MORPHOLOGICAL AND BIOCHEMICAL STUDIES IN GRAIN AMARANTH (*Amaranthus spp.*)

By
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THESIS

Submitted in partial fulfilment of the
requirement for the degree of

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2006

DECLARATION

I, hereby declare that this thesis entitled **"Morphological and Biochemical studies in grain amaranth (*Amaranthus spp.*)"** is a bonafide record of research work done by me during the course of research and that it has not been previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Morphological and Biochemical studies in grain amaranth (*Amaranthus spp.*)"** is a bonafide record of research work done independently by **Ms. Smitha K.S under** my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the advisory committee of **Ms. Smitha K.S,** a candidate for the degree of **Master of Science in Horticulture,** with major field in Olericulture, agree that the thesis entitled **"Morphological and Biochemical studies in grain amaranth (*Amaranthus spp.*)"** may be submitted by **Ms. Smitha K.S,** in partial fulfillment of the requirement for the degree.

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Affectionately dedicated to

My parents

&

Brother

Introduction

1. INTRODUCTION

In the developing world, the painful fact is that around 192 million children and 200 million others particularly the pregnant women, experience micronutrient deficiencies leading to infant mortality (Gaddagamath, 2002). Food based strategy to combat malnutrition prevalent among vulnerable segments of the population involves identification of optimal good sources of nutrients and ensuring their availability. Grain amaranth is a unique, nutritionally rich non-cereal crop capable of combating malnutrition and has been identified as an alternative crop to traditional grain crops. Commercialization of under exploited vegetables like grain amaranth will help in solving this problem to a certain extent.

The genus amaranthus contains 40 species and the taxonomists divided the genus into two sections viz., Blitopsis and Amaranthus. The members of the section Blitopsis are characterized by prominent axillary inflorescence and trimerous flowers. Vegetable amaranth types belong to this section. Most of the grain amaranth types come under the section Amaranthus with dibasic chromosome number, terminal panicles, and pentamerous flowers (Mallika, 1987). The three promising species to which grain amaranth types belong are *Amaranthus caudatus*, *A.hypochondriacus* and *A.cruentus*. It is an annual plant with robust stem and large showy inflorescence loaded with seeds. Pal and Khoshoo (1974) observed that in grain amaranths, each glomerule contained one male flower and about 250 female flowers. The higher number of female flowers was claimed to be advantageous for its exploitation as grain. Amaranth plants are blessed with C_4 photosynthetic pathway, thus enabling them to produce more carbohydrates and to withstand adverse conditions like drought than C_3 plants.

Grain amaranth was considered to be one of the important food crops for the ancient middle and South American civilizations and even today this is an important food crop in Latin America. The plant is grown abundantly in northern India, Manchuria, Southeast Asia and Africa (Kauffman and Weber, 1988., Irvin

et al. ,1981). It is a multipurpose crop grown for leaf, grain and for ornamental purposes. Grain amaranths are nutritionally rich, characterized by high content of protein, fibre, aminoacids, minerals, vitamins and food energy which is better than most of the known and heavily utilized cereals and other food grains. Amaranth grains are a good source of high quality protein (14-18%) due to relatively good content of essential amino acids (lysine 5%). The amino acid composition of amaranth protein corresponds more closely to that of FAO / WHO recommended protein standard for optimum nutrition. Leaves are rich in vitamins and minerals and are edible with biological value comparable or even superior to common vegetables of popular consumption. A few species are reported to have medicinal properties (Watt, 1972). The tiny seeds of grain amaranths are popped or parched and milled for flour or gruel. Grains find use in commercial preparations like bakeries, confectionaries as breakfast item, snacks etc.

In India, grain amaranths are under cultivation in the North Indian hills and also in the plains of Gujarat. In South India, cultivation is scattered in pockets in the tribal areas. A wide range of genetic diversity for various phenological traits like plant colour, growth habit, inflorescence colour, seed colour etc. was observed in North West Himalayas and Nilgiri hills. Despite it's nutritional importance and genetic diversity, no systematic work has so far been initiated in Kerala Agricultural University for the conservation and utilization of this crop. Hence the present study was undertaken with the following objectives.

1. Collection, maintenance and evaluation of variability in grain amaranth accessions.
2. Genetic cataloguing of the germplasm collected based on IBPGR descriptor for amaranth.
3. Biochemical analysis for important nutrient factors.
4. Identification of superior genotypes for homestead and for commercial cultivation.

Review of literature

2. REVIEW OF LITERATURE

Grain amaranth was selected as an under exploited tropical plant with promising economic value from among 400 selected by a National Academy of Sciences Select Panel (NAS, 1980). A survey conducted by Thiesen *et al.* (1980) identified amaranth as one of five crops, which should receive immediate further study as a food crop better adapted to environmental stress. Both of these studies represent concern for identifying a broader variety of plant species, which have potential as major food sources, and for developing these for more efficient food production in our world economy. An overview of works concluded in grain amaranth pertaining to genetic variability, heritability, correlation studies, path analysis, genetic divergence, nutritional use and importance, food use etc. is presented here under.

2.1. Genetic variability

Mohideen *et al.* (1983) evaluated eight grain amaranth types and found that genotypes differ considerably in plant height, branch number, duration and yield and identified both tall and dwarf plants with high yield potential.

Study conducted by Imeri *et al.* (1987) on agronomic-chemical and nutritional characterization of twenty five amaranth (*Amaranthus caudatus*) cultivars revealed significant variability in yield, grain size and protein quality.

Kulakow and Jain (1990) reported that the amaranth has broad genetic variability with diversity in plant type, number of inflorescence, seed colour, earliness, protein content, plant height, seed and green matter

yield, resistance to pests and diseases and adaptation to soil type, pH, climate, rainfall and day length.

Prakash and Pal (1991), after studying sixty-one accessions of amaranth reported a variation for carotenoid content from 90-200 $mgkg^{-1}$ in vegetable types and from 60-200$mgkg^{-1}$ in grain types. The variation in leaf protein was 14-30gkg^{-1} and 15-43gkg^{-1} for vegetable and grain types respectively.

Genetic variability for eleven characters in 144 genotypes of grain amaranth (belonging to four *Amaranthus spp.*) was studied. A considerable amount of phenotypic and genotypic variability was observed for plant fresh weight, inflorescence fresh weight, rachis per inflorescence, grain yield followed by stem dry weight, stem girth at collar region and plant height. (Lohithaswa *et al.*, 1996).

Genetic variability studies in forty genotypes of amaranth revealed that the phenotypic coefficients of variability for all the characters studied (PCV and GCV) were maximum for leaf stem ratio, number of leaves and fresh weight of leaves and minimum for stem girth (Revanappa and Madalgeri, 1997).

Genetic variability studies were carried out using 300 germplasm lines of grain amaranth (*Amaranthus spp*) of Faizabad and the results revealed significant variability for various growth and yield contributing traits like days to flower and maturity, plant height, spikes number, length, weight and grain yield. (Awasthi, 1999).

Studies were conducted in the lateritic zone of West Bengal to investigate the pattern of inheritance of seed yield and associated characters in thirty genotypes of grain amaranth. For the seven traits

studied, genotypic and phenotypic coeffients of variation were highest for number of branches per plant, main panicle length, number of panicle per plant and plant height (Ghosh *et al.*, 1999).

To understand the variability within "Plainsman" grain amaranth cultivars, 140 selfed families from a random sample of these cultivars were evaluated at 3 different environments in Western Nebraska during 1995. Overall, a small amount of genetic variance was observed. Plant height showed the relative largest variance followed by grain yield. No genetic variance was observed in 1000 seed weight. (Guillen *et al.*, 1999).

Genetic variability study conducted by Guillen *et al.* (1999) in plainsman grain amaranth showed that the expression of morphological and agronomic traits in a population exhibiting a small degree of genetic variability was effected to a large extent by the environmental conditions and that genetic improvement through a selfing – selection scheme would be limited.

Genetic variability studies using twenty genetically diverse genotypes of grain amaranth (*Amaranthus*) of Himachal Pradesh were carried out by Joshi and Rana (1995) and the results revealed highest phenotypic and genotypic variation coefficients for inflorescence length, grain yield and spikelets per spike.

Sukla and Singh (2000) worked out coefficient of variability and genetic advance for foliage yield and its four main component traits. The heritability estimates in broad sense ranged from 33.24 to 75.00 percent. High heritability coupled with high genetic advance noticed for foliage yield (75.00 percent), leaf size (74.98 percent) and leaves per plant (73.43 percent) indicated the prevalent role of additive gene effects.

2.2. Heritability

Joshi (1986), studying Indian landraces of amaranth, found high heritability of 0.77 for 1000 seed weight, 0.63 for inflorescence length and 0.61 for plant height.

In mass selection experiment with two landrace accessions of amaranth, UCC 192 (*Amaranthus caudatus*) and UCH 213 (*Amaranthus hypochondriacus*), 5% of the tallest and highest yielding plants in both populations were selected for three cycles. Selection gain was largest in the first cycle for both traits. Realized heritability estimates for plant height were 0.22 in the UCC 192 population and 0.49 in UCH 213, and 0.09 in both population for yield (Vaidya and jain, 1987).

High heritability estimates associated with high genetic advance were obtained for weight of stem, leaf/ stem ratio, yield of greens and weight of leaves indicating the usefulness of phenotypic selection, in a study involving 25 genotypes of amaranth by Devdas *et al.* (1989).

Information on heritability and yield correlations is derived from data on eight characters in 35 genotypes collected at Lucknow and UP and grown during kharif under rainfed conditions at Nadia. Panicle weight had the highest estimates of heritability and genetic advance percentage and 1000- grain weight contributed most to grain yield by Das *et al.* (1991).

Espitia (1994), in a population of amaranth races, found high heritability of 0.92 for plant height and a moderately high heritability of 0.43 for grain yield.

Heritability and genetic advance were studied in twenty genotypes of grain amaranth (*Amaranthus spp.)* by Joshi and Rana (1995) and found highest for inflorescence length, grain yield and spikelets per spike.

Heritability and genetic advance were studied for eleven characters in 144 genotypes of grain amaranth belonging to four *Amaranth spp*. by Lohithaswa *et al.* (1996). High heritability coupled with moderate genetic advance was observed for plant height and days to 50 per cent flowering indicating that additive gene effects were operating for these characters and selection pressure could be applied on them for yield improvement. Moderate heritability with moderate genetic advance values were observed for both plant and inflorescence fresh weight, rachis per inflorescence and stem girth at collar region indicating the importance of both additive and non additive gene actions for these characters.

Heritability and genetic advance were studied in thirty genotypes of grain amaranth by Ghosh *et al.* (1999) and the results revealed high heritability together with high to moderate genetic advance for number of branches, main panicle length, plant height, number of panicles per plant and seed yield.

Information on heritability was derived from data on five yield components in "plainsman" grain amaranth cultivars by Guillen *et al.* (1999). Estimates of broad sense heritability showed the largest heritability for plant height followed by stem diameter, grain yield per plant, and panicle length. Zero heritability was observed for 1000 seed weight.

Fifteen genotypes of amaranth were evaluated for yield, yield attributes, quality characters, oxalate and reaction to leaf blight and leaf webber. High values of PCV and GCV were obtained for most of the

characters. High heritability coupled with high genetic gain was observed for leaf length, leaf width, leaf weight, fibre, oxalate and reaction to leaf blight indicating scope for improvement through selection (Priya and Celine, 2001).

Genetic variability, heritability, and genetic advance for yield, quality and resistance to leaf blight in vegetable amaranth genotypes were studied by Sindhu (2002). High heritability was observed for days to 50 percent bolting (98.96 percent) and the genetic gain, as a percentage of mean was 26.14.

2.3. Correlation studies

Mohideen and Shanmughasubramanian (1974) found that green yield of amaranth had a significant positive correlation with the number of leaves, weight of leaves, leaf length, leaf breadth, length of stem, weight of stem and diameter of stem. Hauptli and Jain (1977) in an evaluation of genetic variation in amaranth collections reported that seed yield was negatively correlated with stem growth in two weedy types while it was positively correlated with yield in domesticated types.

In *Amaranthus lividus*, Prasad *et al.* (1979) observed positive association between yield and leaf size. The seed yield increased with increase in leaf length and leaf width. But as the leaf number increased, a decrease in yield, leaf length and leaf width was found. Hence they recommended that more emphasis should be given during selection to leaf size than to leaf number, which was negatively correlated with yield.

The relationship of leaf nitrate reductase and proteinase activities to the grain protein level and grain yield was investigated in four species of grain amaranth (*Amaranthus hypochondriacus*, *Amaranthus cruentus*,

Amaranthus edulis and *Amaranthus paniculatus*) by Ramamurthy *et al.* (1982). A strikingly positive correlation between the leaf proteinase activity and the grain protein content was found. Although there was no definite correlation between the leaf proteinase levels and the grain yield, the integrated leaf nitrate reductase activity was positively correlated with the grain yield.

Plant height and leaf length were positively correlated with yield in a study in grain amaranth genotypes by Hauptli and jain (1980).

The relationship between yield and protein and fat content for 13 cultivars representing three species of grain amaranth (*Amaranthus cruentus*, *Amaranthus caudatus* and *Amaranthus hypochondriacus*) were studied. The results revealed that yield and protein were negatively correlated whereas yield and fat were positively correlated, but both were not statistically significant (Bressani *et al.*, 1987).

Agronomic, chemical and nutritional characteristics of 25 amaranth (*Amaranthus caudatus*) cultivars were studied. It was possible to establish significant positive correlations between yield- protein, methionine-cystine, methionine-lysine and threonine-leucine and significant negative correlations between protein-cystine, fat-methionine and cystine-leucine. Furthermore, it is not possible to select cultivars of higher yield on the basis of seed weight, since these two variables are negatively correlated, although not statistically significant (Imeri *et al.*, 1987).

In a study conducted by Agong and Ayiecho (1992), the populations 1008 and 1024 of *Amaranthus hypochondriacus* and 1034 and 434 of *Amaranthus cruentus* were planted in the long and short rainy seasons of 1988-89 at Nairobi, Kenya. Data were recorded on a total of six yield and growth related traits and data were tabulated on correlation

coefficients between the six traits. In all cases, head weight was positively correlated with seed yield per plant, indicating that selection for heavier heads would result in higher grain yield.

Agong and Ayiecho (1992) reported high correlation between the traits viz; plant height, days to flowering and days to maturity in grain amaranths.

Varalakshmi and Reddy (1994) reported that green yield of vegetable amaranth showed highly significant positive correlation with plant height, leaf length, leaf weight and stem weight.

Grain yield showed some significant positive correlation with plant height, leaf length and breadth, inflorescence length and spikelets per spike in a study of 20 genetically diverse genotypes of grain amaranth grown in Himachal Pradesh during 1991-1992 (Joshi and Rana, 1995).

Seed yield was positively correlated with number of branches per plant and plant height was significantly correlated with days to flowering, number of panicles and main panicle length in a study conducted using 30 genotypes of grain amaranth in West Bengal by Ghosh *et al.* (1999).

A correlation analysis for yield and yield components were conducted using 66 amaranth genotypes grown in Lucknow and UP during 1997-98. The genotypic correlation was generally higher than the corresponding phenotypic correlation. At the phenotypic level, significant and positive association was observed between grain yield per plant and plant height and leaf size, plant height and number of primary branches per plant, number of spikelets per spike and number of nodes per plant and leaf size. At the genotypic level, grain yield per plant was positively

correlated with other traits. Leaf size was positively correlated with all the characters except inflorescence length (Sudhir *et al.*, 2003).

2.4. Path coefficient analysis

Vijayakumar *et al.* (1982) conducted studies on growth and development of certain types of amaranths namely *A.tricolor*, *A.tristis*, *A.dubius* and *A.blitum* and observed that the plant height was positively associated with the yield of greens (stem and leaves) at all stages of growth.

Path coefficient analysis done in grain amaranth by Pandey (1984) found that grain yield per plant, harvest index, weight per 1000 seeds had the direct effect on yield.

Analysis of data on yield per plant and its components from 20 genetically diverse genotypes of grain amaranth indicated that leaf length makes the largest direct positive contribution to yield, followed by number of leaves, plant height and 1000 grain weight (Joshi and Rana, 1995).

Path analysis of yield components in grain amaranth showed that plant density made a positive direct contribution to grain yield (Apaza *et al.*, 2002).

A study by Sudhir *et al.* (2003) showed that leaf size was indirectly associated with grain yield via the number of days to flowering, number of days to maturity, plant height and number of inflorescence per plant. Plant height was also indirectly and positively associated with grain yield via the number of days to flowering, number of inflorescence per plant, inflorescence length and leaf size. Leaf size, plant height, number of

inflorescence per plant, inflorescence length and number of days to maturity comprised the major yield components.

Path coefficient analysis in grain amaranth *(Amaranthus hypochondriacus)* by Ananda and Dhanpal (2006) found that grain yield per plant, number of panicle per plant, panicle length and test weight of seeds had the direct impact on grain yield.

2.5. Genetic divergence

The absence of relationship between genetic diversity and geographical diversity indicates that forces other than geographical origin such as exchange of genetic stocks, genetic drift, spontaneous variation, natural and artificial selection are responsible for genetic diversity, as reported by Nagaraj and Prasad (1980).

Fatokun (1985) suggested that leaf length, dry weight of leaf and grain yield are important in forming the clusters in genotypes.

Twenty genotypes selected from various districts of Himachal pradesh and Utter Pradesh hills were subjected to cluster analysis and were grouped into nine clusters using multivariate analysis of genetic divergence for grain yield per plant and six yield related characters. The popping size contributed the maximum divergence followed by protein content, grain yield, inflorescence length, days to maturity and 1000 grain weight. Geographic distribution was not found related to genetic diversity as varieties from the same ecogeographic region were found in different clusters (Joshi and Rana, 1995).

Genetic divergence using Mahalanobis D^2 statistics was worked out in 22 entries of *Amaranthus spp by Elba et al.* (1997) in order to ascertain

similarities among entry performances. Entries were grouped into three clusters that were differentiable in terms of yield means and stability. Cluster analysis established clusters independently to that of their origin, species and other discrete seed characters. Also, similarity and dissimilarity of response pattern among members of a same cluster were evident.

Diversity for grain yield and other morpho-physiological characters has been reported in amaranth germplasm (Bansal and Sharma, 1998).

Genetic divergence, using Mahalanobis D^2 statistics was worked out in 40 amaranth accessions comprising thirteen species by Dehmer (2001) and the results revealed the visibility of three main clusters, which correspond to the three grain amaranth gene pools. In the first cluster, the three-grain amaranth species were found together with the weedy *Amaranthus retroflexus* separated in another sub cluster (primary gene pool). *Amaranthus palmeri* and *Amaranthus lividus* as the two species of the secondary gene pool examined, constituted the second, intermediately related cluster, *Amaranthus albus*, *Amaranthus gracilis* and *Amaranthus tricolor* were found in the third, most distant cluster.

Verma *et al.* (2002) grouped sixty-eight genotypes of grain amaranth (*Amaranthus hypochondriacus*) into nine clusters. The clustering pattern revealed that the genetic diversity might not be related to the geographical diversity. The average intercluster distance was maximum between cluster eight and nine.The groups of genotypes were highly divergent from each other. The genotypes in these clusters revealed substantial differences in the means for the four traits studied. Genotypes IC-95453, IC-35746, IC-35634 and IC-35778 were important for a breeder for exploiting their potential in breeding programme.

2.6. Nutritional use and importance

FAO (1973) reported that tryptophan deficiency of maize protein could be alleviated by substitution of amaranth. As per the report in American health and Nutrition (1973) one-fourth cup of amaranth flour supplied 60% of the RDA of iron.

Carlsson (1974) reported that the proximate composition of amaranth seeds was 15-18% crude protein, 50-70% starch and 4-8 % fat.

High level of calcium had been reported in Amaranth species (Mugerwa and Bwabye, 1974 and Castenedac *et al.*, 1986). Calcium content of amaranth grain ranged from 193-389 mg per 100 g (Joshi and Rana, 1991). Bressani (1992) also reported that 100g of amaranth grain contain 217-303 mg of calcium, 21-104 mg of iron and 556-600 mg of phosphorus.

Carlsson (1980) and Becker *et al.* (1981) reported that total lipid content of grain amaranth ranged from 5.4 to 17% dry matter and had high level of unsaturation (75 %) containing almost 50% linoleic acid.

The *Amaranthus caudatus* starch was reported to be completely non glutinous (Okuno and Sakaguch, 1981). High susceptibility of *A.hypochondriacus* and *A.caudatus* starch granules to amylases was reported by Tomita *et al.* (1981).

Amaranth was reported to be one of the rare plants whose leaves are eaten as a vegetable and the seeds are used as cereals (Kauffman and Hass 1983., Becker ,1989).

In amaranth grain, most of the seed volume is occupied by the embryo that accounted for the high lysine content as reported by Oke (1983).

According to Saunders and Becker (1984) and Singhal and Kulkarni (1988), amaranth grain is a pseudocereal possessing the usual characteristics of cereals such as blend taste, ease of cooking and substantial quantity of protein and fat as compared to most cereals.

Vijayakumar and Shanmugavelu (1985) reported that grain amaranth leaves contain more amount of fiber than vegetable amaranth. As per the report of Parker (1985), the stem and leaf juices of grain amaranth is used in the treatment of kidney stones by the tribes in Tamilnadu and Kerala hills

Castenedac *et al.* (1986) reported that the protein content of amaranths is similar to that of spinach.

According to Yanez *et al.* (1986), the starch component of amaranth is distinctive and it finds application in specialized food and industry.

Mallika (1987) reported that grain amaranth types have only lower levels of oxalate and nitrate as compared to vegetable amaranth.

Pederson *et al.* (1987) reported that amino acid profiles of food could be raised significantly by amaranth substitution.

You *et al.* (1987) reported the nutritional compositions of seeds, leaves and stem in ten grain amaranth cultivars from USA including cultivars of *Amaranthus hypochondriacus*, *Amaranthus hybridus* and *Amaranthus cruentus* grain amaranth cultivars from China. The seeds

contained higher levels of protein, lysine and oil than cereal grains but less leucine. Levels of protein and lysine were high in stems suggesting that it may be valuable as a forage crop.

According to Gupta and Wagle (1988), the crude fiber content of green leafy vegetables ranged from 7.2 to 13.95 per cent. Caloric density, fiber and mineral contents of amaranth were reported to be more than the conventional grains (Becker, 1989). The fiber and iron content of amaranth was found to be three times and five times more than that of wheat. It contained two times more calcium than milk (Thomas, 2005).

Morales *et al.* (1988) reported that ordinary maize meal supplemented with 12.7% (weight) of toasted amaranth flour could provide a nutritionally superior source of protein that can satisfy the protein requirement of young children and provide approximately 70% of diet energy.

According to Singhal and Kulkarni (1988), a combination of rice and amaranth in 9:1 ratio had been reported to approach the FAO/ WHO protein specifications.

Nutritive value of grain amaranth and its supplementary value with other cereals had been described by Raju (1990), Reddy *et al.* (1992) and Bhuvaneswari *et al.* (2001).

Joshi and Rana (1991) identified that amaranth protein has nearly twice the lysine content of wheat protein, three times that of maize, and the same as found in milk.

The availability studies of iron and β carotene from amaranth indicated that these are excellent sources of iron and β carotene. Daily

inclusion of amaranth in the diet of children could help to alleviate their iron and vitamin A deficiencies which could lead to blindness in thousands of children each year (Joshi and Rana, 1991).

Rathod and Udipi (1991) also developed weaning mixtures using malted, roasted and puffed amaranth grains, which could be used at the community level to produce low cost nutrient rich weaning mixes.

Amaranth grain is utilized in the development of homemade weaning mixtures due to its high nutritive value (Gupta and Sengal, 1992). Seralathan *et al.* (1993) also developed highly nutritious weaning foods using grain amaranth.

Jijiamma and Prema (1993) studied the nutritional composition and organoleptic qualities of two cultivars of amaranths (*Amaranthus tricolor*- red and green type) during the rainy and summer seasons. Leaf protein content was unaffected by seasons. The red cultivar, however, when grown in the summer season had better organoleptic quality.

Prakash *et al.* (1993) reported that the content of vitamin C was higher in grain types than vegetable types and it varied between 62 and 288mg per 100 gram.

According to Vetter (1994), a suitable content of lysine and tryptophan together with a low content of leucine in amaranth grains makes it a high quality supplement for Maize, which is rich in leucine but poor in lysine and tryptophan. Combining amaranth with wheat corn or brown rice resulted in a complete protein as high in food value as fish, red meat or poultry (Thomas, 2005).

Danz *et al.* (1998) reported that non-fermentable fiber present in amaranth grain lowers serum cholesterol without increasing the risk of cancer.

Jyothi *et al.* (1999) reported that uses of grain amaranth were found to improve the acceptability and protein quality and quantity of malt mixes when compared to ragi malt

Kalac and Moudry (2000) compared the advantage of amaranth grains with conventional cereals and reported high content of proteins and balanced amino acid composition in amaranth grains.

Gaddagamath (2002) reported that supplementation of the diet with amaranth seeds is the economical way of combating protein energy malnutrition.

Berger *et al.* (2003), in a study of the cholesterol lowering properties of amaranth grain and oil in Hamsters, reported that the amaranth oil significantly reduced non HDL cholesterol and raised HDL cholesterol, as well as lowering very low density lipoprotein cholesterol by 21-50.

Hibi *et al.* (2003) reported that amaranth grain (*Amaranthus hypochondriacus*) and its extract inhibited antigen- specific IgE production through augmenting Th1 cytokinine responses *in vivo* and *in vitro,* and it has got immunological effects *in vivo* or *in vitro*.

Shin *et al.* (2004) reported that amaranth squalene has got hypocholesterolaemic effect and it can be mediated by increased fecal elimination of steroids through interference with cholesterol absorption. The relatively high content of essential amino acids in amaranth grain predetermines its use as a substitution of meat and bone meals (Pisarikova

et al., 2005). According to Thomas (2005) amaranth contains tocotrienols, a form of vitamin E, which have cholesterol lowering activity in humans.

2.7. Food use

The red dye from amaranth leaves and inflorescence is used to colour alcoholic beverages in Bolivia and northwestern Argentina, to colour maize dough in Mexico and in the Southwestern United States (Saur, 1950). It is also used to dye foods and beverages in Ecuador (Hauptli and Jain, 1980).

As per the report of Sanchez- Marroquin *et al.* (1980), flour processed from amaranth seeds could be used in tortillas, breads, cookies, pasta, marzipan and available as an ingredient in a commercial breakfast cereal (Teutonico and Knorr, 1984).

Thomas (2005) reported a variety of use for amaranth grains. Amaranth grain could be used in breakfast cereals or an ingredient in confectionaries. It can be parched or cooked for preparing a gruel or porridge, or milled to produce light coloured flour. The flour contains no glutens and must be blended with wheat flour. As a snack, the tiny grain is popped and tastes like nutty flavored popcorn, or it mixed with honey. The leaves, which are high in protein, vitamins and minerals, are boiled and eaten as greens.

In Nepal, Amaranth seeds are eaten as gruel called "Sattoo" or milled into flour to make chappatis. In Ecuador, the flowers are boiled then the coloured boiling water is added to "aquardrinte" rum to create a drink that purifies the blood (Thomas, 2005).

Materials and Methods

3. METERIALS AND METHODS

Present investigation on "Morphological and Biochemical studies in grain amaranth" was carried out in the Department of Olericulture, College of Horticulture, Vellanikkara during the period November 2005- February 2006.

The experimental site was located at an altitude of 22.5m above mean sea level between $10^0$32'N latitude and $76^0$16'E longitude. The location experiences a warm humid tropical climate. The soil for the experimental site comes under the textural class of sandy clay loam soil and is acidic in reaction.

The project consisted of the following experiments.

1. Genetic cataloguing of grain amaranth accessions
2. Evaluation of variability in grain amaranth accessions
3. Biochemical analysis
4. Statistical analysis

3.1. Genetic cataloguing of grain amaranth accessions

Twenty three accessions collected from different parts of the country (Table-1 and Plate-1) were catalogued based on the IBPGR descriptor developed for amaranth (Table-2).

3.2. Evaluation of variability in grain amaranth accessions

3.2.1. Experimental materials

The experimental materials consisted of twenty three grain amaranth accessions collected from different parts of India.

3.2.2. Experimental methods

Field evaluation of twenty three grain amaranth accessions was conducted during 2005 to 2006. The experiment was laid out in a randomized block design with two replications. Each replication consisted of 23 plots and there were twenty plants per plot. Plot size was $1m^2$ and the spacing was 30×15-cm. Three weeks old seedlings were transplanted to the main field. The crop was raised as per the package of practices for crops (KAU, 2004)

3.2.3. Observations

Five plants per genotype per replication were selected for recording observations

3.2.3.1. Observations on morphological characters

a) Plant height

Five plants were selected randomly in each row at vegetative and flowering stage and their height was recorded and expressed in centimeter

b) Branches per plant

The number of branches per plant was counted at the time of flowering.

c) Length and width of leaf

The fifth fully opened leaf from the terminal bud was harvested from five randomly selected plants on the 30^{th} day of transplanting and the length was measured. The width of the leaf was measured at the region of maximum width and expressed in centimeter

d) Leaf stem ratio

Both leaf yield and stem yield were recorded separately to calculate the leaf stem ratio.

e) Days to 50% flowering

Days to flowering from the date of transplanting were recorded from the plants kept unharvested

f) Crop duration

Number of days taken from the date of transplanting till harvest of seeds was recorded.

g) Vegetable yield (g/plant)

Five plants were randomly selected for recording vegetable yield. The weight of greens from different harvests constitute vegetable yield per plant

h) Grain yield (g/ plant)

Five plants were randomly selected for recording grain yield per plant

i) Pests and disease incidence

Observations on pests and diseases in the main field were recorded

3.3. *Biochemical analysis*

The following biochemical factors were estimated using leaf and grain samples of twenty three genotypes. Leaves taken at 30th day of transplanting from selected plants were used for biochemical study. The following biochemical factors were studied.

3.3.1. Starch

Starch content was analyzed colorimetrically using anthrone reagent (Sadasivam and Manikam, 1992)

The powdered and dried sample was hydrolyzed with 5ml of 2.5N hydrochloric acid and then cooled to room temperature. The residue was then neutralized with solid sodium carbonate until the effervescence ceases. Made up the volume to 100ml and centrifuged. Pipetted 0.5ml of supernatant and made up to 1ml, added 4ml anthrone reagent, heated for eight minutes, cooled rapidly and the intensity of green to dark green colour was read at 630nm. A standard graph was prepared using standard glucose at serial dilutions and glucose content was found out from the standard graph and converted to starch in fresh weight basis.

3.3.2. Protein

The estimation of the protein content was done by Lowry's method (1951).

0.5 gram of the sample was ground well with a pestle and mortar in 5-10ml of the buffer used for the enzyme assay, centrifuged and the supernatant was used for protein estimation. Pipetted 0.2ml of the sample extract and made up to 1ml, added 5ml alkaline copper solution, allowed to stand for 10minutes, added 0.5ml Folin-ciocalteau reagent, incubated at room temperature in the dark for

30minutes. Intensity of blue colour was read at 660nm. A standard graph was prepared and calculated the amount of protein content in the sample.

3.3.3. Vitamin C

The vitamin C content of the fresh sample was estimated by the method of A.O.A.C (1955) using 2,6 dichlorophenol indophenol dye.

One gram of the fresh sample was extracted in four percent oxalic acid using a mortar and pestle and made up to 100ml. 5ml of the extract was pipetted, added 10ml of four per cent oxalic acid and titrated against the dye. Ascorbic acid content of the fresh sample was calculated from the titre value.

3.3.4. β Carotene

β carotene was estimated by the method of A.O.A.C (1970) using saturated n-butanol.

Five gram of powdered and dried sample was placed in a 125ml glass flask and added 50ml water saturated n-butanol from pipette. The flask was stoppered tightly, shook well for one minute and kept overnight, protected from sunlight. Decanted the supernatant, pipetted 0.5ml of the supernatant and diluted with 10ml water saturated butanol and read the colour intensity in a spectrophotometer at 436nm. β carotene content of the sample was calculated from the reading and converted to fresh weight basis.

3.3.5. Iron

The iron content was analyzed colorimetrically using ferric iron, which gives a blood red colour with potassium thiocyanate (Raghuramulu *et al.*, 2003).

To an aliquot of the mineral solution, enough water was added to make up to a volume of 6.5ml followed by one ml of thirty per cent sulphuric acid, one ml of seven per cent potassium per sulphate solution and 1.5ml of 40 per cent potassium thiocyanate solution. The intensity of red colour was measured within 20 minutes at 540nm. Using a standard graph, the iron content of the sample was estimated and converted to fresh weight basis.

3.3.6. Calcium

The calcium content was estimated using titration method with EDTA as suggested by Hesse (1971).

One gram of dried and powdered sample was pre digested with 12ml of 9:4 diacid and volume made up to 100ml. 1ml of aliquot was taken and added to 10ml water, 10 drops of five per cent hydroxylamine, 10 drops of triethanolamine and 2-5ml of ten per cent sodium hydroxide and ten drops of calcon. Then it was titrated using EDTA till the appearance of permanent blue colour. It was expressed in mg per 100g of sample and converted to fresh weight basis.

3.3.7. Fibre

Crude fiber content was estimated by acid-alkali digestion method as suggested by Chopra and Kanwar (1978).

Two gram of the dried and powdered sample was boiled with 200ml of 1.25 per cent sulphuric acid for thirty minutes. It was filtered through a muslin cloth and washed with boiling water and again boiled with 200ml of 1.25 per cent sodium hydroxide for thirty minutes. Again, it was filtered through a muslin cloth and washed with sulphuric acid, water and alcohol. The residue was transferred to a pre weighed ashing dish, dried, cooled and weighed. The residue was then

ignited for thirty minutes in a muffle furnace at 600^{0}C,cooled in a dessicator and reweighed. The fiber content of the sample was calculated from the loss of weight on ignition and then converted to fresh weight basis.

3.4. Statistical analysis

The data were subjected to the following statistical analysis.

1) Estimation of selection parameters
2) Components of heritable variation

A) Variability

Variability existing in the various characters under observation was estimated as per the procedure suggested by Burton (1952).

B) Heritability

Heritability in broad sense was calculated according to the formula suggested by Johnson *et al.* (1955)

H^2 =Vg/Vp ×100 where,

H^2=Heritability (in broad sense) expressed in percentage

Vg=Genotypic variance

Vp=Phenotypic variance

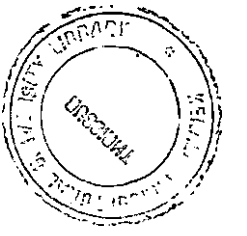
Phenotypic variance (Burton, 1952)

Vp=Vg+E where,

Vp =Phenotypic variance

Vg=Genotypic variance

E=Error mean square



Genotypic variance (Burton, 1952)

Vg= V-E/r where,

Vg= Genotypic variance

E= Error mean square

V= Varietal mean square

r = Number of replications.

C) Phenotypic and genotypic correlations

Phenotypic and genotypic correlation coefficients, multiple correlation between yield and various yield components and among themselves were found out (Rangasamy, 1995).

D) Path coefficient analysis

Association analysis based on genetic correlations of components with yield will not give a true picture of the relative merits and demerits of each of the components to final yield. Hence an assessment of the merit of each character by analyzing the direct and indirect effects of the same towards final yield is of immense value for yield improvement.

Path coefficient analysis suggested by Wright (1921) was applied to study the cause and effect relationship in a system of correlated variables.

Evolving selection index using discriminant function (Hazel, 1943) for selecting suitable genotypes from a highly heterogeneous mass population, the selection should always be based on the minimum number of characters. An estimation of discriminant function based on such most reliable and effective characters is a valuable tool for any breeder. This discriminant function would

ensure a maximum concentration of the desired genes in the plants or in the line selected.

E) Mahalanobis D^2 analysis

Replication mean for each character of each accession was used for analysis of variance. After testing the differences, a simultaneous test of significance of difference with regard to the pooled effects of the ten characters under study was carried out using Wilk's criterion (Rao, 1952).

Original mean values were then transformed into uncorrelated mean using pivotal condensation of common dispersion matrix. From the uncorrelated variables, the actual values of D^2 between any two varieties based on ten characters were grouped into a number of clusters on the basis of D^2 values (Rao, 1952).

F) Duncan's Multiple Range Test was used for interpreting results of biochemical analysis.

Table-1. Grain amaranth accessions used in the study

Sl No	Accessions	Sources
1	GA-2	VPKAS, Almora
2	GA-4	VPKAS, Almora
3	GA-11	NBPGR, Shimla
4	GA-13	NBPGR, Shimla
5	GA-15	NBPGR, Shimla
6	GA-20	UAS, Bangalore
7	GA-22	UAS, Bangalore
8	GA-23	Idukki
9	GA-24	Wayanad
10	GA-25	Palakkad
11	GA-26	Dept of Olericulture, KAU, Vellanikkara
12	GA-27	Tamilnadu
13	GA-28	Tamilnadu
14	GA-29	Dept of Olericulture, KAU,Vellanikkara
15	GA-30	Dept of Olericulture, KAU,Vellanikkara
16	GA-31	Idukki
17	GA-32	Dept of Olericulture, KAU,Vellanikkara
18	GA-33	Tamilnadu
19	GA-34	Dept of Olericulture, KAU,Vellanikkara
20	GA-35	Dept of Olericulture, KAU,Vellanikkara
21	GA-36	Dept of Olericulture, KAU,Vellanikkara
22	GA-37	Dept of Olericulture, KAU,Vellanikkara
23	GA-38	Dept of Olericulture, KAU,Vellanikkara

Table- 2. Amaranth descriptor list.

1. Plant characters.

1.1 Growth habit

1. Erect 2. Prostrate.

1.2 Stem pigmentation.

1. Green 2.Purple/Pink 3. Others

1.3 Stem pubescence.

1. None 2. Low 3. Conspicuous

1.4 Petiole pigmentation

1. Green 2.Purple/Pink 3. Others

1.5 Leaf pigmentation

1. Entire lamina purple or pink
2. Basal area pigmented
3. Central spot
4. Two stripes
5. One stripe
6. Margin and vein pigmented
7. Pale green or chlorotic stripe on normal green
8. Normal green
9. Dark green
10. Others

1.6 Leaf pubescence

1. None 2. Low 3. Conspicuous

1.7 Leaf shape 1. Lanceolate 2.Elliptical 3. Cuneate 4. Obovate 5.Ovatinate 6. Rhombic 7.Oval

1.8 Leaf margin

1. Entire 2. Crenate 3.Undulate 4. Others

1.9 Prominence of leaf veins

1. Smooth 2. Rugose

2. Inflorescence characters

2.1 Terminal inflorescence laterals

1.Present 2. Absent

2.2 Terminal inflorescence shape.

1. Spike 2. Panicle with short branches

3. Panicle with long branches 4. Club shaped at tips 5. Others

2.3. Terminal inflorescence latitude

1. Erect 2. Drooping

2.4. Terminal inflorescence colour

1. Yellow 2. Green 3. Pink 4. Red 5. Others

2.5.Presence of axillary inflorescence

1.Absent 2.Present

Plate.1 A field view of grain amaranth plants

Results

4. RESULTS

Data collected from the present experiment was statistically analyzed and results are presented under the following headings.

4.1 Genetic cataloguing of grain amaranth accessions

4.2 Estimation of variability, heritability and genetic advance

4.3 Correlation studies and path coefficient analysis

4.4 Estimation of divergence

4.5 Biochemical studies

4.1 Genetic cataloguing of grain amaranth accessions

Qualitative characters have a great role in identification of varieties. Twenty-three accessions of grain amaranth were catalogued based on the IBPGR descriptor mentioned in Table-2. Morphological characters like growth habit, stem colour, leaf colour, leaf shape, inflorescence colour and seed colour were recorded and presented in Table-3.

Growth habit of all the accessions were erect (100%) (Table-4). Stem pigmentation varied from purple, maroon and light green. Among the accessions, 52.17 per cent had purple stem, 26 per cent had light green and 21.74 per cent had maroon stem. Accessions viz., GA-23, GA-25, GA-27, GA-28, GA-29, GA-30, GA-31, GA-33, GA-35, GA-36, GA-37 and GA-38, had purple stem colour. In GA-20, GA-24, GA-26, GA-32, GA-34, stem colour was maroon. Colour of the stem was light green in GA-2, GA-4, GA-11, GA-13, GA-15 and GA-22

The leaf pigmentation of 23 accessions came under three classes namely purple, reddish green and green colour. Most of the accessions (56.52%) had purple leaf followed by green (26.08%) and 17.39% had a leaf pigmentation

Table-3. Morphological descriptions of the grain amaranth accessions

Sl. No.	Accessions	Growth habit	Stem colour	Leaf colour	Leaf shape	Inflorescence colour	Seed colour
1	GA-2	Erect	Light green	Green	Elliptical	Off-white	Cream
2	GA-4	,,	Light green	Green	Elliptical	Off-white	Cream
3	GA-11	,,	Light green	Green	Elliptical	Off-white	Cream
4	GA-13	,,	Light green	Green	Elliptical	Off-white	Cream
5	GA-15	,,	Light green	Green	Elliptical	Off-white	Cream
6	GA-20	,,	Maroon	Purple	Lanceolate	Purple	Black
7	GA-22	,,	Light green	Green	Elliptical	Off-white	Cream
8	GA-23	,,	Purple	Purple	Lanceolate	Purple	Black
9	GA-24	,,	Maroon	Purple	Lanceolate	Maroon	Maroon
10	GA-25	,,	Purple	Reddish green	Lanceolate	Purple	Black
11	GA-26	,,	Maroon	Purple	Lanceolate	Maroon	Maroon
12	GA-27	,,	Purple	Reddish green	Rhombic	Purple	Black
13	GA-28	,,	Purple	Reddish green	Lanceolate	Purple	Black
14	GA-29	,,	Purple	Purple	Lanceolate	Purple	Black
15	GA-30	,,	Purple	Purple	Lanceolate	Purple	Black
16	GA-31	,,	Purple	Purple	Lanceolate	Purple	Black
17	GA-32	,,	Maroon	Purple	Rhombic	Maroon	Maroon
18	GA-33	,,	Purple	Purple	Lanceolate	Purple	Black
19	GA-34	,,	Maroon	Reddish green	Rhombic	Purple	Black
20	GA-35	,,	Purple	Purple	Lanceolate	Purple	Black
21	GA-36	,,	Purple	Purple	Lanceolate	Purple	Black
22	GA-37	,,	Purple	Purple	Lanceolate	Purple	Black
23	GA-38	,,	Purple	Purple	Lanceolate	Purple	Black

Table-4. Summary of morphological descriptions of the grain amaranth accessions

SL.No.	Characters	Accessions (%)
1	Growth habit	
	Erect	100
2	Stem pigmentation	
	Purple	52.17
	Light green	26.00
	Maroon	21.74
3	Leaf pigmentation	
	Purple	56.52
	Green	26.08
	Reddish green	17.39
4	Leaf shape	
	Lanceolate	60.86
	Elliptical	26.09
	Rhombic	13.04
5	Inflorescence colour	
	Purple	60.88
	Off white	26.09
	Maroon	13.04
6	Seed colour	
	Black	56.52
	Meroon	13.04
	Cream	30.44

of reddish green. In accessions GA-2, GA-4, GA-11, GA-13, GA-15 and GA-22, leaf colour was green.

Leaf shape of grain amaranth accessions ranged from lanceolate, rhombic and elliptical. Most of the accessions had a lanceolate lamina (60.86%) followed by elliptical (26.09%) and rhombic (13.04%).

Inflorescence colour of twenty three accessions came under three classes namely purple, maroon and off white (Plate.2). Most of accessions (60.88%) had purple inflorescence colour followed by off-white (26.09%) and maroon (13.04%). Inflorescence colour was purple in accessions GA-20, GA-23, GA-25, GA-27, GA-28, GA-29, GA-30, GA-31, GA-33, GA-34, GA-35, GA-36, GA-37 and GA-38. In accessions GA-24, GA-26 and GA-32, inflorescence colour was maroon. Off -white colour of inflorescence was noticed in accessions GA-2, GA-4, GA-11, GA-13, GA-15 and GA-22

Seed colour of grain amaranth accessions ranged from black, maroon and cream. 56.52% accessions had black colour seeds, 30.44% cream coloured and 13.04% accessions had maroon colour seeds. Cream coloured seeds were obtained from accessions GA-2, GA-4, GA-11, GA-13, GA-15 and GA-22 whereas accessions GA-24, GA-26 and GA-32 gave maroon coloured seeds. In accessions GA-20, GA-23, GA-25, GA-27, GA-28, GA-29, GA-30, GA-31, GA-33, GA-34, GA-35, GA-36, GA-37 and GA-38, seed colour was black.

Most of the genotypes were found resistant to almost all diseases and pests.

4.2 Estimation of variability, heritability and genetic advance

The results of analysis of variance of twenty three grain amaranth accessions showed significant difference for all the characters studied viz., plant

Table -5. Analysis of variance for yield and its component characters

Source	Genotypes	Replication	Error	CV	CD
Degrees of freedom	22	1	22		
Plant height at vegetative stage	25.71	3.42	5.09	7.26	5.30
Plant height at flowering stage	1347.49	7.50	8.72	3.42	6.94
No of branches	36.46	9.58	4.31	18.77	4.88
Leaf width	2.60	0.10	0.04	4.74	0.48
Leaf length	15.28	0.60	0.37	4.73	1.44
Vegetable yield/plant	2379.71	109.62	31.24	3.99	13.13
Leaf stem ratio	0.86	0.01	0.59	9.08	0.577
Days to flower	561.20	0.78	20.23	6.99	10.57
Crop duration	387.90	12.5	22.52	5.58	11.15
Grain yield/plant	1188.92	1.47	10.16	6.48	7.49

height (at vegetative stage and flowering stage), number of branches, leaf width, leaf length, vegetable yield per plant, leaf stem ratio, days to flower, crop duration and grain yield per plant (Table-5). The extent of variability present in twenty three accessions with respect to yield and its component characters was measured in terms of mean, and its standard error, range, coefficient of variation at genotypic and phenotypic levels, heritability and genetic advance and are presented in Table-7

4.2.1 Quantitative and qualitative characters

4.2.1.1 Plant height at vegetative stage

Plant height at vegetative stage ranged from 24.6 cm to 37.2 cm and was maximum in GA-24 (37.2 cm) followed by GA-25 (36.2 cm), GA-31 (36.1 cm), GA-34 (34.66 cm) and GA-29 (34.43 cm). At vegetative stage, plant height was the lowest in accession GA-35 (24.60 cm) (Table-6). The mean value for plant height was 31.04 cm and it recorded lowest PCV and GCV values (12.64 and 10.34 respectively). Genetic advance and heritability were also found to be the lowest for this character (5.41 and 67% respectively) (Table-7).

4.2.1.2 Plant height at flowering stage

Plant height at flowering was maximum in accession GA-31 (138.34 cm) (Plate.3) followed by GA-20 (134.2 cm) and GA-26 (124.9 cm). Height was found to be the lowest in accession no GA-22 (53.2 cm) (Table-6). The mean value for this character as observed in Table 7 was 95.24 cm. PCV and GCV values were 30.19 and 30.00 respectively and genetic advance was 52.95. Heritability estimated for this character was the highest (98.7%).

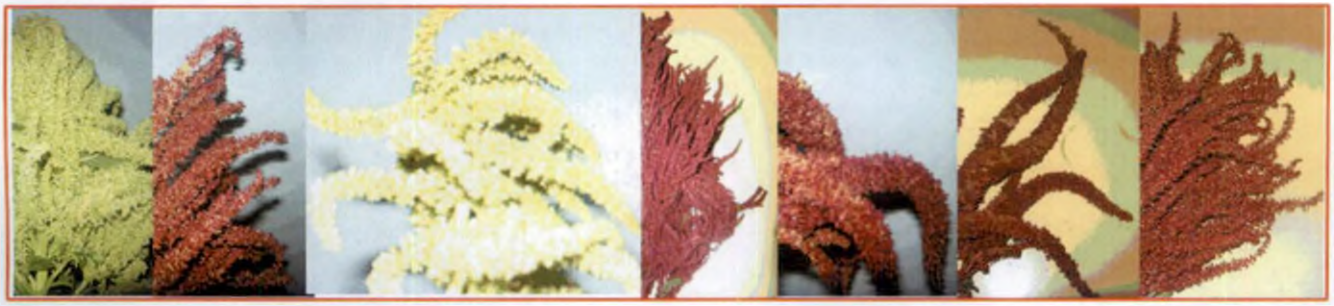


Plate. 2
Variability in inflorescence colour of grain amaranth accessions

Plate.3 GA-31
Accession with maximum plant height, leaf width, length, vegetable yield and crop duration

Table-6. Means of different characters of grain amaranth accessions

Accession No.	Means of different characters									
	Plant height at vegetative stage(cm)	Plant height at flowering Stage(cm)	No. Of branches	Leaf width(cm)	Leaf length(cm)	Vegetable yield/plant(g)	Leaf stem ratio	Days to flower(days)	Crop duration(days)	Grain yield/plant(g)
GA-2	27.80	56.50	5	2.43	10.75	108.00	1.90	40	72	51.00
GA-4	30.00	64.10	6	3.10	10.80	106.00	2.20	45	75	52.50
GA-11	25.15	62.00	5	4.30	8.95	101.3	2.50	40	65	52.50
GA-13	33.66	74.50	5	3.00	10.86	124.00	3.50	43	63	53.30
GA-15	33.16	72	13	4.69	12.10	110.00	3.26	50	80	92.00
GA-20	31.46	134.20	15	6.40	17.66	195.40	3.72	79	102	115.60
GA-22	29.10	53.20	5	3.00	10.10	107.00	3.40	32	62	49.90
GA-23	28.60	78.30	8	4.10	13.15	125.50	3.50	66	78	57.50
GA-24	37.20	95.56	15	5.56	14.16	192.00	2.87	78	105	112.00
GA-25	36.20	124.10	18	6.20	18.10	200.00	3.10	84	105	128.00
GA-26	30.07	124.90	14	3.06	13.20	190.00	2.95	76	95	98.20
GA-27	33.25	124.00	16	4.86	13.06	154.80	3.00	73	94	94.40
GA-28	31.86	90.24	15	4.76	14.13	150.00	2.36	72	90	92.00
GA-29	34.43	91.95	13	4.71	14.16	149.00	3.06	71	89	90.20
GA-30	32.43	90.10	12	4.60	13.80	140.00	1.38	71	85	90.30
GA-31	36.10	138.34	16	6.43	19.93	209.00	3.21	95	115	120.00
GA-32	27.06	86.00	14	4.80	11.06	139.00	3.20	70	85	90.00
GA-33	30.45	67.10	7	3.50	13.70	120.00	1.90	70	85	73.20
GA-34	34.66	78.00	14	4.10	9.96	109.55	2.70	64	81	77.00
GA-35	24.60	66.26	9	5.20	13.76	128.00	2.16	68	80	58.00
GA-36	29.50	60.00	7	4.10	12.23	116.00	2.38	68	88	50.20
GA-37	31.85	84.00	12	4.80	13.40	130.40	1.60	68	80	79.00
GA-38	25.43	71.25	10	2.96	9.43	110.50	2.10	72	90	71.60

4.2.1.3 Number of branches per plant

Number of branches per plant in twenty three grain amaranth accessions ranged from 5 to 18.The highest number of branches per plant (18) was observed in GA-25 followed by GA-27 (16) and GA-31 (16) (Table-6). Number of branches was found to be minimum (5) in accessions GA-2, GA-11, GA-13 and GA-22 . The mean value recorded for number of branches was 11.06 (Table-7). GCV and PCV values were 36.24 and 40.81 respectively. Values for heritability and genetic advance were 78.8% and 7.33 respectively.

4.2.1.4 Leaf width

Leaf width was maximum in GA-31 (6.43 cm) and GA-20 (6.40 cm) followed by GA-25 (6.20 cm) and GA-24 (5.56 cm) (Table-6). The minimum leaf width was recorded in GA-2 (2.43 cm). Leaf width ranged from 2.43 - 6.43 cm with a mean value of 4.37 cm (Table-7). PCV and GCV values were 26.30 and 25.86 respectively and genetic advance was 2.29. Heritability estimated for this character was 96.7%.

4.2.1.5 Leaf length

Leaf length was maximum in GA-31 (19.93 cm) followed by GA-25 (18.10 cm). The minimum leaf length of 8.95 cm was recorded in GA-11. The mean value for leaf length was 14.97 cm (Table-7). PCV and GCV values were 21.56 and 21.04 respectively, and genetic advance was 5.49. Heritability estimated for this character was 95.2%.

4.2.1.6 Vegetable yield/plant

Vegetable yield obtained from a plant was maximum in GA-31 (209 gm) and lowest in GA-11 (101.3 gm). The mean value for vegetable yield/plant

was 155.80 gm. Values for PCV, GCV and genetic advance were 24.84, 24.51 and 69.27 respectively. Heritability estimated for the character was 97.4%.

4.2.1.7 Leaf stem ratio

Leaf stem ratio was maximum in GA-20 (3.72) and minimum in GA-30 (1.38). The mean value for leaf stem ratio was 2.69. PCV and GCV values were 25.22 and 23.53 respectively and genetic advance was 1.22. Heritability estimated for the character was 87% (Table-7).

4.2.1.8 Days to flower

Number of days taken for 50% flowering ranged from 32-95 with a mean value of 63.54. Early flowering was noticed in accession GA-22 (32 days) and GA-31 was the late bolter, which took 95 days for flowering. GCV and PCV values were 25.56 and 26.50 respectively. Heritability and genetic advance was 93% and 36.28 respectively (Table-7).

4.2.1.9 Crop duration

Crop duration was maximum in GA-31 (115 days) followed by GA-24 and GA-25 (105 days). Lowest value for crop duration was recorded in GA-22 (62 days). The mean duration of genotypes was 88.95 days. PCV and GCV values for the character were low recording 16.86 and 15.91 respectively. Heritability and genetic advance was 89% and 26.27% respectively.

4.2.1.10 Grain yield/plant

The highest grain yield obtained from a plant (128g) was in GA-25 (Plate.4) followed by GA-31 (120gm) and GA-20 (115.6g). Grain yield was the lowest in GA-22 (49.9 g). The mean grain yield per plant was 87.14g. GCV and

Plate. 4 GA-25
Accession with maximum grain yield per plant

Plate.5 GA-15
Accession with maximum protein content

Table-7.Range, Mean,Genotypic coefficient of variation (GCV), Phenotypic coefficient of variation(PCV), Heritability, Genetic advance(GA) and Genetic gain as percentage of mean in grain amaranth accessions for important characters

Sl. No.	Characters	Range	Mean ± SEm	GCV	PCV	Heritability (%)	GA	GA % of mean
1	Plant height at Vegetative stage	24.6 - 37.2	31.0443 ± 1.59	10.34	12.64	67.0	5.41	17.42
2	Plant height at flowering stage	53.2 - 138.34	95.2435 ± 2.08	30.00	30.19	98.7	52.95	61.39
3	Number of branches	5 - 18	11.0652 ± 1.46	36.24	40.81	78.8	7.33	66.24
4	Leaf width	2.43 - 6.43	4.3765 ± 0.43	25.86	26.30	96.7	2.29	52.32
5	Leaf length	8.95 - 19.93	14.9761 ± 3.95	21.04	21.56	95.2	5.49	42.36
6	Vegetable yield/plant	101.3 - 209	155.8022 ± 3.95	24.51	24.84	97.4	69.27	49.83
7	Leaf stem ratio	1.38 - 3.72	2.6933 ± 0.17	23.53	25.22	87.0	1.22	45.29
8	Days to flower	32-95	63.5478 ± 3.18	25.56	26.50	93.0	36.28	50.78
9	Crop duration	62 - 115	88.9565 ± 3.35	15.91	16.86	89.0	26.27	30.92
10	Grain yield/plant	49.9-128	87.1417 ± 2.25	49.40	49.83	98.3	49.59	100.91

PCV values were the highest in this character recording 49.40 and 49.83 respectively. Genetic advance was also high with an average value of 49.59. Heritability observed was also very high (98.3%).

4.3 Correlation between yield and components

Correlation studies indicate association of various characters with yield and inter relationship among various component characters at genotypic and phenotypic levels. The estimates of phenotypic and genotypic correlation between different pairs of characters are presented in Table-8 and Table-9

4.3.1 Phenotypic correlation

Number of branches had maximum positive and significant correlation (0.895) with yield per plant. Plant height at flowering stage (0.890), crop duration (0.855) and days to flower (0.758) also had significant positive correlation with grain yield per plant (Table-8)

The characters like plant height at vegetative stage, leaf width, leaf length, vegetable yield per plant, leaf stem ratio had no correlation with yield. Plant height at flowering stage and days to flower had significant positive correlation with crop duration (0.795 and 0.878 respectively). Crop duration had maximum significant positive correlation with days to flower (0.878). Plant height at flowering stage, leaf length and leaf width had significant positive correlation with vegetable yield per plant (0.912,0.834 and 0.777 respectively). Plant height at flowering stage, vegetable yield per plant had positive significant correlation with leaf length (0.769 and 0.834 respectively). Vegetable yield per plant had positive correlation with leaf width (0.777). Plant height at flowering stage had positive significant correlation with number of branches per plant (0.763), leaf length (0.769), vegetable yield per plant (0.912) and crop duration (0.795). Plant height at flowering and vegetable yield per plant and grain yield had maximum

Table –8 Phenotypic correlation coefficients between yield and yield components

Character	Plant height at flowering	No of branches	Leaf width	Leaf length	Vegetable yield/plant	Leaf stem ratio	Days to flower	Crop duration	Grain yield/plant
Plant height at vegetative stage	0.505	0.047	0.405	0.498	0.527	0.068	0.305	0.442	0.621
Plant height at flowering		0.763*	0.666	0.769*	0.912*	0.407	0.735	0.795*	0.890*
No of branches			0.704	0.621	0.718	0.362	0.698	0.701	0.895*
Leaf width				0.520	0.777*	0.621	0.729	0.762	0.708
Leaf length					0.834*	0.807	0.724	0.746	0.785
Vegetable yield/plant						-0.502	0.746	0.845	0.839
Leaf stem ratio							0.539	0.463	0.478
Days to flower								0.878*	0.758*
Crop duration									0.855*

* Significant at p = 0.05 levels

positive correlation with plant height at vegetative stage (0.505, 0.527 and 0.621 respectively).

4.3.2 Genotypic correlation

Number of branches had maximum positive and significant correlation with grain yield per plant (0.980). Plant height at flowering stage (0.927), days to flower (0.769) and crop duration (0.898) had significant positive correlation with yield per plant (Table-9)

The characters like plant height at vegetative stage, leaf width, leaf length, vegetable yield per plant and leaf stem ratio had no correlation with grain yield per plant. Number of branches, plant height at flowering stage, days to flower had significant positive correlation with crop duration. (0.887, 0.844 and 0.976 respectively). Crop duration had maximum significant positive correlation with days to flower (0.976). Vegetable yield per plant had negative correlation with leaf stem ratio (-0.569). Plant height at flowering stage, leaf width, and leaf length had positive significant correlation with vegetable yield per plant (0.908, 0.729 and 0.868 respectively). Plant height at flowering stage, leaf width and vegetable yield per plant had significant positive correlation with leaf length (0.792, 0.852 and 0.868 respectively). Leaf length and vegetable yield per plant had significant positive correlation with leaf width (0.852 and 0.729 respectively). Plant height at flowering stage (0.884), crop duration (0.887) had positive significant correlation with number of branches. Number of branches (0.884), leaf length (0.792), vegetable yield per plant (0.908), crop duration (0.844) had significant positive correlation with plant height at flowering stage. Grain yield per plant (0.730), vegetable yield per plant (0.640), leaf length (0.625) and height at flowering (0.608) had positive correlation with plant height at vegetative stage.

Table-9 Genotypic correlation coefficients between yield and yield components

Characters	Plant height at flowering	No of branches	Leaf width	Leaf length	Vegetable yield/plant	Leaf stem ratio	Days to flower	Crop duration	Grain yield/plant
Plant height at vegetative stage	0.608	0.078	0.488	0.625	0.640	0.213	0.438	0.525	0.730
Plant height at flowering		0.884**	0.679	0.792**	0.908**	0.454	0.772	0.844**	0.927**
No of branches			0.819	0.673	0.820	0.393	0.771	0.887**	0.980**
Leaf width				0.852**	0.729**	0.469	0.770	0.797	0.792
Leaf length					0.868**	0.541	0.752	0.840	0.818
Vegetable yield/plant						-0.569	0.768	0.900	0.800
Leaf stem ratio							0.585	0.545	0.529
Days to flower								0.976**	0.769**
Crop duration									0.898**

**Significant at G=0.01 levels

4.3.3 Path coefficient analysis

Path coefficient analysis provides knowledge of the paths through which a component character influences the expression of economic character like yield. It helps in partitioning the genotypic correlation coefficients into direct and indirect effects of the component characters on yield. Crop duration had maximum direct effect on grain yield per plant (1.711) followed by number of branches (1.506) and leaf width (1.401) (Table-10). Leaf length which exhibited high correlation with yield (0.818) had only low direct effect on grain yield per plant (0.090). The significant positive correlation was mainly due to it's indirect effect through number of branches (0.937) and crop duration (1.270). Plant height at flowering stage exhibited significant positive correlation with yield per plant (0.927) and had high negative direct effect (-0.763). The positive correlation is mainly through it's high indirect effect through number of branches (1.152), leaf width (2.498) and crop duration (1.361). Days to flower had positive genotypic correlation with yield per plant (0.769) and low direct effect (0.325). The significant positive correlation was contributed by indirect effects through crop duration, leaf length, leaf width and number of branches. (1.506, 1.430, 1.040 and 1.053 respectively).

4.4 Divergence studies

D^2 statistics is a valuable tool for obtaining quantitative estimates of divergence between biological populations. Using Mahalanobis D^2 statistics, the twenty-three accessions of grain amaranth were grouped into five clusters (Table-11) and their variable means are presented in Table-12.

Among the five clusters, cluster I and II had six accessions each and cluster III and IV had three accessions each. Cluster V had five accessions in it.

Accessions included in cluster I were GA-2, GA-4, GA-11, GA-13, GA-22 and GA-36 and they recorded lowest values for most of the characters like plant height at vegetative and flowering stage (29.20 and 61.72 cm), number of

Table -10 Path coefficient analysis of grain yield and component characters

Characters	rg	Direct	Plant height at vegetative stage	Plant height at flowering	No of branches	Leaf width	Leaf length	Vegetable yield	Leaf stem ratio	Days to flower	Crop duration
Plant height at vegetative stage	0.730	0.440	-	0.336	0.717	0.100	1.522	0.045	0.480	0.124	0.793
Plant height at flowering	0.927	-0.763	0.223	-	1.152	2.498	0.699	0.828	0.239	0.828	1.361
No of branches	0.980	1.506	0.210	0.227	-	2.649	0.560	0.654	0.120	0.507	1.206
Leaf width	0.792	1.401	0.179	0.442	1.064	-	0.303	0.643	0.07	0.170	1.306
Leaf length	0.818	0.090	0.220	0.510	0.937	0.235	-	0.075	0.235	0.160	1.270
Vegetable yield/plant	0.800	0.663	0.232	0.605	1.085	0.758	2.650	-	-0.457	0.170	1.437
Leaf stem ratio	0.529	0.342	0.031	0.337	0.545	0.243	0.700	0.043	-	0.180	0.760
Days to flower	0.769	0.325	0.135	0.448	1.053	1.040	1.430	0.658	0.678	-	1.506
Crop duration	0.898	1.711	0.204	0.528	1.061	2.850	0.150	0.067	0.501	1.280	-

Residual value =0.077

branches (5.5), leaf width (3.09 cm), leaf length (10.62 cm), vegetable yield (110.38 g), leaf stem ratio (2.26), days to flower (44.66), crop duration (70.83) and grain yield per plant (56.98g). Cluster II included GA-28, GA-29, GA-30, GA-32, GA-34 and GA-37 and they recorded highest mean values for vegetable yield (239.89 g). Cluster III which included GA-20, GA-25 and GA-31 recorded highest mean value for plant height at vegetative and flowering stage (34.59 cm 132.21 cm respectively), number of branches (16.33), leaf width (6.34 cm), leaf length (18.56 cm), leaf stem ratio (3.35), days to flowering (86 days), crop duration (107.33 days) and grain yield (121.2g).

Accessions GA-24, GA-26 and GA-27 came under cluster IV and they recorded an average vegetable yield of 178.93 g and grain yield of 101.53g.

Accessions included in cluster V were GA-15, GA-23, GA-33, GA-35 and GA-38 and they recorded an average vegetable yield of 118.8 g and grain yield of 70.46g (Table-12). The mean value for vegetable yield was the highest in cluster II (239.88 g) followed by cluster III (201.47g) and the lowest mean value for this character was recorded in cluster I (110.38g). Grain yield was the highest in cluster III (121.2g) followed by cluster 1V (101.53g) and lowest in cluster I (56.9g).

Inter and intra cluster D^2 values among the five clusters are given in Table-13. Cluster IV had maximum intra cluster distance (283.64) and the minimum in cluster III (55.13). The intra cluster distance for other clusters were 109.34 (cluster I), 136.45 (cluster II) and 202.41 (cluster V). Maximum inter cluster distance was between cluster I and cluster III (3432.44). The minimum inter cluster distance was between cluster IV and cluster V (223.35) suggesting less genetic divergence among them compared to other clusters (Fig. 1)

Table -11.List of amaranth accessions included in different clusters

Cluster	Accessions	No. Of accessions
I	GA-2, GA-4, GA-11, GA-13, GA-22 and GA-36	6
II	GA-28, GA-29, GA-30, GA-32, GA-34 and GA-37	6
III	GA-20, GA-25 and GA-31	3
IV	GA-24, GA-26 and GA-27	3
V	GA-15, GA-23, GA-33, GA-35 and GA-38	5

Table -12. Cluster means for different quantitative characters

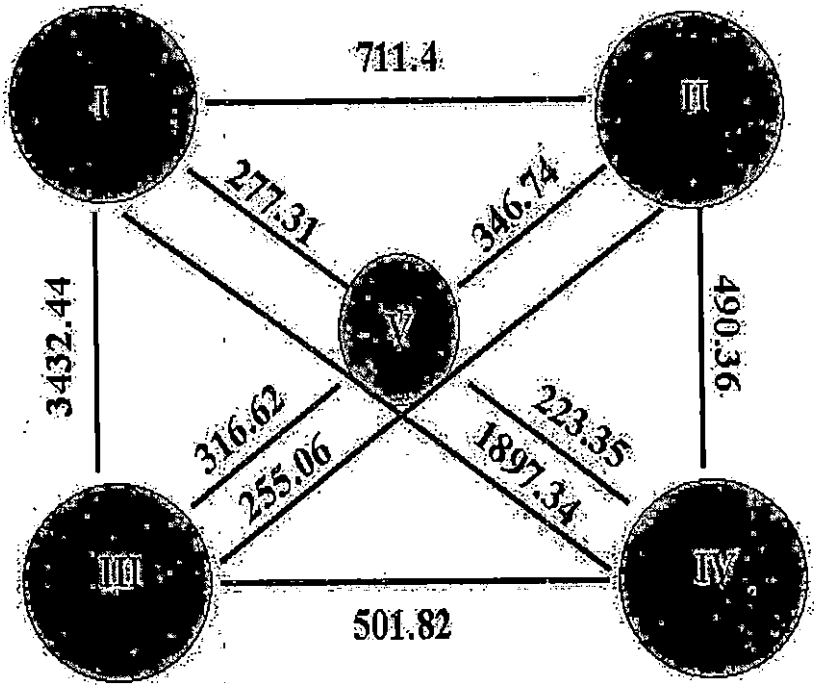
Characters	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
Plant height at Vegetative stage (cm)	29.20	32.05	34.59	33.51	28.45
Plant height at flowering stage (cm)	61.72	86.72	132.21	114.82	70.38
Number of branches	5.50	13.42	16.33	15.00	9.40
Lead width (cm)	3.09	4.53	6.34	4.49	4.48
Leaf length (cm)	10.62	12.75	18.56	13.47	12.43
Vegetable yield/plant (g)	110.38	239.89	201.47	178.93	118.80
Leaf stem ratio	2.26	2.88	3.35	2.94	2.45
Days to flower	44.66	69.33	86.00	75.66	62.20
Crop duration	70.83	85.00	107.33	98.00	80.60
Grain yield/plant (g)	56.98	86.42	121.2	101.53	70.46

Table-13. Average intra and inter cluster D^2 values of five clusters

	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
I	109.34				
II	711.14	136.45			
III	3432.44	255.06	55.13		
IV	1897.34	490.36	501.82	283.64	
V	277.31	346.74	316.62	223.35	202.41

* Values in diagonals indicate intra cluster distance

Fig.1 Statistical distance (D^2) among different clusters of 23 accessions



4.5 Bio chemical studies in grain amaranth accessions

Biochemical constituents viz., starch, protein, Vitamin C, β carotene, iron, calcium and fibre were analyzed in both leaves and grains of grain amaranth accessions. The results obtained in the biochemical study were subjected to Duncan's Multiple Range Test and they are presented below.

4.5.1 Starch

4.5.1.1 Starch content in leaf

Based on starch content in leaf, DMRT classified the different accessions into several groups and each group containing one, two or more genotypes. J group contained maximum number of accessions and minimum was in C group. The accessions belonging to the same group had no significant differences between themselves but they differed from the accessions of other groups.

As revealed in Table-14, starch content of leaf ranged from 4.95g to 7.1g in 100g sample with a mean value of 5.53g. The highest starch content was found in accession GA-29 (7.1g) and GA-33 (7.05g) and the lowest in GA-30 (4.95g) (Fig. 2)

4.5.1.2 Starch content in grain

Based on DMRT classification, B group contained maximum number of genotypes and minimum was in C groups. Starch content in grain ranged from 49.75g to 67.17g in 100g sample with a mean value of 60.2g. The content of starch was the highest in accession GA-22 (67.17g) followed by GA-13 (66.5g), GA-11 (66.15g), GA-33 (66.04g), GA-15 (65.70g) and GA-4 (65.60g). The content of starch was the lowest in GA-36 (49.75g). (Fig.3)

Table-14. Chemical constituents in grain amaranth accessions

Genotypes	Starch (g/100 g)		Protein (g/100 g)		Vitamin C (mg/100 g)	
	Leaf	Grain	Leaf	Grain	Leaf	Grain
GA-2	6.05^{B}	62.21^{D}	3.81^{A}	18.15^{B}	96.70^{R}	5.40^{D}
GA-4	5.27^{FG}	65.60^{B}	2.85^{G}	17.05^{D}	117.55^{P}	3.53^{L}
GA-11	5.57^{D}	66.15^{B}	3.27^{CDF}	17.45^{C}	96.72^{R}	5.30^{D}
GA-13	5.26^{FG}	66.50^{AB}	3.25^{CDF}	17.00^{DE}	222.62^{J}	4.92^{JK}
GA-15	5.05^{HJ}	65.70^{B}	3.42^{BC}	18.65^{A}	121.06^{O}	4.66^{K}
GA-20	5.05^{HJ}	58.00^{G}	3.05^{EF}	15.80^{J}	130.50^{M}	5.67^{HI}
GA-22	5.10^{GHJ}	67.17^{A}	3.47^{B}	18.40^{AB}	360.43^{H}	3.79^{L}
GA-23	6.10^{B}	55.10^{J}	3.05^{EF}	16.76^{DEFG}	297.72^{I}	6.35^{EF}
GA-24	6.05^{B}	56.50^{H}	3.16^{EF}	16.42^{FGHI}	135.60^{L}	6.27^{FG}
GA-25	6.20^{B}	55.50^{IJ}	3.13^{EF}	16.30^{HIJ}	137.70^{K}	5.87^{FH}
GA-26	5.05^{HJ}	62.47^{D}	3.75^{A}	16.06^{HIJ}	412.66^{C}	5.55^{HI}
GA-27	5.46^{DE}	56.96^{H}	3.04^{EF}	15.85^{IJK}	98.90^{Q}	4.89^{JK}
GA-28	5.05^{HJ}	62.87^{D}	3.02^{EF}	16.10^{IJK}	444.55^{B}	7.72^{B}
GA-29	7.10^{A}	60.50^{E}	3.04^{EF}	15.74^{K}	306.55^{G}	6.77^{DE}
GA-30	4.95^{J}	56.60^{H}	2.95^{FG}	16.84^{DEF}	308.70^{F}	5.89^{FGH}
GA-31	5.75^{C}	56.30^{HI}	3.10^{EF}	15.15^{L}	301.74^{H}	5.15^{JK}
GA-32	5.05^{HJ}	59.25^{F}	3.34^{BCD}	15.70^{K}	310.65^{E}	7.69^{B}
GA-33	7.05^{A}	66.04^{B}	3.41^{BC}	16.77^{DEFG}	129.95^{MN}	5.79^{GH}
GA-34	5.15^{GHJ}	60.00^{EF}	3.21^{DF}	16.59^{EFGH}	128.55^{N}	5.45^{HI}
GA-35	5.05^{HJ}	50.05^{K}	3.00^{EFG}	16.20^{HIJ}	500.60^{A}	7.65^{C}
GA-36	5.00^{IJ}	49.75^{K}	3.15^{EF}	15.75^{K}	381.55^{D}	8.32^{A}
GA-37	5.46^{DE}	63.05^{D}	2.95^{FG}	15.95^{JIK}	120.80^{O}	8.05^{B}
GA-38	5.37^{EF}	64.05^{C}	3.17^{EF}	16.40^{GHI}	100.14^{Q}	7.20^{CD}
Mean	5.53	60.2	3.2	16.57	226.17	5.94

Fig.2 Starch content in leaves of various grain amaranth accessions

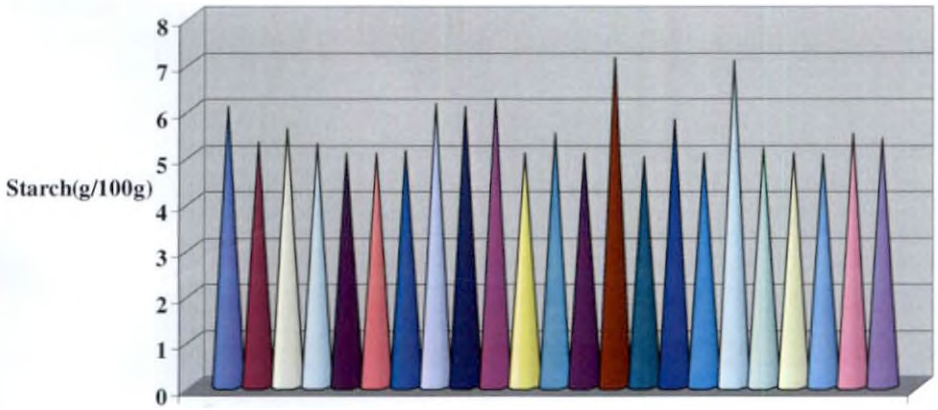
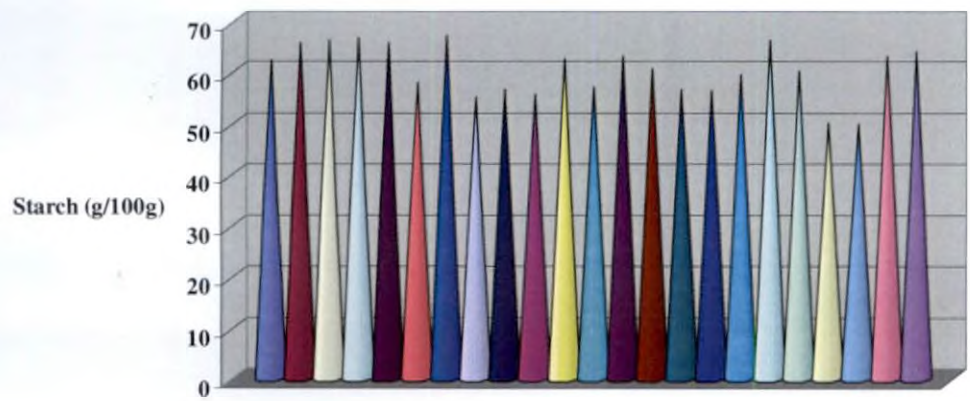


Fig.3 Starch content in grains of various grain amaranth accessions



4.5.2 Protein

4.5.2.1 Protein content in leaf

F group contained maximum number of genotypes and minimum was in A group.

As shown in Table-14, protein content in 100g leaf sample ranged from 2.85g to 3.81g with a mean value of 3.2g. Highest protein content was observed in accession GA-2 (3.81g) and GA-26 (3.75g) and the lowest in GA-4 (2.85g), GA-37 (2.95g) and GA-30 (2.95g) (Fig.4)

4.5.2.2 Protein content in grain

As per DMRT classification, I group contained maximum number of accessions and minimum in A, B and C groups. Protein content in 100g grain sample ranged from 15.15g to 18.65g with a mean value of 16.57g. Highest protein content was observed in accession GA-15 (18.65g) (Plate.5) followed by GA-22 (18.40g) and GA-2 (18.15g) and the lowest in GA-31 (15.15g) (fig.5)

4.5.3 Vitamin C

4.5.3.1 Vitamin C content in leaf

According to DMRT classification, ranks H, M, N, O, Q and R contained more than one accessions in each.

Vitamin C content in 100g leaf sample ranged from 96.7mg to 500.6mg with a mean value of 226.17mg. Highest Vitamin C content was observed in accession GA-35 (500.60mg) and the lowest in GA-11 (96.72mg) and GA-2 (96.70mg) (Fig. 6)

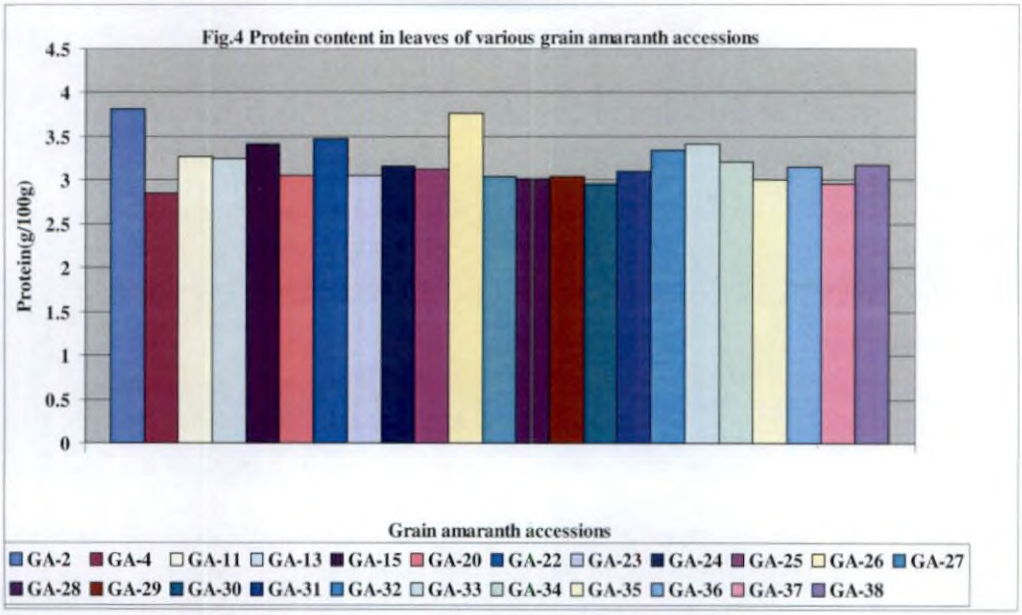


Fig.4 Protein content in leaves of various grain amaranth accessions
Protein(g/100g)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Grain amaranth accessions
GA-2 GA-4 GA-11 GA-13 GA-15 GA-20 GA-22 GA-23 GA-24 GA-25 GA-26 GA-27
GA-28 GA-29 GA-30 GA-31 GA-32 GA-33 GA-34 GA-35 GA-36 GA-37 GA-38

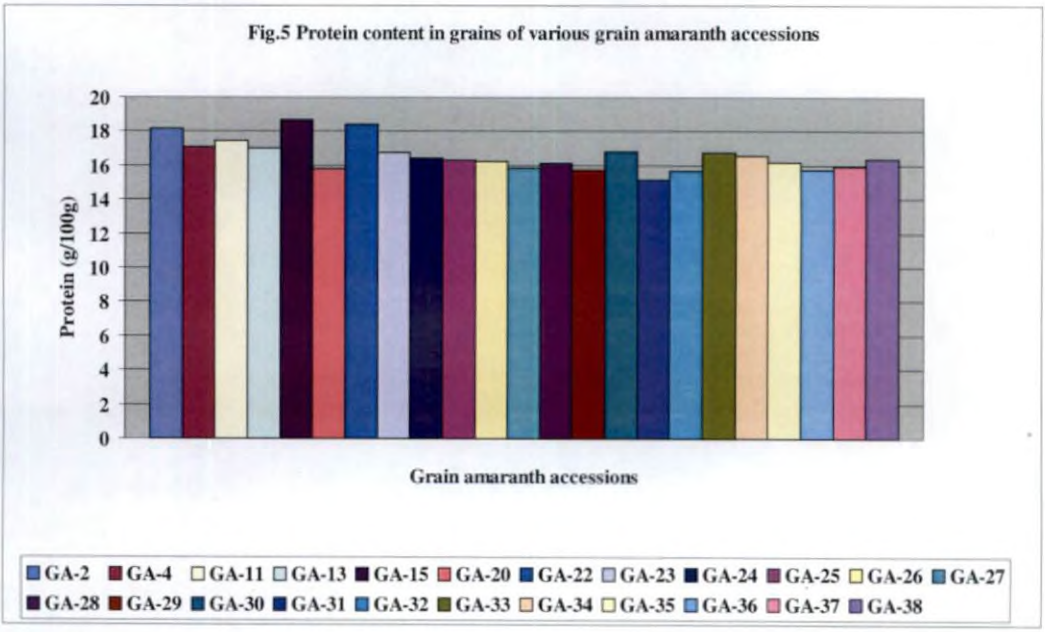


Fig.5 Protein content in grains of various grain amaranth accessions
Protein (g/100g)
20
18
16
14
12
10
8
6
4
2
0
Grain amaranth accessions
GA-2 GA-4 GA-11 GA-13 GA-15 GA-20 GA-22 GA-23 GA-24 GA-25 GA-26 GA-27
GA-28 GA-29 GA-30 GA-31 GA-32 GA-33 GA-34 GA-35 GA-36 GA-37 GA-38

4.5.3.2 Vitamin C content in grain

H group had the maximum number of genotypes and minimum was in A, C, O, E, and L groups.

Vitamin C content in 100g grain sample ranged from 3.53mg to 8.32mg with a mean value of 5.94mg. Highest Vitamin C content was observed in accession GA-36 (8.32mg) and the lowest in GA-4 (3.53mg) and GA-22 (3.79mg) (Table-14 and fig. 7)

4.5.4 β Carotene

4.5.4.1 β Carotene in leaf

Except P and J, all other groups contained single genotype each. As revealed in Table-15, β carotene content in 100g leaf sample ranged from 5995.70µg to 10007.85µg with a mean value of 7127.21µg. Highest β carotene was observed in accession GA-31 (10007.85µg) followed by GA-4 (8902.05µg) and GA-33 (8823.84µg) and the lowest for β carotene was found in GA-15 (5995.70µg) (Fig.8)

4.5.4.2 β Carotene content in grain

More number of grain amaranth accessions came under M group where as the number of accessions coming under A, B, E and I group were minimum (one each). β carotene content in 100g grain sample ranged from 134.17µg to 158.37µg with a mean value of 145.62µg. Highest β carotene content was observed in accession GA-23 (158.37µg) followed by GA-26 (158.33µg) and the lowest in GA-13 (134.17µg), GA-22 (137.65µg), GA-36 (137.95µg), GA-11 (138.35µg) and GA-2 (138.90µg). (Fig. 9)

Table-15. Chemical constituents in grain amaranth accessions

Genotypes	ß carotene (µg/100 g)		Iron (mg/100 g)		Calcium (mg/100 g)		Fibre (g/100 g)	
	Leaf	Grain	Leaf	Grain	Leaf	Grain	Leaf	Grain
GA-2	6327.78^{P}	138.90^{LMN}	15.37^{IJ}	33.78^{K}	295.60^{G}	560.50^{M}	8.38^{FJK}	2.45^{HJ}
GA-4	8902.05^{B}	144.25^{J}	16.63^{EFG}	37.65^{H}	257.55^{I}	587.55^{D}	13.25^{AB}	2.42^{IJ}
GA-11	6448.50^{N}	138.35^{MN}	15.90^{GHI}	36.00^{IJ}	287.45^{H}	564.50^{KL}	8.39^{FJK}	1.15^{L}
GA-13	7746.10^{F}	134.17^{N}	15.45^{HI}	38.5^{G}	299.20^{F}	580.50^{GH}	8.40^{FJK}	1.55^{K}
GA-15	5995.70^{U}	148.61^{H}	17.12^{E}	41.10^{D}	249.15^{J}	559.50^{M}	12.50^{BC}	2.20^{IJ}
GA-20	6328.65^{P}	151.05^{EF}	17.00^{E}	42.27^{C}	300.50^{F}	565.45^{K}	10.25^{E}	3.85^{BC}
GA-22	70002.05^{J}	137.65^{MN}	16.1^{GH}	39.85^{F}	301.05^{F}	595.55^{B}	12.25^{C}	2.45^{HI}
GA-23	7000.07^{J}	158.37^{A}	10.42^{K}	36.10^{IJ}	380.65^{C}	562.60^{L}	10.45^{E}	2.45^{HI}
GA-24	6545.66^{M}	148.83^{GH}	14.75^{J}	36.60^{I}	309.25^{E}	577.45^{IJ}	10.37^{E}	3.74^{C}
GA-25	6613.16^{K}	153.49^{D}	16.88^{EF}	35.85^{IJ}	320.80^{D}	578.75^{HI}	9.75^{E}	3.34^{E}
GA-26	7225.91^{I}	158.33^{B}	22.13^{A}	40.00^{EF}	200.50^{L}	600.75^{A}	14.00^{A}	2.10^{J}
GA-27	6111.25^{R}	146.35^{I}	10.47^{K}	42.47^{C}	199.50^{L}	585.45^{E}	8.45^{FJ}	2.10^{J}
GA-28	6140.50^{Q}	150.42^{PG}	16.60^{EFG}	37.50^{H}	200.50^{L}	575.97^{J}	12.40^{C}	2.77^{FG}
GA-29	6008.62^{S}	155.72^{C}	18.05^{D}	43.17^{B}	380.50^{C}	590.50^{C}	7.87^{JK}	4.55^{A}
GA-30	7885.32^{E}	154.25^{CD}	18.02^{D}	38.91^{G}	301.00^{F}	562.78^{L}	11.85^{CD}	2.65^{FGH}
GA-31	10007.85^{A}	140.61^{L}	21.55^{AB}	35.60^{J}	301.00^{F}	578.60^{HI}	13.25^{AB}	3.67^{CD}
GA-32	8782.38^{D}	142.25^{K}	21.21^{BC}	43.35^{B}	299.50^{F}	583.50^{EF}	8.87^{F}	4.05^{B}
GA-33	8823.84^{C}	139.70^{LM}	20.70^{C}	44.58^{A}	200.50^{L}	599.40^{A}	13.90^{A}	3.22^{E}
GA-34	65554.30^{L}	148.25^{H}	16.25^{FG}	38.20^{GH}	460.67^{A}	585.35^{D}	8.50^{FH}	2.85^{F}
GA-35	7505.96^{H}	$139.60L^{M}$	17.25^{E}	40.65^{DE}	420.50^{B}	600.50^{A}	8.42^{FJK}	2.55^{GH}
GA-36	6000.82^{T}	137.95^{MN}	16.25^{GF}	40.17^{EF}	200.50^{L}	581.65^{FG}	11.25^{D}	2.12^{J}
GA-37	7524.19^{G}	142.71^{JK}	18.10^{D}	40.74^{DE}	379.50^{C}	582.75^{F}	7.57^{K}	4.70^{A}
GA-38	6445.25^{O}	139.50^{LM}	21.02^{BC}	38.25^{GH}	220.50^{K}	564.50^{KL}	13.50^{A}	1.45^{K}
Mean	7127.21	145.62	17.09	39.18	294.16	579.30	10.60	2.85

Fig.6 Vitamin C content in leaves of various grain amaranth accessions

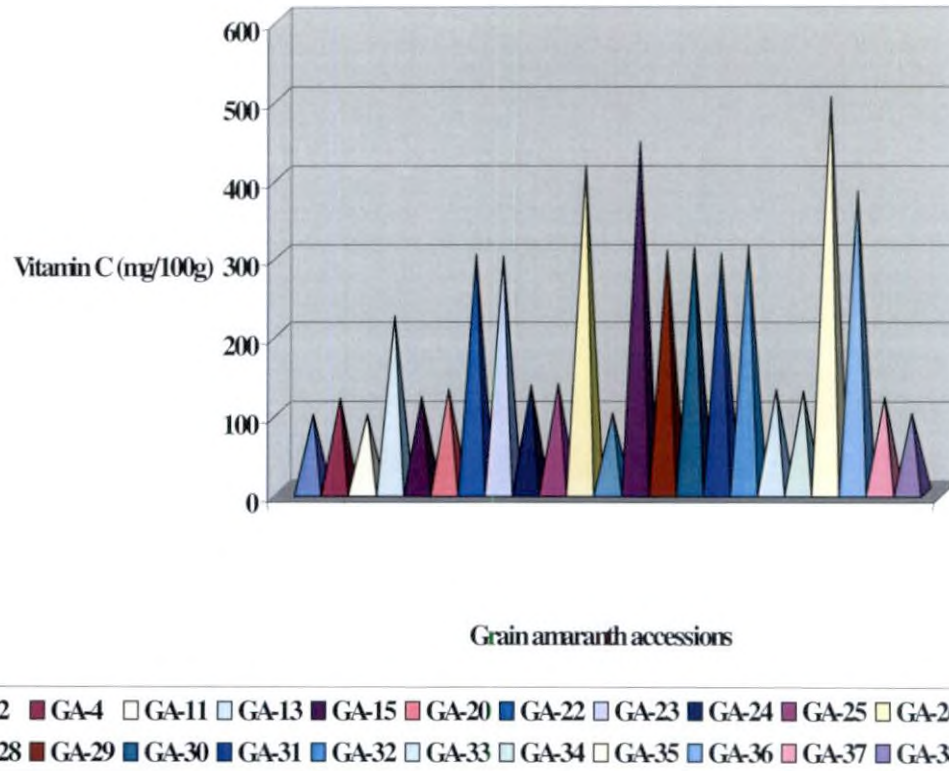


Fig.7 Vitamin C content in grains of various grain amaranth accessions

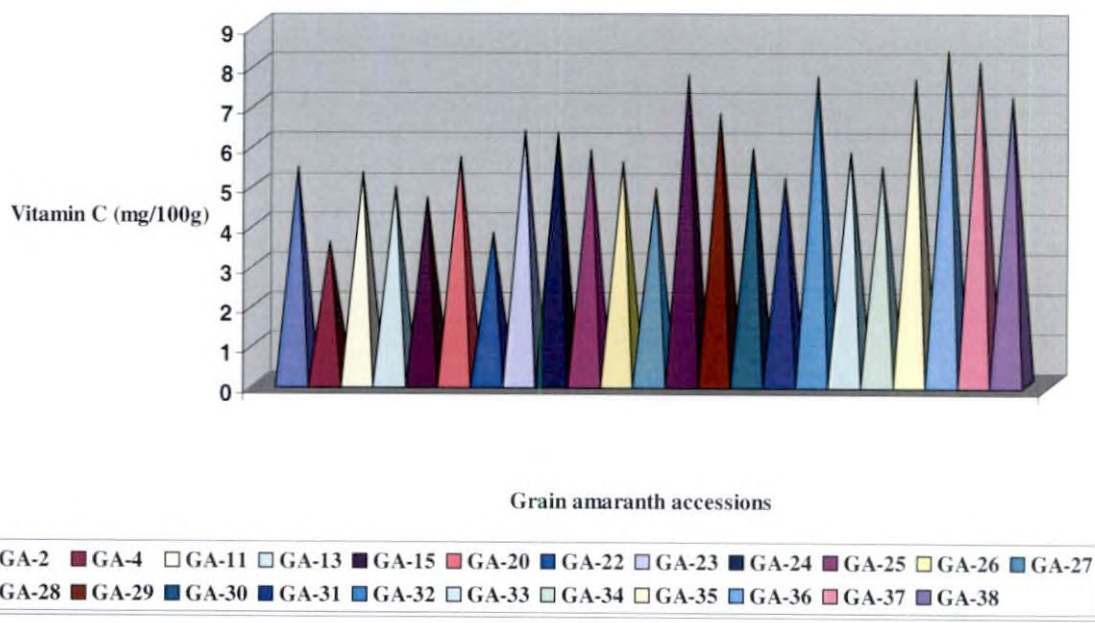


Fig.8 ß-carotene content in leaves of various grain amaranth accessions

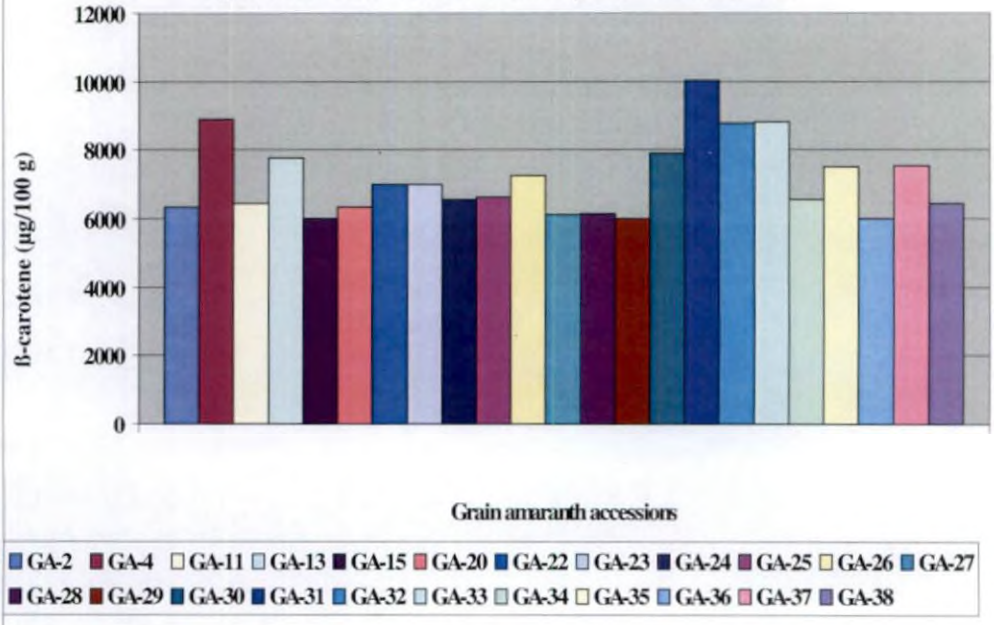
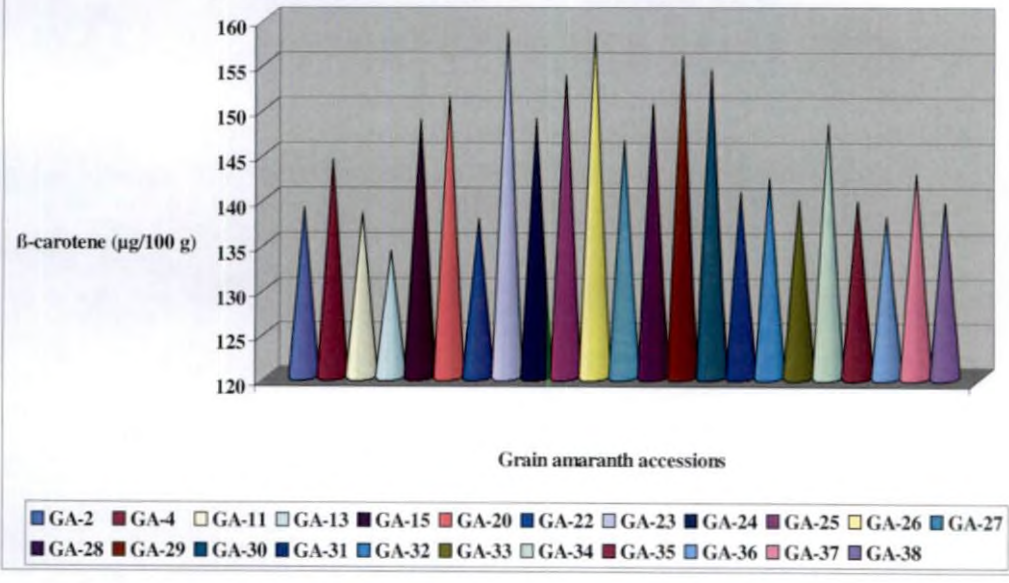


Fig.9 ß-carotene content in grains of various grain amaranth accessions



4.5.5 Iron

4.5.5.1 Iron content in leaf

Based on iron content in leaf, DMRT classified the different genotypes into several groups and each group containing two or more genotypes. The group E and G contained maximum number of genotypes and minimum were in A, K and J group.

Iron content in 100g leaf sample ranged from 10.42mg to 22.13mg with a mean value of 17.09mg. Highest iron content was observed in accession GA-26 (22.13mg) and GA-31 (21.55mg) .The lowest content of iron was found in leaves of GA-23 (10.42mg) and GA-27 (10.47mg) (Fig.10)

4.5.5.2 Iron content in grain

The group J, G, E, I, H contained maximum of four genotypes each and minimum was in A and K group.

Iron content in 100g grain sample ranged from 33.78mg to 44.58mg with a mean value of 39.18mg. Highest iron content was observed in accession GA-33 (44.58mg) followed by GA-32 (43.35mg) and GA-29 (43.17mg). Iron content was the lowest in GA-2 (33.78mg) (Fig.11)

4.5.6 Calcium

4.5.6.1 Calcium content in leaf

Based on calcium content in leaf, DMRT classified the different genotypes into several groups and each group containing one, two or more genotypes. The group F contained maximum number of genotypes followed by group L and C and all other group contained single genotype each. The genotype

Fig.10 Iron content in leaves of various grain amaranth accessions

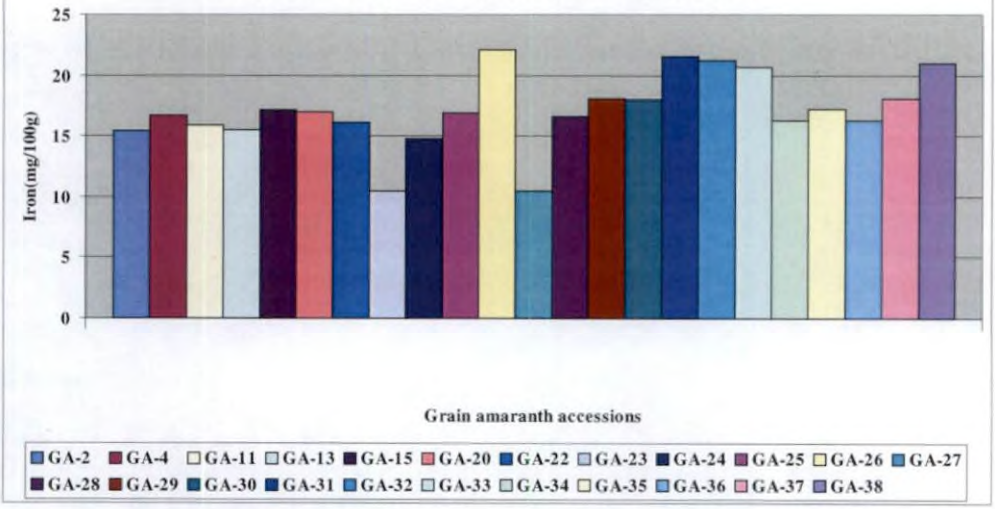
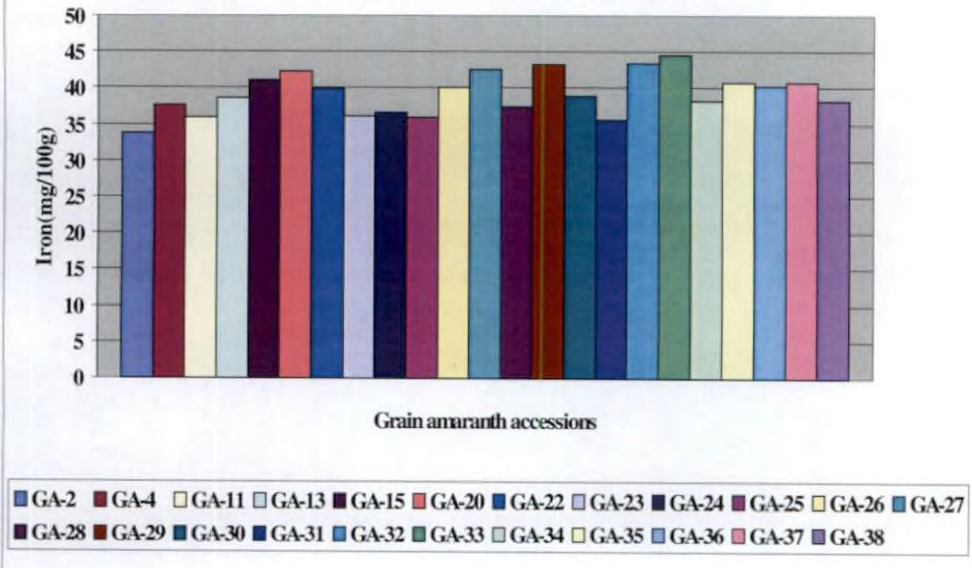


Fig.11 Iron content in grains of various grain amaranth accessions



belonging to the same group had no significant differences between themselves but they differed from the genotypes of other groups.

As shown in Table-15, calcium content in 100g-leaf sample ranged from 199.50mg to 460.67mg to with a mean value of 294.16mg. Calcium values of more than 400mg was observed in accessions GA-34 (460.67mg) and GA-35 (420.50mg). Calcium content was found to be the lowest in GA-27 (199.50mg), GA-28, GA-26, GA-33 and GA-36 (200.50mg in all the accessions) (Fig.12)

4.5.6.2 Calcium content in grain

As per DMRT classification, L group contained maximum number of genotypes and minimum was in B, C, and D group.

Calcium content in100g grain sample ranged from 559.50mg to 600.75mg with a mean value of 579.30mg. Highest calcium content was observed in accessions GA-26 (600.75mg), GA-35 (600.50mg) and GA-33 (599.40mg). The content of calcium was found to be the lowest in accessions GA-15 (559.50mg) and GA-2 (560.50mg) (Fig.13)

4.5.7 Fibre

4.5.7.1 Fibre content in leaf

According to DMRT classification, most of the accessions belong to the rank of F, J and K and minimum number in D rank. As revealed in Table-15, fibre content in 100g leaf sample ranged from 7.57g to 14g with a mean value of 10.60g. Highest fibre content was observed in accession GA-26 (14g) followed by GA-33 (13.9g), GA-38 (13.5g), GA-4 (13.25g) and GA-31 (13.25g). Fibre content was the lowest in GA-37 (7.57g), GA-29 (7.87g), GA-2 (8.38g), GA-35 (8.42g), GA-13 (8.4g) and GA-11 (8.39g) (Fig.14)

Fig.12 Calcium content in leaves of various grain amaranth accessions

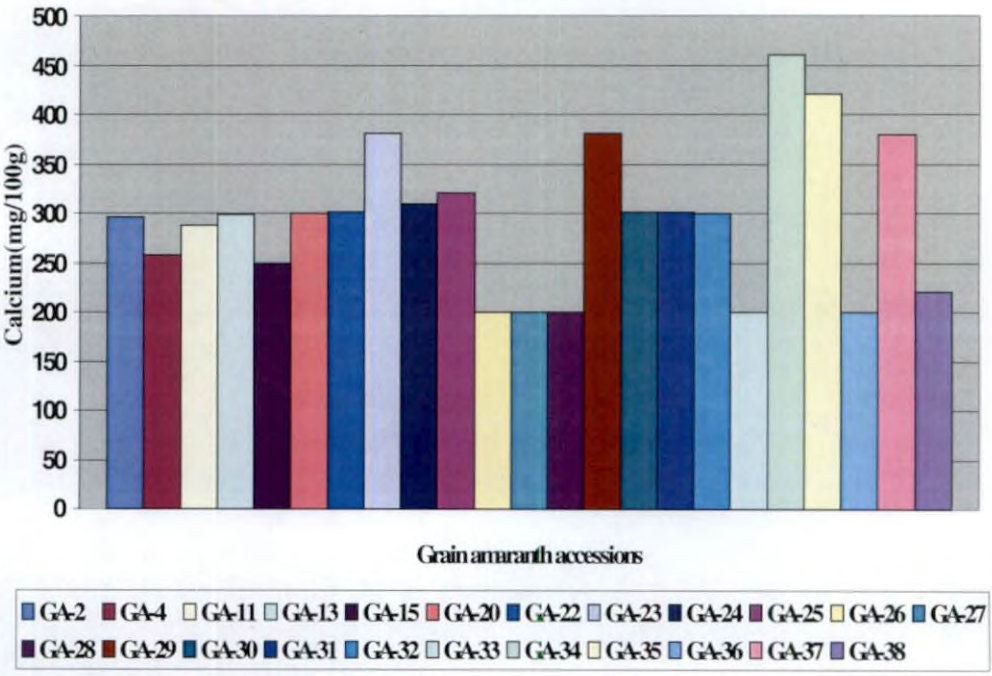
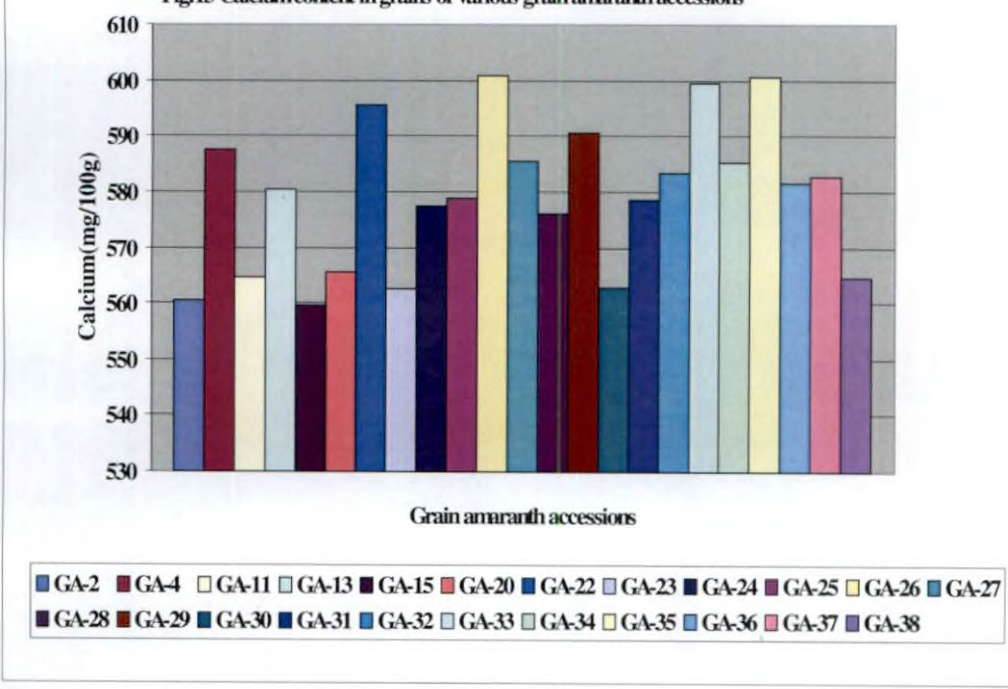


Fig.13 Calcium content in grains of various grain amaranth accessions



4.5.7.2 Fibre content in grain

I and H group contained maximum number of genotypes and minimum were in L group.

Fibre content in 100g grain sample ranged from 1.15g to 4.7g with a mean value of 2.85g. Highest fibre content was observed in accession GA-37 (4.7g) and GA-29 (4.55g). Fibre content was the lowest in GA-11 (1.15g) (Table-15 and Fig.15)

Fig.14 Fibre content in leaves of various grain amaranth accessions

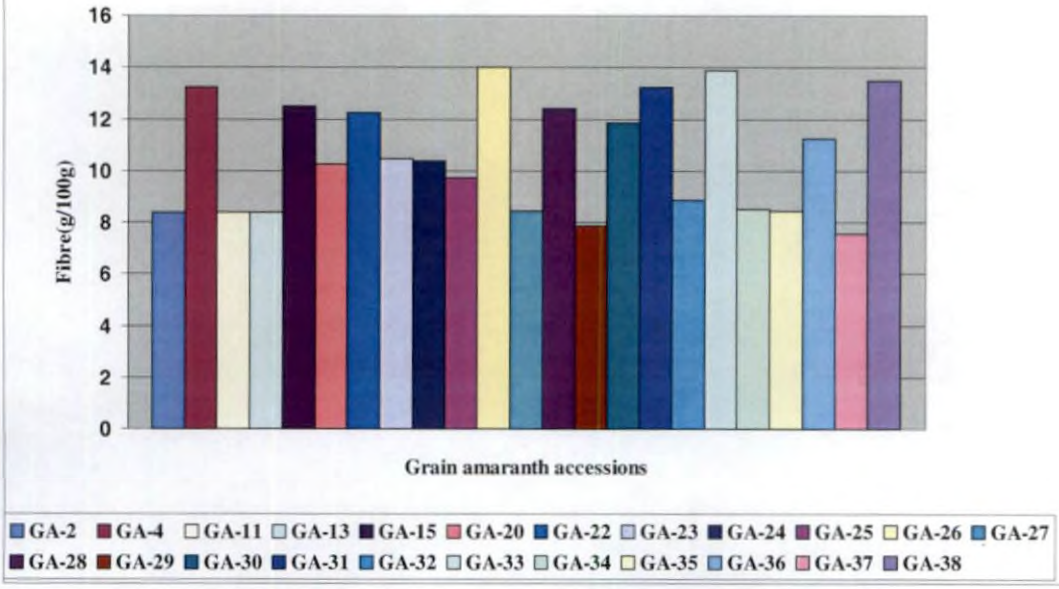
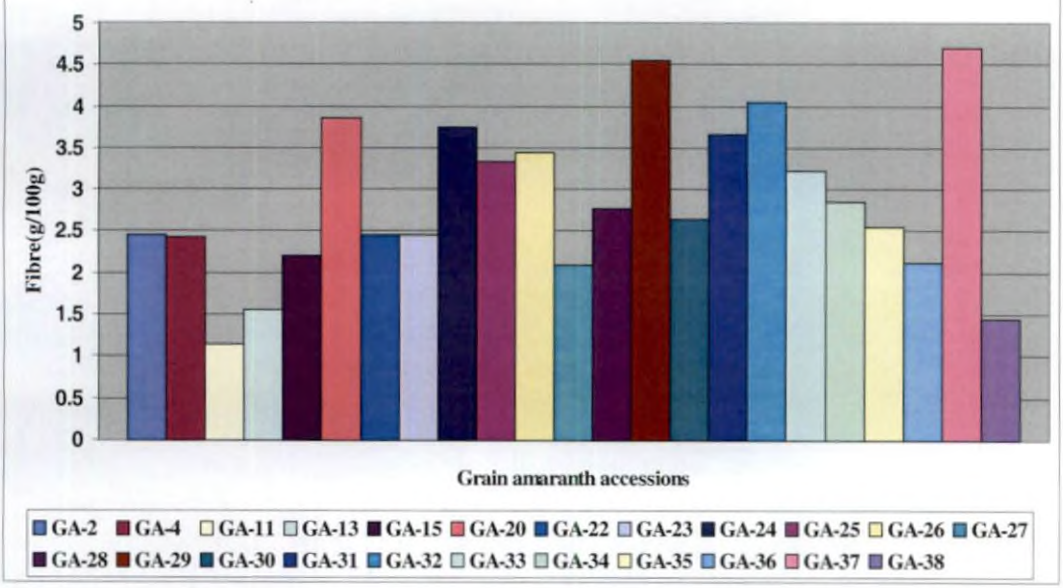


Fig.15 Fibre content in grains of various grain amaranth accessions



Discussion

5. DISCUSSION

Grain amaranth is an underexploited, hardly popular vegetable with high nutritive value. It is a multipurpose crop where both leaves and grains are utilized. Low cost of production, high nutritive value and diverse use in food preparations points to the potentiality of the crop. In spite of the nutritional importance and genetic diversity of the crop, very little effort is made to upgrade the genetic make up of grain amaranth in the country.

In any plant improvement programme, the main objective is the development of elite varieties through production breeding. Basic information on genetic variability, heritability and genetic advance is of vital importance to the breeder for formulating appropriate breeding strategy. Analysis of nutrient content in leaf and grain are very important before popularizing any crop.

Results obtained in the study entitled " Morphological and Biochemical studies in grain amaranth" are discussed and presented under the following headings.

5.1 Genetic cataloguing in grain amaranth accessions
5.2 Estimation of variability, heritability and genetic advance
5.3 Correlation studies and path coefficient analysis
5.4 Genetic divergence
5.5 Biochemical analysis in grain amaranth accessions

5.1 Genetic cataloguing in grain amaranth accessions

Cataloguing of the accessions based on a standard descriptor is useful in international exchange of information about the accessions in a scientific way. This can be utilized for indirect selection and also in understanding the characters of the accessions easily and quickly.

All the accessions studied had erect growth habit and the branches were distributed all along the stem. The stem pigmentation noticed was purple, maroon and light green. Majority of the accessions had purple stem. Mohideen *et al.* (1983) reported brown, green, orange, yellowish green, yellow with purple tint and crimson coloured stems in *Amaranthus spp.* Hamid *et al.* (1989) reported that variation in stem colour might be due to genetic make up. The leaf pigmentation noticed in the collections of the present study were purple, reddish green and green colour. Most of the accessions had purple leaf followed by green and reddish green. In accessions GA-2, GA-4, GA-11, GA-13, GA-15 and GA-22, leaf colour was green. Leaf shape of grain amaranth accessions. ranged from lanceolate, rhombic and elliptical. Most of the accessions had a lanceolate lamina followed by elliptical and rhombic. Inflorescence colour of twenty three accessions came under three classes namely purple, maroon and off-white. Most of accessions had purple inflorescence colour followed by off-white and maroon. Inflorescence colour was purple in accessions, GA-20, GA-23, GA-25, GA-27, GA-28, GA-29, GA-30, GA-31, GA-33, GA-34, GA-35, GA-36, GA-37 and GA-38. In accessions GA-24, GA-26 and GA-32, inflorescence colour was maroon. Off-white colour of inflorescence was noticed in accessions GA-2, GA-4, GA-11, GA-13, GA-15 and GA-22

Seed colour of grain amaranth accessions ranged from black, maroon and cream. 56% accessions had black colour seeds, 30% cream coloured and 13% accessions had maroon colour seeds. Cream coloured seeds were obtained from accessions GA-2, GA-4, GA-11, GA-13, GA-15 and GA-22 whereas accessions GA-24, GA-26, GA-32 gave maroon coloured seeds. In accessions GA-20, GA-23, GA-25, GA-27, GA-28, GA-29, GA-30, GA-31, GA-33, GA-34, GA-35, GA-36, GA-37 and GA-38, the seed colour was black. Variations in leaf shape, inflorescence colour and seed colour was reported earlier by Mallika (1987). Most of the genotypes were found to be free from almost all diseases and pests. This may be due to the thick and fibrous nature of the stem and leaves.

Twenty three grain amaranth accessions exhibited significant differences for all the quantitative characters studied. The characters like grain yield per plant, plant height, number of branches, leaf length, leaf width, vegetable yield per plant, leaf stem ratio, days to flower, crop duration are the economically important traits in amaranth. In the present study wide variation was observed in plant height and number of branches per plant. Maximum plant height was recorded in accession GA-31 (138.34 cm) and minimum was in GA-22 (53.2cm). The number of branches per plant was maximum in accession GA-25 and minimum in accessions GA-2, GA-11, GA-22 and GA-13. Variations in plant height and number of branches per plant among different accessions of grain amaranth was reported by Ghosh *et al.* (1999) and Mohideen *et al.* (1983).

In the present study, there was significant variation among the accessions for leaf length, leaf width and vegetable yield per plant. Leaf length was maximum in GA-31 (19.93cm) and minimum in GA-11 (8.95cm). Leaf width also was maximum in GA-31 (6.43cm) and minimum in GA-2 (2.43cm). Vegetable yield per plant was maximum in GA-31 (209g) and lowest in GA-11 (101.3g). The existence of high variability for yield and yield attributes in amaranths was reported by many workers (Mohideen *et al.*, 1983., Pan *et al.*, 1991., Devdas *et al.*,1992., Varalakshmi and Reddy,1994., Hossain and Rahman,1999).

Leaf stem ratio is an important character in amaranth indicating the palatability of the produce. A leaf stem ratio of 1.0 to 1.5 is reported to be optimum and it is aimed at in any selection programme (Mohanalekshmi *et al.*, 1998). In this study, maximum leaf stem ratio recorded was in GA-20 (3.72) and minimum in GA-30 (1.38). The variation in leaf stem ratio within and between species of *Amaranthus* was reported earlier by Mohideen and Muthukrishnan (1981)

Variation was noticed in days to flowering and crop duration. GA-22 was the earliest genotype to produce flowers (32 days) and GA-31 was the late bolter (95 days). Duration of crop was found to be maximum in GA-31 (115 days) and minimum in GA-22 (62 days). The types which flowered earlier maintained their earliness in seed maturity also. Late flowering types were found to be high vegetable yielders since more number of harvests of greens were obtained. These results are in line with the results reported by Mohideen *et al.* (1983). Variation for these characters among different species of *Amaranthus* was reported by Devdas ,1982., Priya ,1998., Hossain and Rahman, 1999., and Krishnakumary, 2000.

Wide variation was observed in grain yield per plant. In the present study, the accession GA-25 recorded the highest grain yield per plant (128g) whereas lowest grain yield was recorded in GA-22 (49.9g). This increase in grain yield can be attributed to increase in plant height, number of branches, leaf width, leaf length and crop duration. In general, types with a higher duration recorded comparatively higher yields as against types with a lesser duration (Mohideen *et al.*, 1983).

5.2 Estimation of variability, heritability and genetic advance

Success of any breeding programme depends primarily on the extent of variability, heritability, expected genetic advance etc. which are the primary prerequisites for all crop improvement programmes (Johnson *et al.*, 1955). In the present investigation, the genetic contribution in the phenotypic expressions was studied to realize the performance of grain amaranth genotypes. The variation may be due to genetic and environmental effects. Coefficient of variations viz., phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) are better indices for comparison of characters with different units of measurement than estimates of quantitative variations like range and mean.

Phenotypic coefficient of variation ranged from 12.64 to 49.83 and genotypic coefficient of variation ranged from 10.34 to 49.40. Among the biometric characters, grain yield per plant had the highest phenotypic coefficient of variation (49.83) and genotypic coefficient of variation values (49.40) followed by number of branches per plant (40.81 and 36.24) and plant height at flowering stage (30.19 and 30.00). Higher PCV and GCV found in most of the characters revealed great extent of variability suggesting good scope for selection. Further more, the magnitude of genetic variation nearly approached the phenotypic variation in all the characters, indicating that the selection on phenotypic basis will hold good scope on genotypic upgradation.

Heritability and genetic advance are important selection parameters. Heritability estimates along with genetic advance are more helpful in predicting the gain under selection than heritability estimates alone. However it is not necessary that a character showing high heritability will also exhibit high genetic advance (Johnson *et al.*, 1955). In the present study, high heritability along with high genetic gain was observed in plant height at flowering stage (98.7, 52.95 respectively) followed by grain yield per plant (98.3,49.59 respectively). Guillen *et al.* (1999) observed the same trend of high heritability for plant height at flowering stage and grain yield per plant. Even though heritability values give an indication of effectiveness of selection based on phenotypic performance, it does not necessarily mean a high genetic advance for a particular character. Heritability along with estimates of expected genetic advance should be considered while making selections.

5.3 Correlation studies and path coefficient analysis

Correlation coefficient is a statistical measure used to find out the degree and direction of relationship between two or more variables. High positive correlation between two traits makes simultaneous improvement in two or more attributes, whereas negative association indicates the need to compromise between desirable characters.

In the current experiment, plant height at flowering stage, number of branches, leaf length, leaf width, vegetable yield per plant, days to 50 per cent flowering and crop duration showed positive genotypic and phenotypic correlation with grain yield per plant. Justifying the present results, positive and significant correlation of yield with other plant characters was reported by Sudhir *et al.* (2003). Leaf stem ratio had negative correlation with green yield per plant and also had low correlation with grain yield per plant. Such a negative correlation was earlier reported by Mohideen and Muthukrishnan (1979). From this study, it is evident that selection based on plant height, number of branches, leaf width, leaf length, days to 50 per cent flowering and crop duration will result in higher yield.

Path coefficient analysis is simply a standardized regression coefficient, which reveals whether the association of characters with yield is due to their direct effect or is a consequence of their indirect effects via other component characters.

In the present study, path analysis was performed for grain yield per plant by taking it as a dependent variable and nine other characters such as plant height at vegetative and flowering stage, number of branches, leaf width, leaf length, vegetable yield per plant, leaf stem ratio, days to flower and crop duration as independent variables.

Crop duration had maximum direct effect on grain yield per plant (1.711) followed by number of branches (1.506) and leaf width (1.401). Leaf length which exhibited high correlation with yield (0.818) had only low direct effect on grain yield per plant (0.090). The significant positive correlation was mainly due to it's indirect effect through number of branches (0.937) and crop duration (1.270). Plant height at flowering stage exhibited significant positive correlation with yield per plant (0.927) and had high negative direct effect (-0.763). The positive correlation is mainly through it's high indirect effect through number of branches (1.152), leaf width (2.498) and crop duration (1.361). Days to flower had positive genotypic correlation with yield per plant (0.769) and low direct effect (0.325). The significant positive correlation was contributed by indirect effects through crop duration, leaf length, leaf width and number of branches (1.506, 1.430, 1.040 and 1.053 respectively). It is evident that selection for increased number of branches, leaf width and crop duration leads to higher yield.

5.4 Genetic divergence

Selection of parents for hybridization programme is mainly based on genetic diversity. More divergent the parents, the more will be the expression of heterosis. Mahalanobis D^2 statistic is a powerful tool for measuring genetic distance in plant breeding experiments. It permits precise comparison of all the genotypes by considering large number of characters simultaneously.

Genetic divergence using Mahalanobis D^2 statistics was worked out in twenty three accessions of different grain *Amaranthus spp.* in order to ascertain similarities among their performances. These were grouped into five clusters that were differentiable in terms of yield means and stability. Among the five clusters, clusters I and II had six accessions each and clusters III and IV had three accessions each. Cluster V had five accessions in it. Such an irregular pattern of distribution was reported by Verma *et al.* (2002), Dehmer (2001) and Elba *et al.* (1997). In the present study, the mean value for vegetable yield was the highest in

cluster II (239.88g) followed by cluster III (201.47g) and highest grain yield was noticed in cluster III (121.2g). Maximum inter cluster distance was between cluster I and III (3432.44) and minimum between cluster IV and V. Divergent studies indicated genetic divergence between genotypes and identified genotypes having maximum genetic distance value which can be utilized for development of F_1 hybrids suited for the state

5.5 Biochemical analysis in grain amaranth accessions.

Nutritive composition of amaranthus was studied by various workers and they reported existence of variability (Vijayakumar and Shanmugavelu, 1985; Hossain *et al.*, 1999; Kowsalya *et al.*, 2001). The present study reveals wide variation in nutritive value among the accessions. Variations in quality parameters like β carotene, fibre, Vitamin C etc. were reported in amaranth accessions by Celine *et al.* (2006).

Among the different grain amaranth accessions studied, the accessions GA-29 (7.1g) and GA-33 (7.0g) were found to be the best with respect to its mean starch content in leaf which was found to be significantly different from all the other accessions selected for the study. The mean starch content in 100g leaf sample varied from 4.95g to 7.1g with a mean value of 5.53g. The mean fibre content in 100g leaf sample ranged from 7.57g to 14g with a mean value of 10.60g. These values were higher than those reported by Bressani *et al.* (1988), Gopalan *et al.* (1989), NIN (1995), Singade *et al.* (1995) and Shankaracharya (1998) for various leafy vegetables like mustard greens, spinach, mint, coriander leaves, chekkurmanis leaves, curry leaves, amaranth, gogu, and tender tamarind leaves in which the fibre content varied from 0.7 to 6.4 per cent. Guerrero and Isasa (1997) observed a fibre content of 4 to 6 per cent in chenopodium leaves. Vitamin C content in 100g leaf sample ranged from 96.7mg to 500.6mg with a mean value of 226.17mg. Placida and Meena (1991), Yadav and Seghal (1997) and Reddy (1999) reported a vitamin C content of 280mg $100g^{-1}$ in sauropus

leaves, 220.97 to 377.65mg $100g^{-1}$ in bathua and fenugreek leaves and 120 to 220 mg $100g^{-1}$ in amaranth, agathi, mustard, drumstick and broccoli leaves. Vitamin C content of most of the accessions was found to be higher than the values reported by Mosha *et al.* (1995) in which the content varied from 89 to 99 mg $100g^{-1}$.

Regarding the β carotene content, the best accession identified in the present study was GA-31 (10007.85μg) and it's content in 100g leaf sample ranged from 5995.7μg to 1000.7μg with a mean value of 7127.21μg. The results were almost similar to the β carotene content of different leafy vegetables such as amaranth, drumstick, coriander, curry leaves, spinach, agathi and *Beta vulgaris* as reported by Choudhary and Rajendran (1980), Menon (1980), Nambiar and Seshadri (1998), Shankarcharya (1998) and Reddy (1999). The mean protein content in 100g leaf sample ranged from 2.85g to 3.81g with a mean value of 3.21g. This was found to be almost similar to the protein content of chekkurmanis, amaranth, spinach and drumstick leaves as reported by Gopalan *et al.* (1989), Prakash *et al.* (1994), Singade *et al.* (1995), Raja *et al.* (1997) and Shankaracharya (1998). Calcium content in 100g leaf sample ranged from 199.5mg to 460.67mg with a mean value of 294.16mg. The calcium content of the leaves in the present study was found to be in accordance with the values reported by Lucas (1988) and Neeliyara (1988) in various green leafy vegetables like amaranth, basella, waterleaf, and winged bean leaf. Iron content in 100g leaf sample ranged from10.42mg to 22.13mg with a mean value of 17.09mg. The iron content observed in the present study was in accordance with the iron content of different leafy vegetables like drumstick, chekkurmanis, coriander, *Amaranthus spinosus*, colocasia etc. analysed in different parts of the country in which the values varied from 2 to 32.5mg $100g^{-1}$ [Chawla *et al.* (1988), Chandrasekhar *et al.* (1990) and Shankaracharya (1998)].

The present study reveals that 100g amaranth grains contain 49.75-67.7g starch, 15.15-18.65g of protein, 3.53-8.32 mg vitamin C, 134.17-158.37μg of β carotene, 33.78-44.58 mg of iron, 559.50-600.75 mg of calcium and 1.15-4.7g

fibre. These values were found to be almost similar to the values reported by Carlsson (1974), Joshi and Rana (1991), Bressani (1992), NIN (1996) and Munjal *et al.* (1999)

It is evident in the present study that accessions GA-24, GA-15 and GA-30 can be selected as the better genotypes considering their high protein content and yield. Therefore these lines can be recommended for both homestead and commercial cultivation after ascertaining their superiority and stability in multi-location, multi-environment studies.

Summary

6. SUMMARY

The investigation on "Morphological and Biochemical studies in grain amaranth" was undertaken in the Department of Olericulture, College of Horticulture,Vellanikkara during November 2005- February 2006. The experimental material consisted of twenty-three grain amaranth accessions collected from different parts of India. The twenty-three accessions were grown in a randomized block design to asses the extent of variability and divergence among accessions and to group them based on D^2 values. Correlation and path coefficient analysis of yield and contributing components were also studied in the experiment. Chemical constituents viz., starch, protein, vitamin C, β carotene, iron, calcium and fibre were analyzed in both leaves and grains of twenty three grain amaranth accessions and the results obtained in the study were subjected to Duncan's Multiple Range Test. The findings of the study are summarized as follows.

The twenty three grain amaranth accessions differed significantly for all the characters, which clearly indicates the existence of abundant variability among the accessions selected for the study. Growth habit of all the accessions were erect. Stem pigmentation varied from purple (52.17%), maroon (21.74%) and light green (26%). Most of the accessions had purple leaf (56.52%) followed by green (26.08%) and reddish green (17.39%). The prominent leaf shape noticed in these accessions was lanceolate (60.86%) followed by elliptical (26.09) and rhombic (13.04%). 60.88% accessions had puple inflorescence followed by off-white (26.09%) and maroon (13.04%) colour. Seed colour of these accessions varied from black (56.52%), cream (30.44%) and maroon (13.4%). The coefficients of variation, heritability, genetic advance and genetic gain for ten characters were interpreted to study the existing variation. Plant height at flowering was maximum in accession GA-31 (138.34cm) followed by GA-20 (134.2cm) and minimum in GA-22 (53.2cm). Number of branches per plant was the highest in GA-25 (18) and minimum number of branches was 5. Leaf width and length were maximum in GA-31 with values of 6.43 and 19.93cm

respectively. Vegetable yield obtained from a plant was maximum in GA-31 (209g) and lowest in GA-11 (101.3g). Leaf stem ratio was the highest in GA-20 (3.72) and minimum in GA-30 (1.38). Late flowering was observed in GA-31 and GA-22 was the earliest bolter. Crop duration was found maximum in GA-31 (115 days) and minimum in GA-22 (62 days). Highest grain yield from a plant (128g) was obtained in GA-25 followed by GA-31 (120g) and yield was lowest in GA-22 (49.9g). The genotypic coefficient of variation was maximum for grain yield per plant (49.40) followed by number of branches (36.24) and plant height at flowering stage (30.00) and it was minimum for plant height at vegetative stage (10.34) and crop duration (15.91).

The highest heritability estimates in the study was obtained for plant height at flowering stage (98.7%) and grain yield per plant (98.3%).

Genotypic correlation studies of yield with component characters indicated that number of branches had maximum positive and significant correlation with yield per plant (0.980) followed by plant height at flowering stage (0.927), days to flower (0.769) and crop duration (0.898). Leaf stem ratio exhibited lowest correlation with grain yield per plant (0.529). The phenotypic correlation was less than genotypic correlation in almost all the cases.

Path coefficient analysis conducted in twenty three grain amaranth accessions revealed that crop duration had maximum positive direct effect on grain yield per plant (1.711) followed by number of branches (1.506) and leaf width (1.401). The highest negative direct effect on yield was exhibited by plant height at flowering stage (-0.763).

The accessions were grouped in to five clusters based on Mahalanobis D^2 statistic. Among the five clusters, clusters I and II had six accessions each and clusters III and IV had three accessions each. Cluster V had five accessions in it. Accessions included in cluster I recorded lowest values for most of the characters

like height at flowering (61.72cm), number of branches (5.5), leaf width (3.09cm), leaf length (10.62cm), vegetable yield (110.38g), leaf stem ratio (2.26), days to flower (44.66) and grain yield per plant (56.98g). Cluster III which included accessions GA-20, GA-25 and GA-31 recorded highest mean values for plant height at flowering stage (132.21cm), number of branches (16.33), leaf width (6.34cm), leaf length (18.56cm), leaf stem ratio (3.35), days to flowering (86days), crop duration (107.33days) and grain yield (121.2g). The intra cluster distance D was maximum in cluster IV (283.64) and minimum in cluster III (55.13). The intra cluster distance for other clusters were 109.34 (cluster I), 136.45 (cluster II) and 202.41 (cluster V). Maximum inter cluster distance was found between cluster I and cluster III (3432.44) and minimum between cluster IV and cluster V (223.35) suggesting less genetic divergence among them compared to other clusters.

Based on chemical constituents present in both leaves and grains, DMRT classified the different accessions into several groups. Significant differences were noticed between accessions for the nutrient factors studied. The starch content per 100g of leaf ranged from 4.95 to 7.1g and 49.75 to 67.17g in grain with the highest value in accession GA-22. The protein content ranged from 2.85 to 3.81g and 15.15 to 18.65g in 100g of leaf and grain respectively. Highest protein content of 18.65g was obtained in the grains of accession GA-15. Vitamin C content per 100g of leaf ranged from 96.7 to 500.6mg and 3.53 to 8.32mg in grains with the highest value in accession GA-36. The β carotene content ranged from 5995.70 to 10007.85µg and 134.17µg to 158.37µg in 100g of leaf and grain respectively. Highest β carotene content of 158.37µg was obtained in the grains of accession GA-23. Calcium content per 100g of leaf ranged from 199.50 to 460.67mg and 559.40 to 600.75mg in grains with the highest value in the grains of accession GA-26. Iron content per 100g of leaf ranged from 10.42 to 22.13mg and 33.78 to 44.58mg in grains with the highest value in accession GA-33. Fibre content per 100g of leaf ranged from 7.57 to 14g and 1.15 to 4.7g in grains with the highest value in the grains of accession GA-37

It is evident in the present study that accessions GA-24, GA-15 and GA-30 can be selected as the better genotypes by virtue of their high protein content and yield. Therefore these lines can be considered for recommendation for both homestead and commercial cultivation.

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*Originals not seen

Abstract

MORPHOLOGICAL AND BIOCHEMICAL STUDIES IN GRAIN AMARANTH (*Amaranthus spp.*)

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ABSTRACT OF THE THESIS

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ABSTRACT

The investigation on "Morphological and biochemical studies in grain amaranth" was undertaken in the Department of Olericulture, College of Horticulture, Vellanikkara, Thrissur during November 2005-February 2006. The objectives of the study was to catalogue and evaluate grain amaranth accessions for assessing their variability and field performance, to analyse important nutrient factors and to identify superior genotypes for cultivation.

Twenty three grain amaranth accessions collected from different parts of India were utilized for the study. The extent of variability, correlation between yield and its component characters, path coefficient analysis and divergence among twenty three accessions were assessed. The twenty three accessions were significantly different for the ten characters studied. The accession GA-25 (grain yield of 128g/plant) was emerged as high yielder followed by GA-31 (120g/plant) and GA-20 (115.6g/plant).

Growth habit of all the accessions were erect. Stem pigmentation varied from purple, maroon and light green. The leaf pigmentation of twenty-three accessions came under three classes namely purple, reddish green and green colour. Most of the accessions had purple leaf pigmentation, lanceolate leaf lamina and purple inflorescence colour. Seed colour ranged from black, maroon and cream. Most of the accessions were found resistant to almost all diseases and pests.

The accessions were grouped in to five clusters based on Mahalanobis D^2 statistic. Among the five clusters, clusters I and II had six accessions each and cluster III and IV had three accessions each. Cluster V had five accessions in it. Out of the five clusters, cluster III had maximum mean values for plant height at flowering, number of branches, leaf width and length, leaf stem ratio, crop

duration and grain yield whereas cluster I recorded lowest values for most of the characters studied. The intra cluster distance D was maximum in cluster IV (283.64) and the minimum in cluster III (55.13). The intra cluster distance for other clusters were 109.34 (cluster I), 136.45 (cluster II) and 202.41 (cluster V). Maximum inter cluster distance was found between cluster I and cluster III (3432.44) and minimum between cluster IV and cluster V (223.35) suggesting less genetic divergence among them compared to other clusters.

Based on chemical constituents present in both leaves and grains, DMRT classified the different accessions into several groups. The starch content per 100g of leaf ranged from 4.95 to 7.1g and 49.75 to 67.17g in grain with the highest value in accession GA-22. The protein content ranged from 2.85 to 3.81g and 15.15 to 18.65g in 100g of leaf and grain respectively. Highest protein content of 18.65g was obtained in the grains of accession GA-15. Vitamin C content per 100g of leaf ranged from 96.7 to 500.6mg and 3.53 to 8.32mg in grains with the highest value in accession GA-36. The β carotene content ranged from 5995.70 to 10007.85µg and 134.17µg to 158.37µg in 100g of leaf and grain respectively. Highest β carotene content of 158.37µg was obtained in the grains of accession GA-23. Calcium content per 100g of leaf ranged from 199.50 to 460.67mg and 559.40 to 600.75mg in grains with the highest value in the grains of accession GA-26. Iron content per 100g of leaf ranged from 10.42 to 22.13mg and 33.78 to 44.58mg in grains with the highest value in accession GA-33. Fibre content per 100g of leaf ranged from 7.57 to 14g and 1.15 to 4.7g in grains with the highest value in the grains of accession GA-37

The accessions GA-24, GA-15 and GA-30 having high protein content and yield can be selected as the better genotypes which can be considered for recommendation for both homestead and commercial cultivation.