79 cm with an average length of 37.59 cm. The genotype, IC-415264 had longest panicle length (60.79cm) followed by IC-415462 (56.33 cm). The genotypes recorded for maximum panicle length were IC-415264 (60.5cm) followed by KBGA-1 (58.25cm) in *kharif* experiment ranging from 15.2 cm to 60.5cm averaging with 38.09 cm, while the genotype BGA-3 had minimum panicle length in both the season with 14.21 cm and 15.2 cm in summer and *kharif* experiment respectively.

4.2.10 Panicle fresh weight (g)

Panicle fresh weight ranged from 102.81g to 328.73 g with an overall mean of 190.18 g. The genotype IC-415264 (328.73g) recorded maximum panicle fresh weight followed by BGA-16 (327.0g). The genotype IC-415284 (102.81g) had lowest panicle fresh weight in summer, where as in *kharif* Panicle fresh weight ranged from 99.81g to 327.0g with the average weight 184.34g the genotype

BGA-16 (327.0g) recorded maximum panicle fresh weight followed by IC-415264 (319.14g) and lowest panicle fresh weight recorded by IC-415284 (99.81g).

4.2.11 Panicle dry weight (g)

The panicle dry weight was maximum in the genotype, IC-415264 (198.50g) IC-415448 (177.5g) and minimum in BGA-3 (29.11g) and the over all mean of panicle dry weight was 74.34g in summer. In *kharif* panicle dry weight recorded maximum of 198.50 g in IC-415264 and 171.5 g in EC-519554 and lowest was recorded in BGA-3 (32.03 g).

4.2.11 1000 seed weight (g)

In summer experiment the 1000 seed weight was ranged from 0.50 to 1.55 g with mean weight of 0.79 g. The genotype BGA-28 (1.55 g) recorded maximum 1000 seed weight followed by EC-519554 (1.40g) and minimum 1000 seed weight was in BGA-14 (0.50 g). In *kharif* experiment minimum 1000 seed weight was observed in BGA-14 and BGA-3 (0.50 g). The genotype EC-519554 (1.40g) recorded maximum 1000 seed weight followed by IC-415272 (1.15 g) with over all mean of 0.78g.

4.2.2 Variability parameters, variability, heritability and genetic advance

The variability parameters such as range, variance, genetic and phenotypic coefficient of variation, heritability and genetic advance were estimated for hundred genotypes in both summer and *kharif* experiments of grain amaranth and results of both the experiments were furnished here under (Table 4 and Table 5). In summer experiment the phenotypic and genotypic variances were very high for number of leaves per plant (4730.21; 4725.84), panicle fresh weight (3999.60 ; 3995.31), plant height (1362.91 ; 1354.69), dry weight of panicle (964.81; 959.24), Panicle length (155.92; 151.27) and Days to maturity, grain yield per plant, days to 50% flowering and number of branches exhibited moderate

genotypic and phenotypic variation. The rest of the traits like stem girth at the ground level, stem girth at collar region and 1000 seed weight exhibited very low variances both at genotypic and phenotypic levels. In *kharif* experiment the phenotypic and genotypic variances were very high for number of leaves per plant (4738.09 ; 4734.29), dry weight of panicle (3759.9 ; 3747.21), Panicle length (1268.34 ; 1260.27), 1000 seed weight (954.35 ; 942.08), panicle fresh weight (152.57 ; 152.50) and Days to maturity, days to 50% flowering and plant height exhibited moderate genotypic and phenotypic variation where as stem girth at the ground level, stem girth at collar region, number of leaves per plant and grain yield exhibited very low variances both at genotypic and phenotypic levels .

Number of leaves per plant (45.48; 42.22), plant height (37.91; 37.20), fresh weight of panicle (37.68; 33.04), panicle length (36.00; 33.15) number of leaves per plant (35.90; 35.18), grain yield per plant (35.68; 33.47) and 1000 seed weight (19.53;18.60) recorded high co-efficient of variability. While the traits such as days to 50% flowering (14.85;14.28), stem girth at the crown level (6.87; 6.01), stem girth at ground level (8.75; 7.63) and days to maturity (9.81; 9.31) recorded medium to low co-efficient of variability in summer experiment. In *kharif* experiment genotypic and phenotypic coefficient of variation were high for number of branches per plant (49.31 ; 47.84), dry weight of panicle (44.87; 43.36), grain yield per plant (39.63; 38.33), plant height (38.24; 38.12), number of leaves per plant (36.33; 36.14), fresh weight of panicle (35.74; 33.21), panicle length (34.66; 32.42) and moderate co-efficient of variability in 1000 seed weight (17.49;16.01) and days to 50% flowering (14.57;14.36). While the traits stem girth at collar region (6.87; 6.01), stem girth at the ground level (8.75; 7.36) and days to maturity (9.72; 9.68) recorded low co-efficient of variability. The PCV was higher than the respective GCV for all the characters in both experiments done in summer and *kharif*.

In summer traits with high heritability were Stem girth at collar region (99.1%), days to 50 per cent flowering (99.08%), days maturity (98.1%), stem girth at the ground level (96.3%) number of branches (93.1%), plant height (93%),1000 seed weight (91.2%), seed yield per plant (88.1%), number of leaves (85.1%), panicle fresh weight (84.0%) and dry weight of panicle (82.0%). Panicle length (54%) exhibited moderate heritability among the characters studied. In *kharif* experiment all traits exhibited high heritability and maximum heritability was noticed in plant height (98%) followed by days maturity (99.2%), Stem girth at collar region (98.9%), days to 50 per cent flowering (97.1%), stem girth at the ground level (95.4%), number of branches (94.1%) seed yield per plant (93.3%), dry weight of panicle (84.0%), 1000 seed weight (83.8%), panicle length (82.0%), panicle fresh weight (81.8%) and number of leaves (76%).

Genetic advance as per cent mean was very high for number of branches per plant (99.6%), followed by dry weight of panicle (86.94%), stem girth at the ground level (76.59%), plant height (76.39%), number of leaves per plant (73.67%), panicle fresh weight (68.68%), panicle length (68.15%), stem girth at collar region (67.55%) and grain yield per plant (64.69%), 1000 seed weight (36.49%) and days to 50 percent flowering (29.28%), while days to maturity (19.79%) recorded moderate genetic advance in summer season (Table 4). Whereas in *kharif* season high genetic advance was recorded in number of branches per plant (95.60%), followed by dry weight of panicle (88.74%), plant height (78.28%), stem girth at the ground level (77.81%), grain yield per plant (76.36%), number of leaves (74.79%), panicle fresh weight (68.29%), stem girth at collar region (67.55%), panicle length (66.78%), and while the traits 1000 seed weight (30.20%), days to 50 percent flowering (29.16%) and days to maturity (19.88%) recorded moderate genetic advance (Table 5).

4.3 Inter-relationship

The phenotypic and genotypic correlation coefficient between seed yield and its attributes were estimated for summer and *kharif* experiment (data is presented in the table 6 and table 7 respectively).

4.3.1 Inter relationship between yield and yield components

Grain yield per plant showed a highly significant positive correlation with stem girth at the ground level, stem girth at collar region, number of leaves per plant, plant height, panicle length, panicle fresh weight, dry weight of panicle and 1000 seed weight was observed both at genotypic and phenotypic level in summer experiment (Table 6 and 8) and also in *kharif* experiment (Table 7 and 9).

In the summer experiment magnitude of correlation with grain yield at genotypic level, which is more important than the phenotypic level per plant was highest in case of dry weight of the panicle (0.892) followed by fresh weight of panicle (0.829), 1000 seed weight (0.680), panicle length (0.592), plant height (0.446), stem girth at crown level (0.427) stem girth at ground level (0.418) and number of leaves per plant (0.411). The other characters like days to 50 per cent flowering, days to maturity, number of branches showed either negative or positive correlation both at genotypic and phenotypic levels (Table 6). While in *kharif* experiment magnitude of correlation with grain yield per plant at genotypic level was highest in dry weight of the panicle (0.850) followed by fresh weight of panicle (0.827), 1000 seed weight (0.759), panicle length (0.598), plant height (0.445), number of leaves per plant (0.411), stem girth at ground level (0.408) and stem girth at crown level (0.406) these traits also showed highest magnitude of positive correlation at the phenotypic level. The other characters like days to 50 per cent flowering, days to maturity and number of branches showed either negative or positive correlation both at genotypic and phenotypic levels (Table 7).

Table 6 : Genotypic correlation coefficient value on yield in Grain amaranth (Summer 2008)

Character	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	1.000	0.646**	0.067	0.087	0.075	0.084	0.020	-0.158	-0.037	-0.025	0.065	-0.014
X_2		1.000	0.128	0.192	0.125	-0.146	0.171	0.073	0.107	0.103	0.216*	0.158
X_3			1.000	0.945**	0.323**	-0.271	0.916**	0.625**	0.499**	0.429**	0.449**	0.418**
X_4				1.000	0.300**	-0.246	0.895**	0.613**	0.534**	0.452**	0.470**	0.427**
X_5					1.000	-0.494	0.326**	0.418**	0.445**	0.373**	0.437**	0.411**
X_6						1.000	-0.310	-0.458	-0.504	-0.490	-0.364	-0.549
X_7							1.000	0.726**	0.482**	0.410**	0.409**	0.446**
X_8								1.000	0.649**	0.583**	0.519**	0.592**
X_9									1.000	0.806**	0.635**	0.829**
X_{10}										1.000	0.666**	0.892**
X_{11}											1.000	0.680**
X_{12}												1.000

* - significance at 5% level

** - significance at 1% level

X_1- days to 50 % flowering

X_2- days to maturity

X_3- stem girth at ground level (cm)

X_4- stem girth at crown level (cm)

X_5- number of leaves per plant

X_6 number of branches per plant

X_7 – plant height (cm)

X_8- panicle length (cm)

X_9- fresh weight of the panicle (g)

X_{10}- dry weight of the panicle (g)

X_{11}- 1000 seed weight (g)

X_{12}- grain yield per plant (g)

Table 7 : Genotypic correlation coefficient value on yield in Grain amaranth (*kharif* 2008)

Character	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	1.000	0.620**	0.033	0.080	0.077	0.071	0.014	-0.150	-0.048	-0.058	0.011	-0.035
X_2		1.000	0.115	0.194	0.128	-0.168	0.180	0.099	0.113	0.118	0.216*	0.151
X_3			1.000	0.948**	0.332**	-0.294	0.907**	0.627**	0.514**	0.411**	0.379**	0.408**
X_4				1.000	0.307**	-0.271	0.891**	0.625**	0.531**	0.447**	0.375**	0.406**
X_5					1.000	-0.523	0.329**	0.419**	0.449**	0.353**	0.447**	0.411**
X_6						1.000	-0.331	-0.479	-0.534	-0.527	-0.541	-0.595
X_7							1.000	0.742**	0.484**	0.421**	0.364**	0.445**
X_8								1.000	0.647**	0.583**	0.536**	0.598**
X_9									1.000	0.784**	0.674**	0.827**
X_{10}										1.000	0.775**	0.850**
X_{11}											1.000	0.759**
X_{12}												1.000

* - significance at 5% level

** - significance at 1% level

X_1- days to 50 % flowering

X_2- days to maturity

X_3- stem girth at ground level (cm)

X_4- stem girth at crown level (cm)

X_5- number of leaves per plant

X_6 number of branches per plant

X_7 – plant height (cm)

X_8- panicle length (cm)

X_9- fresh weight of the panicle (g)

X_{10}- dry weight of the panicle (g)

X_{11}- 1000 seed weight (g)

X_{12}- grain yield per plant (g)

Table 8 : Phenotypic correlation coefficient value on yield in Grain amaranth (Summer 2008)

Character	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	1.000	0.635**	0.066	0.089	0.073	0.084	0.017	-0.158	-0.037	-0.025	0.068	-0.010
X_2		1.000	0.125	0.188	0.123	-0.139	0.173	0.073	0.105	0.102	0.206*	0.145
X_3			1.000	0.940**	0.322**	-0.259	0.910**	0.622**	0.498**	0.428**	0.422**	0.393**
X_4				1.000	0.298**	-0.233	0.889**	0.609**	0.532**	0.451**	0.447**	0.399**
X_5					1.000	-0.477	0.326**	0.418**	0.444**	0.373**	0.416**	0.386**
X_6						1.000	-0.299	-0.441	-0.485	-0.473	-0.334	-0.496
X_7							1.000	0.723**	0.480**	0.409**	0.385**	0.420**
X_8								1.000	0.648**	0.582**	0.497**	0.554**
X_9									1.000	0.806**	0.605**	0.778**
X_{10}										1.000	0.635**	0.836**
X_{11}											1.000	0.592**
X_{12}												1.000

* - significance at 5% level

** - significance at 1% level

X_1- days to 50 % flowering

X_2- days to maturity

X_3- stem girth at ground level (cm)

X_4- stem girth at crown level (cm)

X_5- number of leaves per plant

X_6 number of branches per plant

X_7 – plant height (cm)

X_8- panicle length (cm)

X_9- fresh weight of the panicle (g)

X_{10}- dry weight of the panicle (g)

X_{11}- 1000 seed weight (g)

X_{12}- grain yield per plant (g)

Table 9 : Phenotypic correlation coefficient value on yield in Grain amaranth (*Kharif* 2008)

Character	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	1.000	0.610**	0.036	0.079	0.077	0.066	0.015	-0.148	-0.048	-0.054	0.016	-0.035
X_2		1.000	0.115	0.193	0.127	-0.160	0.178	0.099	0.112	0.115	0.192	0.145
X_3			1.000	0.926**	0.324**	-0.274	0.886**	0.612**	0.500**	0.396**	0.334**	0.385**
X_4				1.000	0.305**	-0.259	0.884**	0.620**	0.528**	0.443**	0.350**	0.396**
X_5					1.000	-0.508	0.328**	0.419**	0.448**	0.351**	0.409**	0.397**
X_6						1.000	-0.322	-0.464	-0.518	-0.511	-0.471	-0.556
X_7							1.000	0.739**	0.482**	0.417**	0.331**	0.427**
X_8								1.000	0.646**	0.578**	0.489**	0.578**
X_9									1.000	0.779**	0.621**	0.803**
X_{10}										1.000	0.708**	0.826**
X_{11}											1.000	0.683**
X_{12}												1.000

* - significance at 5% level

** - significance at 1% level

X_1- days to 50 % flowering

X_2- days to maturity

X_3- stem girth at ground level (cm)

X_4- stem girth at crown level (cm)

X_5- number of leaves per plant

X_6 number of branches per plant

X_7 – plant height (cm)

X_8- panicle length (cm)

X_9- fresh weight of the panicle (g)

X_{10}- dry weight of the panicle (g)

X_{11}- 1000 seed weight (g)

X_{12}- grain yield per plant (g)

In general, the genotypic correlation co-efficients were higher than their respective phenotypic correlation co-efficients in both summer and *kharif* experiments.

4.3.2 Interrelationship between seed yield and its contributing traits.

Days to 50% flowering showed significant positive correlation with days to maturity, stem girth at ground level, stem girth at collar region, number of leaves per plant, number of branches per plant, plant height and 1000 seed weight and showed negative correlation with panicle length, panicle fresh weight and panicle dry weight at both genotypic and phenotypic level in both summer (Table 6 and 8) and *kharif* experiments (Table 7 and 9).

Days to maturity showed significant positive correlation with 1000 seed weight and negative correlation with number of branches per plant both at genotypic and phenotypic level in both summer (Table 6 and 8) and *kharif* (Table 7 and 9) experiments.

Number of branches per plant showed negative correlation with all the traits except the character days to 50 percent flowering plant both at genotypic and phenotypic level in both summer (Table 6 and 8) and *kharif* (Table 7 and 9) experiments.

Panicle length showed positive association with plant height (rg = 0.726, rp = 0.723), panicle fresh weight (rg = 0.649, rp = 0.648), stem girth at ground level (rg = 0.625, rp = 0.622), stem girth at crown level (rg = 0.613, rp = 0.609), dry weight of the panicle (rg = 0.583, rp = 0.582), 1000 seed weight (rg = 0.519, rp = 0.497) and number of leaves per plant (rg= 0.418, rp = 0.418) at genotypic and phenotypic level in summer (Table 4 and 5) experiment, while in *kharif* positive association of panicle length found with plant height (rg = 0.742, rp = 0.739), panicle fresh weight (rg = 0.647, rp = 0.646), stem girth at ground level (rg = 0.627,

rp = 0.612), stem girth at collar region (rg = 0.625, rp = 0.620), dry weight of the panicle (rg = 0.583, rp = 0.578), 1000 seed weight (rg = 0.536, rp = 0.536) and number of leaves per plant (rg =0.419, rp = 0.419) at genotypic and phenotypic level.

Significant positive genotypic and phenotypic correlation of plant height in summer experiment (table 6 and 8) was observed with stem girth at ground level (rg =0.916, rp = 0.910), stem girth at collar region (rg =0.895, rp = 0.889), panicle length (rg = 0.726, rp = 0.723) panicle fresh weight (rg = 0.482; rp = 0.480), dry weight of panicle (rg = 0.410, rp = 0.409), 1000 seed weight(rg = 0.409, rp = 0.385) number of leaves per plant (rg =0.326, rp = 0.326). In *kharif* experiment (table 7 and 9) Significant positive genotypic and phenotypic correlation of plant height was observed with stem girth at ground level (rg =0.907, rp = 0.886), stem girth at collar region (rg =0.891, rp = 0.884), panicle length (rg = 0.742, rp = 0.739) panicle fresh weight (rg = 0.484; rp = 0.482), dry weight of panicle (rg = 0.421, rp = 0.417), 1000 seed weight (rg = 0.364, rp = 0.331) number of leaves per plant (rg =0.329, rp = 0.328).

Panicle fresh weight in summer experiment showed significant positive correlation with dry weight of panicle (rg = 0.806, rp = 0.806), panicle length (rg = 0.649, rp = 0.648), 1000 seed weight (rg = 0.635, rp = 0.605), stem girth at the crown level (rg = 0.534, rp = 0.532), stem girth at the ground level (rg = 0.499, rp = 0.498), plant height (rg = 0.482, rp = 0.480) and number of leaves (rg = 0.445, rp = 0.444) both at genotypic and phenotypic level (table 6 and 8). While in *kharif* experiment Panicle fresh weight showed significant positive correlation with dry weight of panicle (rg =0.779, rp = 0.779), 1000 seed weight (rg = 0.674, rp = 0.621), panicle length (rg = 0.647, rp = 0.646), stem girth at the crown level (rg = 0.531, rp = 0.528), stem girth at the ground level (rg = 0.514, rp = 0.500), plant height

(rg = 0.484, rp = 0.482) and number of leaves (rg = 0.449, rp = 0.448) both at genotypic and phenotypic level (table 7 and 9)

Correlation coefficient both at genotypic and phenotypic level revealed positive significant association of dry weight of panicle with 1000 seed weight in summer (rg = 0.666, rp = 0.635) and *kharif* (rg = 0.775, rp = 0.708) experiments .

Negative significant association of number of branches with all the traits except days to 50 percent flowering at genotypic and phenotypic level in both the season was observed.

In general, genotypic correlation co-efficient values were greater than their respective phenotypic correlation coefficient in both the season (Table 6, 8, 7 & 9).

4.4 Path co-efficient analysis

Path co-efficient analysis was carried out at genotypic level in summer and *kharif* experiment taking seed yield as a dependent character and the characters which were significantly correlated with seed yield *viz.,* stem girth at collar region, plant height, panicle length, fresh weight of panicle, dry weight of panicle, and 1000 seed weight as independent characters were observed (Table10 and 11 in summer and *kharif* experiment respectively). The direct and indirect effects of different characters on grain yield were presented below.

4.4.1 Direct effects of different characters on seed yield

Among the characters studied at genotypic level in summer experiment, dry weight of panicle exhibited very high positive direct effect (0.583) followed by plant height (0.396) and fresh weight of panicle (0.322) on seed yield per plant. Lowest direct positive effect of 0.132 was exerted by 1000 seed weight was observed. The residual effect was 0.364 (Table 10). Where as in *kharif*

Table 10 : Direct (diagonal) and indirect (above and below diagonal) effects of characters on grain yield in Grain amaranth at genotypic level (Summer 2008)

Characters	Stem girth at crown level	Plant height (cm)	Panicle length (cm)	Fresh weight of the panicle (g)	Dry weight of the panicle (g)	1000 seed weight (g)	Correlation coefficient on yield
Stem girth at crown level	**-0.306**	0.354**	-0.067	0.172	0.262**	0.062	0.477**
Plant height (cm)	-0.274	**0.396****	-0.079	0.155	0.238*	0.054	0.490**
Panicle length (cm)	-0.187	0.288**	**-0.109**	0.209*	0.338**	0.069	0.608**
Fresh weight of the panicle (g)	-0.163	0.191	-0.071	**0.322****	0.468**	0.084	0.831**
Dry weight of the panicle (g)	-0.138	0.162	-0.063	0.260**	**0.583****	0.088	0.892**
1000 seed weight (g)	-0.144	0.162	-0.056	0.205*	0.386**	**0.132**	0.685**

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

Residual effect= 0.3648

experiment high direct positive effect was noticed in fresh weight of panicle (0.429) followed by dry weight of panicle (0.395) and plant height (0.352) on seed yield per plant. Lowest direct positive effect of 0.164 was exerted by 1000 seed weight on grain yield. The residual effect was 0.408 (Table11).

4.4.2 Indirect effect of different characters on seed yield per plant

4.4.2.1 Dry weight of panicle (g)

At genotypic level, dry weight of panicle showed highest positive indirect effect on grain yield via fresh weight of panicle (0.26), plant height (0.162) and 1000 seed weight (0.088) it also showed negative indirect effect on seed yield through panicle length (-0.063) and stem girth at collar region (-0.138) in summer experiment. In *kharif* it showed positive indirect effect on grain yield via fresh weight of panicle (0.336), plant height (0.148) and 1000 seed weight (0.127). It exhibited negative indirect effect on seed yield through panicle length (-0.063) and stem girth at collar region (-0.153).

4.4.2.2 Fresh weight of panicle (g)

Observations in summer experiment revealed positive indirect effect of fresh weight of panicle on seed yield per plant *via* dry weight of panicle (0.468), plant height (0.191), 1000 seed weight (0.084) and negative Indirect effect of fresh weight of panicle on seed yield per plant via stem girth at crown level (-0.163) and panicle length (-0.071). In *kharif* season at genotypic level, fresh weight of panicle showed positive indirect effect on seed yield per plant *via* dry weight of panicle (0.310), plant height (0.171), 1000 seed weight (0.111) and negative Indirect effect of fresh weight of panicle on seed yield via stem girth at collar region (-0.153) and panicle length(-0.047) was recorded.

Table 11 : Direct (diagonal) and indirect (above and below diagonal) effects of characters on grain yield in Grain amaranth at genotypic level (*Kharif* 2008)

Character	Stem girth at crown level	Plant height (cm)	Panicle length (cm)	Fresh weight of the panicle (g)	Dry weight of the panicle (g)	1000 seed weight (g)	Correlation coefficient on yield
Stem girth at crown level	**-0.343**	0.314**	-0.046	0.228*	0.177	0.062	0.392**
Plant height (cm)	-0.305	**0.352****	-0.054	0.208*	0.167	0.060	0.428**
Panicle length (cm)	-0.214	0.261**	**-0.073**	0.278**	0.230**	0.088	0.571**
Fresh weight of the panicle (g)	-0.182	0.171	-0.047	**0.429****	0.310**	0.111	0.792**
Dry weight of the panicle (g)	-0.153	0.148	-0.043	0.336**	**0.395****	0.127	0.812**
1000 seed weight (g)	-0.129	0.128	-0.039	0.289**	0.306**	**0.164**	0.719**

* - significance at 5% level

** - significance at 1% level

Residual effect = 0.4087

4.4.2.3 1000 seed weight (g)

In summer experiment 1000 seed weight showed positive indirect effect on seed yield per plant *via* dry weight of panicle (0.386), fresh weight of panicle (0.319) and lowest indirect effect *via* plant height (0.162) and negative indirect effect on seed yield per plant via stem girth at crown level (-0.144) and panicle length (-0.056) at genotypic level.

Positive indirect effect of 1000 seed weight on seed yield per plant in *kharif* season was observed via dry weight of panicle (0.306), fresh weight of panicle (0.289) and lowest indirect effect *via* plant height (0.128) and it showed negative indirect effect on seed yield per plant via stem girth at crown level (-0.129) and panicle length (-0.039) at genotypic level.

The indirect effect of 1000 seed weight through dry weight of panicle and fresh weight of panicle was more than its direct effect on seed yield at genotypic path in both the seasons.

4.4.2.4 Panicle length (cm)

Panicle length displayed positive indirect effect on seed yield per plant *via* dry weight of panicle (0.338), Plant height (0.288) and fresh weight of panicle (0.209) for rest of the traits it showed small positive or negative indirect effect in summer experiment .

While in *kharif* panicle length exhibited positive indirect effect on seed yield per plant *via* fresh weight of panicle (0.209), dry weight of panicle (0.338) and Plant height (0.288) and it showed negative indirect effect through stem girth at collar region (-0.343) at genotypic level.

4.4.2.5 Plant height (cm)

At genotypic level, Plant height showed positive indirect effect on seed yield per plant *via* dry weight of panicle (0.238) and fresh weight of panicle (0.155) and through rest of the characters it exhibited small positive or negative indirect effect in summer.

In *kharif* it showed highest positive indirect effect on seed yield per plant through fresh weight of panicle (0.208) followed by dry weight of panicle (0.167) with little positive indirect effect through 1000 seed weight (0.060) and negative indirect effects through Stem girth at crown level (-0.305) at genotypic level.

4.4.2.6 Stem girth at collar region (cm)

In summer experiment at genotypic level stem girth at collar region showed positive indirect effect on grain yield *via* plant height (0.354) followed by dry weight of panicle (0.262) and fresh weight of panicle (0.172), negative indirect effect on grain yield per plant *via* panicle length (-0.067). And in *kharif* season stem girth at collar region showed positive indirect effect on grain yield via plant height (0.314) followed by fresh weight of panicle (0.228) and dry weight of panicle (0.238) and negative indirect effect on grain yield per plant via panicle length (-0.007).

4.5 Study of genetic divergence

Genetic diversity in 100 lines of grain amaranth using D^2 statistic was estimated under two seasons and the genotypes were grouped into respective cluster.

4.5.1 Crop constellations

By using the estimated D^2 values, 100 genotypes were grouped into 12 and 14 clusters in the experiment done in summer and *kharif* season respectively, following the method suggested by Tocher (Rao, 1952). The distribution pattern of

genotypes into various clusters in summer and *kharif* experiment is shown in table 12 and table 13 respectively.

The clustering pattern in summer experiment revealed that the cluster X to be the larger of all consisting 22 genotypes followed by cluster I with 21 genotypes, cluster II with 11 genotypes, cluster V and cluster VI each with 10 genotypes, cluster XII with 9 genotypes, while 7 genotypes were grouped into cluster VII. Remaining Clusters (III, IV, VIII and IX) were had only two genotypes each thus, accommodating total of 100 genotypes fitted in 12 clusters.

Whereas 14 clusters were formed in the *kharif* divergence studies with cluster I being largest of all with 23 genotypes followed by cluster XIII with 11 genotypes, clusters III, VI, VII and XII each having 9 genotypes, clusters X and IX accommodating 7 and 4 genotypes respectively, only 2 genotypes per cluster were observed in clusters II, IV, V, VIII and XI.

4.5.2 Intra-cluster distance

In summer experiment intra cluster distance was highest in the cluster XII with D^2 value of 62558.8 followed by cluster II (53970.6) and cluster X (44890.1). Intra cluster D^2 and D values are given in table 14 & 16

Cluster III recorded highest intra cluster distance of 16715 in *kharif* experiment followed by Cluster XIV (11725) and Cluster X (8841), lowest being recorded by cluster II (12). Intra cluster D^2 and D values are given in table 15 & 17.

4.5.3 Inter cluster distance

Inter cluster D^2 and D values of cluster in summer experiment are given in table 14 & 16. The Cluster III and Cluster IX were nearest to each other with an

Table 12 Categorization of Grain amaranth genotypes into different clusters (Summer 2008)

Cluster	Number	Members										
I	21	IC-415274	IC-415254	IC-415271	IC-421885	IC-519548	IC-423544	IC-415236	IC-415268	IC-415280	IC-415243	IC-415320
		IC-415448	IC-415466	IC-415433	IC-519543	IC-415318	IC-415462	IC-423410	IC-415314	IC-415316	1C-415290	
II	11	IC-415284	IC-415331	IC-403548	IC-423398	IC-519512	IC-415224	IC-415220	IC-415250	IC-415252	BGA-18	BGA-4
III	2	IC-423408	IC-413426									
IV	2	IC-423400	IC-423117									
V	10	IC-415264	IC-415272	IC-415266	IC-415448	IC-415449	IC-38127	IC-38312	IC-415232	IC-415258	BGA-26	
VI	10	IC-415222	IC-519558	IC-415387	IC-415317	IC-423408	IC-423448	IC-37316	IC-415498	BGA-23	BGA-22	
VII	7	1C-415318	IC-415297	IC-415262	EC-519549	EC-519526	EC-519517	BGA-8				
VIII	2	BGA-19	BGA-14									
IX	2	BGA-21	BGA-25									
X	22	IC-423408	BGA-28	EC-519527	EC-519531	EC-519522	EC-519542	EC-519532	EC-524457	BGA-12	BGA-6	BGA-3
		BGA-21	BGA-11	BGA-1	BGA-7	BGA-17	BGA-27	BGA-5	BGA-9	BGA-24	BGA-20	GA-1
X1	2	BGA-10	BGA-15									
XII	9	BGA-16	GA-2	SUVARNA	IC-42311	KBGA-1	EC-519592	IC-415290	IC-415282	EC-519554		

Table 13 : Categorization of Grain amaranth genotypes into different clusters (*Kharif* 2008)

Cluster	no	Members										
I	23	IC-415274	IC-415254	IC-415271	IC-421885	IC-519548	IC-423544	IC-415236	IC-415268	IC-415280	IC-415243	IC-415320
		IC-415448	IC-415466	IC-415433	IC-519543	IC-415318	IC-415462	IC-423410	IC-415314	IC-415316	IC-415284	IC-415331
		1C-415318										
II	2	IC-415232	1C-415290									
III	9	IC-403548	IC-423398	IC-519512	IC-415224	IC-415220	IC-415250	IC-415252	IC-423408	IC-413426		
IV	2	IC-423400	IC-423117									
V	2	BGA-4	GA-2									
VI	9	IC-415264	IC-415272	IC-415266	IC-415448	IC-415449	IC-38127	IC-38312	IC-415258	BGA-26		
VII	9	IC-415222	IC-519558	IC-415387	IC-415317	IC-423408	IC-423448	IC-37316	BGA-23	BGA-22		
VIII	2	IC-415262	IC-415282									
IX	4	IC-415498	IC-415297	BGA-28	BGA-12							
X	7	EC-519549	EC-519526	IC-423408	EC-519527	EC-519517	BGA-5	BGA-24				
XI	2	BGA-19	BGA-14									
XII	9	EC-519531	EC-519522	EC-519542	EC-519532	EC-524457	BGA-18	BGA-8	BGA-10	BGA-15		
XIII	11	BGA-21	BGA-6	BGA-3	BGA-21	BGA-11	BGA-1	BGA-7	BGA-17	BGA-27	BGA-25	BGA-9
XIV	9	BGA-16	BGA-20	GA-1	SUVARNA	IC-42311	KBGA-1	EC-519592	IC-415290	EC-519554		

Table 14 : Average inter cluster (above diagonal) and intra-cluster (diagonal) D^2 values for 12 cluster in Grain amaranth (Summer 2008)

CLUSTER	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
I	**40586.1**	44448.2	55849.9	74712.5	42904.2	63126.4	36154.6	77151.3	52226.9	46800.1	51696.4	49883.5
II		**53970.6**	57653.5	76441.2	48988.8	64903.0	40329.7	78910.2	54158.7	50898.6	54910.6	55540.3
III			**24.4**	2922.7	87775.5	3394.8	27818.2	4075.3	303.8	34503.1	1395.7	83085.1
IV				**28.8**	113461.7	5210.8	41983.1	707.3	4168.2	47175.9	4160.5	106386.8
V					**38769.4**	96807.0	50094.9	116335.6	82668.3	62174.7	82798.4	46617.3
VI						**6244.0**	33624.7	6315.3	4096.8	40093.0	4778.8	90924.1
VII							**27884.9**	44662.9	25293.6	33704.4	26093.3	52547.1
VIII								**225.7**	5803.7	49298.4	5379.9	109537.1
IX									**289.2**	32363.7	1558.4	78530.0
X										**44890.1**	32771.9	64131.9
XI											**1127.2**	78789.9
XII												**62558.8**

Table 15 : Average inter cluster (above diagonal) and intra-cluster (diagonal) D^2 Values for 12 cluster in Grain amaranth (*Kharif* 2008)

Cluster	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
I	**6017**	4975	12655	23409	6288	7050	18555	24397	9495	14198	25212	6496	22438	8709
II		**12**	15323	34194	5712	4709	26906	33427	4911	20000	36370	4908	32058	6388
III			**16715**	17801	9951	15717	14111	17294	22209	12838	19151	12709	16787	17298
IV				**20**	19320	30835	3392	3825	42862	8509	253	24412	2699	32317
V					**24**	8270	12104	14498	13526	9205	21143	4184	16032	9281
VI						**8052**	24843	31506	8472	18898	32790	7887	29287	8936
VII							**2785**	2616	35761	6326	4020	18097	3333	26021
VIII								**62**	45577	7907	4188	22606	2893	32663
IX									**5931**	27776	45191	11093	41579	9872
X										**8841**	9589	13889	7980	20171
XI											**179**	26406	3057	34411
XII												**6466**	22288	9281
XIII													**3726**	30620
XIV														**11725**

Table 16 : Inter cluster (above diagonal) and intra-cluster (Diagonal) distance in grain amaranth (Summer 2008)

Cluster	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
I	**201.46**	210.83	236.33	273.34	207.13	251.25	190.14	277.76	228.53	216.33	227.37	223.35
II		**232.32**	240.11	276.48	221.33	254.76	200.82	280.91	232.72	225.61	234.33	235.67
III			**4.94**	54.06	296.27	58.27	166.79	63.84	17.43	185.75	37.36	288.25
IV				**5.36**	336.84	72.19	204.90	26.60	64.56	217.20	64.50	326.17
V					**196.90**	311.14	223.82	341.08	287.52	249.35	287.75	215.91
VI						**79.02**	183.37	79.47	64.01	200.23	69.13	301.54
VII							**166.99**	211.34	159.04	183.59	161.53	229.23
VIII								**15.03**	76.18	222.03	73.35	330.96
IX									**17.01**	179.90	39.48	280.23
X										**211.87**	181.03	253.24
XI											**33.57**	280.70
XII												**250.12**

Table 17 : Inter cluster (above diagonal) and Intra-cluster (diagonal) distance in Grain amaranth (*Kharif* 2008)

Cluster	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
I	**77.6**	70.5	112.5	153.0	79.3	84.0	136.2	156.2	97.4	119.2	158.8	80.6	149.8	93.3
II		**3.5**	123.8	184.9	75.6	68.6	164.0	182.8	70.1	141.4	190.7	70.1	179.0	79.9
III			**129.3**	133.4	99.8	125.4	118.8	131.5	149.0	113.3	138.4	112.7	129.6	131.5
IV				**4.5**	139.0	175.6	58.2	61.9	207.0	92.2	15.9	156.2	52.0	179.8
V					**4.9**	90.9	110.0	120.4	116.3	95.9	145.4	64.7	126.6	96.3
VI						**89.7**	157.6	177.5	92.0	137.5	181.1	88.8	171.1	94.5
VII							**52.8**	51.1	189.1	79.5	63.4	134.5	57.7	161.3
VIII								**7.9**	213.5	88.9	64.7	150.4	53.8	180.7
IX									**77.0**	166.7	212.6	105.3	203.9	99.4
X										**94.0**	97.9	117.9	89.3	142.0
XI											**13.4**	162.5	55.3	185.5
XII												**80.4**	149.3	96.3
XIII													**61.0**	175.0
XIV														**108.3**

inter cluster distance of 17.43. Cluster V and VIII were most diverse clusters as distance between them was 341.08. Cluster XII was most diverse cluster as many clusters showed maximum inter cluster distance with it. Wherein *kharif* experiment (Table 15 & 17) there were 14 clusters, the Cluster IV and Cluster XI were nearest to each other with an inter cluster distance of 15.9 . The most diverse clusters were cluster VIII and IX as distance between them was 213.5. Cluster III was most diverse cluster as many clusters showed maximum inter cluster distance with it.

4.5.3.1 Summer experiment

Cluster I which comprised 21 genotypes was closely related to Cluster VII, V, II and X with respect to D value of 190.14, 207.13, 210.83, and 216.33, respectively. Where it was more diverse with respect to cluster VIII (277.76) followed by IV (273.34) and VI (251.25) III (236.33), IX (228.53) XI (227.37) and cluster XII (223.35).

Cluster II, which comprised of 11 genotypes in the entire cluster showed low diversity with cluster VII (200.82) followed by cluster V (221.33) and X (225.61). clusters VIII, IV and VI were being more diverse with 'D' values of 280.91, 276.48 and 254.76 respectively.

Cluster III comprised 2 genotypes with less divergence with Clusters IX (17.43), XI (37.36), IV (54.06) and cluster VI (58.27). Exhibited more divergence with cluster V (296.27), XII (288.25) and cluster X (185.75).

Cluster IV showed closer relationship with cluster VIII, III, XI, IX and VI with D values of 26.60, 54.06, 64.50, 64.56 and 72.19, whereas cluster IV was more diverse from cluster V, XII, II, I and X with 'D' values of 336.84, 326.17, 276.48, 273.34 and 217.20 respectively.

Cluster V was less diverse towards clusters I and cluster XII with D values 207.13 and 215.91 respectively and VIII followed by IV, VI, XI, and IX with D values of 341.08, 336.84, 311.14, 287.75 and 287.52 respectively.

Cluster VI which comprised of ten genotypes was closely related with cluster VIII (79.47) followed by cluster IV (72.19) and showed less divergence with clusters III (58.27), IX (64.01) and XI (69.13) and exhibited more divergence from cluster V, XII, II and cluster I with D values of 311.14, 301.54, 254.76 and 251.25 respectively.

Cluster VII was closely spaced to cluster IX (159.04), XI (161.53) and III (166.79) and cluster VII showed more divergence with XII followed by V and VIII clusters, with respect to D values of 229.23, 223.82 and 211.34 respectively.

Cluster VIII exhibited close proximity with cluster IV (26.60) and cluster V (341.08) and XII (330.96) showed maximum distance.

Cluster IX exhibited more closeness with cluster III and XI with D value of 17.43 and 39.48 respectively and showed more diversity with cluster V with D value of 287.52 and cluster XII (280.23).

Cluster X showed less divergence with cluster XI (181.03) and showed maximum diversity with cluster XII (253.24).

Cluster XI was in close proximity with cluster III (37.36) and maximum inter cluster distance with cluster V (287.75) and followed by XII (280.70).

Cluster XII showed maximum distance with all most all the clusters and the cluster V nearest with D value 215.91 and the farthest was cluster VIII (330.96).

4.5.3.2 *Kharif* experiment

Cluster I comprised a maximum of 23 genotypes of all 14 clusters and the largest among the rest of the clusters, was closely related to cluster II followed by V, XII and VI with respect to D value of 70.05, 79.3, 80.60 and 84.0 respectively, and exhibited less divergence from cluster XIV (93.3) and IX (97.04). Maximum diversity was observed from cluster XI (158.8), VIII (156.2), VI (153.0) and XIII (149.8).

Cluster II, found in close proximity with cluster VI (68.6), nearest clusters were cluster IX and XII each being at a genetic distance of 70.1 followed by I, V and XIV with respect to 'D' values of 70.5, 75.6 and 79.9 respectively, with D value of 190.7 cluster XI was considered to be more diverse form cluster II followed by IV (184.9), VIII (182.8) and cluster XIII (179.0).

Cluster III was showed less diversity from cluster V (99.8) followed by XII (112.7) and X (113.3), and showed more divergence from Cluster IX (149.0) followed by XI (138.4), IV(133.4) and with clusters VIII and XIV each with D value of 131.5.

Cluster IV showed closer relationship with cluster XI (15.9) followed by XIII (52.0), VII (58.2), and VIII with D value 61.9, whereas cluster IV was more diverse from cluster IX (207.0) followed by II (184.9) and cluster XIV (179.8).

Cluster V was closely related to cluster XII (64.7) followed by II (75.6) and I (79.3), cluster V was more diverse from cluster X followed by cluster IV, XIII, VIII and IX with D value of 145.4, 139.0, 126.6, 120.4 and 116.3 respectively (Table 17).

Cluster VI which comprised of nine genotypes was closely related with cluster II, I, XII, V, IX and XIV with D value of 68.6, 84.0, 88.8, 90.9, 92.0 and

94.5. Whereas, cluster VI exhibited more divergence from cluster XI and VIII with D values of 181.1 and 177.5 respectively.

Cluster VII was closely spaced to cluster VIII, XIII, IV and cluster XI with D values 51.1, 57.7, 58.2 and 63.4 respectively. Cluster VII showed more divergence with cluster IX (189.1) followed by cluster II, XIV and cluster VI with respect to D values of 164.0, 161.3 and 157.6 respectively.

Cluster VIII exhibited more diversity with cluster IX (213.5) followed by cluster II, XIV, VI and cluster I with respect to D values of 182.8, 180.7, 177.5 and 156.2 respectively. Whereas, cluster VII showed close proximity with cluster VII (51.1) followed by XIII (53.8), IV (61.9) and cluster XI (64.7).

Cluster IX exhibited more closeness with cluster II with D value of 70.1 followed by cluster VI (92.0) and with cluster I (97.4), exhibited more diversity with cluster VIII (213.5), followed by cluster XI (212.6), XIII (203.9) and IV (207.4).

Cluster X was nearer to cluster VII (79.5) and showed maximum diversity with cluster IX (166.7) followed by XIV (142.0) and cluster II (141.4).

Cluster XI was in close proximity with cluster IV (15.9) and maximum inter cluster distance with cluster IX (212.6) and followed by II (190.7).

Cluster XII exhibited more closeness with cluster V with D value of 64.7 followed by cluster II (70.1) and with cluster VI (88.8). Exhibited more diversity with cluster XI (162.5) followed by IV (156.2), VIII (150.4) and XIII (149.3).

Cluster XIII showed close proximity with cluster IV (52.0) followed by VIII (53.8) and XI (55.3). It showed maximum inter cluster distance with IX (203.9) and II (179.0).

Cluster XIV comprised nine cluster showed minimum inter cluster distance to the cluster II (79.9) and farthest to the cluster XI (185.5).

4.5.4 Contribution of different clusters towards divergence

In summer experiment fresh weight of panicle contributed more towards divergence and stem girth at the collar region was the least contributor to genetic divergence, fresh weight of panicle was the single largest contributor to divergence with 48.57 per cent followed by grain yield per plant (30.93%), dry weight of panicle (10.18%), panicle length (2.93%), number of leaves (2.77%), 1000 seed weight (2.00%), days to 50% flowering (0.75%), plant height (0.65%), stem girth at ground level (0.46%), Days to maturity (0.38%), number of branches (0.28%) and stem girth at the crown level (0.1%) no trait showed zero contribution towards divergence (Table 20).

While in *kharif* experiment (Table 21) panicle length contributed more towards divergence and stem girth at ground level was the least contributor to genetic divergence, panicle length was the single largest contributor to divergence with 44.73 per cent followed by grain yield per plant (30.59%), number of leaves (12.12%), dry weight of panicle (4.42%), fresh weight of panicle (3.68%), 1000 seed weight (2.08%), Days to maturity (1.39%), plant height (0.61%), number of branches (0.18%), days to 50% flowering (0.10%), stem girth at the crown level (0.06%) and stem girth at the ground level (0.04%). All the characters contributed for genetic divergence in varying proportions with stem girth at the ground level and stem girth at the crown level were being very low contributors.

4.5.5 Cluster mean analysis

In summer experiment there were 12 clusters accommodating 100 genotypes, the genotypes in cluster VIII recorded less number of days to 50 percent flowering (35.70) followed by genotypes in cluster I (39.9). While the

Table 18 : Nearest and farthest clusters from the each cluster based on D value in Grain amaranth (Summer 2008)

Cluster	Nearest cluster with D value	Farthest cluster with D value
I	VII (190.144)	VIII(277.761)
II	VII (200.823)	VIII(280.91)
III	IX (17.431)	XII (288.245)
IV	VIII (26.595)	V(336.841)
V	I (207.13)	VIII(341.08)
VI	III(58.27)	V(311.14)
VII	IX (159.04)	VII(229.231)
VIII	IV(26.6)	V(341.08)
IX	III(17.43)	V(287.52)
X	IX (179.9)	XII (253.243)
XI	III (37.359)	V (287.747)
XII	V (215.91)	VIII(330.964)

Table 19 : Nearest and farthest clusters from the each cluster based on D value in Grain amaranth (*Kharif* 2008)

Cluster	Nearest cluster with D value	Farthest cluster with D value
I	II(70.5)	XI(158.8)
II	VI(68.6)	XI(190.7)
III	V(99.8)	IX(149)
IV	XI(15.9)	IX(207)
V	XII(64.7)	XI(145.4)
VI	II(68.6)	XI(181.1)
VII	VIII(51.1)	IX(189.1)
VIII	VII(51.1)	IX(213.5)
IX	II(70.1)	VIII(213.5)
X	VII(79.5)	IX(166.7)
XI	IV(15.9)	II(190.7)
XII	V(64.7)	XI(162.5)
XIII	IV(52)	IX(203.9)
XIV	II(79.9)	XI(185.5)

Table 20 : Contribution of characters towards genetic divergence in Grain amaranth (Summer 2008)

Sl. No.	Characters	Percent contribution (%)
1.	Days to 50 % flowering	0.75
2.	Days to maturity	0.38
3.	Stem girth at ground level (cm)	0.46
4.	Stem girth at crown level (cm)	0.10
5.	number of leaves per plant	2.77
6.	Number of branches per plant	0.28
7.	Plant height (cm)	0.65
8.	Panicle length (cm)	2.93
9.	Fresh weight of the panicle (g)	48.57
10.	Dry weight of the panicle (g)	10.18
11.	1000 seed weight (g)	2.00
12.	Grain yield per plant (g)	30.93

Table 21 : Contribution of characters towards genetic divergence in Grain amaranth (*Kharif* 2008)

Sl no	characters	Rank	Percent contribution
1.	Days to 50 % flowering	5	0.10
2.	Days to maturity	69	1.39
3.	Stem girth at ground level (cm)	2	0.04
4.	Stem girth at crown level (cm)	3	0.06
5.	number of leaves per plant	600	12.12
6.	Number of branches per plant	9	0.18
7.	Plant height (cm)	30	0.61
8.	Panicle length (cm)	2214	44.73
9.	Fresh weight of the panicle (g)	182	3.68
10.	Dry weight of the panicle (g)	219	4.42
11.	1000 seed weight (g)	103	2.08
12.	Grain yield per plant (g)	1514	30.59

genotypes in cluster IX took maximum number of days for 50 percent flowering (50.75) followed by genotypes in cluster VII (35.70). The results were presented in the table 22.

Whereas in *kharif* experiment there were 14 clusters, the genotype in cluster XI recorded less number of days to 50 percent flowering (35.00) followed by genotypes in cluster II (35.50). While the genotypes in cluster V took maximum number of days for 50 percent flowering (54.75) followed by genotypes in cluster X (50.19). The results were presented in the table 23.

The genotypes in cluster VIII took less number of days to mature (63.63), when compared with genotypes in cluster III which took more days to mature (89.13) in summer season. In *kharif*, genotypes in cluster XI took minimum days to mature (63.00), when compared with genotypes in cluster V which took more days to mature (92.46).

Cluster mean for stem girth at ground level in summer experiment ranged from 4.50 to 9.51cm, represented by cluster IX and Cluster XII respectively. Cluster V with 10.74cm stem girth at ground level recorded maximum while cluster IV recorded low stem girth at the ground level with 4.34cm in *kharif* experiment.

Cluster mean for stem girth at collar region was maximum in cluster XII (5.03cm) minimum cluster mean in IV cluster (2.72) in summer experiment. Stem girth at collar region ranged from 2.20 to 5.30cm, represented by cluster IV and cluster IX respectively in *kharif* experiment.

Genotypes in cluster XII with cluster mean value of 217.04 recorded maximum number of leaves per plant whereas, Genotypes in cluster VIII with cluster mean value of 102.61 recorded minimum number of leaves per plant in summer experiment. In *kharif* experiment genotypes in cluster II with cluster mean

Table 22 : Mean value of cluster over different characters in Grain amaranth (Summer 2008)

Cluster	Character											
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
I	39.90	78.04	7.70	4.07	213.35	8.17	110.65	45.76	211.70	77.24	0.78	23.18
II	43.17	83.03	6.90	4.00	202.57	7.66	95.02	39.51	208.03	86.72	0.83	24.47
III	46.67	89.13	5.05	3.20	136.63	17.89	69.85	22.89	130.85	49.58	0.69	14.02
IV	46.42	64.64	4.75	2.72	109.45	18.11	65.25	21.56	117.60	42.93	0.65	12.88
V	41.18	80.49	8.43	4.75	216.88	8.94	114.37	47.41	244.25	103.65	0.87	25.54
VI	44.73	85.70	6.42	3.55	157.88	12.83	90.45	28.24	125.41	52.84	0.72	16.96
VII	48.28	85.92	6.49	3.73	207.02	7.59	86.00	36.94	181.65	65.92	0.78	19.45
VIII	35.70	63.63	5.83	3.47	102.61	20.40	71.12	18.65	116.37	42.62	0.58	9.25
IX	50.75	86.61	4.50	2.82	141.46	16.48	62.23	20.81	135.22	48.67	0.77	16.64
X	46.01	81.85	7.26	3.98	186.56	11.26	91.86	32.92	178.47	65.06	0.77	20.07
XI	44.27	83.58	6.41	3.09	135.04	9.33	79.48	35.40	137.28	43.50	0.76	12.25
XII	46.98	84.45	9.51	5.03	217.04	7.04	128.86	42.81	229.33	96.36	0.89	28.51

X_1- days to 50 % flowering

X_2- days to maturity

X_3- stem girth at ground level (cm)

X_4- stem girth at crown level (cm)

X_5- number of leaves per plant

X_6 number of branches per plant

X^7 – plant height (cm)

X_8- panicle length (cm)

X9- fresh weight of the panicle (g)

X10- dry weight of the panicle (g)

X11- 1000 seed weight (g)

X12- grain yield per plant (g)

Table 23 : Mean value of cluster over different characters in Grain amaranth (*Kharif* 2008)

Cluster	Character											
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
I	39.67	78.39	6.88	3.27	200.86	9.14	100.38	45.09	201.71	73.27	0.78	21.07
II	35.50	76.00	9.99	4.01	261.55	7.13	120.17	50.44	209.91	81.34	0.81	20.81
III	41.00	81.93	5.83	2.92	189.20	10.42	79.14	36.63	196.60	83.03	0.80	22.33
IV	45.85	64.00	4.34	2.20	106.00	18.55	60.57	21.56	114.17	39.73	0.64	11.13
V	54.75	92.46	10.74	5.20	258.89	2.88	118.25	37.34	205.21	79.00	0.86	19.93
VI	40.46	80.37	7.82	4.01	209.59	9.54	107.91	47.18	240.15	103.02	0.88	24.12
VII	44.97	85.24	5.31	2.55	152.33	13.88	67.91	25.35	120.68	50.00	0.74	14.15
VIII	40.50	84.75	4.97	2.72	184.51	4.98	62.49	19.27	140.35	62.89	0.68	15.68
IX	45.45	86.00	10.12	5.30	197.64	11.60	142.43	55.45	170.58	63.86	0.74	16.85
X	50.19	84.92	5.83	2.95	166.18	12.38	78.50	30.19	173.24	59.97	0.75	17.80
XI	35.00	63.00	5.43	2.87	99.80	20.90	65.30	19.65	112.97	39.43	0.57	7.13
XII	46.99	83.21	7.84	3.80	241.77	8.34	100.32	43.82	194.57	69.72	0.79	17.83
XIII	42.96	78.60	4.92	2.59	136.72	13.86	62.97	21.99	138.35	48.52	0.68	14.56
XIV	47.55	83.45	8.98	4.20	212.18	8.10	126.73	47.05	227.21	92.02	0.91	26.24

X_1- days to 50 % flowering

X_2- days to maturity

X_3- stem girth at ground level (cm)

X_4- stem girth at crown level (cm)

X_5- number of leaves per plant

X_6 number of branches per plant

X_7 – plant height (cm)

X_8- panicle length (cm)

X_9- fresh weight of the panicle (g)

X_{10}- dry weight of the panicle (g)

X_{11}- 1000 seed weight (g)

X_{12}- grain yield per plant (g)

value of 261.55 recorded maximum number of leaves per plant whereas, genotypes in cluster XI with cluster mean value of 99.80 recorded minimum numbers of leaves per plant.

Lowest number of branches per plant (7.04) was found in the cluster XII while maximum of number of branches per plant (20.40) was observed in cluster VIII in summer experiment. The genotype with low mean value for number of branches per plant (2.88) was found in cluster V, while highly branched genotypes with the mean value (20.90) were accumulated in cluster XI in *kharif* experiment.

The tallest genotype (128.86 cm) was included in the cluster XII followed by V (114.37 cm). The shortest genotype (62.23 cm) was included in the cluster IX in summer season. In *kharif* season the tallest genotype (142.43 cm) was included in the cluster IX followed by XIV (126.73 cm). The shortest genotype (60.57 cm) was included in the cluster IV.

The cluster V included genotypes with maximum mean panicle length (47.41 cm) and cluster VIII with genotypes of minimum mean panicle length of 18.65 cm was observed in summer experiment. Where as in *kharif* experiment cluster mean of panicle length was ranged from 19.27 to 55.45 cm represented by clusters VIII and IX respectively.

In summer season genotypes in cluster VIII showed minimum of panicle fresh weight (116.37 g). The cluster mean in cluster XII showed maximum panicle fresh weight of 229.33g. Whereas, in *kharif* season cluster mean in cluster XI showed minimum panicle fresh weight of 112.97g and cluster VI with maximum panicle fresh weight of 240.15g.

Panicle dry weight was found maximum in cluster V with mean cluster value of 103.65g and minimum in cluster VIII with mean cluster value of 42.62g

in summer season. Whereas, in *kharif* season genotypes in cluster VI showed maximum of panicle dry weight (103.02g) and the cluster mean in cluster XII showed minimum panicle dry weight of 39.43g.

Genotypes exhibiting maximum 1000 seed weight were found in cluster XII (0.89) while cluster VIII (0.58) contained genotypes with minimum 1000 seed weight were observed in summer season. In *kharif* season genotypes exhibiting maximum 1000 seed weight were found in cluster XIV (0.91) while cluster XI (0.57) contained genotypes with minimum 1000 seed weight.

Cluster XII had genotypes with highest cluster mean seed yield of 28.51g while genotypes in cluster VI (9.25g) recorded lowest cluster mean seed yield in summer experiment. While in *kharif* experiment cluster XIV recorded highest seed yield per plant (26.24 g), whereas minimum seed yield per plant was recorded in cluster XI (7.13 g). The cluster mean values of 12 characters for twelve and fourteen clusters were presented in the table 22 and 23 for summer and *kharif* experiments respectively.

4.6 QUALITY CHARACTER

Amaranth grains are rich source of protein and excellent source of micronutrients. The data on protein percentage is presented in table 24.

4.6.1 Grain protein content

Grain amaranth is the rich source of protein and are excellent source of micronutrients the present investigation was carried to estimate the total seed protein. The protein content in the entire collection was ranged from 9.53 to 16.17% with mean value of 13.1% (Table 24). Highest protein content was recorded in the genotype IC-415331 (16.17%) followed by BGA-26 (15.49%), KBGA (15.32%), IC-415449 (15.17%), IC-421885 (15.11%) and IC-415318 (15.07%). The genotypes IC-415266 recorded the lowest protein content (9.53%) compared to the check Suvarna (13.89%).

Table 24 : Seed protein percentage of 100 genotypes of Grain amaranth

Sl.No	Genotypes	Protein content (%)	Sl. No	Genotypes	Protein content (%)
1	IC-415331	16.17	51	1C-415318	13.17
2	BGA-26	15.49	52	GA-2	13.16
3	KBGA-1	15.32	53	BGA-21	13.09
4	IC-415449	15.17	54	BGA-10	13.06
5	IC-421885	15.11	55	1C-415290	13.05
6	IC-415318	15.07	56	BGA-11	13.04
7	IC-415271	14.99	57	IC-423448	12.88
8	IC-415236	14.88	58	IC-415448	12.87
9	IC-415284	14.88	59	IC-519512	12.87
10	EC-519549	14.74	60	BGA-23	12.86
11	IC-415272	14.62	61	EC-519554	12.79
12	EC-519526	14.54	62	BGA-8	12.71
13	IC-423544	14.51	63	IC-415250	12.63
14	IC-415252	14.48	64	IC-38312	12.57
15	IC-37316	14.37	65	IC-415254	12.54
16	IC-415224	14.28	66	IC-415448	12.52
17	BGA-15	14.25	67	IC-415243	12.48
18	EC-519522	14.2	68	BGA-22	12.48
19	BGA-28	14.07	69	BGA-1	12.47
20	BGA-27	14.03	70	BGA-21	12.46
21	EC-519532	14.02	71	BGA-18	12.4
22	IC-415220	14.01	72	IC-415232	12.39
23	BGA-16	13.95	73	IC-423398	12.16
24	Suvarna(c)*	13.89	74	BGA-17	12.08
25	BGA-19	13.88	75	EC-519531	12.04
26	IC-423410	13.87	76	BGA-12	12.04
27	EC-519542	13.87	77	BGA-5	12.03
28	GA-1	13.87	78	IC-415268	12.01
29	IC-415262	13.84	79	IC-519543	11.89

30	BGA-6	13.79	80	IC-423400	11.88
31	IC-423408	13.77	81	IC-415387	11.84
32	IC-415297	13.77	82	EC-524457	11.74
33	IC-423408	13.76	83	IC-415290	11.73
34	IC-415280	13.73	84	BGA-7	11.69
35	BGA-14	13.7	85	IC-415316	11.67
36	BGA-20	13.66	86	IC-519558	11.67
37	IC-415274	13.64	87	BGA-4	11.67
38	IC-415282	13.6	88	IC-415462	11.58
39	EC-519527	13.59	89	IC-415258	11.58
40	IC-415466	13.58	90	IC-415317	11.57
41	IC-403548	13.58	91	IC-415498	11.57
42	IC-423408	13.55	92	BGA-9	11.56
43	IC-423117	13.53	93	IC-415314	11.49
44	IC-415433	13.5	94	IC-38127	11.49
45	IC-519548	13.47	95	BGA-25	11.48
46	IC-42311	13.45	96	BGA-3	11.47
47	EC-519517	13.43	97	IC-415264	11.42
48	IC-413426	13.4	98	EC-519592	11.36
49	BGA-24	13.36	99	IC-415222	10.58
50	IC-415320	13.32	100	IC-415266	9.53
	MIN		9.53		
	MAX		16.17		
	MEAN		13.1		
	S.Em $\pm$		0.066		
	CD at 5%		0.13		

* Check

Table 25 : Mean values of Grain amaranth genotypes over 12 different characters (Summer 2008)

Genotypes	Characters											
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
IC-415264	45.90	84.24	12.68	6.90	169.16	5.65	173.14	60.79	328.73	198.50	0.98	43.50
EC-519554	44.37	84.84	10.83	5.61	179.58	10.41	115.38	51.27	287.42	171.50	1.40	40.50
IC-519512	40.30	80.80	6.70	4.11	243.97	6.70	101.26	47.49	246.63	140.00	0.84	39.50
IC-415448	38.76	79.29	5.50	3.68	193.89	4.05	92.75	55.31	298.90	177.50	0.90	38.50
IC-42311	40.29	80.80	6.73	4.11	137.50	7.75	99.23	46.49	246.63	123.00	0.84	37.00
IC-415280	44.89	83.33	11.75	6.32	160.08	5.05	151.72	49.42	312.80	170.50	0.96	37.00
BGA-16	45.90	83.33	11.80	6.79	263.92	14.94	152.28	53.87	327.00	85.17	0.87	37.00
IC-415448	38.77	79.29	5.60	3.68	195.14	5.26	97.00	55.31	298.90	90.04	0.90	34.50
IC-421885	48.46	85.85	9.60	4.33	246.53	6.25	158.05	51.96	237.94	87.96	0.90	34.00
IC-415254	41.83	69.19	11.65	5.08	248.76	7.18	119.00	39.32	254.47	86.09	0.87	33.50
IC-423408	58.65	88.38	5.65	3.04	146.30	12.23	79.25	21.83	301.00	93.00	0.68	31.50
KBGA-1	45.90	92.92	12.51	6.90	102.81	1.14	189.05	57.25	313.75	100.31	0.94	30.87
IC-423398	40.81	82.82	5.70	3.04	273.50	7.52	88.71	39.68	166.50	82.14	0.88	30.50
IC-415250	37.74	79.79	6.85	3.68	79.50	5.46	93.61	45.67	307.23	96.29	0.90	30.28
Suvarna(c)*	55.08	90.90	8.72	4.11	380.50	2.25	163.89	44.67	221.39	84.96	0.93	30.05
IC-415224	39.79	80.80	8.80	4.75	175.29	5.36	110.45	46.35	298.00	150.00	1.08	29.02
IC-415449	39.78	80.80	8.80	4.65	175.29	5.36	101.02	46.35	298.00	93.04	0.91	27.91
GA-1	55.59	93.43	8.72	4.54	216.44	4.25	109.43	42.13	191.06	71.85	0.90	27.50
IC-415282	40.80	85.35	5.05	3.15	186.70	4.55	64.88	18.27	143.21	74.00	0.69	26.50
EC-519522	41.31	80.80	9.85	5.18	230.85	10.41	128.80	51.13	275.99	89.61	0.87	26.23
BGA-26	45.39	88.38	12.85	7.52	235.95	16.69	175.55	47.83	269.15	90.41	0.90	26.23
1C-415318	43.36	82.32	3.95	3.25	237.02	5.26	68.20	46.95	257.61	87.02	0.86	25.46
IC-415268	37.24	69.69	8.80	4.22	215.71	4.25	103.31	44.96	282.62	91.30	0.87	25.43
IC-415320	43.36	82.32	3.90	3.25	240.27	5.26	66.25	47.95	257.61	87.02	0.86	25.19
IC-519548	37.24	76.76	9.75	4.65	237.26	4.70	141.89	49.93	276.65	89.30	0.85	24.50
IC-415290	47.94	83.83	9.46	4.00	240.65	6.70	159.93	50.76	141.00	87.96	0.90	24.44
EC-519531	49.57	81.81	8.75	4.65	379.28	11.85	114.75	45.78	211.58	84.17	0.82	24.40
IC-403548	40.30	82.82	4.75	3.25	381.79	5.57	59.64	29.43	210.57	83.35	0.82	24.20
1C-415290	35.71	76.76	10.65	4.75	265.52	6.70	128.50	50.44	216.22	85.79	0.77	23.93
IC-415232	35.70	76.76	10.65	4.75	263.52	7.75	125.28	50.44	216.22	85.79	0.77	23.72
BGA-28	45.90	83.33	11.80	6.79	263.92	14.94	145.77	53.87	231.28	85.17	1.55	23.68
IC-415271	37.75	69.19	8.70	4.11	270.31	6.29	99.00	44.45	212.90	84.15	0.72	23.23
IC-423544	35.71	76.76	10.65	4.75	265.52	7.25	127.75	50.44	216.22	85.79	0.77	22.99
BGA-12	45.90	83.83	12.50	6.79	256.00	15.46	147.05	54.82	216.77	86.26	0.90	22.91
BGA-18	55.08	92.92	10.85	6.47	260.75	2.06	132.00	37.05	210.04	83.38	0.86	22.40

BGA-8	48.96	80.80	8.65	4.33	232.18	7.73	108.10	43.75	191.35	70.87	0.79	22.36
IC-37316	48.46	90.90	5.60	3.04	240.54	6.70	73.81	25.87	118.50	71.87	0.78	22.21
BGA-4	55.08	92.92	10.75	6.26	257.48	2.06	129.63	36.14	210.04	83.38	0.88	21.89
GA-2	55.08	92.92	10.93	5.93	265.94	2.75	121.32	36.55	212.72	83.38	0.86	21.72
BGA-20	48.96	80.80	8.75	4.00	211.54	9.50	114.25	41.93	193.15	72.80	0.85	21.48
EC-519542	46.92	81.31	6.90	4.00	270.60	6.70	94.10	40.81	218.39	82.91	0.82	21.38
EC-519532	47.94	85.60	5.65	3.25	283.72	3.61	67.20	47.41	221.87	82.15	0.78	21.38
IC-415220	38.26	73.73	9.70	4.11	181.50	6.49	122.88	50.03	210.75	81.69	0.82	21.19
BGA-21	45.40	91.91	5.70	3.36	254.26	10.82	79.40	25.38	196.21	80.92	0.79	21.13
IC-415331	40.81	80.30	4.30	3.25	187.92	8.45	75.71	36.53	209.61	80.61	0.78	20.94
EC-524457	47.94	85.85	11.75	5.93	257.01	7.73	151.50	48.63	200.04	79.12	0.77	20.87
EC-519549	58.66	92.42	6.55	3.90	196.60	10.75	87.75	25.89	168.28	65.28	0.95	20.83
IC-38312	37.23	74.74	6.70	3.90	185.40	9.25	96.98	44.01	165.38	54.67	0.69	20.67
IC-415272	36.72	76.76	4.90	2.50	260.06	8.25	71.61	41.76	202.48	75.29	1.15	20.44
IC-415316	38.77	82.82	3.85	2.50	261.59	5.25	74.77	39.12	201.42	77.83	0.77	20.44
EC-519526	42.34	84.34	5.85	3.25	256.58	7.75	79.67	28.02	201.49	72.84	0.86	20.36
EC-519517	49.57	80.30	8.65	4.33	242.41	7.73	99.97	41.93	194.20	70.87	0.77	20.11
IC-423410	39.28	83.33	3.75	2.50	255.01	8.66	72.80	41.71	204.52	78.89	0.77	20.06
IC-415266	38.25	77.77	3.90	2.50	235.31	7.32	56.26	37.85	196.29	71.40	0.75	19.68
IC-415314	39.79	83.33	6.70	3.68	240.37	9.65	97.14	42.24	196.73	75.76	0.75	19.68
IC-415387	57.12	88.38	5.90	3.36	240.21	8.76	81.30	26.89	107.00	70.01	0.77	19.34
IC-415258	48.71	77.77	5.70	3.47	214.31	8.35	85.47	40.90	198.20	99.50	0.76	19.27
IC-415318	40.30	88.38	6.65	3.58	235.64	8.76	97.75	40.69	193.72	59.57	0.75	19.09
IC-519543	48.72	76.76	5.60	3.25	238.03	7.30	90.70	38.76	198.20	59.80	0.76	19.09
IC-415462	38.26	84.34	13.65	7.54	187.67	7.52	225.09	56.33	206.50	53.53	0.70	18.89
IC-415498	38.26	84.34	13.65	7.50	184.42	7.52	231.98	56.33	142.07	53.53	0.70	18.83
IC-415262	40.81	85.35	5.60	3.47	186.70	4.40	70.80	18.27	145.92	55.34	0.69	18.53
BGA-17	35.20	68.18	5.50	3.15	193.66	12.88	64.92	21.83	164.04	67.67	0.72	18.32
BGA-27	52.54	92.42	7.65	3.90	100.29	15.66	89.65	25.43	117.89	60.00	0.67	18.00
BGA-6	35.20	69.19	4.85	2.72	104.52	18.03	58.65	16.75	119.35	48.18	0.68	17.77
IC-415243	38.26	83.83	8.70	3.90	135.81	15.68	129.75	51.55	131.85	47.78	0.68	17.67
IC-415433	37.24	73.73	6.70	3.68	186.65	13.25	91.38	44.01	165.38	54.67	0.71	17.62
BGA-24	56.62	88.38	5.65	3.15	96.72	15.66	68.85	21.83	121.10	46.10	0.66	17.52
IC-423408	38.26	67.17	6.20	3.36	186.19	14.53	84.50	26.89	139.90	52.52	0.70	17.30
BGA-22	38.76	87.87	6.55	3.47	141.83	5.75	81.45	27.61	129.84	49.34	0.79	17.30
IC-415274	39.28	68.18	5.75	3.36	75.50	11.25	86.41	42.16	106.00	54.78	0.68	17.13
IC-415252	46.41	83.13	3.60	2.40	106.17	19.89	53.98	24.25	116.19	42.41	0.66	17.13
BGA-23	38.26	88.38	5.85	3.15	139.50	7.73	78.48	26.50	132.77	49.34	0.69	17.05
BGA-7	40.30	80.30	5.60	3.47	92.47	4.64	64.54	17.77	114.52	40.57	0.70	17.01
EC-519527	46.51	79.39	6.80	3.90	140.98	16.69	98.65	44.06	134.89	48.14	0.67	16.96

BGA-11	27.55	59.59	5.80	3.47	142.27	5.36	80.19	24.74	119.13	47.45	0.67	16.79
BGA-25	51.52	89.39	4.85	2.72	132.37	19.05	63.52	23.86	134.78	49.89	0.73	16.79
IC-415466	40.30	72.22	4.65	3.15	182.57	12.88	79.00	35.01	139.97	52.51	0.69	16.65
IC-423408	46.41	89.39	4.90	3.25	134.40	17.75	69.90	23.39	130.85	49.58	0.69	16.54
BGA-21	49.98	83.83	4.15	2.93	150.54	13.91	60.95	17.77	135.67	47.45	0.80	16.49
BGA-9	49.99	87.87	4.15	2.61	150.09	11.75	53.78	17.77	232.00	47.45	0.69	16.49
IC-415317	45.40	86.36	6.60	3.58	131.73	18.81	87.00	25.87	130.30	48.81	0.85	16.28
IC-415236	36.73	72.72	4.60	3.25	136.36	13.25	86.34	45.26	135.18	48.97	0.68	16.16
IC-415222	47.43	88.38	3.85	2.50	104.66	21.13	54.53	17.75	119.14	44.46	0.67	15.77
BGA-5	44.38	86.86	5.70	3.36	102.45	11.75	70.69	20.81	119.13	45.43	0.70	15.52
IC-38127	45.39	88.38	12.65	7.65	235.95	16.69	165.64	48.83	269.15	90.41	0.88	15.50
BGA-1	38.26	66.16	6.60	3.68	114.55	10.82	90.17	25.38	116.30	43.39	0.66	15.26
IC-423117	46.42	64.64	4.90	2.72	108.76	18.03	67.00	21.56	116.69	42.42	0.64	15.26
IC-423448	51.01	90.90	4.20	2.72	105.29	21.0	61.75	23.39	119.25	45.34	0.66	13.50
BGA-15	43.35	83.33	6.20	2.50	129.25	12.00	79.23	36.29	141.40	52.50	0.72	13.00
IC-415284	40.30	83.33	3.90	2.72	81.13	14.65	77.32	41.96	102.81	30.74	0.65	12.10
IC-519558	44.37	84.34	5.75	2.83	104.43	16.25	69.75	25.36	115.31	43.22	0.64	12.00
BGA-10	45.19	83.83	6.62	3.68	140.84	6.65	79.73	34.52	133.16	34.50	0.80	11.50
IC-413426	46.93	88.88	5.20	3.15	138.86	18.03	69.80	22.39	130.85	49.58	0.69	11.50
BGA-19	38.25	66.16	6.20	3.58	97.71	20.10	69.00	18.02	114.82	39.59	0.66	10.50
IC-423400	46.41	64.64	4.60	2.72	110.14	18.19	63.50	21.56	118.51	43.43	0.66	10.50
BGA-3	51.52	85.35	5.45	2.72	96.53	17.00	49.27	14.21	110.70	29.11	0.50	9.50
EC-519592	47.43	65.15	9.56	4.65	194.46	12.88	93.84	26.14	170.87	57.00	0.60	8.50
IC-415297	54.28	95.95	6.20	3.58	97.69	9.50	87.50	53.80	112.70	39.24	0.54	8.50
BGA-14	33.16	61.11	5.45	3.36	107.52	20.71	73.25	19.29	117.92	45.64	0.50	8.00
MIN	27.55	59.59	3.60	2.40	75.50	1.14	49.27	14.21	102.81	29.11	0.50	8.00
MAX	58.66	95.95	13.65	7.65	381.79	21.13	231.98	60.79	328.73	198.50	1.55	43.50
MEAN	43.91	81.44	7.32	4.04	192.85	10.04	99.77	37.59	190.18	74.34	0.79	21.54

* Check

X_1- days to 50 % flowering

X_2- days to maturity

X_3- stem girth at ground level (cm)

X_4- stem girth at crown level (cm)

X_5- number of leaves per plant

X_6 -number of branches per plant

X_7 – plant height (cm)

X_8- panicle length (cm)

X_9- fresh weight of the panicle (g)

X_{10}- dry weight of the panicle (g)

X_{11}- 1000 seed weight (g)

X_{12}- grain yield per plant (g)

Table 26 : Mean values of Grain amaranth genotypes over 12 different characters (*Kharif* 2008)

Genotypes	Characters											
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
IC-415264	42.50	83.70	11.79	5.92	166.40	5.15	166.64	60.79	319.14	209.00	0.98	40.00
IC-415448	38.50	79.75	5.10	3.06	189.98	5.55	89.89	55.31	290.19	149.50	0.97	38.13
IC-519512	40.25	81.00	6.00	3.44	245.89	6.50	94.02	47.49	239.43	140.00	0.83	37.25
EC-519554	43.75	84.00	9.83	4.78	178.67	10.39	110.56	52.27	279.03	171.50	1.40	36.00
BGA-16	45.50	82.25	11.30	5.83	261.75	15.50	141.42	54.87	327.00	80.73	0.86	35.13
IC-415280	43.00	82.50	10.75	5.41	155.81	3.05	150.45	49.42	292.58	170.50	0.95	34.50
IC-415254	42.50	68.44	12.15	4.30	243.59	7.93	109.21	39.32	254.13	77.22	0.86	34.50
IC-42311	39.75	80.00	6.20	3.44	139.50	7.50	94.89	47.49	239.43	123.00	0.83	32.75
IC-421885	47.98	86.35	9.10	3.63	240.95	7.00	149.01	51.96	222.07	84.82	0.82	32.00
IC-415448	38.38	79.29	5.10	3.06	191.39	5.62	91.33	55.31	290.19	86.66	0.89	31.75
IC-423408	57.25	86.75	5.06	2.48	141.35	11.48	72.58	22.83	301.00	93.00	0.67	29.63
IC-415250	37.37	79.50	6.85	3.06	79.50	6.15	86.81	45.67	298.27	91.53	0.89	29.63
KBGA-1	45.50	92.00	11.45	5.92	100.40	2.80	182.08	58.25	304.60	95.44	0.93	28.99
IC-423398	40.40	82.50	4.46	2.48	270.50	7.40	82.20	39.68	166.50	77.79	0.88	28.25
Suvarna(c)*	55.50	90.00	8.15	3.44	376.97	3.00	157.66	45.67	214.93	80.54	0.92	28.18
IC-415224	38.00	80.50	8.30	4.01	174.50	5.60	98.92	46.35	289.31	150.00	1.08	27.50
IC-415449	38.00	80.00	8.30	3.92	174.50	5.60	96.62	46.35	289.31	88.38	0.90	26.83
GA-1	54.75	94.18	8.15	3.82	211.14	4.00	104.79	43.13	185.49	67.82	0.90	25.63
1C-415318	42.25	81.75	3.73	2.68	233.17	6.80	60.95	47.95	250.09	82.54	0.85	25.00
IC-415268	38.25	70.19	9.80	3.53	211.89	7.00	96.91	44.96	264.86	85.92	0.86	24.50
IC-415320	42.93	81.75	3.90	2.68	235.67	5.62	62.01	47.95	250.09	84.18	0.85	24.38
IC-415290	47.97	84.33	8.59	3.34	240.00	6.45	153.82	51.76	141.00	83.45	0.89	24.13
BGA-26	44.25	88.00	13.50	6.49	234.63	17.85	163.24	48.83	261.30	88.99	0.89	23.85
IC-415220	38.75	73.00	9.00	3.44	178.50	6.65	114.40	50.03	204.60	77.36	0.81	23.00
IC-423544	36.50	76.50	10.18	4.01	261.55	8.00	120.17	50.44	209.91	81.34	0.76	23.00
IC-415232	35.50	75.50	10.15	4.01	261.55	6.75	120.17	50.44	209.91	81.34	0.85	22.88
IC-415271	35.00	69.44	8.20	3.44	263.46	5.80	89.55	44.45	213.85	79.74	0.71	22.63
EC-519542	46.50	81.25	6.49	3.34	270.63	7.50	89.60	41.81	212.02	78.55	0.81	22.50
IC-415282	40.50	84.75	4.58	2.58	184.76	4.80	61.53	19.27	139.03	74.00	0.68	22.13
EC-519522	41.25	80.00	9.26	4.39	229.55	11.30	121.71	52.13	267.94	87.11	0.86	21.50
BGA-12	45.50	83.00	11.75	5.83	254.75	16.25	136.51	55.82	210.45	81.79	0.89	21.04
BGA-28	44.95	82.75	11.08	5.83	263.75	12.00	141.42	54.87	224.54	80.73	0.86	20.75
BGA-18	54.50	92.00	10.22	5.54	260.15	3.16	123.06	38.05	203.91	79.00	0.85	20.50

EC-524457	47.47	85.85	10.98	5.06	255.76	8.50	144.21	49.63	194.20	74.86	0.76	20.50
IC-519548	36.75	77.00	9.75	3.92	233.77	4.95	133.63	49.93	257.94	82.29	0.84	20.28
BGA-4	54.50	92.00	11.28	5.35	256.00	3.25	120.17	37.14	203.91	79.00	0.87	20.02
IC-37316	47.75	90.00	4.97	2.48	236.44	7.50	66.93	25.87	118.50	74.25	0.91	20.00
IC-415316	36.50	82.50	3.85	2.01	255.09	6.75	63.87	39.12	195.55	73.62	0.76	20.00
IC-403548	37.75	82.50	4.55	2.68	383.31	5.70	54.80	29.43	204.43	78.97	0.81	19.95
IC-415331	40.40	80.75	4.50	2.68	183.92	8.60	69.94	36.53	203.49	80.03	0.86	19.88
GA-2	55.00	92.92	10.20	5.06	261.77	2.50	116.33	37.55	206.51	79.00	0.85	19.84
IC-415272	35.75	76.00	4.15	2.01	255.06	7.75	68.07	41.76	196.57	87.50	1.15	19.81
EC-519531	49.30	81.00	8.12	3.92	379.00	12.50	110.08	46.78	205.41	79.76	0.81	19.63
EC-519532	47.50	83.50	5.06	2.68	283.75	4.50	62.88	48.41	215.39	77.80	0.78	19.51
IC-415498	37.75	83.75	12.70	6.52	181.61	8.40	211.02	56.33	137.93	56.77	0.69	19.50
BGA-21	44.75	90.00	5.20	2.77	250.06	11.50	73.07	26.38	190.48	76.62	0.79	19.25
BGA-20	48.48	80.00	8.12	3.34	207.54	9.25	105.75	42.93	187.52	68.74	0.84	19.23
1C-415290	35.50	76.50	9.83	4.01	261.55	7.50	120.17	50.44	209.91	81.34	0.76	18.75
EC-519549	56.75	91.25	5.83	3.25	194.76	12.00	81.24	26.89	163.37	61.43	0.95	18.50
IC-519543	48.88	76.50	5.10	2.68	232.04	8.48	86.99	38.76	192.42	56.11	0.75	18.50
IC-415266	37.75	77.00	3.90	2.01	231.31	7.55	53.17	37.85	190.56	67.37	0.80	18.38
IC-415314	37.89	82.75	7.00	3.06	234.22	8.68	98.44	42.24	190.99	70.66	0.79	18.25
IC-415258	47.38	76.50	5.30	2.87	214.20	8.05	81.53	40.90	192.42	99.50	0.80	18.18
EC-519526	42.25	82.75	5.44	2.68	253.05	7.00	76.62	29.02	195.61	68.78	0.86	18.13
IC-415317	44.25	85.75	6.10	2.96	130.00	19.38	79.79	25.87	126.50	45.44	0.85	18.00
IC-423410	38.89	83.25	3.75	2.01	250.99	8.25	71.22	41.71	198.55	76.96	0.76	18.00
EC-519517	48.80	79.75	7.93	3.63	240.89	9.50	96.52	42.93	188.53	66.86	0.76	17.88
IC-38312	36.25	74.00	6.20	3.25	184.60	12.25	92.70	44.01	160.55	51.13	0.68	17.88
IC-415262	40.50	84.75	5.37	2.87	184.26	5.15	63.45	19.27	141.66	51.78	0.68	17.23
IC-415318	39.25	86.25	6.15	2.96	230.83	9.50	95.45	40.69	188.07	55.89	0.74	17.00
BGA-8	48.50	80.00	7.93	4.23	230.73	7.91	99.98	44.75	185.76	66.86	0.79	16.63
BGA-17	35.25	67.00	4.28	2.58	192.28	13.50	59.48	22.83	159.26	63.76	0.71	16.45
BGA-27	52.25	91.25	6.32	3.25	98.13	16.35	82.68	26.43	114.45	60.00	0.66	16.13
BGA-9	49.50	87.00	3.63	2.10	146.38	14.50	49.03	18.77	232.00	44.12	0.68	16.10
IC-415243	36.25	83.50	8.20	3.25	131.05	19.88	121.62	51.55	128.01	49.50	0.67	16.00
IC-415274	38.89	67.50	5.25	2.77	73.50	13.50	80.82	42.16	108.00	52.37	0.81	15.50
IC-415236	36.50	72.50	4.60	2.68	129.32	15.00	80.75	45.26	125.94	53.58	0.72	15.50
BGA-22	38.50	88.37	6.28	2.87	138.16	8.50	74.99	28.61	126.06	45.96	0.79	15.43
BGA-23	37.75	87.00	5.85	2.58	136.93	8.50	72.20	27.50	128.89	45.96	0.68	15.17
IC-415466	40.75	72.97	4.15	2.58	180.54	12.68	85.36	35.01	135.89	53.28	0.68	15.00
BGA-25	51.25	88.25	4.60	2.20	131.33	21.30	58.17	24.86	130.84	46.49	0.72	14.92

IC-415462	37.88	83.25	14.00	6.59	184.11	7.72	219.07	56.33	206.50	50.02	0.69	14.88
IC-415387	57.00	87.75	5.65	2.77	236.27	10.00	73.07	26.89	107.00	66.02	0.76	14.63
BGA-11	27.50	60.00	5.80	2.87	140.83	6.35	73.80	25.74	115.66	44.12	0.66	14.54
EC-519527	46.30	78.80	6.30	3.25	137.66	15.35	94.51	45.06	130.95	44.79	0.66	14.33
IC-415433	36.87	74.23	5.20	3.06	185.10	11.73	92.96	44.01	160.55	51.13	0.70	14.25
BGA-21	49.50	83.50	3.63	1.91	148.50	15.50	55.76	18.77	131.71	44.12	0.80	14.24
IC-423408	46.25	88.25	4.90	2.68	132.35	18.11	64.22	23.39	127.03	46.19	0.62	14.16
IC-423117	45.96	64.50	4.58	2.20	105.90	17.50	60.57	21.56	113.28	39.24	0.63	14.13
IC-38127	43.75	88.38	12.15	6.59	235.63	16.10	159.36	48.83	261.30	85.82	0.76	14.00
BGA-24	55.75	89.13	5.06	2.58	94.33	16.35	63.17	22.83	117.57	42.81	0.65	13.64
IC-415222	46.97	87.75	3.85	2.01	102.83	18.25	48.55	17.75	115.67	41.22	0.66	13.40
BGA-6	35.25	68.25	5.10	2.20	101.26	18.50	53.60	17.75	115.87	44.83	0.67	13.40
BGA-1	37.75	65.25	5.92	3.06	111.83	11.50	83.16	26.38	112.90	40.18	0.65	13.39
IC-415252	43.75	82.15	3.75	2.02	102.68	19.65	50.96	24.25	112.80	39.23	0.65	13.26
BGA-7	39.25	80.55	4.97	2.87	89.68	6.00	59.13	18.77	111.18	37.45	0.70	13.13
IC-423408	38.25	66.25	5.63	2.77	184.50	15.80	77.87	26.89	135.82	49.04	0.73	13.00
BGA-5	44.25	86.00	5.20	2.77	101.22	15.00	64.89	21.81	115.66	42.16	0.69	12.52
BGA-15	43.25	82.25	5.63	2.01	127.75	11.25	75.47	37.29	137.27	49.02	0.71	10.63
IC-423448	51.00	90.00	3.73	2.20	103.65	20.50	55.28	23.39	115.77	42.08	0.65	10.13
IC-415284	39.90	83.75	3.90	2.20	77.95	17.65	79.09	41.96	99.81	47.00	0.64	9.35
BGA-10	44.65	83.00	6.87	3.06	138.60	8.40	75.95	35.52	129.27	34.50	0.80	9.13
BGA-19	37.25	65.75	5.90	2.96	94.83	20.50	63.31	19.02	111.47	36.50	0.65	9.00
BGA-3	50.25	83.50	4.68	2.20	93.73	17.50	44.80	15.21	107.47	32.03	0.50	8.63
IC-423400	45.75	63.50	4.10	2.20	106.09	19.60	60.57	21.56	115.05	40.22	0.65	8.13
IC-413426	46.50	88.00	4.68	2.58	135.60	18.00	65.95	23.39	127.03	46.19	0.68	8.00
IC-519558	43.25	84.25	5.75	2.29	102.22	16.50	62.49	25.36	111.95	40.02	0.63	7.63
IC-415297	53.60	94.50	4.95	2.96	90.44	9.75	80.75	54.80	109.41	36.15	0.53	6.13
EC-519592	46.75	64.25	9.05	3.92	193.68	14.00	89.65	27.14	165.89	57.00	0.60	6.13
BGA-14	32.75	60.25	4.95	2.77	104.78	21.0	67.30	20.29	114.48	42.37	0.50	5.25
MIN	27.50	60.00	3.63	1.91	73.50	2.50	44.80	15.21	99.81	32.03	0.50	5.25
MAX	57.25	94.50	14.00	6.59	383.31	21.30	219.07	60.79	327.00	209.00	1.40	40.00
MEAN	43.30	80.94	6.87	3.37	189.45	10.57	93.12	38.09	184.34	70.79	0.78	19.36

* Check

X_1- days to 50 % flowering

X_2- days to maturity

X_3- stem girth at ground level (cm)

X_4- stem girth at crown level (cm)

X_5- number of leaves per plant

X_6 -number of branches per plant

X_7 – plant height (cm)

X_8- panicle length (cm)

X_9- fresh weight of the panicle (g)

X_{10}- dry weight of the panicle (g)

X_{11}- 1000 seed weight (g)

X_{12}- grain yield per plant (g)

DISCUSSION

V. DISCUSSION

The main aim of plant breeding programme is to improve the plant traits for agronomic, economic and nutritional values. However, the important quantitative traits are under polygenic control and display a great variety of genotypes x environment interaction. The knowledge about nature and extent of variability present in the germplasm collections is important in planning a sound breeding strategy. In addition to this information on various genetic parameters, association between traits will provide a strong insight into genetic control of those traits. The evaluation of germplasm is a pre-requisite to identify the superior sources for various traits and for their efficient utilization in further breeding programme.

Classification of genetic stock based on the genetic variability is an important step in any crop improvement programme. Success of plant breeding depends on the selection of parents, which are genetically more diverse for various traits. Therefore, collection of information on genetic variability, their heritability and genetic advances are important. Yield is a function of several complex characters and their interactions with environment.

Grafius (1964) has pointed out that it would be more meaningful if the structure of yield were provided through its components rather than *per* se performance. For improving yield through breeding, it is necessary to study these yield components, their interrelationship with yield and their direct and indirect contributions. Genotypic and phenotypic correlations reveal degree of association between different traits. These parameters help to base selection procedures to a required balance when two opposite desirable characters affecting the principal characters are being selected (Falconer, 1960). It also helps to improve different characters simultaneously.

Path coefficient analysis gives the information on direct and indirect effects of component characters on yield, which finally make up correlation coefficient. Mahalanobis D^2 statistic is used to quantify the degree of genetic divergence present in the populations and to know the contributions of different characters towards the divergence.

Therefore, in the present study, an attempt has been made to assess the genetic parameters, such as variability, heritability, genetic advance, character association, path coefficient analysis and genetic diversity in 100 accessions of grain amaranth including *Amaranthus hypochondriacus, A. cruentus* and *A. edulis.* The results obtained have been discussed in this chapter under following headings.

1) Analysis of variance

2) Variability parameters, heritability and genetic advance

3) Interrelationship and path analysis

4) Genetic divergence

6) Nutritional analysis

5.1 Analysis of variance

Analysis of variance indicated highly significant differences among the collections for all the 12 characters studied in both summer and *kharif* experiment. The wide differences observed in the traits may be attributed to their genetic make up and evolution under different ecological niches. These range of values provide a bright scope to select the desirable material and can be used in breeding programmes for further improvement.

5.2 Genetic variation

5.2.1 *Per se* performance for yield and yield contributing traits

The information on *per* se performance of the germplasm accession is important for selection of better genotype, but in the grain amaranth, not only yield but quality parameters such as protein content, minerals and resistance to drought, short duration, better stand ability are also important.

In the present study of genetic divergence , the genotypes IC-415264 (43.5 g), EC-519544 (40.50g), IC-519512 (39.5g) and IC-415448 (38.50g) were excellent grain yielders, over check (suvarna 30.05 g) in summer. In *kharif* experiment, the genotypes IC-415264 (40.0g), IC-415448 (38.13g) IC-519512 (39.5g) EC-519544 (40.50g), and were excellent grain yielders over check (suvarna 30.05 g). This can be attributed to higher panicle fresh weight, higher panicle dry weight, higher panicle length and higher 1000 seed weight. While BGA-14 was the poorest yielder in both experiments which may be due to low panicle fresh weight, panicle dry weight, low panicle length and low 1000 seed weight. These findings are in conformity with the results of Patgar (2003) and Hazra (2004).

5.2.2 Variability, heritability and genetic advance parameters

Genetic variability which is an index of diversity forms the basis for improvement of crop plants can be enriched by collecting genotypes from different eco- geographical regions or from the segregation of natural or artificial hybrids .Genetic variability is the basic knowledge required for breeders to improve the crops by adopting suitable selection criterion. The value of phenotypic variability includes genotypic, environment and interaction due to genotype and environment. Assessment of heritable and non heritable components of variability are important for the breeder when genetic component is more, it is also necessary to understand

IC – 415264

EC - 519554

Plate 1 : Top yielding genotypes of Grain amaranthus

IC-519512

IC-415448

Plate 2 : Top yielding genotypes of Grain amaranthus

the inter relationships existing among the characters to achieve fruitful results through selection.

In the present investigation, analysis of variance for all the 12 characters in both summer and *kharif* experiment revealed highly significant differences among genotypes this information suggested that sufficient variability existed for these characters to facilitate improvement through selection. However, analysis of variance by itself is not enough and conclusive to explain all the inherent genotypic divergence in the collections. This is revealed by determining the total genetic variability inherent in the genotypes obtained after due partitioning of the phenotypic variance (Charles and Smith, 1939; Grafius, 1964). Thus, it is necessary to work out phenotypic and genotypic coefficients of variation.

The phenotypic coefficient of variation was higher than the genotypic coefficient of variation for all the character studied in both seasons. The characters like number of branches, dry weight of panicle, grain yield, plant height, and number of leaves, fresh weight of panicle and panicle length showed high phenotypic and genotypic coefficient of variation in summer experiment as well as in *kharif* experiment. Hence, it may be expected that simple selection would be highly effective for further improvement and no wide difference between PCV and GCV among all the characters in both the season also justifies the selection as an effective method. Low values of PCV and GCV were observed for stem girth at collar region, stem girth at ground level, days to maturity, days to 50% flowering and 1000 seed weight in both summer and *kharif* experiments which indicates less chance to improve these characters by direct visual selection.

Low values of phenotypic and genotypic coefficient of variation observed for days to maturity in the present investigation was also reported by many workers, (Joshi, 1986; Pushpa Rekha, 1986; Maruthi, 1987; and Patgar 2003).

Similarly low GCV and PCV values observed for days to 50% flowering was in agreement with the results of Maruthi (1987), Lohithaswa (1992), Patgar (2003), Hazra (2004) and Kusuma *et al.* (2007).

Stem girth exhibited low variation with respect to both GCV and PCV. Maruthi (1987) also reported low GCV value for stem girth at collar region and so by kusuma *et al.,* (2007). Pushpa Rekha (1986) observed high co-efficient of variation for number of leaves per plant. Lohithaswa *et al.,* (1996) and Revanappa and Madalgeri (1997) reported high PCV and GCV for the seed yield, fresh weight of panicle, dry weight of panicle and number of branches per plant .

Hauptli and Jain (1984) observed high coefficient of variation for seed yield with respect to both GCV and PCV (Puspha Rekha, 1986, Patgar, 2003, Hazra, 2004 and Kusuma *et al*., 2007).

The co-efficient of variation at genotypic and phenotypic levels explain only the extent of variability in different traits, but this variation fails to explain the amount of heritable portion. In this situation, heritability in broadsense has an important role in the determining the heritable portion of variation.

Knowledge of heritability of a trait is an essential measure to breeder in choosing suitable genotypes to employ in improving the trait under specified situation. The results in the summer experiment revealed higher heritability estimate for most of the characters viz., plant height, days to 50 percent flowering, stem girth collar region, days to maturity, stem girth at ground level, number of branches per plant, 1000 seed weight, grain yield, number of leaves, dry weight of the panicle, fresh weight of panicle and panicle length exhibited moderate heritability. Whereas, in *kharif* all characters exhibited high heritability and maximum heritability was noticed in plant height. High heritability indicates less influence of environment and is governed by additive gene effects. For the

character with low heritability, selection may be considerably difficult or virtually impractical due to the masking effect of environment on genotypic effect (Singh *et al.,* 1998)

High heritability for grain yield per plant, plant height, number of leaves and days 50 percent flowering were also noticed by previous workers (Revanappa and Madalgeri, 1997 and Waghmode *et al*., 1997). While high heritability for plant height and days to maturity was reported by Joshi (1986).

Guillen Portal *et al.* (1999) reported high estimation of broad sense heritability for plant height, stem girth, grain yield per plant and panicle length.

Lohithaswa *et al.* (1996) observed high heritability of days to 50% flowering, days to maturity and plant height. High heritability for panicle length and seed yield was reported by Das *et al.,* (1991).

The characters which show moderate to low heritability values are liable to considerable influence by extraneous factors. The estimates of heritability however, indicates only the effectiveness with which selection of genotypes can be based on their phenotypic performance but fail to indicate the amount of progress expected from selection (Johnson *et al.,* 1955a). This suggests that heritability estimates in broad sense do not serve as true indicator of the genetic potentiality of the genotypes.

Genetic advance under selection depends mainly on the extent of genetic variability in the base population, intensity of the selection, magnitude of the masking effect of environment and interaction components of variability.

In summer experiment, number of leaves, number of branches, dry weight of panicle and plant height showed high heritability coupled with high genetic advance which indicated additive gene action in the control of making these

characters to respond better for selection. While in *kharif* experiment high to moderate heritability coupled with low genetic advance was noted in days to maturity, days to 50 percent flowering and 1000 seed weight whereas, traits like number of branches, dry weight of panicle exhibited high heritability coupled with high genetic advance showing they were least influenced by extraneous factor and could respond effectively for selection. Remaining traits which had lower genetic advance suggests that these traits might be conditioned by non additive gene action and thus selection based on these characters may not be effective.

Joshi and Rana (1995) noticed high heritability coupled with low genetic advance in traits *viz.,* days to maturity, and days to 50 percent flowering and 1000 seed weight.

Patgar (2003) and Hazra (2004) also found high heritability coupled with high genetic advance for number of leaves and dry weight of panicle. Joshi (1986) observed high heritability coupled with high genetic advance for panicle length, plant height, seed yield and protein content.

Waghmode *et al*. (1997) observed high heritability coupled with high genetic advance for plant height, number of branches and grain yield per plant.

High heritability coupled with moderate genetic advance in the character indicates that the variability is due to both additive and non additive interaction of genes. The characters exhibited low heritability with moderate genetic advances indicates influence of non-additive gene effect in governing these characters. Hence, selection of genotypes on the basis of these characters makes less effective in further breeding programme. The character with high genotypic variance and high heritability coupled with high genetic gain would be effective for selection in improvement of the crop.

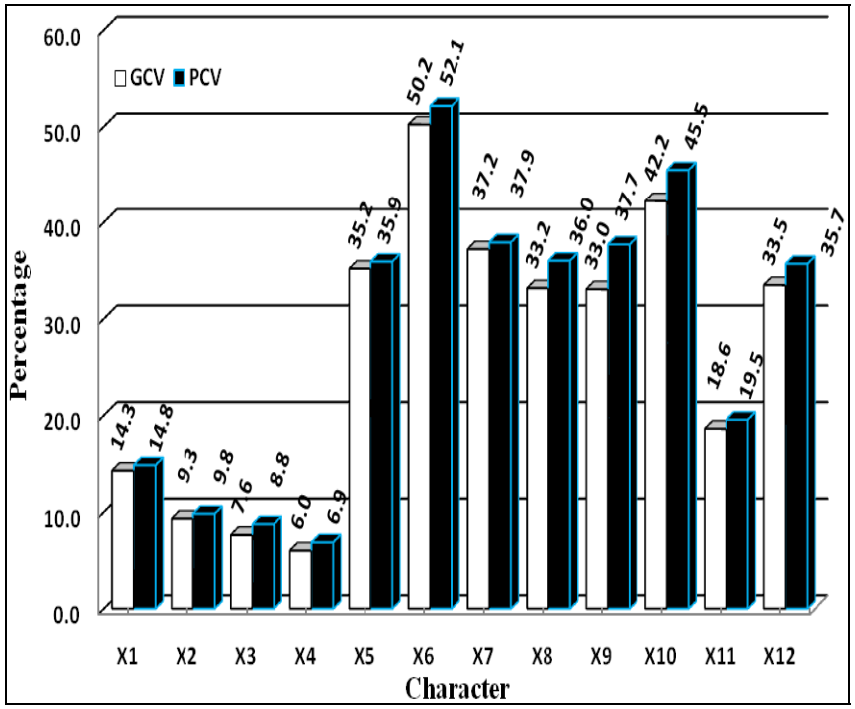

Fig. 1 : Graph showing Genotypic and Phenotypic Coefficient of Variability

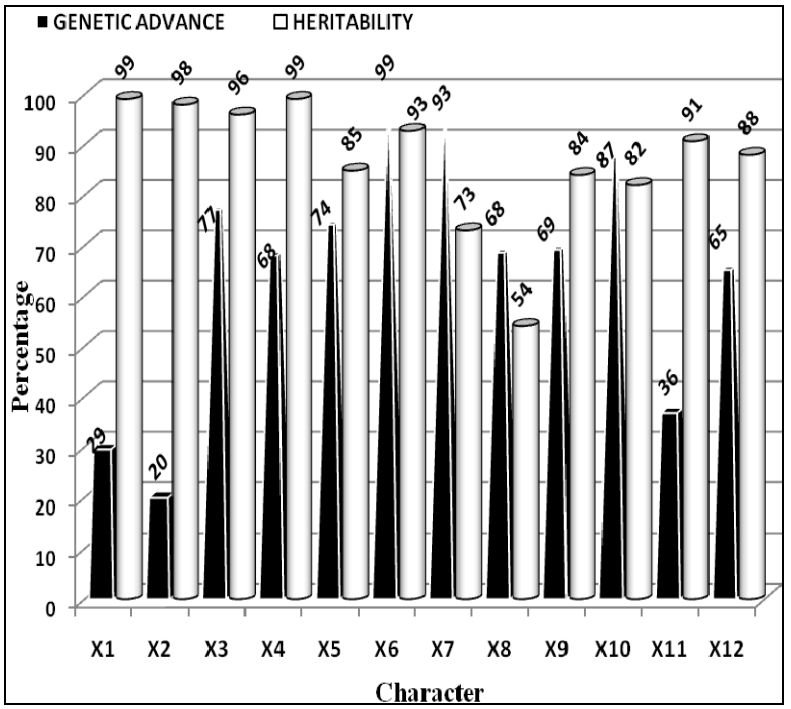

Fig. 2 : Graph showing Heritability and Genetic advance

X_1- days to 50 % flowering

X_2- days to maturity

X_3- stem girth at ground level (cm)

X_4- stem girth at crown level (cm)

X_5- number of leaves per plant

X_6 number of branches per plant

X_7 – plant height (cm)

X_8- panicle length (cm)

X_9- fresh weight of the panicle (g)

X_{10}- dry weight of the panicle (g)

X_{11}- 1000 seed weight (g)

X_{12}- grain yield per plant (g)

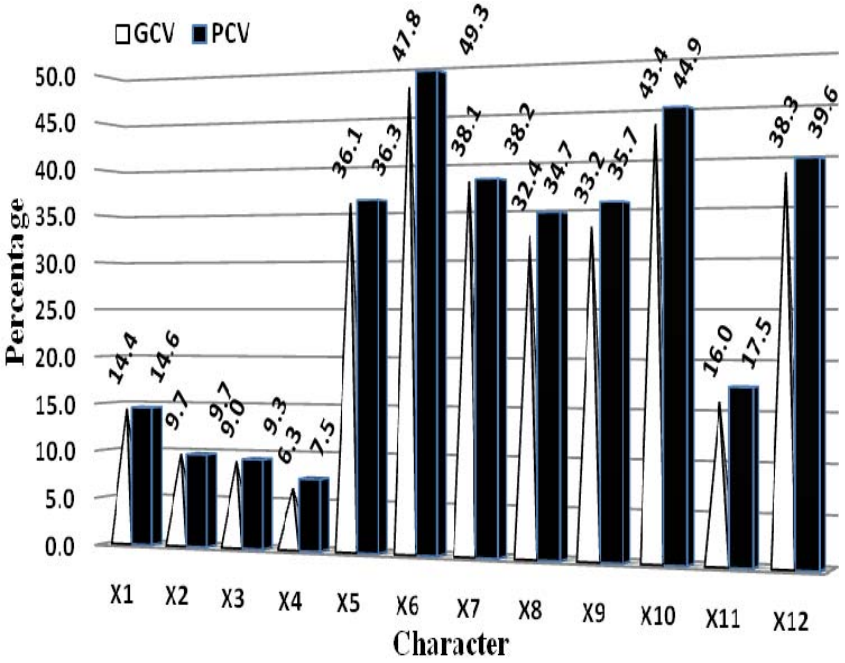

Fig. 3: Graph showing Genotypic and Phenotypic Coefficient of Variability

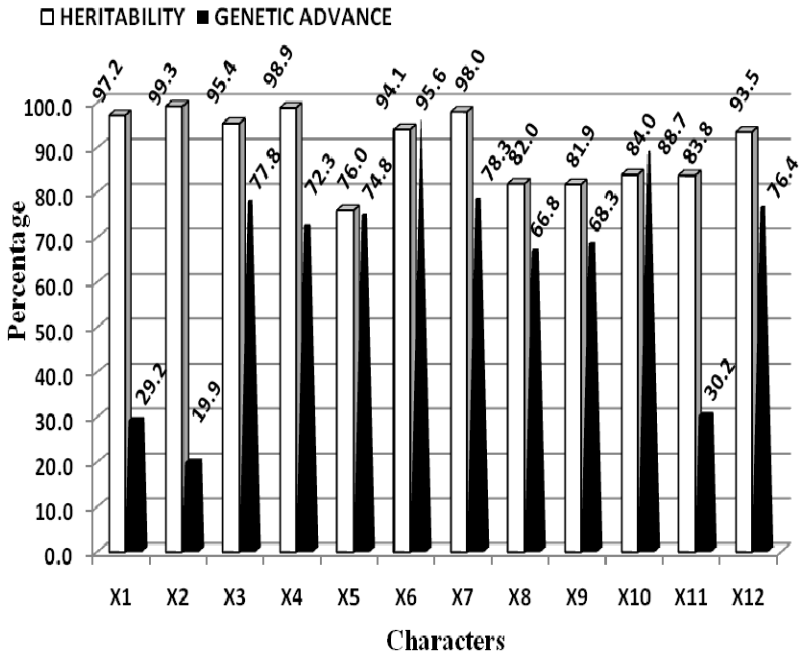

Fig 4: Graph showing Heritability and Genetic advance

X_1- days to 50 % flowering

X_2- days to maturity

X_3- stem girth at ground level (cm)

X_4- stem girth at crown level (cm)

X_5- number of leaves per plant

X_6 number of branches per plant

X_7 – plant height (cm)

X_8- panicle length (cm)

X_9- fresh weight of the panicle (g)

X_{10}- dry weight of the panicle (g)

X_{11}- 1000 seed weight (g)

X_{12}- grain yield per plant (g)

5.3 Correlation and path analysis studies

5.3.1 Correlations

The phenotype of a plant is the result of interaction of a large numbers of factors so the final yield is the sum total of the effects of several component characters. Yield is the final phenotypic performance of the plant, which is influenced by various factors such as genetic, environment and their interactions. This complex quantitative character is under control of polygenes. Polygenes are highly sensitive to the environment. Hence, the selection of superior genotype based on yield alone may not be effective. For the rational approach towards the improvement of yield, selection has to be operated through associated characters.

Study of association of yield components with yield assumes special importance and forms basis for selecting desired strains. Correlation coefficient measures the magnitude and direction of association among the characters. The genotypic correlations between different characters within a plant often arise because of either genetic linkages or pleiotropy (Herald, 1939). It is important to the breeders to establish and understand the existing relationship between the yield and yield contributing characters.

Genotypic correlation indicates the true genetic performance of genes actually governing the characters whereas, phenotypic correlations do not indicate the magnitude and direction of genetic correlation.

Relationship between phenotypic and genotypic correlation indicate the characters with high heritability estimates have lower environment correlation (Falconer, 1981) when phenotypic correlation is more than genetic correlation indicates the role of the low heritability coupled with the higher environmental correlation.

5.3.2 Correlation among grain yield and yield components

Genotypic correlations were higher than the corresponding phenotypic correlations. Low phenotypic correlation values can be explained due to masking or modifying effects of environment on genetic association between the characters (Pandey, 1979, Patgar, 2003 Hazra, 2004 and Kusuma 2007).

Dry weights of panicle, fresh weight of panicle, 1000 seed weight, Stem girth at ground level, Plant height, panicle length, stem girth at crown level and number of leaves were significantly positively correlated with seed yield at both genotypic and phenotypic level in summer experiment. And traits, days to 50 percent flowering and number of branches exhibited negative correlation with yield. In *kharif* season same traits as that of summer season showed positive correlation with yield wherein 1000 seed weight, dry weight and fresh weight of panicle exhibited high positive correlation with yield and days to 50 percent flowering and number of branches being negatively correlated with yield. The results are in consonance with findings of Patgar (2003).

Maruthi (1987) observed negative correlation of days to 50 percent flowering on yield. The same trait in the present investigation recorded negative association with yield in both summer and *kharif* season.

Das *et al.* (1991) reported significant association of seed yield with panicle length, 100 grain weight and plant height.

Pushpa Rekha (1986) observed significant correlation of seed yield with panicle length, dry weight of panicle, and stem girth, number of leaves. Positive association of plant height and number of fresh weight of panicle with seed yield per plant was reported by Sudhir Shukla and Singh (2003).

Verma *et al.* (2002) observed high significant positive association of plant height with seed yield. Andani Gowda *et al.* (1999) observed positive correlation of seed yield with plant height, panicle length and fresh weight of panicle. Selection of the traits which are positively correlated with yield helps in improvement of crops by boosting the yield of the concerned genotypes so selection with greater efficiency can be practiced on yield through these positively correlated traits. The trait with high genotypic correlation and moderate phenotypic correlation suggests the influence of extraneous factors on the association of such traits.

5.3.3 Association among the yield components

Many times there are some traits though they are negatively related with yield known to influence other traits which are positively associated with yield factor. So, it is also important to know the association between different yield components. In this study positive significant association of plant height was recorded with panicle fresh weight, panicle length, number of leaves, dry weight of panicle, 1000 seed weight and with stem girth except days to 50 percent flowering and days to maturity and negative association with number of branches which also negatively associated yield at genotypic and phenotypic level in both summer and *kharif* experiment.

Association of number of branches was negative but significant with all the traits which are in turn positively correlated seed yield. It indicates that increase in the number of branches certainly decreases plant height and panicle length which are positively associated with yield. Yield contributing traits like panicle fresh weight, panicle length, number of leaves, dry weight of panicle, 1000 seed weight, stem girth and number of leaves contributes to the yield through increasing photosynthetic ability. This suggests that selection for traits like number of branches, days to 50 percent flowering and days to maturity which have negative

association with other positively correlated yield contributing traits should be kept at minimum in order to maximize the yield. These results are in consonance with findings of Maruthi (1987) and Hazra (2004), Positive correlation of number of leaves, dry weight of panicle and panicle length were observed by Ghosh *et al*., (1999). Sudhir Shukla and Singh (2003) observed positive correlation of plant height with fresh weight of panicle and 1000 seed weight.

Lohithaswa (1992) observed positive correlation for panicle fresh weight with stem girth. Panicle fresh weight can be considered for selecting high yielding lines.

Panicle length showed positive significant association with plant height, fresh weight of panicle, dry weight of panicle, stem girth ground level and stem girth at collar region whereas, negative association was found with number of branches at genotypic and phenotypic level in summer and *kharif* experiment. Panicle length supported by plant height provided with thick stem girth provides better standability and more number of leaves. Hence, there is an increase in the photosynthetic activity due to increase in green biomass. These results are in conformity with the results of Patgar (2003). Pushpa Rekha (1986) observed positive association of panicle length with panicle weight suggested increased panicle length would result in increasing panicle weight.

Positive association of panicle length with plant height and weight of panicle was reported by Ghosh *et al.* (1999). It is clear from the results that increase in girth of the stem accommodates more number of leaves with an increase in plant height. This results in the accumulation of more photosynthates and it would translocate into the production of more number of spikelets per panicle and can bear more seeds.

1000 seed weight showed significant positive association with plant height, panicle fresh weight, dry weight of panicle, number of leaves and panicle length. Whereas, negative but significant association was found with number of branches. Hazra (2004) also reported similar findings.

Patgar (2003) observed significant positive association of dry weight of panicle with stem girth, plant height, number of leaves, panicle length, and number of spikes per panicle and fresh weight of panicle.

Stem girth exhibited positive significant association with plant height, paniclefresh weight and panicle length in both seasonal experiment at genotypic and phenotypic level. This result was in conformation with the reports of Pushpa Rekha (1986), Patgar (2003) and Hazra (2004).

Patgar (2003) observed negative association of days to maturity, number of branches, dry weight of stem and number of leaves. Pushpa Rekha (1986) observed the negative significant association of days to maturity with number of branches.

The report of various workers on correlation in different crops, revealed that strength and direction of correlation in different character combination depends on the nature of experimental material and environment and items in which they have been studied (Falconer, 1960).

In the present study, plant height, fresh weight of panicle, dry weight of panicle, number of leaves, panicle length, stem girth at ground level, stem girth at collar region and 1000 seed weight showed significantly positive association with yield in both experiment. These characters can be taken for improvement in the grain yield.

5.4 Path coefficient analysis

The association between two characters is not a simple relationship but is rather the product of the interaction of direct and indirect causes. Correlation coefficient does not give any idea about the real contribution of an independent character to the final yield. Path coefficient is a tool, which provides an effective measure of direct and indirect cause of association and depicts the importance of each factor involved in contributing to the final yield. Although the estimates of correlation coefficients are helpful in determining components of complex trait such as yield, they do not provide exact picture of the relative importance of direct and indirect influence of each of them. But the technique of path analysis introduced by Wright (1921) which is simply a standardized partial regression analysis, appears to be helpful in elucidating pattern of association through direct and indirect effects.

Dewey and Lu (1959) demonstrated the utility of this analysis in plant selection in crested wheat grass. This method is based on the fact that the degree of influence of one variable upon another can be defined in quantitative terms. It is assumed that the causal system visualized taken into account all the factors involved in determining the end product. Since the determination of such factor is very complex, it is obviously not possible to have a complete path diagram. This situation justifies the inclusion of residual pathway in the analysis. The residual pathway is treated independently from other paths. However, Srivatsava and Sharma (1976) pointed out a flaw in the use of this technique from their analysis in rice. They found that there is no definite selection of characters to be included in the analysis and that the analytical results varied according to the characters that were chosen.

In the present investigation results of path coefficient analysis pertaining to seed yield per plant using genotypic correlation matrix for stem girth at collar

region, plant height, panicle length, fresh weight of panicle, dry weight of panicle and 1000 seed weight have been studied under summer and *kharif* season the results presented in the table 10 and 11 for summer and *kharif* experiment respectively are discussed here under.

In the genotypic path, plant height, fresh weight of panicle and dry weight of panicle, were most important as they had higher magnitude of direct effects on seed yield and 1000 seed weight showed low but positive direct effect on seed yield while stem girth at ground level exhibited significant negative direct effect and panicle length low but negative direct effect on seed yield in summer and also in *kharif* experiment.

Dry weight of panicle showed significant high direct effect on yield and also registered as main channel for other components *viz.,* plant height, fresh weight of panicle and 1000 seed weight to direct their influence towards grain yield. Similar observations also noted with panicle fresh weight in both summer and *kharif* season. These results are in consonance with findings of Maruthi (1987).

Fresh weight of panicle also exhibited significant indirect effects on yield through dry weight of panicle and positive insignificant indirect effect through plant height and 1000 seed weight in *kharif* season. Whereas, in summer it showed positive but low indirect effects on yield through these traits except dry weight of panicle where it showed significant high positive indirect effect so, direct selection for panicle fresh weight can bring considerable improvement in yield due to its high indirect effect and positive direct effects through other characters. This result is in conformity with the findings of Patgar (2003) and Hazra (2004).

Stem girth at crown level showed negative direct effect nevertheless, positive but significant indirect effects of stem girth at crown level was exerted

through plant height and insignificant indirect effects through fresh weight of panicle, dry weight of panicle and 1000 seed weight in *kharif* season. While in summer it showed significant indirect effects not only through plant height but also through dry weight of panicle and insignificant indirect effect through fresh weight of the panicle and 1000 seed weight. Direct selection for panicle fresh weight can bring considerable improvement in yield due to its high indirect effect and positive direct effects through other characters. This result is in conformity with the findings of Patgar (2003).

Positive direct effect of 1000 seed weight on yield per plant in both summer and *kharif* season was noticed and this was supplemented by positive indirect effects through panicle fresh weight and dry weight of panicle. Das (1991) reported high direct effect of 100 seed weight on seed yield. So 1000 seed weight can also be considered during selection for improving yield of grain amaranth.

In the present study, all the characters exhibited high significant and positive correlation with seed yield. From the above discussion, it can be concluded that due emphasis should be given to the characters *viz.,* fresh weight of panicle and dry weight of panicle while making selection.

5.5 Genetic diversity analysis

In the crop improvement programme genetic diversity has been considered as an important factor, which is an essential pre-requisite for hybridization programme for obtaining high yielding progenies. Quantitative measurement of genetic divergence among individual character have enabled plant breeders to understand the racial affinities and evolutionary pattern in various species of cultivated plants as well as in making decisions for the selection of best parental combination in hybridization programme (Morishima and Oka, 1960).

Inclusion of divergent parents in hybridization programme serves the purpose of combining desirable genes, so as to obtain desirable recombinants. Quantitative measurement of genetic diversity would be more useful in preliminary evaluation of the genotypes under study.

Generalized distance, which had been employed in the present study, is a statistic related to the co-efficient of racial likeness developed by Mahalanobis (1936) and Rao (1952). It is a weighted co-efficient, similar to squared distance, in which both the variance of separate characters and the correlations among the characters are taken into account. D^2 statistic could be applied to three or more populations, whose status need not be known previously. Clustering pattern obtained by D^2 does not substantially change with the addition of more characters. It is based on second-degree statistics and is self weighing on the basis of genetic variability of the characters. D^2 values between pair of populations amount to a measure of genetic divergence when the effect of environment has been same for populations under study.

In summer experiment 100 genotypes were grouped into 12 clusters based on the D^2 values and 14 clusters in *kharif* experiment. Clustering pattern showed appreciable amount of divergence among the genotypes in both experiments. Cluster X to be the largest consisting of 22 genotypes followed by Cluster I, with 21 genotypes in summer experiment whereas largest cluster in *kharif* experiment was cluster I comprising 23 genotypes followed by cluster XIII with 11 clusters . In this study, the intra-cluster D^2 value ranged from 24.4 to 62558.8 in summer season while in *kharif* season the intra-cluster D^2 value ranged from 12.0 to 16715.0. The average intra cluster distance for cluster XII was maximum followed by cluster II, X and I while minimum was found in cluster III. Whereas in *kharif it* was the cluster III which had maximum average intra cluster distance and minimum intra cluster distance was observed in cluster II. This indicates that, the

genotypes in the cluster XII in summer and cluster III in *kharif* were more diverse than the genotypes in the other clusters. The results of the intracluster distance indicated that, the maximum amount of heterosis is expected in cross combination involving the genotypes of most divergent cluster. The intra cluster value of cluster XII in summer season and III in *kharif* season indicated that genotypes in these clusters might have different genetic architecture than the genotypes included in rest of the clusters.

In summer the inter cluster D^2 values exhibited a wide range of cluster distance from 17.43 to 341.08. The cluster VIII and cluster V were strictly more diverse from the rest of the clusters followed by cluster XII and VII. While in *kharif* season the inter cluster D^2 values exhibited a wide range of cluster distance from 15.9 to 213.5. The cluster VIII and cluster IX were more diverse from the remaining clusters. The criteria used for selection of varieties as parents for hybridization using D^2 analysis is the inter cluster distance. Those genotypes included in clusters with maximum inter cluster distance are obviously genetically more divergent. Hence, it would be logical to incorporate genotypes from these clusters in further breeding programmes. The minimum inter cluster D value (17.43) was observed between cluster III and IX in summer and 15.9 inter cluster D value was noted between IX and IV in *kharif* experiment, indicating close genetic association between the genotypes of these two clusters.

5.5.2 Contribution of characters towards divergence

Among the 12 characters studied, the most important character contributing to the total divergence was fresh weight of panicle in summer season, this result is in consonance with Kusuma *et al.* (2007) who also reported similar findings and other characters which showed more divergence were grain yield followed by dry weight of panicle and rest of the characters contributed less to divergence, and stem girth at crown level contributed least to genetic divergence. In *kharif*

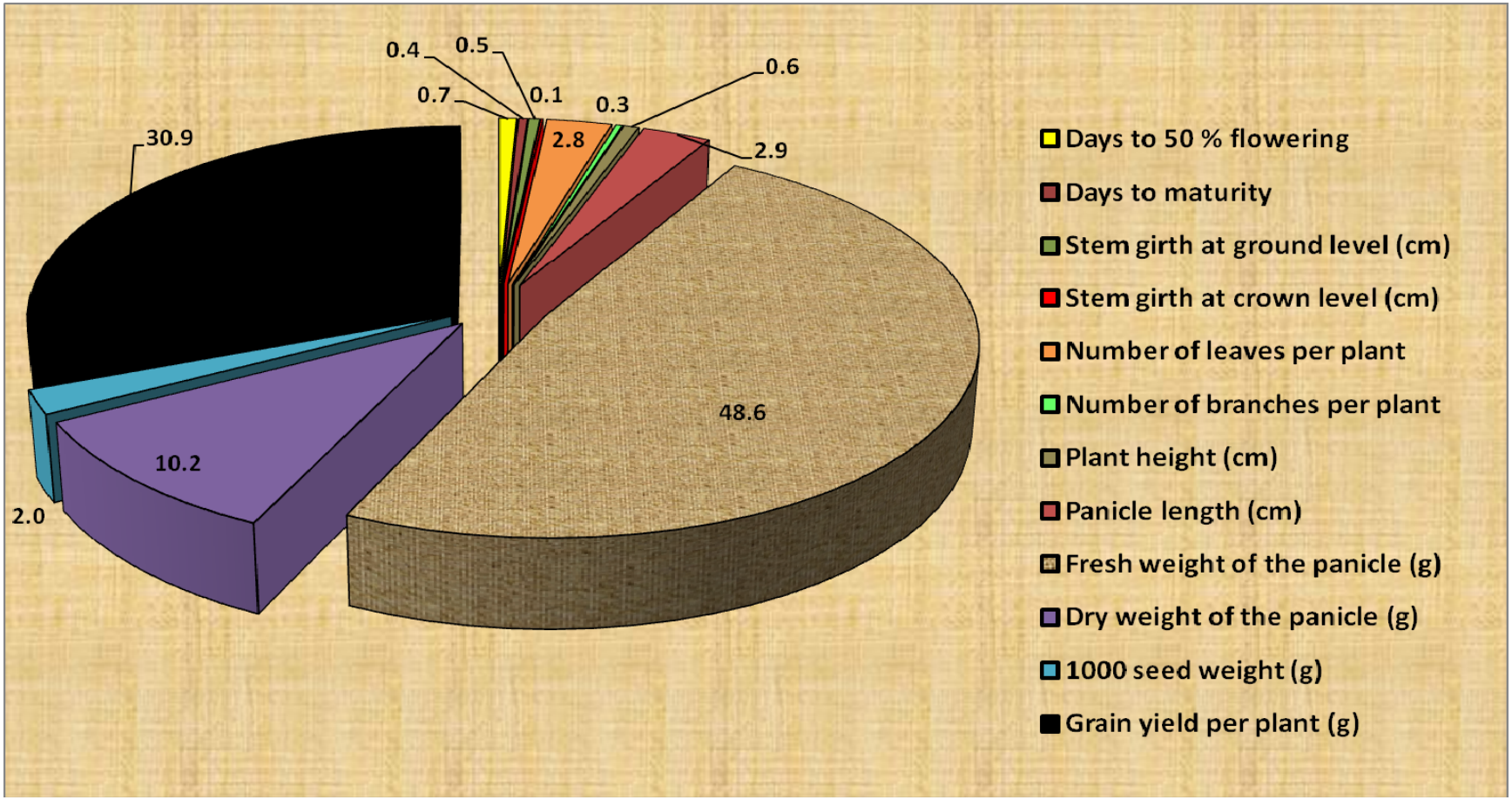

Fig. 5 : Diagram depicting percent contribution of characters to genetic divergence (Summer)

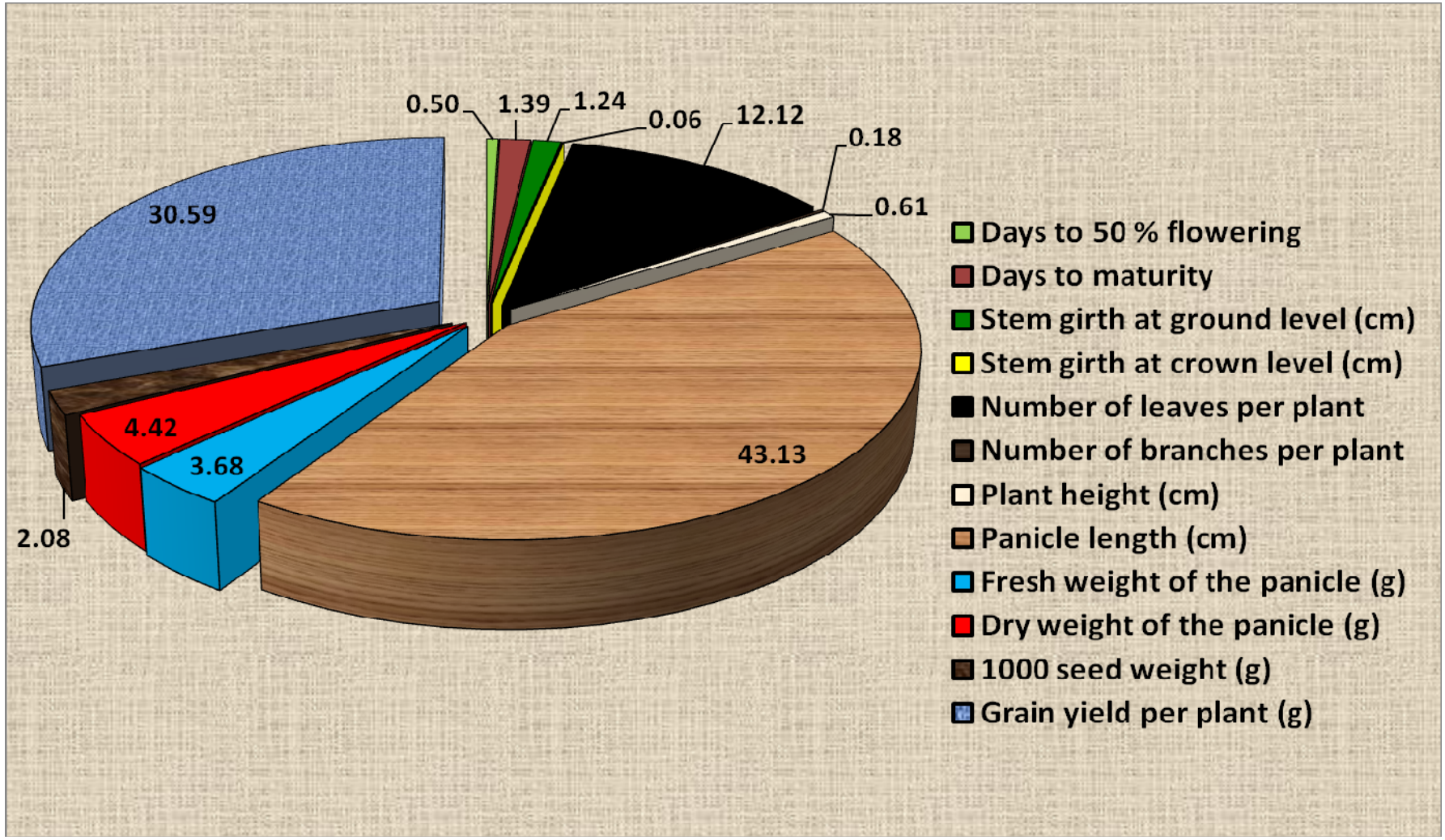

Fig.6: Diagram depicting percent contribution of characters to genetic divergence (*kharif*)

maximum contribution towards divergence was observed in panicle length and Seed yield per plant, followed by number of leaves per plant. Stem girth at crown level contributed least towards genetic divergence in both seasons. No trait exhibited zero contribution towards divergence in both seasons. These observations are also in accordance with the report of earlier workers, for seed yield per plant (Joshi and Rana, 1995; Waghmode *et al*., 1997), for number of leaves (Datta and Mukherjee, 2004, and Khumkar and Singh, 2002), days and to maturity (Joshi and Rana, 1995 and Bergale *et al*., 2001), number of branches (Khumkar and Singh, 2002), Panicle length (Joshi and Rana, 1995; Asthana *et al*., 1998, Datta and Mukherjee, 2004), fresh weight of panicle (Lohithaswa, 1992 and Asthana *et al*., 1998), dry weight of panicle (Patgar, 2003) and Plant height (Tiwari *et al*., 2004; Shiv Datt and Mani, 2003; and Indra Singh and Garg, 2003).

It is evident from the above results that, for selection of genetically diverse genotypes for hybridization, material should be screened for seed yield per plant, fresh weight of panicle, panicle length, and number of leaves per plant.

5.5.3 Analysis of cluster means

Analysis of cluster means indicated presence of variation among the 12 clusters in summer and 14 clusters in *kharif*, which were grouped according the D^2 analysis. In this investigation, cluster VIII in summer and cluster XI and II in *kharif* season had early flowering genotypes and rest of the genotypes in other clusters exhibited moderate to late flowering genotypes. The results indicate the presence of more diversity in the germplasm.

Cluster VIII and IV comprised genotypes with early maturing trait and cluster III comprised those genotypes which were late maturing in summer whereas, in *kharif* genotypes in cluster XI and IV were early maturing and high cluster mean value exhibited by genotypes in cluster V with 92.46 mean days for

maturity. So genotypes in the collection exhibited divergence with respect to days to maturity this provides an ample opportunity for breeder to choose his material through selection to get early maturing lines.

Cluster XII and V in summer season includes those genotypes with thick stem girth at ground level and at collar region. Genotypes which had thick stem girth at basal node also had thick stem at crown region this quality of thick stem added for the yield of the plant as a result genotypes present in these clusters were those which recorded high cluster mean value for yield and this is evident from the fact that the genotypes with thinner stem which are found in cluster IV and VIII were low yielders. Whereas, in *kharif* season clusters IX, V and II included the genotypes having thicker stem with moderate to high yielding capacity and clusters IV, VIII and XIII had thinner stem. The trait stem girth is important as it prevents lodging and gives better stand ability to crop.

Clusters VIII, IV and III in summer comprised genotypes with higher cluster mean value for number of branches. In *kharif*, genotypes in cluster XI and IV showed higher cluster mean value for this trait, the genotypes in these clusters recorded lower cluster mean value for seed yield and they were low yielders and this was evident from the fact that the genotypes included in the cluster XII, V and I in summer and genotypes in clusters II, V, XII and XIV in *kharif* which recorded higher cluster mean value for yield were all moderately branched genotypes.

The genotypes included in the cluster XII ,V and I exhibited high cluster mean values for number of leaves per plant and the same genotypes in these clusters recorded higher cluster mean values for plant height, panicle length, fresh weight of panicle , dry weight of panicle and 1000 seed weight and these traits ultimately reflected in higher yield in summer. However in *kharif* season genotypes in clusters II, V, XII and XIV had higher cluster mean value for number of leaves and also they were high seed yielders this was evident from the

fact that genotypes in these clusters were reported to have moderate to higher cluster mean values for plant height, panicle length, fresh weight of panicle, dry weight of panicle and 1000 seed weight. From this observation it is apparent that genotypes in clusters XII, V and I in summer season and clusters XIV, II, V and XII in *kharif* season had higher cluster mean values for most of the traits studied. So, the genotypes in these clusters has immense potential which provides ample opportunity for grain amaranth breeder to harness through selection or could combine novel traits via hybridization utilizing these genotypes.

Rational choice of parents on the basis of their genetic diversity can provide the scope for rapid improvement. Hybridization between the genetically divergent genotypes will result in accumulation of favorable genes and produces a wide spectrum of variation in the segregating progeny (Shiva Datta and Mani, 2003).

5.6 Seasonal effects on characters

In both seasonal experiments it was the number of leaves per plant which exhibited high phenotypic and genotypic variances followed by panicle fresh weight in summer experiment and followed by dry weight of panicle in *kharif* experiment. 1000 seed weight exhibited low variability in summer, in *kharif* it was grain yield which showed low variability at both genotypic and phenotypic level.

Genotypic and phenotypic coefficients of variation were high for number of leaves in summer but it was number of branches in *kharif*. Irrespective of the season PCV was higher than the respective GCV for all the characters in both experiments done in summer and *kharif*.

Stem girth at color region recorded high heritability and low heritability by panicle length in summer season whereas it was plant height which exhibited high

heritability and low heritability by number of leaves in *kharif* season. Number of branches exhibited high genetic advance in both the season.

Dry weight of the panicle showed a highly significant positive correlation with grain yield in summer and also in *kharif* season. Genotypic correlation co-efficients were higher than their respective phenotypic correlation co-efficients in both summer and *kharif* experiments.

Dry weight of panicle exhibited very high positive direct effect on grain yield in summer whereas it was fresh weight of panicle in *kharif* season. The indirect effect of 1000 seed weight through dry weight of panicle and fresh weight of panicle was more than its direct effect on seed yield at genotypic path in both seasons.

100 genotypes based on the mean values of characters were grouped into 12 clusters in summer and 14 clusters in *kharif* season indicating better exhibition of diversity in *kharif* season due to varied response of the genotypes to rain fall pattern, as a result some genotypes which moved to different cluster when they were evaluated in another season for instance, most of the genotypes which were in cluster XII in summer earlier moved to cluster XIV when they were analyzed in *kharif* season.

5.7 Quality characters

In developing countries like India mal nutrition is rampant and especially poor is the easy target. Grain amaranth as got high nutritive value nevertheless easily affordable by poor because of low cost of cultivation, besides protein, it is also rich in minerals and vitamins. Further, it can serve as supplement to the rice, wheat and other staple food crops. From this point of view, the present investigation was under taken to study the quality character like protein content and to identify genotypes with high protein content in their grains.

5.7.1 Protein content

The main virtue of the grain amaranth seed lies in its high protein (8-22%) and this crop rich in the amino acid lysine (0.73-0.84%) which is deficient in other crops like wheat, barley and corn. It is the total proportion of protien and amino acid composition of the protein in the seed which determines nutritive quality of the crop. In the present investigation due emphasis was laid on total protein percentage in relation to other constituents of the grain. Protein content ranged from 9.53 to 16.17 per cent. Pant (1983) and Munjal *et al.* (1999) reported similar results. Wide variation in the protein content among genotypes may be due to differences in their genetic make up and availability of nitrogenous nutrients, age and season (Bressani, 1987). The genotypes IC-415331 and IC-415266 recorded high and low protein content in their grains. Close observation among top yielding genotypes revealed that as yield of the genotypes increased the protein content tend to decrease (fig 7) so, while planning for crop improvement through breeding due attention should be paid towards balancing yield and protein content of the genotypes in order to create better acceptance among farmers.

Future line of work:

1. Variability studies indicated high genetic variability for number of leaves per plant, fresh weight of panicle, plant height, dry weight of panicle, panicle length and protein content. This indicates that there is variation available for these traits, which can be exploited either by direct selection for improving these characters or by involving them in hybridization work giving due consideration to diversity and possible complementation of yield components in such planned hybridization work.

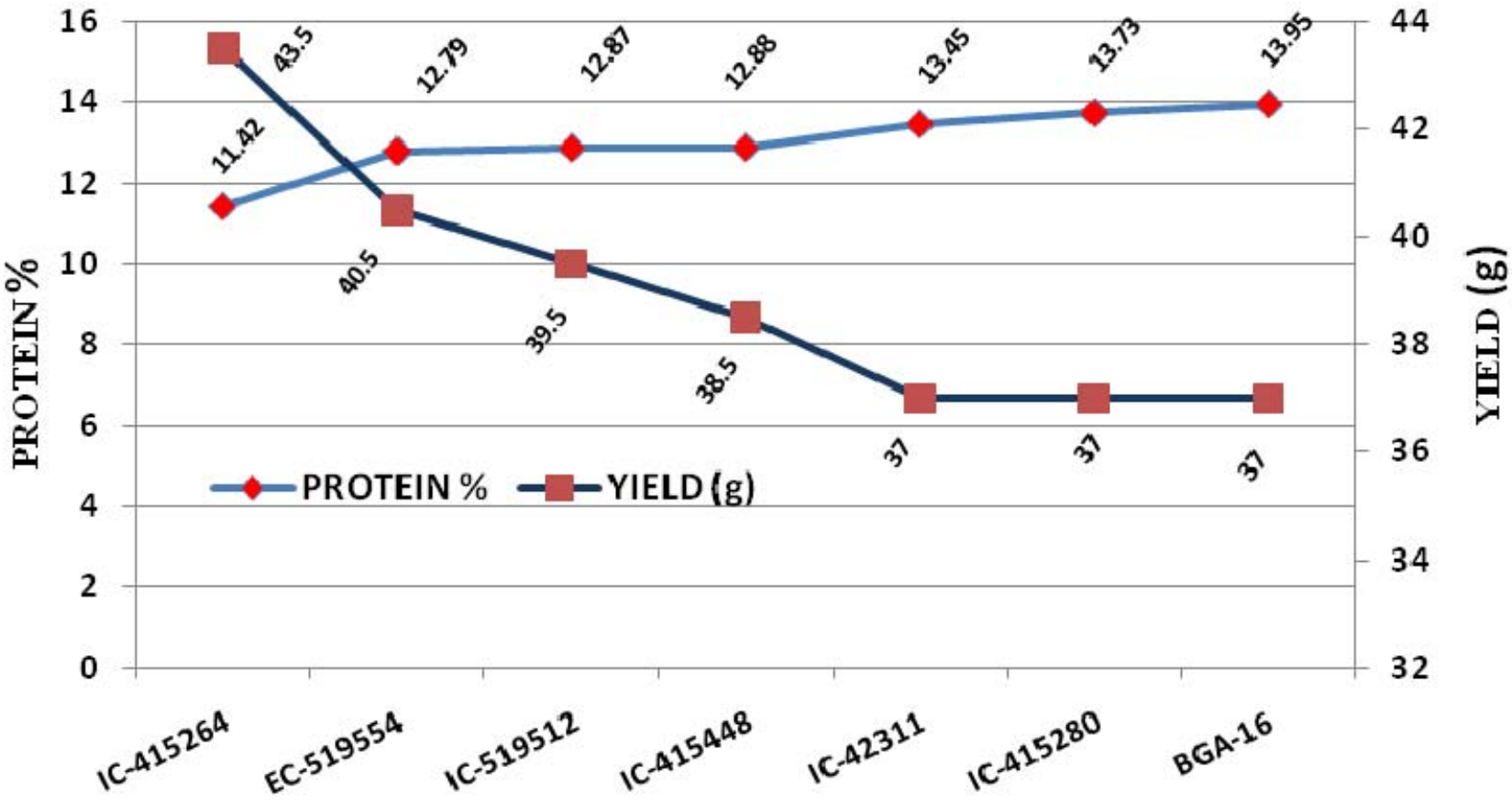

Fig. 7 : Grain yield and protein content of 7 top performing Grain amaranth genotypes

IC-5331

BGA – 26

Plate 3 : genotypes with high seed protein

IC-415449

KBGA-1

Plate 4 : Genotypes with high seed protein

2. Crosses can be planned between genotypes of cluster III with genotypes of cluster VIII and V (summer experiment) and between genotypes of cluster IV and XI with genotypes of cluster IX and VIII (*kharif* experiment) to get wide spectrum of variability for different yield contributing characters in the segregating generation.
3. Based on the mean performance of the genotypes, the accession IC-415264, EC-519544, IC-415264 and IC-519512 were identified as significantly better yielder than the check suvarna in both seasonal experiments. These genotypes are also promising for total grain protein percent. The performances of these are to be evaluated across different seasons or locations.
4. Shattering of grains during harvesting due to low adherence capacity of the panicle is the major problem that is a major contributor to post harvest losses, so thrust should be laid on breeding methods that aims at development of non-shattering, early maturing, non lodging and bold seeded types in the segregating generation & of new crosses.

A comprehensive germplasm collection of these under utilized food plants is the only adequate means of maintaining genes for future breeding needs. In order to build up and broaden the existing genetic base, it is important to extensively explore as much of the known area of cultivation as much possible. Grain amaranth is highly nutritious, studies on the quality parameters such as essential amino acids are very important. Till regular work in this crop is initiated, selection and standardization of uniform high yielding lines for multilocation yield evaluation is essential to select types having wider adaptability in different agroecological zones. Correlation, genetic divergence, adaptability, inheritance and combining ability studies are other essential areas where due attention could be paid for varietal improvement in grain amaranthus.

SUMMARY

VI. SUMMARY

Amaranths (*Amaranthus spp*.) belonging to the family Amaranthaceae, include the most common leafy vegetables grown in the Indo-Gangetic plains of eastern India. The cultivated amaranths are utilized as food grains, leafy vegetables, and forage crops in diverse geographic areas, such as America, China, Greece, Italy, Russia, Nepal, and India. The superior nutrition, drought tolerance, disease and pest resistance, high yield in production, and increasing rate of consumption have made this native American crop more attractive for cultivation in developing countries such as India. Compared with traditional crops, this pseudocereal is rich in protein (17–19% of dry weight) with double the amount of essential amino acids than wheat grain protein. Considering its agronomic importance, attention should be given to the cultivation, conservation, and sustainable utilization of this promising crop. Despite being a self-pollinated crop, varying amounts of out crossing and frequent interspecific and intervarietal hybridization have brought wide variation in amaranth genotypes. Amaranths also exhibit tremendous diversity related to their wide adaptability to different ecogeographic situations.

An important topic in germplasm conservation studies is the evaluation of genetic isolation, and thus, it is necessary to evaluate the genetic diversity of local amaranths for implementing effective conservation strategies. Identification and preservation of germplasm are necessary for maintaining genetic diversity, studying local genetic material, and even to choose ecotypes having high nutritional interest in their place of origin. The present investigation was carried in summer and *kharif seasons* of 2008, experimental plot laid out in simple lattice design and replicated twice. 100 genotypes in grain amaranth germplasm collection were studied in both the seasons with an objective of studying genetic variability, character association, path analysis, and genetic

diversity for 12 characters and evaluating genotypes for total protein content. In summer experiment 100 genotypes were grouped into 12 clusters based on the D^2 values and 14 clusters in *kharif* experiment clustering pattern showed appreciable amount of divergence among the genotypes in both experiments. Cluster X to be the largest consisting of 22 genotypes followed by Cluster I, with 21 genotypes in summer experiment whereas largest cluster in *kharif* experiment was cluster I comprising 23 genotypes followed by cluster XIII with 11 clusters . Analysis of cluster means indicated the presence of variation among the 12 clusters in summer and 14 clusters in *kharif*, which were grouped according the D^2 analysis. The results indicate the presence of more diversity in the germplasm. Among the 12 characters studied, the most important character contributing to the total divergence was fresh weight of panicle in summer season. In *kharif* maximum contribution towards divergence was observed in panicle length and Seed yield per plant. In both seasonal experiments it was the number of leaves per plant which exhibited high phenotypic and genotypic variances followed by panicle fresh weight in summer experiment and followed by dry weight of panicle in *kharif* experiment. 1000 seed weight exhibited low variability in summer, in *kharif* it was grain yield which showed low variability at both genotypic and phenotypic level.

Genotypic and phenotypic coefficients of variation were high for number of leaves in summer but it was number of branches in *kharif*. Irrespective of the season PCV was higher than the respective GCV for all the characters in both experiments done in summer and *kharif*.

Stem girth at collar region recorded high heritability and low heritability by panicle length in summer season whereas it was plant height which exhibited high heritability and low heritability by number of leaves in *kharif* season. Number of branches exhibited high genetic advance in both the season.

Dry weight of the panicle showed a highly significant positive correlation with grain yield in summer and also in *kharif* season. Genotypic correlation co-efficients were higher than their respective phenotypic correlation co-efficients in both summer and *kharif* experiments.

Dry weight of panicle exhibited very high positive direct effect on grain yield in summer whereas it was fresh weight of panicle in *kharif* season. The indirect effect of 1000 seed weight through dry weight of panicle and fresh weight of panicle was more than its direct effect on seed yield at genotypic path in both the seasons.

Wide variation in the protein content among genotypes may be due to differences in their genetic make up and availability of nitrogenous nutrients, age and season. Close observation among top yielding genotypes revealed that as, yield of the genotypes increased the protein content tend to decrease so, while planning for crop improvement through breeding due attention should be paid towards balancing yield and protein content of the genotypes in order to create better acceptance among farmers.

100 genotypes based on the mean values of characters were grouped into 12 clusters in summer and 14 clusters in *kharif* season indicating better exhibition of diversity in *kharif* season due to varied response of the genotypes to rain fall pattern.

Inclusion of divergent parents in hybridization programme serves the purpose of combining desirable genes, so as to obtain desirable recombinants. Quantitative measurement of genetic diversity would be more useful in preliminary evaluation of the genotypes under study.

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