

**Morphological Characterization and Variability Studies
in Vegetable Amaranth (*Amaranthus* spp.) under
Temperate Conditions**

Labiba Riyaz Shah
(2015-H-99-M)



Division of Vegetable Science

Faculty of Horticulture

**Sher-e-Kashmir University of Agricultural Sciences &
Technology of Kashmir**

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**Morphological Characterization and Variability Studies
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Thesis

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Technology of Kashmir**

in partial fulfilment of requirements for the award of the degree of

**Master of Science in Horticulture
(Vegetable Science)**

2017



*Dedicated
To my
Parents*

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Faculty of Horticulture, Division of Vegetable Science

Certificate – I

This is to certify that the thesis entitled, “**Morphological Characterization and Variability Studies in Vegetable Amaranth (*Amaranthus* spp.) under Temperate Conditions**” submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science in Horticulture (Vegetable Science)**, to the **Faculty of Horticulture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** is a record of bonafide research work carried out by **Ms. Labiba Riyaz Shah (Regd. No. 2015-H-99-M)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that any help or information received during the course of investigation has duly been acknowledged.

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ABSTRACT

The present investigation entitled “Morphological Characterization and Variability Studies in Vegetable Amaranth (*Amaranthus* spp.) Under Temperate Conditions” was undertaken to establish morphological characterization, estimate the coefficients of variability, heritability, genetic gain, correlation coefficients, path analysis in twenty seven genotypes of vegetable amaranth. The experiment was laid out in randomized complete block design (RCBD) with three replications and a spacing of 30 cm × 30 cm. Observations were recorded on various morphological, quantitative and quality traits. Characterization indicated wide variability with respect to leaf colour, inflorescence colour and stem colour. Other traits also exhibited considerable variability. Analysis of variance revealed significant differences among genotypes for all the traits studied. The maximum range was recorded for plant height (59.66-302.99cm) followed by number of leaves plant⁻¹ (50.20-170.33), vitamin C content (39.37-130.70 mg/100g), leaf yield (10.73-89.68q ha⁻¹) and leaf area (4.51-68.42cm²). The highest phenotypic and genotypic coefficients of variability were observed for lateral spikelet length followed by anthocyanin content, inflorescence length, leaf area, stem thickness and petiole length leaf, yield per hectare, leaf yield plant⁻¹, plant height, number of branches plant⁻¹, leaf length, number of leaves plant⁻¹. In general the phenotypic

coefficients of variation were slightly higher than the corresponding genotypic coefficients of variation, which indicates the minor role of environment in the expression of traits. The estimates of heritability in broad sense were high for all the characters. *Per se* performance of the experimental material indicated SKAU-A-7, SKAU-A-18, SKAU-A-24, SKAU-A-14, SKAU-A-22 and SKAU-15 to be important in respect of leaf yield, yield contributing and quality traits. Correlation coefficients revealed that the leaf yield plant⁻¹ exhibited significant positive association with plant height ($r_g=0.74$, $r_p=0.73$) followed by inflorescence length ($r_g=0.66$, $r_p=0.64$), stem thickness ($r_g=0.52$, $r_p=0.50$), number of branches plant⁻¹ ($r_g=0.50$, $r_p=0.45$), petiole length ($r_g=0.43$, $r_p=0.42$), leaf area ($r_g=0.34$, $r_p=0.33$), leaf length ($r_g=0.33$, $r_p=0.32$), number of leaves plant⁻¹ ($r_g=0.27$, $r_p=0.26$) and total chlorophyll content ($r_g=0.26$, $r_p=0.25$) suggesting improvement of leaf yield through improvement of these component traits. Path coefficient analysis revealed high direct positive effect on leaf yield via plant height followed by inflorescence length, petiole length, vitamin C content, anthocyanin content, leaf area and total chlorophyll content revealing their importance in selection.

Key words: Characterization, Variance, Heritability, Correlation, Path coefficient analysis, *Amaranthus* spp.

Signature of Student

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Dated: _____

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Chapter – 1

INTRODUCTION

Amaranth belongs to the genus *Amaranthus* and family Amaranthaceae. The word “Amaranth” means everlasting. The genus *Amaranthus* includes 50-60 species having cultivated for leaf as well as for grains, few are ornamental and wild species. Centers of diversity for *Amaranthus* are Central and South America, India and South East Asia with secondary centers of diversity in West and East Africa. The leafy *Amaranthus* is said to be native of India (Shanmugavelu, 1989). Resembling spinach in appearance, *Amaranthus* leaves come varied in colors ranging from green, purple, red and gold and are found in the foot hills of the Himalayas to the coasts of South India. These are the most important leafy vegetables of the tropical countries in the South Asia, South East Asia, Central Africa, Ethiopia, and the Pacific. In India, various domesticated forms are grown in Tamil Nadu, Andhra Pradesh, Karnataka and Kerala (Khurana *et al.*, 2013).

In India, *Amaranthus* has been recognized as an underexploited vegetable crop with promising economic value and medicinal properties, hence the estimation of the extent of its cultivation is not available. It forms an integral part of various regional cuisines in the country. It is commonly known as chaulai for green coloured plant type or Lal saag in India. It is one of the cheapest grown leafy vegetable with low production cost and therefore often considered as “Poor man’s Spinach”. It is suitable for kitchen gardens and fits well in crop rotation because of its very short duration and large yield of edible matter per unit area and time. It is biotic and abiotic stress tolerant with wider adaptability (Lee *et al.*, 2008) and can be grown round the year under varied soil and agro climatic conditions (Katiyar *et al.*, 2000 and Shukla and Singh, 2000) except extreme winters.

Amaranthus is a rich source of nutrients and serves as an alternative source of nutrition for people in developing countries where bulk of population has little

access to protein rich food (Prakash and Pal, 1991 and Shukla *et al.*, 2003). The plant has been reported to possess many medicinal and anticancer properties (Dasgupta and De, 2007). It has been used traditionally in treatment of piles and as a decongestant (Joshi and Rana, 1991). The stem and leaf extracts are used in the treatment of kidney stones. The leaves of *Amaranthus* constitute an inexpensive and a rich source of carotene and its regular consumption helps in easing digestion and weight management. *Amaranthus* leaves have been reported to contain three times more calcium and vitamin B than spinach leaves and twenty times more calcium than lettuce leaves (Bradtke, 2013). It is a good source of iron and dietary fiber hence good for anemia patients and is also good for reducing cholesterol and risk of cardiovascular diseases.

In Jammu and Kashmir, the crop is grown on a limited scale in kitchen and market gardens. It is also available as non-conventional leafy vegetable in the orchards of Kashmir and the preparation of *Amaranthus* with *Portulaca*, as a mixed vegetable is relished by all sections of the society and is considered to have a cooling effect. The crop is gaining attention of consumers in respect of its nutritional quality. However due to limited availability of cultivars, the crop has not been commercially exploited.

Characterization and evaluation of genetic resources can provide breeders with valuable information on effective utilization of genetic resources for the breeding programmes. Collection, evaluation of germplasm including land races offer considerable scope to identify suitable types for any particular region. Yield is an ultimate criterion which a plant breeder has to keep in view. Yield of a crop is a complex quantitative trait, considerably affected by environment. Higher yield can be achieved by improving its component traits. Limited information on interrelationship among traits is available in vegetable amaranth (Shukla *et al.*, 2010). Information on the amount and direction of association between yield and yield related characteristics is important for rapid progress in selection and genetic improvement of a crop (Ashish *et al.*, 2008). Correlation coefficient analysis is a

handy technique, which elaborates the degree and extent of relationship among important plant characters and it provides basic criteria for selection which leads to directional model based on yield and its components in the field experiments. Correlation between two or more plant characters and yield provide suitable means for indirect selection. Limited information on interrelationship among traits is available in vegetable amaranth (Shukla and Singh, 2000). Green yield can possibly be improved through the knowledge of interrelationship among various agronomic characters along with direct and indirect influence of component characters on yield. This helps in the prediction of correlated response to differential selection and identification of traits that serve as useful indicators of more important traits under consideration (Jhonson *et al.*, 1955). Component analysis of this relationship reveals the importance of most important traits towards yield. Path coefficient analysis developed and described by Wright (1921) and used by Dewey and Lu (1959) is an efficient statistical technique specially designed to quantify the interrelationship of different components and their direct and indirect effects on yield. Partitioning of total correlation into direct and indirect effect by path coefficient analysis helps in making the selection more effective. Since no study has been undertaken in Indian temperate conditions till date in this behalf hence a planned effort has been undertaken to evaluate different varieties of Amaranth under the agroclimatic conditions of Kashmir with the following broad objectives:

- To study morphological characterization of *Amaranthus* spp. under temperate environment using NBPGR descriptor for Agri – Horticultural crops (Mahajan *et al.*, 2000).
- To determine the magnitude of variability for various characters in *Amaranthus* spp.
- To study correlation of various traits with the yield of *Amaranthus* spp.

Chapter – 2

REVIEW OF LITERATURE

The understanding of magnitude and nature of variability, the extent to which a character is heritable and the indirect and direct effects of components on yield including their interrelationships, has been found very important for the improvement of yield and its components in vegetables. Relevant information to the present study is summarized under the following headings:

- 2.1 Morphological characterization
- 2.2 Variability
- 2.3 Heritability and genetic advance
- 2.4 Correlation characters
- 2.5 Path coefficient analysis

2.1 Morphological characterization

Wu *et al.* (2000) evaluated two hundred twenty nine genotypes of twenty *Amaranthus* species categorized for leaf colour, stem colour, seed colour, and other quantitative traits. The results indicated that genotypes had green and red colours as dominant classes for stem colour and only one genotype had orange stem colour. Leaf colour was green for most genotypes while red or mosaic of red, yellow and green colour also occurred. Seed colour had three classes viz. black, brown and yellow.

Varalakshmi (2004) characterized forty-six accessions of Amaranth and the results revealed that all plants of all the accessions were erect, with no spines. Stem pigmentation ranged from green to purple and green with purple streaks at the base. Leaf pubescence was not present in the majority of the lines, but it was low in two lines. Leaf colour ranged from green to purple, leaf veins and margins pigmented and pinkish green. Leaf shape ranged from lanceolate to cuneate and

obovate. The leaf veins were prominent in only two lines and the petiole pigmentation ranged from green to purple and pinkish green. Inflorescence density ranged from low to dense and intermediate. Inflorescence colour ranged from green to pink and pinkish green, greenish pink and light pink.

Andini *et al.* (2012) evaluated Amaranth accessions (*Amaranthus* spp.), which consisted of fifty three accessions from Indonesia, twenty six accessions from United States Department of Agriculture (USDA) and five accessions from Nepal. High variability in leaf colour, with green as the predominant colour was shown. In the Indonesian group, other leaf colours included red -purple, green-variegated red or vice versa and very dark green. While as in other accessions, the leaf colours observed were green-variegated red or vice versa, red-purple, and red-purple- variegated green.

Akaneme and Ani (2013) evaluated five accessions of *Amaranthus hybridus* and the results revealed that accessions differed with respect to characters like mature stem colour, leaf pigmentation, colour of leaf margin, petiole pigmentation, flower colour and seed colour.

2.2 Variability

The crop improvement programme largely depends on the extent of variability present. There are two kinds of variability in crop plants - genetic and environmental. The non-genetic or phenotypic variability is the result of genetic and environmental interaction. However it is not of much use to breeders since it cannot be perpetuated from generation to generation. Therefore, in order to make selection and improvement programmes effective, it is essential to partition the total variability existing in a germplasm into genetic, phenotypic and environmental components. This enables the breeder to adopt a suitable breeding programme. So variability is a key factor, which determines the amount of progress expected from selection. The potential for improvement in crops is proportional to the magnitude of genetic variability present in the germplasm. The

study of genetic variability was made for the first time by great biologist Fisher (1918) and subsequently, the estimation of genotypic and phenotypic variations were used to predict the expected genetic response. Subsequently, a number of other workers have also discovered several techniques for the estimation of components of variance (Wright, 1921; Lush, 1940; Robinson *et al.*, 1951).

Wu *et al.* (2000) studied two hundred twenty nine genotypes of twenty *Amaranthus* species and observed wide variability for plant height, maturity, leaf number plant⁻¹, branch number plant⁻¹ and yield plant⁻¹. Shukla and Singh (2002) studied sixty six Amaranth genotypes for agronomic traits, viz. days to flower and maturity, plant height, stem diameter, number of branches, nodes and inflorescences per plant, inflorescence length, leaf size, number of spikelets per spike, and grain yield per plant. A wide range of variation for days to flower (44.33-75.33 days) and days to maturity (123.5-160.0 days), plant height (31.67-125.33 cm), number of branches (4.33-19.67), nodes (4.83-32.10) and inflorescences (15.5-213.00) per plant, inflorescence length (10.00-39.00 cm), number of spikelets per spike (1.00-5.00), leaf size (11.20-144.79 cm²) and grain yield was observed. The highest coefficient of variability was observed in the number of inflorescence per plant (39.76) followed by leaf size (34.68 cm²).

Rani and Veeraragavathatham (2003) evaluated fifty-seven lines of *Amaranthus* species and reported that the phenotypic and genotypic variability expressed as coefficients over mean (PCV and GCV, respectively) were the highest for green yield per plant (84.66 and 81.53%) followed by stem weight per plant (76.04 and 75.08%), leaf weight per plant (58.77 and 55.70%) and leaf number (57.22 and 54.69%). Similarly, Varalakshmi (2004) evaluated forty-six accessions of Amaranth and reported that wide range of variability existed for the traits viz. plant height, basal lateral branch length, top branch length, leaf width, petiole length, inflorescence length, inflorescence lateral length, axillary branch length and days to 50% flowering. There was a high coefficient of variation for

basal lateral branch length, axillary branch length, inflorescence lateral length and top lateral branch length.

Shukla *et al.* (2006) studied thirty strains of vegetable amaranth (*Amaranthus tricolour* L.) and reported that the values of phenotypic coefficient of variability were greater than corresponding genotypic coefficient of variability values though in many cases difference were small.

Shukla *et al.* (2006) studied twenty nine strains of vegetable amaranth (*Amaranthus tricolour* L.) for two successive seasons and reported that genotypic coefficient of variation (GCV) values ranged from 6.80 to 28.25%. The traits viz., fiber content, branches plant⁻¹, leaves plant⁻¹, plant height and stem diameter showed lowest values of GCV. Vyas *et al.* (2006) revealed the presence of considerable amount of genetic variability for all characters under study in sixty genotypes of *Amaranthus*. Estimates of genotypic coefficient of variation (GCV) were very close to the phenotypic coefficient of variation (PCV) for all characters. Celine *et al.* (2007) reported the presence of remarkable variability for yield, quality and resistance to leaf blight in eighty nine diverse accessions of *Amaranthus*.

Anuja and Mohideen (2007) reported that there were highly significant differences between hundred *Amaranthus* genotypes for green yield and other characters. The PCV was higher as compared to GCV for most of the characters. High genotypic coefficient was observed for number of leaves, yield of greens, root weight, leaf weight, stem weight and leaf area. Pan *et al.* (2008) studied twenty four indigenously collected germplasm line for nine quantitative characters. Highly significant differences were observed among the collected germplasm for all the characters. The maximum extent of genetic variability was exhibited by leaf-stem ratio followed by total yield of greens per plot, girth of stem and length of leaf. The high GCV values for girth of stem and width of leaf were also observed.

Joydip *et al.* (2010) conducted studies on 22 genotypes of vegetable amaranth. Observations on days to marketable maturity, plant height, stem girth, leaf number, leaf length, leaf width, dry weight (leaf and stem), leaf: stem ratio, chlorophyll a, chlorophyll b and green yield were recorded. The ANOVA revealed significant differences among genotypes implying the presence of genetic variability in the experimental material for studied traits. High to moderate estimates (>30%) of coefficients of variation (GCV and PCV) for majority of the traits were recorded.

Joshi *et al.* (2011) evaluated thirty one accessions of *Amaranthus* and found that germplasm showed a wide range of variability in plant height, number of branches, leaf length, leaf width, petiole length, leaf weight plant⁻¹, stem weight per plant and seed yield plant⁻¹. Smitha and Krishnakumary (2011) conducted an experiment to evaluate the variability and performance of twenty three grain amaranth accessions. The study showed that phenotypic coefficients of variation was higher than corresponding genotypic coefficients of variation for most of the traits and ranged from 12.64 to 49.83. Highest genotypic coefficient of variation was recorded for grain yield and plant height at flowering suggesting good scope for selection.

Anuja (2012) studied 14 characters in 100 genotypes of vegetable amaranth (*Amaranthus* spp.) for two seasons and reported the presence of considerable amount of phenotypic and genotypic variability for number of leaves, root weight and leaf weight in both the seasons.

Mandal *et al.* (2012) studied seventeen genotypes of *Amranthus* which included four improved varieties and thirteen local types. Significant differences were observed among the entries for all the studied characters *i.e.* plant height, stem girth, number of leaves plant⁻¹, leaf length, leaf width, stem fresh weight, leaf-stem ratio, yield plant⁻¹ and yield ha⁻¹. Mobina *et al.* (2013) studied seven metric traits in *Amaranth* cultivars and reported the considerable amount of genetic variability for all the characters except rachis inflorescence⁻¹. The highest

values of PCV and GCV were shown by 1000 seed weight, seed yield plant⁻¹ and inflorescence plant⁻¹.

Akaneme and Ani (2013) evaluated five accessions of the species of *Amaranthus* and reported highly significant differences for leaf width, hypocotyl length, days to 50% flowering, 500 seed weight and leaf length. High GCV and PCV values were revealed by each quantitative trait under study. Chattopadhyay *et al.* (2013) evaluated eleven genotypes of vegetable amaranth collected from different places in the country for different horticultural traits and reported high to moderate GCV and PCV value for shoot weight plant⁻¹, green yield plant⁻¹, shoot leaf ratio, leaf weight, number of leaves plant⁻¹ and plant height.

Hasan *et al.* (2013) evaluated seventeen genotypes of stem amaranth (*Amaranthus tricolour* L.). The genotypes varied significantly for all the characters studied. High values of GCV and PCV were observed in leaf weight (77.54 and 80.14% respectively) and dry weight without rind (74.42 and 74.47% respectively). Khurana *et al.* (2014) conducted a trial in *Amaranthus* and reported that analysis of variance revealed highly significant differences for all the characters studied. The values of phenotypic coefficient of variation (PCV) were higher than those of genotypic coefficient of variation (GCV) in both seasons for all the characters.

Gerrano *et al.* (2014) studied genotypes of thirty two *Amaranthus* species and reported highly significant differences for all phenotypic traits, indicating the existence of high genetic variability. Sarker *et al.* (2014) studied thirty vegetable amaranth genotypes for nutrient composition, antioxidant content, and twelve yield contributing traits and reported high range of variability and high genotypic variance for all the traits except calcium, protein and beta carotene content. Close differences between genotypic and phenotypic variances, genotypic and phenotypic coefficient of variations were observed for all the traits. Vujacic *et al.* (2014) studied ten Amaranth genotypes and found variability in total leaf mass plant⁻¹, grain yield plant⁻¹ as well as total grain yield.

Abe *et al.* (2015) evaluated thirty two *Amaranthus* genotypes and revealed that genotypes exhibited great variability with highly significant differences in phenotypic characteristics. High variability was exhibited by plant height, leaf area, number of leaves, panicle length, fresh biomass, dry biomass and grain yield.

Salvadora *etal.* (2017) carried out a study on twenty traits in ten *Amaranthus* accessions belonging to *Amaranthus tricolour* L. Comparison of genotypic co-efficient of variation (GCV) and phenotypic co-efficient variation (PCV) for different traits indicated that the values of PCV were higher as compared to GCV due to the influence of environment. High GCV and PCV were observed for leaf length, leaf breadth, stem weight, seed yield per plant and anthocyanin content.

2.3 Heritability and genetic advance

Heritability has been widely used in determining the degree to which a character may be transmitted from parents to offsprings. Heritability is a measure of the genetic relationship between parents and progeny. Robinson *et al.* (1949) defined heritability as the additive genetic variance in per cent of the total variance. The term heritability, is also defined in more specific ways on consideration in response to selection e.g. narrow sense heritability measured as the ratio of additive genetic variance to the total phenotypic variance (Wright, 1921) and broad sense heritability is the ratio of total genotypic variance to the observed phenotypic variance (Lush, 1949). High heritability along with high genetic advance are important for making effective selections. Johnson *et al.* (1955) pointed out that without genetic advance the estimates of heritability would not be of practical importance in selection based on phenotypic appearance and therefore genetic advance should be considered along with heritability in streamlining the coherent selection breeding programme.

Shukla *et al.* (2000) studied foliage yield and its four main component traits in vegetable amaranth (*Amaranthus* spp.). The heritability estimates in broad

sense ranged from 33.24 to 75.00%. High heritability coupled with high genetic advance was noticed for foliage yield, leaf size and leaves plant⁻¹, indicating the prevalent role of additive gene effects. Rani and Veeraragavathatham (2003) evaluated fifty-seven lines of *Amaranthus* and observed that heritability ranged from 73.33 to 97.00%. High heritability coupled with high genetic advance as percent of mean were obtained for green yield per plant (92.56% and 161.36%), stem weight per plant (97.00% and 152.40%), leaf number per plant (91.31% and 107.65%) and leaf weight per plant (89.94% and 108.77%) followed by the other traits such as plant height (85.93% and 44.37%), leaf length (82.68% and 47.80%), leaf breadth (74.26% and 45.72%) and stem girth (73.33% and 47.87%), which suggested additive gene effects controlling these traits.

Shukla *et al.* (2003) studied sixty six derivatives of *Amaranthus hypochondriacus* and *Amaranthus cruentus* and reported that heritability was high for all the characters examined. Genetic gain was highest for the number of inflorescence plant⁻¹, number of nodes plant⁻¹, leaf size and number of primary branches plant⁻¹. Shukla *et al.* (2005) conducted an experiment on twenty nine vegetable amaranth genotypes (*Amaranthus tricolour* L.) and data was recorded for plant height, stem diameter, branches per plant, leaves per plant, leaf size, protein content and foliage yield. Heritability values were high for all the characters in all the cuttings and pooled values. Foliage yield showed maximum heritability in all 4 cuttings followed by plant height and leaf size. Genetic gain was highest for foliage yield followed by leaf size and stem diameter. In general, the genetic advance values were high in all the cuttings for foliage yield, plant height, leaf size and stem diameter.

Vyas *et al.* (2006) evaluated sixty genotypes of *Amaranthus cruentus* for ten characters viz. days to 50% flowering, plant height, branches per plant, panicle length, days to maturity, grain yield per plant, straw yield per plant, 1000-seed weight, harvest index and protein content. Heritability was high for all characters, except panicle length. Genetic advance was high for grain yield per plant,

branches per plant and straw yield per plant, indicating the presence of additive genetic variance for these characters.

Shukla *et al.* (2006) studied twenty nine strains of vegetable amaranth (*Amaranthus tricolour* L.) for two successive seasons and reported that the heritability estimates were high for all the traits and ranged from 89% for branches per plant to 98% for foliage yield. Highest expected genetic advance as percent of mean was noticed for ascorbic acid (57.48%), followed by foliage yield (48.30%) and leaf size (29.51%).

Shukla *et al.* (2006) conducted studies on thirty strains of *Amaranthus tricolour* L. and reported that the heritability estimates were high for most of the traits, with potassium and calcium showing high values, while comparatively lower values were recorded for magnesium and nickel.

In a study conducted by Gerrano *et al.* (2006), genetic parameters were estimated for fourteen phenotypic traits. Thousand seed weight, dry biomass, number of leaves, leaf length and panicle length showed high heritability estimates and genetic advance. Anuja and Mohideen (2007) studied genetic variability and heritability in hundred genotypes of *Amaranthus* and found that heritability estimates in general were high for most of the characters. High heritability coupled with high genetic advance (as per cent of mean) was observed for number of leaves, root length, root weight, leaf weight and stem weight.

Pan *et al.* (2008) evaluated twenty four indigenously collected germplasm lines of *Amaranthus tricolour* L. and found that heritability was high for leaf-stem ratio, width of leaf, length of leaf, days to first clipping, number of clipping, girth of stem and total yield of greens plot⁻¹. High heritability along with high genetic advance was observed for leaf-stem ratio, width of leaf, total yield of greens plot⁻¹ and length of leaf. Joydip *et al.* (2010) studied twenty two genotypes of vegetable amaranth and recorded observations on days to marketable maturity, plant height, stem girth, leaf number, leaf length, leaf width, dry weight (leaf and stem), leaf:

stem ratio, chlorophyll a, chlorophyll b and green yield. High to moderate estimates (>50%) of heritability (broad sense) and high to moderate genetic advance (>35%) for majority of the traits indicated the possibility of improvement in morphological and phenological traits through selection.

Smitha and Krishnakumary (2011) conducted an experiment on twenty three grain amaranth accessions. High heritability and genetic advance were recorded for grain yield and plant height at flowering suggesting good scope for selection.

Ahammed *et al.* (2012) studied twenty two genotypes of stem amaranth and reported that heritability estimates in broad sense were higher for leaf weight plant⁻¹ followed by leaves plant⁻¹, primary branches plant⁻¹, stem weight plant⁻¹ and yield ha⁻¹. Leaf weight plant⁻¹, stem weight plant⁻¹ and yield ha⁻¹ exhibited high value of heritability along with high genetic advance. Again, high heritability coupled with high genetic advance for plant height, number of leaves, leaf length, leaf width and green yield per plant was reported by Anuja (2012) in Amaranth.

Hasan *et al.* (2013) evaluated seventeen genotypes of stem amaranth (*Amaranthus tricolour* L.) and reported high heritability with high genetic advance as percent of mean for number of leaves, leaf weight and marketable yield which demonstrated the presence of additive gene effects. Khurana *et al.* (2013) evaluated twenty four genotypes of *Amaranthus* spp for two seasons and reported that heritability estimates were in general high for all the characters in both seasons ranging from 89.05 to 99.99 per cent. High values of heritability coupled with high genetic gain for the characters like total green yield and leaf area index were also obtained. Mobina *et al.* (2013) in a study in eight Amaranth cultivars indicated existence of high estimates of heritability for seed yield per plant and length of inflorescence among characters.

Venkatesh *et al.* (2014) studied hundred germplasm accessions of grain amaranth and reported that all the traits studied exhibited high heritability. High

genetic advance as per cent of mean was observed for days to 50 percent flowering, stem girth, number of leaves per plant, plant height, panicle length, panicle width and grain yield plant⁻¹.

Salvadora *et al.* (2017) carried out an investigation to study twenty traits in ten *Amaranthus* accessions belonging to *Amaranthus tricolour* L. High estimates of heritability coupled with high genetic advance were recorded for plant height, number of leaves per plant, leaf length, leaf breadth, leaf weight, stem weight, green yield per plant, seed yield per plant, anthocyanin and nitrate content where heritability ranged from 80.21 to 97.62% and genetic advance from 30.51 to 57.15%. Hence it was suggested that these characters need to be given more importance in selection as these are expected to be controlled by additive genes.

2.4 Correlation characters

Correlation co-efficient analysis measures the mutual relationship between various plant characters and determines the component characters on which selection could be based for the genetic improvement in yield. The basic concept of correlation was first developed by Galton (1889) and later it was elaborated by Fisher (1918) and Wright (1921) in the improvement of plant breeding programmes. The preliminary information on the nature and magnitude of genetic variation in the available material and association of characters with yield and among themselves is most important for a plant breeder for the development of good quality and high yielding varieties. However, yield being the resultant of interaction between a number of factors i.e. inherent and environmental, it is therefore, difficult to estimate or select for this complex character directly. Hence the association is usually determined by studying the correlations of different characters under study with yield.

The phenotypic correlation coefficient gives the extent of relationship between the two characters which include the genetic and environmental

influences whereas genotypic correlation coefficient indicates the real association between two traits and may be useful in selection (Johnson *et al.*, 1955).

Shukla *et al.* (2003) conducted a correlation analysis for yield and yield components (number of days to flowering, number of days to maturity, plant height, number of primary branches per plant, number of inflorescences per plant, inflorescence length, number of spikelet's spike⁻¹, number of nodes plant⁻¹ and leaf size) using sixty six *Amaranthus* genotypes. 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 spikelet's spike⁻¹, number of nodes plant⁻¹ and leaf size; number of spikelet's spike⁻¹ and number of nodes per plant and leaf size and number of nodes per plant and leaf size.

Shukla *et al.* (2005) conducted an experiment on twenty nine vegetable amaranth (*Amaranthus tricolour* L.) genotypes and data was recorded for plant height, stem diameter, branches per plant, leaves per plant, leaf size, protein content and foliage yield. It was reported that plant height was positively correlated with foliage yield in all the cuttings. In the first and second cuttings, genotypic correlation was positive for most of the characters, except for protein content in the first cutting and branches per plant in the second cutting. There was a moderate positive correlated response for plant height, leaf size, leaves per plant and stem diameter in the first two cuttings.

Sixty-one genotypes of *Amaranthus* (*Amaranthus hypochondriacus*) were studied for yield and yield-contributing characters by Kalpande *et al.* (2007). The grain yield per plant was positively and significantly correlated with number of spikelets per inflorescence (0.837), stem girth (0.787), 50 ml volume seed weight (0.732), inflorescence length (0.730), inflorescence girth (0.617), plant height (0.490), and harvest index (0.458) and leaf area per plant (0.379). Pan *et al.* (2008) evaluated twenty four indigenously collected germplasm of *Amaranthus*

tricolour L. including two released varieties and reported that the total yield of greens plot⁻¹ was found to be positively and significantly correlated with duration of harvest.

Prajapati *et al.* (2009) studied the interrelationship between grain yield and eight contributing characters (days to 50% flowering, plant height, number of branches per plant, panicle length, days to maturity, straw yield per plant, 1000-seed weight and harvest index) in sixty diverse genotypes of *Amaranthus* (*Amaranthus cruentus*). The grain yield exhibited significant and positive correlation with straw yield per plant, harvest index, 1000-seed weight and number of branches per plant. These four characters accounted for 66% of the total variation in grain yield.

Joydip *et al.* (2010) studied twenty two genotypes of vegetable amaranth and recorded observations on days to marketable maturity, plant height, stem girth, leaf number, leaf length, leaf width, dry weight (leaf and stem), leaf: stem ratio, chlorophyll a, chlorophyll b and green yield. The correlation between green yield and its components such as plant height stem girth, leaf length, leaf width, leaf and stem dry weights was significant and positive indicating the possibility of indirect selection and realizing correlated response. However, days to marketable maturity had negative correlation with plant height, stem dry weight and chlorophyll contents.

Shukla *et al.* (2010) conducted an investigation to elucidate the interrelationship among various agronomic and quality traits in thirty nine distinct cultivars of vegetable amaranth (*Amaranthus tricolour* L.). Among the agronomic traits, plant height and number of inflorescence exhibited significant positive association with foliage yield, while chlorophyll a, chlorophyll b, carotenoid, fiber and ascorbic acid were positively correlated with foliage yield. Chlorophyll a and chlorophyll b exhibited significant positive association with carotenoid, fiber and ascorbic acid. Ascorbic acid was positively correlated with fiber and carotenoid. Protein was associated with plant height, branches per plant and 500 seed weight.

Aruna (2012) studied six genotypes of vegetable amaranth and thirty F₁ hybrids and reported that the correlation coefficient between yield of greens with weight of leaves was highest both at genotypic level and at phenotypic level.

Anuja (2012) studied thirteen quantitative characters in hundred genotypes of vegetable amaranth and observed highly significant and positive correlation of green yield with leaf weight, stem weight and plant height. Hasan *et al.* (2013) evaluated seventeen genotypes of vegetable amaranth and reported strong positive association of yield with leaf weight, stem weight, stem diameter, dry weight with rind and dry weight without rind.

Upadhyay and Maurya (2013) studied eighteen traits in ten germplasm lines of vegetable amaranth (*Amaranthus tricolour* L.) and reported that foliage yield showed positive genotypic and phenotypic association with chlorophyll a, carotenoids, fiber, protein, cadmium, nickel, chromium and manganese. However, only carotenoids and cadmium were significantly correlated with foliage yield.

Khurana *et al.* (2013) conducted an experiment on genetic variability in twenty four genotypes of *Amaranthus*. Total green yield exhibited highly significant and positive correlation with plant height, number of branches per plant⁻¹, leaf length, leaf width, number of leaves, and leaf area index both at genotypic and phenotypic levels and negative correlation with oxalate content. Kendre *et al.* (2013) studied twenty genotypes of Amaranth and revealed that, plant height and petiole length exhibited positive and significant association with the yield in Amaranth which indicated their relative importance in leaf yield.

Patial *et al.* (2014) evaluated twenty two genotypes of Amaranth (*Amaranthus* spp.) for twelve quantitative traits and observed that all the traits were positively correlated with grain yield. Also, harvest index was positively correlated with days to maturity.

Sarker *et al.* (2015) studied forty three vegetable amaranth genotypes to study genetic association among mineral elements, quality and agronomic traits

and reported that biological yield had significant positive correlation with shoot weight, shoot/root weight diameter of stem base and leaf area. Also Sarker *et al.* (2015) studied twenty five vegetable amaranth genotypes and found significant and positive correlation of iron, manganese, ascorbic acid and number of leaves plant⁻¹ with foliage yield.

Hailu *et al.* (2015) evaluated thirty six accessions of *Amaranthus* sps. and found that the green leaf yield per plant showed positive and significant relationship with stem diameter, plant height, inter node length, top branch and average branch length.

Salvadora *et al.* (2017) carried out a study on twenty traits in ten *Amaranthus* accessions belonging to *Amaranthus tricolour* L. Significant and positive correlation of green yield per plant with plant height, stem girth, number of leaves plant⁻¹, number of branches plant⁻¹, leaf length, leaf breadth, ascorbic acid and crude fiber content was observed.

2.5 Path coefficient analysis

The study of simple correlation does not provide an exact picture of relative importance of direct and indirect influence of each of the component characters towards the desired characters. So, this can be overcome by following path coefficient analysis technique by further partitioning the correlation coefficient into direct and indirect effects.

Shukla *et al.* (2003) conducted an experiment using sixty six *Amaranthus* genotypes for yield and yield components (number of days to flowering, number of days to maturity, plant height, number of primary branches per plant, number of inflorescences per plant, inflorescence length, number of spikelet's spike⁻¹, number of nodes plant⁻¹ and leaf size). It was reported 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 inflorescences per plant. Plant height was also indirectly and positively associated with grain yield via the number of days to

flowering, number of inflorescences per plant, inflorescence length and leaf size. Leaf size, plant height, number of inflorescences per plant, inflorescence length and number of days to maturity comprised the major yield components.

Rana *et al.* (2005) studied hundred genotypes of *Amaranthus hypochondriacus* and reported that path analysis revealed the significance of inflorescence length, number of leaves and plant height for selecting better yielding genotypes.

Sixty-one genotypes of *Amaranthus* (*Amaranthus hypochondriacus*) were studied for yield and yield contributing characters by Kalpande *et al.* (2007). The interrelationship studies revealed high positive direct effect on grain yield by number of spikelets per inflorescence (4.307) followed by plant height (3.705), harvest index (1.311), inflorescence girth (0.779) and days to maturity (0.104).

Pan *et al.* (2008) studied twenty four indigenously collected germplasm lines of *Amaranthus tricolour* L. including two released varieties. Path coefficient analysis of different characters contributing towards total yield of greens revealed that duration of harvest had maximum positive direct effect on total yield. The indirect effect of duration of harvest via number of clippings was maximum and positive.

Shukla *et al.* (2010) conducted an investigation to elucidate the interrelationship among various agronomic and quality traits in thirty nine distinct cultivars of vegetable amaranth (*Amaranthus tricolour* L.) and reported that chlorophyll a, carotenoid content and inflorescence length revealed high positive direct effect on foliage yield while branches plant⁻¹, leaf size, seed yield, chlorophyll b, moisture content and ascorbic acid showed negative path coefficient with foliage yield. Anuja (2012) studied with thirteen quantitative characters in hundred genotypes of vegetable amaranth and path coefficient analysis revealed that stem weight, leaf weight and root weight were the most important yield component traits.

In a study conducted by Aruna (2012), six genotypes of vegetable amaranth and thirty F1 hybrids were studied to estimate the correlation and path analysis and it was reported that weight of leaves and weight of stem had higher and direct contribution to the yield. Hasan *et al.* (2013) evaluated seventeen genotypes of vegetable amaranth and path analysis indicated that stem weight had maximum direct effect on marketable yield followed by leaf weight, leaf number and yield of stem amaranth. Plant height had the highest negative direct effect on marketable yield (-0.008); leaf number showed positive direct effect with marketable yield (0.008) and leaf length showed the negative direct effect with marketable yield (-0.022). This character also showed negative indirect effect with stem diameter (-0.010), but result was ultimately the total positive significant correlation with marketable yield (0.489). Leaf weight showed the maximum direct positive effect with marketable yield (0.090) and revealed no effect with days to first flowering (0.00), which ultimately resulted in the total positive significant correlation with marketable yield.

Kendre *et al.* (2013) studied twenty genotypes of Amaranth and path analysis revealed that stem diameter exerted highest direct effect over yield followed by petiole length, leaf area and number of leaves, but plant height exhibited the negative direct effect on yield. Patial *et al.* (2014) evaluated twenty-two genotypes of Amaranth (*Amaranthus* spp.) and found that harvest index, aerial biomass plant⁻¹ and days to maturity also had high phenotypic and genotypic direct effects on seed yield plant⁻¹.

Sarker *et al.* (2014) studied thirty vegetable amaranth genotypes and reported that the fiber content (0.616), leaf area (0.464), diameter of stem base (0.420) and beta carotenoid (0.347) had high positive direct effects on foliage yield. Hailu *et al.* (2015) studied thirty six accessions of *Amaranthus* spp. and found that the highest and positive direct effect was exerted by biomass per plant followed by average branch length and these characters had significant correlations with green leaf yield.

Venkatesh *et al.* (2014) evaluated hundred genotypes of grain amaranth to estimate correlation and path coefficients among ten quantitative traits including grain yield in grain amaranth. Path co-efficient analysis revealed maximum positive direct effect of number of leaves per plant (0.575) on grain yield followed by seed weight (0.234), panicle length (0.221) and plant height (0.124). The study suggests that selection of varieties with higher number of leaves per plant, seed weight, panicle length and plant height will help the breeder to select the genotypes which can give better grain yield.

Salvadora *et al.* (2017) carried out an investigation to study twenty traits in ten *Amaranthus* accessions belonging to *Amaranthus tricolour*. Path analysis revealed that the number of branches per plant exerted the highest direct effect on green yield per plant and was indirectly influenced through days to flower appearance, stem girth, number of leaves per plant, leaf length and leaf breadth. It was concluded that green yield could be increased substantially in vegetable amaranthus through the indirect selection based on plant height, number of leaves per plant, leaf length, leaf breadth, green yield per plant, seed yield per plant, anthocyanin and nitrate content.

Chapter - 3

MATERIALS AND METHODS

The present investigation entitled “**Morphological Characterization and Variability Studies in Vegetable Amaranth (*Amaranthus* spp.) Under Temperate Conditions**” was conducted at Urban Technology Park Habak, during *kharief* 2016. The area is located at 34.15° N latitude and 74.83° E longitude. The climate is temperate characterized by mild summers. June and July are the hottest months while January and February are the coldest. The maximum rain fall is received during March to April.

3.1 Experimental material

Twenty seven diverse genotypes of vegetable amaranths were collected from different agro climatic regions of country (Table-1) and evaluated for various morphological, yield and yield attributing traits at the experimental fields at Urban Technology Park Habak, SKUAST-Kashmir, during *Kharif* 2016. The names of the varieties/genotypes are given in the Table-1.

The single factor experiment was laid out in randomized complete block design (RCBD) with three replications. The whole experimental area was divided into three blocks each of which was then divided into 27 double lines to represent the 27 treatments. The treatments were distributed randomly to the double lines of each block with a spacing of 30 cm × 30 cm. The experimental fields were well prepared and standard cultural, manural and plant protection practices were followed to ensure a healthy crop growth.

Table 1: List of vegetable amaranth (*Amaranthus* spp.) genotypes used in the present study

S. No.	Genotypes	S. No.	Genotypes	S. No.	Genotypes
1.	SKAU-A-1	13.	SKAU-A-13	25.	SKAU-A-25
2.	SKAU-A-2	14.	SKAU-A-14	26.	SKAU-A-26
3.	SKAU-A-3	15.	SKAU-A-15	27.	SKAU-A-27
4.	SKAU-A-4	16.	SKAU-A-16		
5.	SKAU-A-5	17.	SKAU-A-17		
6.	SKAU-A-6	18.	SKAU-A-18		
7.	SKAU-A-7	19.	SKAU-A-19		
8.	SKAU-A-8	20.	SKAU-A-20		
9.	SKAU-A-9	21.	SKAU-A-21		
10.	SKAU-A-10	22.	SKAU-A-22		
11.	SKAU-A-11	23.	SKAU-A-23		
12.	SKAU-A-12	24.	SKAU-A-24		

3.2 Characters studied and observational procedures

Observations were recorded on various morphological, yield and quality traits in order to study the magnitude of genetic variability and to characterize the material under study as per the NBPGR descriptor (Mahajan *et al.*, 2000). Five plants were selected at random from each replication and tagged for recording the observations:

3.2.1 Descriptor traits

3.2.1.1 Early plant vigour (PLT_VGR)

Early plant vigour was recorded on visual basis of each tagged plant after 20-25 days of transplanting of seedlings and the genotypes were classified into:

- i. Poor (1)
- ii. Good (2)
- iii. Very good (3)

3.2.1.2 Plant growth habit (GRW_HAB)

Plant growth habit was recorded on visual basis of each tagged plant at the completion of vegetative stage and genotypes were categorized into following classes:

- i. Erect (1)
- ii. Spreading (2)
- iii. Drooping (3)
- iv. Others (99)

3.2.1.3 Leaf colour (LF_CLR)

Leaf colour was recorded on visual basis of each tagged plant on fully grown leaf and genotypes were classified as:

- i. Yellow (1)

- ii. Yellowish orange (2)
- iii. Yellowish green (3)
- iv. Orange (4)
- v. Green (5)
- vi. Greenish orange (6)
- vii. Pink (7)
- viii. Pinkish green (8)
- ix. Reddish yellow (9)
- x. Reddish green (10)
- xi. Red (11)
- xii. Dark red (12)
- xiii. Others (99)

3.2.1.4 Inflorescence colour (INFL_CLR)

Inflorescence colour was recorded on visual basis of each the tagged plant at 50% flowering stage and genotypes were classified as:

- i. Light yellow (1)
- ii. Yellow (2)
- iii. Yellowish orange (3)
- iv. Yellowish green (4)
- v. Orange (5)
- vi. Pink (6)
- vii. Pinkish green (7)
- viii. Purple (8)

- ix. Red (9)
- x. Reddish green (10)
- xi. Green (11)
- xii. Others (99)

3.2.1.5 Inflorescence compactness (INFL_CPT)

Inflorescence compactness was recorded on visual basis of each tagged plant at 50% flowering stage and were categorized into following classes:

- i. Lax (3)
- ii. Intermediate (5)
- iii. Dense (7)
- iv. Others (99)

3.2.1.6 Stem colour (STEM_CLR)

Stem colour was recorded on visual basis of each tagged plant at the time of full heading stage and genotypes were classified as:

- i. Yellow (1)
- ii. Yellowish green (2)
- iii. Orange (3)
- iv. Pink (4)
- v. Red (5)
- vi. Reddish green (6)
- vii. Reddish orange (7)
- viii. Others (99)

3.2.1.7 Stem surface (STEM_SUR)

Stem surface was recorded on visual basis of each tagged plant at the time of heading and genotypes were categorized into following classes:

- i. Smooth (1)
- ii. Ridged (2)
- iii. Others (99)

3.2.1.8 Inflorescence shape (INFL_SHP)

Inflorescence shape was recorded on visual basis of each tagged plant at maturity time and genotypes were categorized into following classes:

- i. Globose (1)
- ii. Semi drooping (2)
- iii. Completely drooping (3)
- iv. Straight (4)
- v. Others (99)

3.2.1.9 Inflorescence spininess (INFL_SPN)

Inflorescence spininess was recorded on visual basis of each tagged plant at maturity time and genotypes were categorized into following classes:

- i. Smooth (pubescent) (1)
- ii. Glabrous (2)
- iii. Prickly (3)
- iv. Spiny (4)
- v. Others (99)

3.2.1.10 Seed transparency (SED_TRN)

Seed transparency was recorded on visual basis on matured seeds of the

tagged plants and genotypes were categorized into following classes:

- i. Translucent (1)
- ii. Opaque (2)
- iii. Others (99)

3.2.1.11 Seed colour (SED-CLR)

Seed colour was recorded on visual basis on matured seeds of the tagged plants and genotypes were classified as:

- i. White (1)
- ii. Creamish (2)
- iii. Pale yellow (3)
- iv. Pink (4)
- v. Red (5)
- vi. Brown (5)
- vii. Black (6)
- viii. Golden (7)
- ix. Others (99)

3.2.2 Quantitative traits

3.2.2.1 Number of days to germination

Number of days to germination were counted from the date of sowing date to the date of emergence of seedlings.

3.2.2.2 Plant height (cm)

The height of five tagged plants was measured in centimeters from the ground level to the highest tip and the average was worked out.

3.2.2.3 Number of branches plant⁻¹

Branches arising from the main stem were counted from five tagged plants and the average was worked out.

3.2.2.4 Number of leaves plant⁻¹

The number of leaves from each picking from each tagged plant was pooled and the total number of leaves plant⁻¹ was noted and average was worked out.

3.2.2.5 Leaf length (cm)

The length of five leaves from each of the five tagged plants was measured in centimeters from the base to tip of the apical portion of leaf by scale and average was worked out.

3.2.2.6 Leaf area (cm²)

The leaf area of five leaves from each of the five tagged plants was recorded with the help of leaf area meter and average was worked out.

3.2.2.7 Petiole length (cm)

Petiole length of five leaves from each of the five tagged plants was measured from the base at the stem to the base of leaf and average was worked out.

3.2.2.8 Stem thickness (mm)

Stem thickness of the tagged plants was measured between third and fourth node by digital vernier caliper and the average was worked out.

3.2.2.9 Number of days to 50% flowering

Number of days to 50% flowering were counted from the date of sowing to the date when 50% of the plants in a row flowered.

3.2.2.10 Inflorescence length (cm)

Inflorescence length of the tagged plants was measured from the base of the inflorescence to the tip of the inflorescence and average was worked out.

3.2.2.11 Lateral spikelet length (cm)

Lateral spikelet length (cm) of the tagged plants was measured at the maturity time on the longest lateral spikelet from the base of the lateral spikelet to the tip of the lateral spikelet and average was worked out.

3.2.2.12 Total leaf yield plant⁻¹(g)

The total weight of leaves obtained from each picking of the tagged plants was pooled and the average leaf yield plant⁻¹ was worked out.

3.2.2.13 1000 seed weight (g)

The weight of 1000 seeds from each plant was taken with a digital weighing machine and its average was calculated.

3.2.2.14 Leaf yield (q ha⁻¹)

The yield per hectare was determined on the basis of yield plant⁻¹.

3.2.3 Qualitative traits

3.2.3.1 Dry matter (per cent)

The leaves from five randomly selected plants were harvested and dried. Weight was recorded in grams and mean was computed by taking average from five plants.

$$\text{Dry matter content (per cent)} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

3.2.3.2 Total chlorophyll (mg g⁻¹)

The chlorophyll content was determined by the method given in Thimmaiah (1999). A known amount of sample was grounded with addition to 20ml of 80% acetone. The grounded sample was centrifuged at 5000 rpm for 5

minutes and supernatant was transferred to a 100ml volumetric flask. The procedure was repeated until the residue was colourless. The volume was made to 100ml with 80% acetone. The absorbance of the solution was read at 645, 663 with the help of double beam UV-VIS spectrophotometer against the solvent (80% acetone) blank.

$$\text{Total Chlorophyll (mg/g)} = 20.2 (A_{645}) + 8.02 (A_{663}) \times \frac{V}{1000 \times W}$$

Where, A= Absorbance at specific wavelength,

V= Final volume of chlorophyll extract in 80% acetone

W= Fresh weight of tissue extracted

3.2.2.3 Ascorbic acid (mg 100g⁻¹)

Ascorbic acid (AA) was determined by titrating a known weight of sample with 2, 6-dichlorophenol indophenol dye using metaphosphoric acid as stabilising agent (AOAC, 1980). Known weight of the sample (100g) was grounded in a pestle and mortar with stabilizing medium (1:5). Homogenate was centrifuged. Supernatant was taken and volume was made up to 50 ml with stabilizing medium and filtered. 10 ml of the aliquot was titrated against 2, 6-dichlorophenol indophenol dye.

Five ml of 3% HPO₃ was added to standard ascorbic acid and titrated with the dye solution to a pink colour. The dye factor i.e. mg of ascorbic acid per ml of dye was determined by using the following formula:

$$\text{Dye factor} = 0.5/\text{titre}$$

The Ascorbic acid content of the sample was calculated by using the following formula:

$$\text{Ascorbic acid (mg 100 g}^{-1}\text{)} = \frac{\text{Titre value} \times \text{Dye factor} \times \text{Volume made up}}{\text{Total weight of the sample} \times \text{Aliquot of sample}} \times 100$$

3.2.3.4 Protein content (per cent)

Protein content was determined by using Kjeldals method as described by Rangana, 1986. Half gram of dried Amaranthus leaves in powdered form per replicate was placed in kjeldal tubes and 5 gm of digestion mixture (potassium sulphate+ copper sulphate + iron sulphate in ratio of 5:0.25:0.5) was added. After adding 10ml of concentrated H₂SO₄, the mixture was heated till colour changed to green. Then the tubes were cooled and 10ml of distilled water was added to each sample. Then tubes were fitted in assembly. Mixture from tubes was poured in flask fitted in assembly containing 25ml of boric acid (4%) and 2-3 drops of mixed indicator. Then 40 to 50 ml of NaOH (40%) was added to it till colour changed to brown. Flask containing boric acid and indicator was titrated with 0.1N HCl till colour changed to pink.

Nitrogen content (N%) was calculated in accordance with the following formula:

$$\text{Nitrogen content (\%)} = \frac{\text{Quantity of sample-Blank(ml)} \times \text{N Of HCl} \times 14}{1000 \times \text{Weight of sample (g)}} \times 100$$

Then percent protein was calculated by multiplying nitrogen content (N%) by 6.25

$$\text{Protein (per cent)} = \text{N\%} \times 6.25$$

3.2.3.5 Fiber content (per cent)

Fiber content was determined as crude fiber by Weende method (1865) given by AOAC (1965).

The sample was subjected to acid and alkali digestion and residue was obtained comprising of ash. The residue was ignited and the organic matter got oxidized and inorganic residue or ash was left behind. The difference in the weight before and after ashing was determined.

$$\text{Crude fiber (per cent)} = \frac{W_1 - W_2}{W} \times 100$$

Where,

W g = weight of sample

W₁ g = Residue (crude fiber + minerals)

W₂ g = ash remained

3.2.3.6 Anthocyanin content (mg 100g⁻¹)

Anthocyanin content was calculated by the method as described by Rangana (1986). 10 g of leaf sample was taken and diluted to 100 ml with ethanolic HCl (95% ethanol, 1.5 N HCl) and kept in refrigerator overnight at 4°C. Then it was filtered using Whatman filter paper number 1. Filtrate was taken in a cuvet and its O.D was taken at 535nm using Spectrophotometer against 95% alcohol as blank. Total anthocyanin was calculated using the following equation:

$$\text{Total O.D} = \frac{\text{O.D at 535 nm} \times \text{Volume made}}{\text{Weight of sample}} \times 100$$

$$\text{Total anthocyanin (mg/100 g)} = \frac{\text{Total O.D}}{98.2}$$

3.3 Statistical and biometrical analysis

The data recorded during the present investigation was subjected to the following statistical and biometrical analysis.

- Analysis of variance and estimation of the components of variance,
- Estimation of heritability and genetic advance,
- Estimation of phenotypic and genotypic correlation coefficients and
- Component contribution of different traits to the leaf yield plant⁻¹ (Path analysis).

3.3.1 Analysis of variance and estimation of the components of variance

3.3.1.1 Analysis of variance

The analysis of variance for different characters under study was carried out to test the significance of variation among the treatments. The analysis of variance was done as per procedure described by Panse and Sukhatme (1967).

The Analysis of variance table was set up as under:

Source of variation	d.f	SS	MSS	F ratio	Expected mean Square
Replication	r-1	SS(R)	SS(R)/r - 1	MS(R)/MSE	-
Treatments (Genotypes)	t-1	SS(T)	SS(T)/ t-1	MS(T)/MSE	$\sigma^2_e + r\sigma^2_g$
Error	(r-1) (t-1)	SS(E)	SS(E)/(r-1) (t-1)		σ^2_e

Where, d.f = Degree of freedom

SS	=	Sum of squares
MSS	=	Mean sum of squares
r	=	Number of replications
t	=	Number of treatments
σ^2_e	=	Error variance
σ^2_g	=	Genotypic variance

The significance of differences was tested by F-test comparing calculated F-value with tabulated F-value at 5 and 1 per cent level of significance at appropriate degree of freedom. When cal. F values were greater than corresponding F tab. values, the treatments were considered to be significant.

Standard error of differences between treatment mean was calculated as

$$S.E \text{ (diff)} = [2MS (E)/ R]^{1/2}$$

Critical difference (C.D. at 5%) = Standard error of difference $SE(d) \times t(5\%)$ at error d.f.
 $= (2MS(E)/r)^{1/2} \times t(5\%)$ at error d.f.

Where,

$MS(E)$ = Error mean square

r = Number of replications

3.3.1.2 Genotypic variance

Genotypic variance was calculated using the method suggested by Panse and Sukhtame (1967)

$$\sigma^2_g = \frac{MS(T) - MS(E)}{r}$$

Where,

σ^2_g = Genotypic variance,

$MS(T)$ = Mean sum of squares due to genotypes,

$MS(E)$ = Mean sum of squares due to error, and

r = Number of replications

3.3.1.3 Phenotypic variance

Phenotypic variance was calculated as per the procedure given by Warner (1952).

$$\sigma^2_p = \sigma^2_g + \sigma^2_e$$

Where,

σ^2_p = Phenotypic variance

σ^2_g = Genotypic variance, and

σ^2_e = Error variance

3.3.1.4 Phenotypic, genotypic and environmental co-efficients of variation

The magnitude of phenotypic co-efficient of variation (PCV) and genotypic co-efficient of variation (GCV) existing in a trait was worked out by the formula given by Burton and De Vane (1953):

$$PCV = \frac{\sqrt{\sigma^2 p}}{\bar{X}} \times 100$$

Where,

$\sigma^2 p$ = Phenotypic variance, and

$\bar{X}$ = Grand mean of the trait studied

$$GCV = \frac{\sqrt{\sigma^2 g}}{\bar{X}} \times 100$$

Where,

$\sigma^2 g$ = Genotypic variance, and

$\bar{X}$ = Grand mean of the trait studied

$$ECV = \frac{\sqrt{\sigma^2 e}}{\bar{X}} \times 100$$

Where,

$\sigma^2 e$ = Error variance, and

$\bar{X}$ = Grand mean of the trait studied

3.3.2 Estimation of heritability(b.s) and genetic advance

3.3.2.1 Heritability (broad sense)

Heritability in broad sense was estimated as per the procedure given by Burton and Devane (1953), Johnson *et al.* (1955).

$$h^2_{(b.s)} = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

Where,

$h^2_{(b.s)}$ = Estimate of heritability in broad sense,

σ^2_g = Genotypic variance, and

σ^2_p = Phenotypic variance

3.3.2.2 Genetic advance

Genetic advance at 5 per cent selection intensity was worked out by using the formula given by Johnson *et al.* (1955).

$$GA = k \sigma_p h^2_{(b.s)}$$

Where,

GA = Genetic advance of the trait,

$h^2_{(b.s)}$ = Broad sense heritability

σ_p = Phenotypic standard deviation and

k = Selection differential (constant) at 5% selection intensity
i.e. 2.06 as given by Allard (1960)

3.3.3 Estimation of covariances and correlation coefficients

The correlation coefficients were calculated by using variances and co-variances. The components of covariance were estimated from Analysis of co-variance as:

Source of variation	d.f	TSP	MSP	F ratio	Expected mean square
Replication	r-1	SP(R)	SP(R)/SP(E)	MSP(R)/MSP(E)	-
Treatments(Genotypes)	t-1	SP(T)	SP(T)/SP(E)	MSP(T)/MSP(E)	$\sigma^2_{e_x e_y} + r \sigma^2_{g_x g_y}$
Error	(r-1) (t-1)	SP(E)	SP(E)	MSP(E)	$\sigma^2_{e_x e_y}$
Total	rt-1				

Where,

d.f	=	Degree of freedom
TSP	=	Total sum of products
MSP	=	Mean sum of products
r	=	Number of replications
t	=	Number of treatments
SP(R)	=	Total sum of products due to replications
SP(T)	=	Total sum of products due to treatments
SP(E)	=	Total sum of products due to error
MSP(R)	=	Mean sum of products due to replications
MSP(T)	=	Mean sum of products due to treatments
MS(E)	=	Mean sum of products due to error
$\sigma^2 e_x e_y$	=	Error co-variance between two traits
$\sigma^2 g_x g_y$	=	Genotypic co-variance between two traits.

Further,

$$\sigma^2 e_x e_y = \text{MSP(E)} = \text{Environmental co- variance}$$

$$\sigma^2 g_x g_y = \frac{\text{MSP(T)} - \text{MSP(E)}}{R} = \text{Genotypic co- variance}$$

$$\sigma^2 p_x p_y = \sigma^2 e_x e_y + \sigma^2 g_x g_y = \text{Phenotypic co- variance}$$

Correlation coefficients were calculated as per formula given by Al-Jibouri *et al.* (1958).

Genotypic correlation co-efficient, $r_{xy} (g)$ is given by

$$r_{xy} (g) = \frac{\sigma^2 g_x g_y}{\sqrt{\sigma^2 g_x \cdot \sigma^2 g_y}}$$

Phenotypic correlation coefficient, $r_{xy} (p)$ is given by

$$r_{xy} (p) = \frac{\sigma^2 p_x p_y}{\sqrt{\sigma^2 p_x \cdot \sigma^2 p_y}}$$

Environmental correlation coefficient, $r_{xy} (e)$ is given by

$$r_{xy} (e) = \frac{\sigma^2 e_x e_y}{\sqrt{\sigma^2 e_x \cdot \sigma^2 e_y}}$$

Where,

$r_{xy} (g)$	=	Genotypic correlation coefficients, between a pair of characters x and y
$r_{xy} (p)$	=	Phenotypic correlation coefficients, between a pair of characters x and y
$\sigma^2 g_x g_y$	=	Genotypic covariances, for a pair of characters x and y
$\sigma^2 p_x p_y$	=	Phenotypic covariances, for a pair of characters x and y
$\sigma^2 g_x$	=	Genotypic variance for character x
$\sigma^2 g_y$	=	Genotypic variance for character y
$\sigma^2 p_x$	=	Phenotypic variance for character x
$\sigma^2 p_y$	=	Phenotypic variance for character y

Test of significance

“t” test was applied to test the significance of a correlation co-efficients as per following formula:

$$t = \frac{r (n - 2)^{0.5}}{(1 - r^2)^{0.5}}$$

Where,

r = correlation coefficient

n = number of pairs of observations

Calculated value of “t” (t_{cal}) was compared with tabulated values of “t” (t_{tab}) given by Fisher and Yates (1963) at $n - 2$ degrees of freedom. Any value ($\pm$) exceeding the table value of t at $n-2$ d.f is significant.

3.3.4 Path co-efficient analysis

The methodology suggested by Wright (1921) and Li (1956) was adopted using the formula given by Dewey and Lu (1959) to carry out path coefficient analysis to measure the direct influence of one variable upon the other and to partition the total correlation into direct and indirect effects. Path coefficients were calculated by simultaneous solution of the following equation

$$\begin{array}{rcl}
 r_{1y} & = & P_{1y} + r_{12}P_{2y} + r_{13}P_{3y} + r_{14}P_{4y} + \dots r_{1n}P_{ny} \\
 r_{2y} & = & r_{12}P_{1y} + P_{2y} + r_{23}P_{3y} + r_{24}P_{4y} + \dots r_{2n}P_{ny} \\
 & & \downarrow \quad \downarrow \quad \downarrow \quad \downarrow \quad \downarrow \\
 & & r_{12} \quad r_{23} \quad r_{34} \quad r_{4n} \quad r_{1n} \\
 & & \downarrow \quad \downarrow \quad \downarrow \quad \downarrow \quad \downarrow \\
 r_{ny} & = & r_{1n}P_{1y} + r_{2n}P_{2y} + r_{3n}P_{3y} + r_{4n}P_{4y} + \dots + P_{ny}
 \end{array}$$

Where,

$P_{1y}, P_{2y}, P_{3y} \dots P_{ny}$ are the direct path effects of independent variables (1, 2, 3 n) on dependent variable (y)

$r_{12}, r_{13}, r_{14} \dots r_{1n}, r_{23}, r_{24} \dots r_{2n}, r_{34} \dots r_{3n}, r_{4n} \dots r_{(n-1)n}$ are the possible coefficients of correlation between various independent variables and

$r_{1y}, r_{2y}, r_{3y} \dots r_{ny}$ are the coefficients of correlation of independent variables with the dependent variable y.

The residual effect (i.e. the variation in yield because of unaccounted associations) was calculated from the following formula:

$$P^2_{xy} = 1 - (P^2_{1y} + 2 r_{12} P_{1y} P_{2y} + 2r_{13}P_{1y}P_{3y} + \dots + P^2_{2y} + 2 r_{23} P_{2y} P_{3y} + 2 r_{24}P_{2y} P_{4y} + \dots + P_{2ny})$$

$$\text{Residual effect, } R = (P^2_{xy})^{1/2}$$

Chapter – 4

EXPERIMENTAL FINDINGS

The present investigation entitled “Morphological Characterization and Variability Studies in Vegetable Amaranth (*Amaranthus* spp.) Under Temperate Conditions” was undertaken at Urban Technology Park, Habak, Division of Vegetable Science, SKUAST-Kashmir during *kharief* season 2016. The experiment was laid in RCBD design with three replications. The experimental material consisted of twenty seven genotypes of Vegetable Amaranthus on various qualitative and quantitative traits. The data collected was analyzed as per standard statistical procedures to obtain results. The experimental results thus obtained are presented under following headings:

- 4.1 Morphological characterization
- 4.2 Mean performance and analysis of variance
- 4.3 Variability and genetic components of variation
- 4.4 Correlation
- 4.5 Path coefficient analysis

4.1 Morphological Characterization

Morphological characterization revealed variation among all the genotypes for all the characters under study. Various morphological characteristics are presented in Tables 2.1 to 2.11.

4.1.1 Early plant vigour (PLT_VGR)

Most of the genotypes showed good early plant vigour. However very good early plant vigour was exhibited by SKAU-A-7, SKAU-A-12, SKAU-A-13 and SKAU A-22. Rest of the genotypes viz. SKAU-A-5, SKAU-A-6, SKAU-A-8, SKAU-A-17, SKAU-A-25 and SKAU-A-26 were poor in their early plant vigour.

4.1.2 Plant growth habit (GRW_HAB)

All of the genotypes were of erect growth habit except SKAU-A-17 and SKAU-A-22 which showed spreading growth habit.

Table 2.1: Morphological characterization for early plant vigour in vegetable amaranth (*Amaranthus* spp.)

S. No.	Genotypes	Early plant vigour	S. No.	Genotypes	Early plant vigour
1.	SKAU-A-1	Good	15.	SKAU-A-15	Good
2.	SKAU-A-2	Good	16.	SKAU-A-16	Good
3.	SKAU-A-3	Good	17.	SKAU-A-17	Poor
4.	SKAU-A-4	Good	18.	SKAU-A-18	Good
5.	SKAU-A-5	Poor	19.	SKAU-A-19	Good
6.	SKAU-A-6	Poor	20.	SKAU-A-20	Good
7.	SKAU-A-7	Very good	21.	SKAU-A-21	Good
8.	SKAU-A-8	Poor	22.	SKAU-A-22	Very good
9.	SKAU-A-9	Good	23.	SKAU-A-23	Good
10.	SKAU-A-10	Good	24.	SKAU-A-24	Good
11.	SKAU-A-11	Good	25.	SKAU-A-25	Poor
12.	SKAU-A-12	Very good	26.	SKAU-A-26	Poor
13.	SKAU-A-13	Very good	27.	SKAU-A-27	Good
14.	SKAU-A-14	Good			



Poor



Good



Very good

Plate 1: Morphological characterization for early plant vigour in various vegetable amaranth genotypes (*Amaranthus* spp.)

Table 2.2: Morphological characterization for plant growth habit in vegetable amaranth (*Amaranthus* spp.)

S. No	Genotypes	Plant growth habit	S. No	Genotypes	Plant growth habit
1.	SKAU-A-1	Erect	15.	SKAU-A-15	Erect
2.	SKAU-A-2	Erect	16.	SKAU-A-16	Erect
3.	SKAU-A-3	Erect	17.	SKAU-A-17	Spreading
4.	SKAU-A-4	Erect	18.	SKAU-A-18	Erect
5.	SKAU-A-5	Erect	19.	SKAU-A-19	Erect
6.	SKAU-A-6	Erect	20.	SKAU-A-20	Erect
7.	SKAU-A-7	Erect	21.	SKAU-A-21	Erect
8.	SKAU-A-8	Erect	22.	SKAU-A-22	Spreading
9.	SKAU-A-9	Erect	23.	SKAU-A-23	Erect
10.	SKAU-A-10	Erect	24.	SKAU-A-24	Erect
11.	SKAU-A-11	Erect	25.	SKAU-A-25	Erect
12.	SKAU-A-12	Erect	26.	SKAU-A-26	Erect
13.	SKAU-A-13	Erect	27.	SKAU-A-27	Erect
14.	SKAU-A-14	Erect			



Erect



Spreading

Plate-2: Morphological characterization for plant growth habit in various vegetable amaranth genotypes (*Amaranthus* spp.)

4.1.3 Leaf colour (LF_CLR)

Leaf colour showed a wide range of variation. SKAU-A-1, SKAU-A-3, SKAU-A-5, SKAU-A-8, SKAU-A-11, SKAU-A-12, SKAU-A-15, SKAU-A-19, SKAU-A-24, SKAU-A-26 and SKAU-A-27 had red coloured leaves, while as SKAU-A-2, SKAU-A-4, SKAU-A-6, SKAU-A-7, SKAU-A-9, SKAU-A-10, SKAU-A-13, SKAU-A-14, SKAU-A-17, SKAU-A-22 and SKAU-A-23 had green coloured leaves. SKAU-A-16 had yellowish green leaves while as SKAU-A-20 and SKAU-A-21 had pinkish green leaves. SKAU-A-25 and SKAU-A-18 had reddish green leaves.

4.1.4 Inflorescence colour (INFL_CLR)

Wide range of variation was existed inflorescence colour. SKAU-A-1, SKAU-A-3, SKAU-A-5, SKAU-A-8, SKAU-A-11, SKAU-A-12, SKAU-A-15, SKAU-A-19, SKAU-A-24, SKAU-A-26 and SKAU-A-27 had red coloured inflorescences while as SKAU-A-2, SKAU-A-4, SKAU-A-9, SKAU-A-10, SKAU-A-13, SKAU-A-14, SKAU-A-21, SKAU-A-23 and SKAU-A-25 had green inflorescences. SKAU-A-16, SKAU-A-20 and SKAU-A-18 had reddish green inflorescences. SKAU-A-6, SKAU-A-17 and SKAU-A-22 had yellowish green inflorescences. SKAU-A-7 had pink coloured inflorescence.

4.1.5 Inflorescence compactness (INFL_CPT)

Inflorescence compactness in most of the genotypes was intermediate, except SKAU-A-7, SKAU-A-16, SKAU-A-18 SKAU-A-19, SKAU-A-24 and SKAU-A-25 were dense.

4.1.6 Stem colour (STEM_CLR)

Wide range of variation was found among genotypes for stem colour. SKAU-A-1, SKAU-A-3, SKAU-A-5, SKAU-A-8, SKAU-A-11, SKAU-A-12, SKAU-A-15, SKAU-A-19, SKAU-A-24, SKAU-A-26 and SKAU-A-27 had red stem colours. SKAU-A-2, SKAU-A-4, SKAU-A-6, SKAU-A-7, SKAU-A-9, SKAU-A-10, SKAU-A-13, SKAU-A-14, SKAU-A-16 and SKAU-A-23 had yellowish green stem colours. SKAU-A-17, SKAU-A-20, SKAU-A-21 and SKAU-A-22 had pink stem colour. SKAU-A-18 and SKAU-A-25 had reddish green stem colours.

4.1.6 Stem colour (STEM_CLR)

Wide range of variation was found among genotypes for stem colour. SKAU-A-1, SKAU-A-3, SKAU-A-5, SKAU-A-8, SKAU-A-11, SKAU-A-12, SKAU-A-15, SKAU-A-19, SKAU-A-24, SKAU-A-26 and SKAU-A-27 had red stem colours. SKAU-A-2, SKAU-A-4, SKAU-A-6, SKAU-A-7, SKAU-A-9, SKAU-A-10, SKAU-A-13, SKAU-A-14, SKAU-A-16 and SKAU-A-23 had yellowish green stem colours. SKAU-A-17, SKAU-A-20, SKAU-A-21 and SKAU-A-22 had pink stem colour. SKAU-A-18 and SKAU-A-25 had reddish green stem colours.

4.1.7 Stem surface (STEM_SUR)

The genotypes SKAU-A-1, SKAU-A-2, SKAU-A-3, SKAU-A-4, SKAU-A-5, SKAU-A-6, SKAU-A-7, SKAU-A-9, SKAU-A-10, SKAU-A-15, SKAU-A-19, SKAU-A-21 and SKAU-A-23 had ridged stem surfaces. Rest of the genotypes had smooth stem surfaces.

4.1.8 Inflorescence shape (INFL_SHP)

Inflorescence shape of most genotypes was straight except SKAU-A-5, SKAU-A-11, SKAU-A-12, SKAU-A-16, SKAU-A-18, SKAU-A-19, SKAU-A-20, SKAU-A-23 and SKAU-A-24 which had semi- drooping inflorescence shape.

4.1.9 Inflorescence spininess (INFL_SPN)

Most of the genotypes had smooth inflorescences, i.e. without spines. However SKAU-A-2, SKAU-A-4, SKAU-A-9, SKAU-A-10, SKAU-A-22 and SKAU-A-23 had spiny inflorescences and SKAU-A-6, SKAU-A-7, SKAU-A-16 and SKAU-A-21 had prickly inflorescences.

4.1.10 Seed transparency (SED_TRN)

All the genotypes under study had opaque seeds.

4.1.11 Seed colour (SED_CLR)

Most of the genotypes had black coloured seeds, except SKAU-A-1, SKAU-A-7, SKAU-A-8, SKAU-A-12, SKAU-A-14, SKAU-A-15, SKAU-A-22 and SKAU-A-24 had brown coloured seeds.

Table 2.3: Morphological characterization for leaf colour in vegetable amaranth (*Amaranthus* spp.)

S. No	Genotypes	Leaf colour	S. No	Genotypes	Leaf colour
1.	SKAU-A-1	Red	15.	SKAU-A-15	Red
2.	SKAU-A-2	Green	16.	SKAU-A-16	Yellowish green
3.	SKAU-A-3	Red	17.	SKAU-A-17	Green
4.	SKAU-A-4	Green	18.	SKAU-A-18	Reddish green
5.	SKAU-A-5	Red	19.	SKAU-A-19	Red
6.	SKAU-A-6	Green	20.	SKAU-A-20	Pinkish green
7.	SKAU-A-7	Green	21.	SKAU-A-21	Pinkish green
8.	SKAU-A-8	Red	22.	SKAU-A-22	Green
9.	SKAU-A-9	Green	23.	SKAU-A-23	Green
10.	SKAU-A-10	Green	24.	SKAU-A-24	Red
11.	SKAU-A-11	Red	25.	SKAU-A-25	Reddish green
12.	SKAU-A-12	Red	26.	SKAU-A-26	Red
13.	SKAU-A-13	Green	27.	SKAU-A-27	Red
14.	SKAU-A-14	Green			



Pinkish green



Red



Green



Yellowish green



Reddish green

Plate-3: Morphological characterization for leaf colour in various vegetable amaranth genotypes (*Amaranthus* spp.)

Table 2.4: Morphological characterization for inflorescence colour in vegetable amaranth (*Amaranthus* spp.)

S. No	Genotypes	Inflorescence colour	S. No	Genotypes	Inflorescence colour
1.	SKAU-A-1	Red	15.	SKAU-A-15	Red
2.	SKAU-A-2	Green	16.	SKAU-A-16	Reddish green
3.	SKAU-A-3	Red	17.	SKAU-A-17	Yellowish green
4.	SKAU-A-4	Green	18.	SKAU-A-18	Reddish green
5.	SKAU-A-5	Red	19.	SKAU-A-19	Red
6.	SKAU-A-6	Yellowish green	20.	SKAU-A-20	Reddish green
7.	SKAU-A-7	Pink	21.	SKAU-A-21	Green
8.	SKAU-A-8	Red	22.	SKAU-A-22	Yellowish green
9.	SKAU-A-9	Green	23.	SKAU-A-23	Green
10.	SKAU-A-10	Green	24.	SKAU-A-24	Red
11.	SKAU-A-11	Red	25.	SKAU-A-25	Green
12.	SKAU-A-12	Red	26.	SKAU-A-26	Red
13.	SKAU-A-13	Green	27.	SKAU-A-27	Red
14.	SKAU-A-14	Green			



Green



Pink



Red



Reddish green



Yellowish green

Plate-4: Morphological characterization for inflorescence colour in various vegetable amaranth genotypes (*Amaranthus* spp.)

Table 2.5: Morphological characterization for inflorescence compactness in vegetable amaranth (*Amaranthus* spp.)

S. No.	Genotypes	Inflorescence compactness	S. No.	Genotypes	Inflorescence compactness
1.	SKAU-A-1	Intermediate	15.	SKAU-A-15	Intermediate
2.	SKAU-A-2	Intermediate	16.	SKAU-A-16	Dense
3.	SKAU-A-3	Intermediate	17.	SKAU-A-17	Intermediate
4.	SKAU-A-4	Intermediate	18.	SKAU-A-18	Dense
5.	SKAU-A-5	Intermediate	19.	SKAU-A-19	Dense
6.	SKAU-A-6	Intermediate	20.	SKAU-A-20	Intermediate
7.	SKAU-A-7	Dense	21.	SKAU-A-21	Intermediate
8.	SKAU-A-8	Intermediate	22.	SKAU-A-22	Intermediate
9.	SKAU-A-9	Intermediate	23.	SKAU-A-23	Intermediate
10.	SKAU-A-10	Intermediate	24.	SKAU-A-24	Dense
11.	SKAU-A-11	Intermediate	25.	SKAU-A-25	Dense
12.	SKAU-A-12	Intermediate	26.	SKAU-A-26	Intermediate
13.	SKAU-A-13	Intermediate	27.	SKAU-A-27	Intermediate
14.	SKAU-A-14	Intermediate			

Table 2.6: Morphological characterization for stem colour in vegetable amaranth (*Amaranthus* spp.)

S. No.	Genotypes	Stem color	S. No.	Genotypes	Stem color
1.	SKAU-A-1	Red	15.	SKAU-A-15	Red
2.	SKAU-A-2	Yellowish green	16.	SKAU-A-16	Yellowish green
3.	SKAU-A-3	Red	17.	SKAU-A-17	Pink
4.	SKAU-A-4	Yellowish green	18.	SKAU-A-18	Reddish green
5.	SKAU-A-5	Red	19.	SKAU-A-19	Red
6.	SKAU-A-6	Yellowish green	20.	SKAU-A-20	Pink
7.	SKAU-A-7	Yellowish green	21.	SKAU-A-21	Pink
8.	SKAU-A-8	Red	22.	SKAU-A-22	Pink
9.	SKAU-A-9	Yellowish green	23.	SKAU-A-23	Yellowish green
10.	SKAU-A-10	Yellowish green	24.	SKAU-A-24	Red
11.	SKAU-A-11	Red	25.	SKAU-A-25	Reddish green
12.	SKAU-A-12	Red	26.	SKAU-A-26	Red
13.	SKAU-A-13	Yellowish green	27.	SKAU-A-27	Red
14.	SKAU-A-14	Yellowish green			



Dense



Intermediate

Plate-5: Morphological characterization for inflorescence compactness in various vegetable amaranth genotypes (*Amaranthus* spp.)



Yellowish green



Pink



Red



Reddish green

Plate-6: Morphological characterization for stem colour in various vegetable amaranth genotypes (*Amaranthus* spp.)

Table 2.7: Morphological characterization for stem surface in vegetable amaranth (*Amaranthus* spp.)

S. No	Genotypes	Stem surface	S. No	Genotypes	Stem surface
1.	SKAU-A-1	Smooth	15.	SKAU-A-15	Ridged
2.	SKAU-A-2	Ridged	16.	SKAU-A-16	Smooth
3.	SKAU-A-3	Ridged	17.	SKAU-A-17	Smooth
4.	SKAU-A-4	Ridged	18.	SKAU-A-18	Smooth
5.	SKAU-A-5	Ridged	19.	SKAU-A-19	Ridged
6.	SKAU-A-6	Ridged	20.	SKAU-A-20	Smooth
7.	SKAU-A-7	Ridged	21.	SKAU-A-21	Ridged
8.	SKAU-A-8	Smooth	22.	SKAU-A-22	Smooth
9.	SKAU-A-9	Ridged	23.	SKAU-A-23	Ridged
10.	SKAU-A-10	Ridged	24.	SKAU-A-24	Smooth
11.	SKAU-A-11	Smooth	25.	SKAU-A-25	Smooth
12.	SKAU-A-12	Smooth	26.	SKAU-A-26	Smooth
13.	SKAU-A-13	Smooth	27.	SKAU-A-27	Smooth
14.	SKAU-A-14	Smooth			



Ridged



Smooth

Plate 7: Morphological characterization for stem surface in various vegetable amaranth genotypes (*Amaranthus* spp.)

Table 2.8: Morphological characterization for inflorescence shape in vegetable amaranth (*Amaranthus* spp.)

S. No	Genotypes	Inflorescence shape	S. No	Genotypes	Inflorescence shape
1.	SKAU-A-1	Straight	15.	SKAU-A-15	Straight
2.	SKAU-A-2	Straight	16.	SKAU-A-16	Semi drooping
3.	SKAU-A-3	Straight	17.	SKAU-A-17	Straight
4.	SKAU-A-4	Straight	18.	SKAU-A-18	Semi drooping
5.	SKAU-A-5	Semi drooping	19.	SKAU-A-19	Semi drooping
6.	SKAU-A-6	Straight	20.	SKAU-A-20	Semi drooping
7.	SKAU-A-7	Straight	21.	SKAU-A-21	Straight
8.	SKAU-A-8	Straight	22.	SKAU-A-22	Straight
9.	SKAU-A-9	Straight	23.	SKAU-A-23	Semi drooping
10.	SKAU-A-10	Straight	24.	SKAU-A-24	Semi drooping
11.	SKAU-A-11	Semi drooping	25.	SKAU-A-25	Straight
12.	SKAU-A-12	Semi drooping	26.	SKAU-A-26	Straight
13.	SKAU-A-13	Straight	27.	SKAU-A-27	Straight
14.	SKAU-A-14	Straight			



Semi drooping



Straight

Plate-8: Morphological characterization for Inflorescence shape in various vegetable amaranth genotypes (*Amaranthus* spp.)

Table 2.9: Morphological characterization for inflorescence spininess in vegetable amaranth (*Amaranthus* spp.)

S. No	Genotypes	Inflorescence spininess	S. No	Genotypes	Inflorescence spininess
1.	SKAU-A-1	Smooth	15.	SKAU-A-15	Smooth
2.	SKAU-A-2	Spiny	16.	SKAU-A-16	Prickly
3.	SKAU-A-3	Smooth	17.	SKAU-A-17	Smooth
4.	SKAU-A-4	Spiny	18.	SKAU-A-18	Smooth
5.	SKAU-A-5	Smooth	19.	SKAU-A-19	Smooth
6.	SKAU-A-6	Prickly	20.	SKAU-A-20	Smooth
7.	SKAU-A-7	Prickly	21.	SKAU-A-21	Prickly
8.	SKAU-A-8	Smooth	22.	SKAU-A-22	Spiny
9.	SKAU-A-9	Spiny	23.	SKAU-A-23	Spiny
10.	SKAU-A-10	Spiny	24.	SKAU-A-24	Smooth
11.	SKAU-A-11	Smooth	25.	SKAU-A-25	Smooth
12.	SKAU-A-12	Smooth	26.	SKAU-A-26	Smooth
13.	SKAU-A-13	Smooth	27.	SKAU-A-27	Smooth
14.	SKAU-A-14	Smooth			

Table 2.10: Morphological characterization for seed transparency in vegetable amaranth (*Amaranthus* spp.)

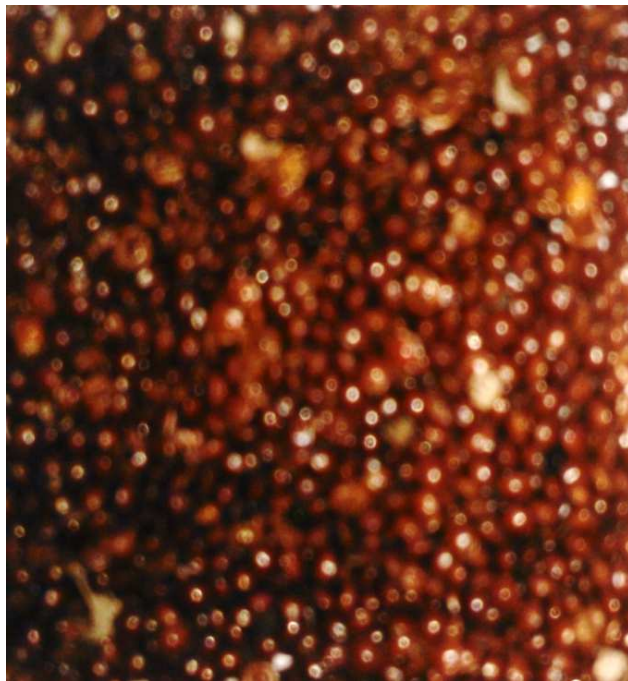
S. No	Genotypes	Seed transparency	S. No	Genotypes	Seed transparency
1.	SKAU-A-1	Opaque	15.	SKAU-A-15	Opaque
2.	SKAU-A-2	Opaque	16.	SKAU-A-16	Opaque
3.	SKAU-A-3	Opaque	17.	SKAU-A-17	Opaque
4.	SKAU-A-4	Opaque	18.	SKAU-A-18	Opaque
5.	SKAU-A-5	Opaque	19.	SKAU-A-19	Opaque
6.	SKAU-A-6	Opaque	20.	SKAU-A-20	Opaque
7.	SKAU-A-7	Opaque	21.	SKAU-A-21	Opaque
8.	SKAU-A-8	Opaque	22.	SKAU-A-22	Opaque
9.	SKAU-A-9	Opaque	23.	SKAU-A-23	Opaque
10.	SKAU-A-10	Opaque	24.	SKAU-A-24	Opaque
11.	SKAU-A-11	Opaque	25.	SKAU-A-25	Opaque
12.	SKAU-A-12	Opaque	26.	SKAU-A-26	Opaque
13.	SKAU-A-13	Opaque	27.	SKAU-A-27	Opaque
14.	SKAU-A-14	Opaque			

Table 2.11: Morphological characterization for seed colour in vegetable amaranth (*Amaranthus* spp.)

S. No	Genotypes	Seed colour	S. No	Genotypes	Seed colour
1.	SKAU-A-1	Brown	15.	SKAU-A-15	Brown
2.	SKAU-A-2	Black	16.	SKAU-A-16	Black
3.	SKAU-A-3	Black	17.	SKAU-A-17	Black
4.	SKAU-A-4	Black	18.	SKAU-A-18	Black
5.	SKAU-A-5	Black	19.	SKAU-A-19	Black
6.	SKAU-A-6	Black	20.	SKAU-A-20	Black
7.	SKAU-A-7	Brown	21.	SKAU-A-21	Black
8.	SKAU-A-8	Brown	22.	SKAU-A-22	Brown
9.	SKAU-A-9	Black	23.	SKAU-A-23	Black
10.	SKAU-A-10	Black	24.	SKAU-A-24	Brown
11.	SKAU-A-11	Black	25.	SKAU-A-25	Black
12.	SKAU-A-12	Brown	26.	SKAU-A-26	Black
13.	SKAU-A-13	Black	27.	SKAU-A-27	Black
14.	SKAU-A-14	Brown			



Black



Brown

Plate-9: Morphological characterization for seed colour in various vegetable amaranth genotypes (*Amaranthus* spp.)

4.2 Mean performance and Analysis of variance

Mean performance of the genotypes for each character is presented in Table-3. The perusal of Table-3 revealed following results:

4.2.1 Days to germination

Number of days to germination ranged from 12.00 to 23.00 days with an overall mean of 16.03. Least number of days to germination was recorded in SKAU-A-7 (12.00 days) and SKAU-A-22 (12.00 days) followed by SKAU-A-4, SKAU-A-11 and SKAU-A-19 (13.00 days each) while as highest number of days to germination was recorded in SKAU-A-27 (23.00 days) followed by SKAU-A-6 (22.00 days), SKAU-A-5, SKAU-A-26 (21.00 days) and SKAU-A-25 (20.00 days).

4.2.2 Plant height (cm)

The mean data and range indicated significant variation in plant height. Plant height ranged from 59.66 to 302.99 cm with an average of 108.65 cm. SKAU-A-7 was found to be the tallest with the height of 302.99cm followed by SKAU-A-14 (153.25 cm), SKAU-A-4 (141.17 cm), SKAU-A-22 (136.00 cm) and SKAU-A-10 (133.36 cm). SKAU-A-11 was found to be the shortest with a plant height of 59.66 cm followed by SKAU-A-6 (63.55 cm), SKAU-A-8 (67.47 cm), SKAU-A-1 (70.95 cm) and SKAU-A-2 (70.95 cm).

4.2.3 Stem thickness (mm)

Stem thickness ranged from 1.98 mm in SKAU-A-6 to 23.96 mm in SKAU-A-7 with an average of 12.51 mm. Least stem thickness was also recorded in SKAU-A-5 (2.25 mm), SKAU-A-3 (2.52 mm), SKAU-A-2 (2.61 mm) and SKAU-A-4 (4.81 mm) while as SKAU-A-18, SKAU-A-21, SKAU-A-24 and SKAU-A-20 recorded highest stem thickness values of 21.90 mm, 21.83 mm, 19.57 mm and 19.50 mm respectively.

Table 3: Mean performance of vegetable amaranth (*Amaranthus* spp.) genotypes with respect to different characters

S. No.	Genotypes	Days to germination	Plant height (cm)	Stem thickness (mm)	No. of branches plant ⁻¹	No. of leaves plant ⁻¹	Leaf length (cm)	Leaf area (cm ²)	Petiole length (cm)	Days to 50% flowering	Inflorescence length (cm)
1.	SKAU-A-1	15.00	70.95	12.58	9.46	72.60	9.26	23.92	4.82	26.33	15.46
2.	SKAU-A-2	14.00	70.95	2.61	13.53	147.58	10.17	31.85	3.48	29.00	32.97
3.	SKAU-A-3	19.00	90.64	2.52	7.20	109.33	8.79	21.10	4.85	30.44	4.06
4	SKAU-A-4	13.00	141.17	4.81	16.86	170.33	8.54	27.50	3.55	30.55	39.25
5.	SKAU-A-5	21.00	73.27	2.25	6.83	88.26	6.62	8.90	2.98	32.16	5.50
6.	SKAU-A-6	22.00	63.55	1.98	13.05	139.26	4.21	4.51	1.81	29.77	2.32
7.	SKAU-A-7	12.00	302.99	23.96	10.25	52.53	15.51	59.38	10.29	46.22	44.34
8.	SKAU-A-8	14.00	67.47	9.68	14.00	82.18	5.28	15.37	3.61	26.77	4.52
9.	SKAU-A-9	15.00	111.38	16.08	16.63	102.83	10.02	31.81	5.65	27.66	18.68
10.	SKAU-A-10	15.00	133.36	11.58	22.73	124.13	9.16	28.30	4.90	27.33	34.30
11.	SKAU-A-11	13.00	59.66	9.88	6.50	132.86	6.25	12.09	2.19	28.33	5.62
12.	SKAU-A-12	15.00	93.07	18.47	12.87	119.11	9.92	24.02	4.61	28.89	15.63
13	SKAU-A-13	17.00	124.94	15.01	16.16	81.00	9.53	22.95	4.01	33.83	20.25
14	SKAU-A-14	16.00	153.25	16.43	14.33	101.58	12.45	31.39	8.14	35.33	14.08
15.	SKAU-A-15	15.00	78.55	15.16	18.99	120.10	10.63	16.93	4.72	30.11	2.58
16.	SKAU-A-16	16.00	127.85	15.14	12.83	73.53	6.47	25.08	2.71	32.50	19.59
17.	SKAU-A-17	14.00	77.82	5.06	25.13	74.86	2.69	4.72	2.10	33.33	2.85
18.	SKAU-A-18	16.00	114.52	21.90	9.05	50.20	10.61	61.00	7.00	31.89	15.63
19.	SKAU-A-19	13.00	106.76	18.35	12.00	68.66	10.67	68.42	5.32	33.16	22.40
20.	SKAU-A-20	14.00	123.85	19.50	15.66	106.26	10.00	25.47	3.54	30.77	26.05
21.	SKAU-A-21	15.00	132.10	21.83	13.60	138.89	4.85	12.91	3.26	29.16	35.81
22.	SKAU-A-22	12.00	136.00	9.76	31.40	168.09	5.95	10.90	2.70	15.17	30.61
23.	SKAU-A-23	14.00	115.75	7.39	8.75	102.15	10.06	19.25	5.08	31.16	18.83
24.	SKAU-A-24	19.00	91.66	19.57	8.16	75.53	11.83	31.30	7.63	32.33	11.70
25.	SKAU-A-25	20.00	92.87	12.14	8.41	97.00	10.06	17.16	4.77	52.22	10.20
26	SKAU-A-26	21.00	76.95	10.98	9.16	84.73	6.95	8.72	2.46	26.33	7.13
27	SKAU-A-27	23.00	102.25	13.05	13.60	61.93	6.76	10.43	2.13	31.66	11.90
	Mean	16.03	108.65	12.51	13.60	101.69	8.64	24.27	4.38	31.20	17.49
	CV	6.21	2.49	4.49	6.57	3.27	3.84	3.56	7.22	3.05	6.60
	CD at 5%	1.63	4.44	0.92	1.46	5.44	0.54	1.41	0.51	1.56	1.89

Contd...

Table 3 contd...

S. No.	Genotypes	Lateral spikelet length (cm)	1000 seed weight (g)	Leaf yield plant ⁻¹ (g)	Leaf yield (q ha ⁻¹)	Dry matter content (%)	Ascorbic acid (mg/100g)	Total chlorophyll content (mg/g)	Anthocyanin content (mg/100g)	Fiber content (%)	Protein content (%)
1.	SKAU-A-1	4.60	1.25	13.89	23.15	8.20	59.93	2.30	0.56	8.41	1.97
2.	SKAU-A-2	8.64	1.03	19.78	32.95	8.72	65.05	4.30	0.03	8.51	0.86
3.	SKAU-A-3	1.91	0.87	18.97	31.61	9.16	50.47	3.05	0.59	7.59	1.08
4.	SKAU-A-4	30.14	1.23	29.72	49.52	8.06	50.93	3.95	0.01	8.67	0.87
5.	SKAU-A-5	3.26	0.90	16.39	27.30	10.16	63.97	3.25	0.57	8.01	1.02
6.	SKAU-A-6	1.41	1.24	17.71	29.50	7.41	54.27	4.39	0.04	7.97	0.92
7.	SKAU-A-7	7.50	1.56	53.82	89.68	10.30	78.39	3.85	0.12	9.10	0.70
8.	SKAU-A-8	2.47	0.90	18.26	30.43	8.91	58.98	2.63	0.56	9.35	1.03
9.	SKAU-A-9	11.65	1.14	19.72	32.86	8.14	72.96	3.75	0.01	9.50	0.72
10.	SKAU-A-10	17.41	1.31	24.18	40.28	8.16	54.38	3.87	0.03	9.11	0.74
11.	SKAU-A-11	0.45	1.20	26.57	44.27	9.86	49.33	2.54	0.57	7.16	1.02
12.	SKAU-A-12	4.00	1.24	21.92	36.5	9.94	63.06	2.44	0.39	7.59	1.01
13.	SKAU-A-13	5.18	1.28	17.29	28.80	9.86	67.63	4.53	0.09	6.97	1.03
14.	SKAU-A-14	3.45	1.22	28.95	48.24	9.21	75.31	3.73	0.07	6.60	0.26
15.	SKAU-A-15	1.92	1.06	19.68	32.79	9.25	130.70	2.16	0.58	7.42	0.76
16.	SKAU-A-16	6.75	0.79	24.96	41.60	9.73	63.00	3.33	0.24	6.80	0.94
17.	SKAU-A-17	2.73	0.72	6.44	10.73	8.94	52.35	3.82	0.08	8.46	0.98
18.	SKAU-A-18	4.20	0.87	20.36	33.93	9.96	70.00	4.71	0.52	7.43	1.26
19.	SKAU-A-19	5.27	1.25	17.55	29.25	7.22	72.00	2.24	0.51	8.28	1.97
20.	SKAU-A-20	7.79	1.21	27.40	45.66	7.79	72.53	4.15	0.28	8.50	0.95
21.	SKAU-A-21	10.86	1.31	49.32	82.19	9.28	46.86	4.41	0.22	9.05	0.86
22.	SKAU-A-22	7.16	0.78	22.10	36.83	8.15	39.37	4.42	0.13	9.38	0.92
23.	SKAU-A-23	4.73	0.91	13.54	22.56	7.92	57.80	4.73	0.06	8.74	0.79
24.	SKAU-A-24	5.11	1.63	21.41	35.67	8.11	85.03	3.09	0.56	7.60	1.85
25.	SKAU-A-25	1.16	0.96	16.69	27.81	8.79	78.72	4.12	0.18	7.42	0.67
26.	SKAU-A-26	1.76	0.91	14.24	23.72	10.00	54.53	2.34	0.44	8.19	1.04
27.	SKAU-A-27	3.86	1.23	10.54	17.56	9.94	41.89	2.04	0.45	8.73	1.02
	Mean	6.12	1.11	21.90	36.50	8.93	64.08	3.47	0.29	8.17	1.01
	CV	11.24	7.40	7.40	7.41	0.76	0.94	6.25	1.86	4.05	2.04
	CD at 5%	1.12	0.13	2.65	4.43	0.11	0.99	0.35	0.00	0.19	0.03

4.2.4 Number of branches plant⁻¹

The number of branches plant⁻¹ ranged from 6.50-31.40 with an overall mean of 13.60. The lowest number of branches plant⁻¹ was found in SKAU-A-11 (6.50) followed by SKAU-A-5 (6.83), SKAU-A-3 (7.20), SKAU-A-24 (8.16) and SKAU-A-25 (8.41) while as the highest number of branches plant⁻¹ were found in SKAU-A-22 (31.40) followed by SKAU-A-17 (25.13), SKAU-A-10 (22.73), SKAU-A-15 (18.99) and SKAU-A-4 (16.86).

4.2.5 Number of leaves plant⁻¹

Number of leaves plant⁻¹ ranged from 50.20-170.33 with an average of 101.69. SKAU-A-4 (170.33) recorded the maximum number of leaves plant⁻¹ followed by SKAU-A-22 (168.09), SKAU-A-2 (147.58), SKAU-A-6 (139.26) and SKAU-A-21 (138.89) while as SKAU-A-18 (50.20) recorded least number of leaves plant⁻¹ followed by SKAU-A-7 (52.53), SKAU-A-27 (61.93), SKAU-A-19 (68.66) and SKAU-A-1 (72.60) recorded the lowest number of leaves plant⁻¹.

4.2.6 Leaf length (cm)

Leaf length ranged from 2.69-15.51cm with an overall mean of 8.64 cm. The minimum leaf length was observed for SKAU-A-17 (2.69 cm) followed by SKAU-A-6 (4.21 cm), SKAU-A-21 (4.85), SKAU-A-8 (5.28 cm) and SKAU-A-22 (5.94 cm) while as the maximum leaf length was observed in SKAU-A-7 (15.50 cm), SKAU-A-14 (12.45 cm), SKAU-A-24 (11.83 cm), SKAU-A-19 (10.67 cm) and SKAU-A-15 (10.63 cm).

4.2.7 Leaf area (cm²)

Leaf area ranged from 4.51-68.42 cm² with an overall mean of 24.27 cm². The maximum leaf area was recorded in SKAU-A-19 (68.42 cm²) followed by SKAU-A-18 (61.00 cm²), SKAU-A-7 (59.38 cm²), SKAU-A-2 (31.85 cm²) and SKAU-A-9 (31.81 cm²) while as the minimum leaf area was recorded in SKAU-A-6 (4.51cm²), followed by SKAU-A-17 (4.72 cm²), SKAU-A-26 (8.72 cm²), SKAU-A-5 (8.90 cm²) and SKAU-A-27 (10.43cm²).

4.2.8 Petiole length (cm)

The petiole length of the genotypes ranged from 1.81-10.29 cm with an overall mean of 4.38 cm. The maximum petiole length was attained by SKAU-A-7 (10.29 cm) followed by SKAU-A-14 (8.14 cm), SKAU-A-24 (7.63 cm), SKAU-A-18 (7.00 cm) and SKAU-A-9 (5.65 cm). The genotypes with minimum petiole lengths were SKAU-A-6 (1.81 cm), SKAU-A-17 (2.10 cm), SKAU-A-27 (2.13 cm), SKAU-A-11 (2.19 cm) and SKAU-A-26 (2.46 cm).

4.2.9 Number of days to 50% flowering

Number of days taken to 50% flowering ranged between 15.17-52.22 days with an overall mean of 31.20. SKAU-A-25 (52.22) took the maximum days for 50% flowering followed by SKAU-A-7 (46.22), SKAU-A-14 (35.33), SKAU-A-13 (33.83) and SKAU-A-17 (33.33) while as the genotypes which took minimum days to 50% flowering were SKAU-A-22 (15.17), SKAU-A-1, SKAU-A-26 (26.33 each), SKAU-A-8 (26.77) and SKAU-A-10 (27.33).

4.2.10 Inflorescence length (cm)

Inflorescence length of genotypes ranged from 2.32-44.34 cm with an average of 17.49 cm. The maximum inflorescence length was recorded in SKAU-A-7 (44.34 cm) followed by SKAU-A-4 (39.25 cm), SKAU-A-21 (35.81 cm), SKAU-A-10 (34.30 cm) and SKAU-A-2 (32.97 cm). The minimum inflorescence length was recorded in SKAU-A-6 (2.32 cm) followed by SKAU-A-15 (2.58 cm), SKAU-A-17 (2.85 cm), SKAU-A-3 (4.06 cm) and SKAU-A-8 (4.52 cm).

4.2.11 Lateral spikelet length (cm)

Lateral spikelet length ranged 0.45 cm -30.14 cm with an overall mean of 6.12 cm. SKAU-A-4 attained the maximum lateral spikelet length of 30.14 cm followed by SKAU-A-10 (17.41 cm), SKAU-A-9 (11.65 cm), SKAU-A-21 (10.86 cm) and SKAU-A-2 (8.64 cm). Minimum lateral spikelet length was recorded in SKAU-A-11 (0.45 cm) followed by SKAU-A-25 (1.16 cm), SKAU-A-6 (1.41 cm), SKAU-A-26 (1.76 cm) and SKAU-A-3 (1.91 cm).

4.2.12 1000 seed weight (g)

1000-seed weight of genotypes ranged from 0.72-1.63 g with an overall mean of 1.11g. Highest 1000 seed weight was observed in SKAU-A-24 (1.63 g) followed by SKAU-A-7 (1.56 g), SKAU-A-10 (1.21 g), SKAU-A-21 (1.31 g), and SKAU-A-13 (1.28 g). Lowest 1000 seed weight was observed in SKAU-A-17 (0.72 g) followed by SKAU-A-22 (0.78g), SKAU-A-16 (0.79 g), SKAU-A-3 (0.87 g) and SKAU-A-18 (0.87 g).

4.2.13 Leaf yield plant⁻¹ (g)

Leaf yield plant⁻¹ ranged from 6.44 to 53.82 g with an average of 21.90g. Highest yield plant⁻¹ was recorded in SKAU-A-7 (53.82 g) followed by SKAU-A-21 (49.32 g), SKAU-A-4 (29.72 g), SKAU-A-14 (28.95 g) and SKAU-A-20 (27.40 g). The lowest yield plant⁻¹ was recorded in SKAU-A-17 (6.44 g) followed by SKAU-A-27 (10.54 g), SKAU-A-23 (13.54 g), SKAU-A-1 (13.89 g) and SKAU-A-26 (14.24 g).

4.2.14 Leaf yield ha⁻¹ (q)

Leaf yield ha⁻¹ ranged from 10.73 q to 89.68 q with an average of 36.50 q. The maximum yield ha⁻¹ was recorded in SKAU-A-7 (89.68 q) followed by SKAU-A-21 (82.19 q), SKAU-A-4 (49.52 q), SKAU-A-14 (48.24 q) and SKAU-A-20 (45.66 q). The lowest leaf yield ha⁻¹ was recorded in SKAU-A-17 (10.73 q) followed by SKAU-A-27 (17.56 q), SKAU-A-23 (22.56 q), SKAU-A-1 (23.15 q) and SKAU-A-26 (23.72 q).

4.2.15 Dry matter content (per cent)

Dry matter content of the genotypes ranged from 7.22-10.30 per cent with an overall mean of 8.93 per cent. The maximum dry matter content was recorded in SKAU-A-7 (10.30 per cent) followed by SKAU-A-5 (10.16 per cent), SKAU-A-26 (10.00 per cent), SKAU-A-18 (9.96 per cent), SKAU-A-12 (9.94 per cent) and SKAU-A-27 (9.94 per cent). Minimum dry matter content was recorded in SKAU-

A-19 (7.22 per cent) followed by SKAU-A-6 (7.41 per cent), SKAU-A-20 (7.79 per cent), SKAU-A-23 (7.92 per cent) and SKAU-A-4 (8.06 per cent).

4.2.16 Ascorbic acid content (mg/100g)

Ascorbic acid content ranged from 39.37 to 130.70 (mg/100g) with an overall mean of 64.08 mg/100g. The highest Ascorbic acid content was recorded in SKAU-A-15 (130.70 mg/100g) followed by SKAU-A-24 (85.03 mg/100g), SKAU-A-25 (78.72 mg/100g), SKAU-A-7 (78.39 mg/100g) and SKAU-A-14 (75.31 mg/100g). The lowest Ascorbic acid content was recorded in SKAU-A-22 (39.37 mg/100g) followed by SKAU-A-27 (41.89 mg/100g), SKAU-A-21 (46.86 mg/100g), SKAU-A-11 (49.33 mg/100g), SKAU-A-3 (50.47mg/100g).

4.2.17 Total chlorophyll content (mg/g)

Total chlorophyll content ranged from 2.04 to 4.73 mg/g with an overall mean of 3.47 mg/g. The highest total chlorophyll content was recorded in SKAU-A-23 (4.73 mg/g) followed by SKAU-A-18 (4.71mg/g), SKAU-A-13 (4.53 mg/g), SKAU-A-22 (4.42 mg/g) and SKAU-A-21 (4.41 mg/g). The lowest total chlorophyll content was recorded in SKAU-A-27 (2.04 mg/g) followed by SKAU-A-15 (2.16 mg/g), SKAU-A-19 (2.24 mg/g), SKAU-A-1 (2.30 mg/g) and SKAU-A-26 (2.34 mg/g).

4.2.18 Anthocyanin content (mg/100g)

Anthocyanin content ranged from 0.01 to 0.59 mg/100g with an overall mean of 0.29 mg/100g. The highest anthocyanin content was recorded in SKAU-A-3 (0.59 mg/100g) followed by SKAU-A-15 (0.58 mg/100g), SKAU-A-5 (0.57 mg/100g), SKAU-A-11 (0.57 mg/100g), SKAU-A-1 (0.56 mg/100g), SKAU-A-8(0.56 mg/100g). and SKAU-A-24 (0.56 mg/100g). The lowest anthocyanin content was recorded in SKAU-A-4(0.01 mg/100g) and SKAU-A-9 (0.01 mg/100g) followed by SKAU-A-2(0.03 mg/100g), SKAU-A-10 (0.03 mg/100g), SKAU-A-6 (0.04 mg/100g) and SKAU-A-23 (0.06 mg/100g).

4.2.19 Fiber content (per cent)

Fiber content of the genotypes ranged from 6.60 per cent to 9.50 per cent with an overall mean of 8.17 per cent. Highest fiber content was recorded in SKAU-A-9 (9.50 per cent) followed by SKAU-A-22 (9.38 per cent), SKAU-A-8 (9.35 per cent), SKAU-A-10 (9.11 per cent) and SKAU-A-7 (9.10 per cent). Lowest fiber content was recorded in SKAU-A-14 (6.60 per cent) followed by SKAU-A-16 (6.80 per cent), SKAU-A-13 (6.97 per cent), SKAU-A-11 (7.16 per cent), SKAU-A-25 (7.42 per cent) and SKAU-A-15 (7.42 per cent).

4.2.20 Protein content (per cent)

Protein content of the genotypes ranged from 0.26 per cent to 1.97 per cent with an overall mean of 1.01 per cent. Highest protein content was recorded in SKAU-A-1 and SKAU-A-19 (1.97 per cent each) followed by SKAU-A-24 (1.85 per cent), SKAU-A-18 (1.26 per cent), SKAU-A-3 (1.08 per cent) and SKAU-A-26 (1.04 per cent). Lowest protein content was recorded in SKAU-A-14 (0.26 per cent) followed by SKAU-A-25 (0.67 per cent), SKAU-A-7 (0.70 per cent), SKAU-A-9 (0.72 per cent) and SKAU-A-10 (0.74 per cent).

4.3 Variability and genetic components of variation

Analysis of variance as presented in Table-4 revealed highly significant differences among all the genotypes under study for all traits thereby indicating a good amount of variability in the present material. The genetic variability estimates including range, genotypic variance (GV), phenotypic variance (PV), environmental variance, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), environmental coefficient of variation, heritability (bs) and genetic advance as a per cent of mean were estimated for each growth and quality character and are presented in Table-5.

The perusal of Table-5 revealed that the range was high for almost all the traits under study indicating that wide variation existed in the population. However, low range was observed for days to germination, 1000 seed weight, dry matter content, total chlorophyll content and fiber content.

Table-4: Analysis of Variance with respect to MSS for various characters in vegetable amaranth (*Amaranthus* spp.)

S. No.	Source of variation	d.f.	Mean sum of squares									
			Days to germination	Plant height (cm)	Stem thickness (mm)	No. of branches per plant	No. of leaves per plant	Leaf length (cm)	Leaf area (cm ²)	Petiole length (cm)	Days to 50% flowering	Inflorescence length (cm)
1.	Replication	2	1.14	10.61	0.25	2.96	6.80	0.09	0.75	0.05	0.4	1.42
2.	Genotypes	26	29.41*	6682.44*	127.37*	101.97*	3265.62*	23.75*	795.42*	12.40*	124.93*	448.21*
3.	Error	52	0.99	7.36	0.31	0.800	11.05	0.11	0.74	0.10	0.90	1.33

*Significant at 5%

Cont...

Table 4 Contd.....

S. No.	Source of variation	d.f.	Mean sum of squares									
			Lateral spikelet length (cm)	1000 seed weight (g)	Leaf yield per plant (g)	Leaf yield (q ha ⁻¹)	Dry matter content (%)	Ascorbic acid content (mg/100g)	Total chlorophyll content (mg/g)	Anthocyanin content (mg/100g)	Fiber content (%)	Protein content (%)
1.	Replication	2	0.01	0.01	1.34	3.68	0.00	0.96	0.18	0.00	0.12	0.00
2.	Genotypes	27	111.19*	0.16*	307.22*	853.32*	2.51*	943.01*	2.28*	0.15*	2.06*	0.43*
3.	Error	52	0.47	0.00	2.63	7.32	0.00	0.36	0.04	0.00	0.10	0.00

*Significant at 5%

The genotypic variances were higher in magnitude as compared to corresponding environmental variances for all the characters, indicating that most of the variance observed was due to the genotype i.e., genetic in nature and the influence of environment was very less.

A close correspondence between the estimates of genotypic and phenotypic coefficients of variations was observed. Environmental coefficients of variation (ECV) were less than genotypic coefficients of variation (GCV) for all the characters indicating that variation was mainly due to genotype.

Phenotypic coefficients of variation (PCV) were found to be higher than corresponding genotypic coefficients of variation (GCV) for all the characters. The highest PCV was observed for lateral spikelet length (99.78) followed by anthocyanin content (75.71), inflorescence length (70.08), leaf area (67.13) and stem thickness (52.22). Lowest estimate of PCV was obtained in case of dry matter content (10.25) followed by fiber content (10.68), days to germination (20.17), days to 50% flowering (20.83) and 1000 seed weight (21.61). GCV also showed the same trend. Highest GCV was observed for lateral spikelet length (99.14) followed by anthocyanin content (75.68), inflorescence length (69.77), leaf area (67.04) and stem thickness (52.03). Fiber content recorded lowest GCV (9.89) followed by dry matter content (10.22), days to germination (19.19), days to 50% flowering (20.60) and 1000 seed weight (20.30). Highest ECV was recorded in lateral spikelet length (11.24) followed by leaf yield (7.41), 1000 seed weight (7.40), leaf yield plant⁻¹ (7.40) and petiole length (7.22). Lowest ECV was recorded in dry matter content (0.99) followed by ascorbic acid content (0.94), anthocyanin content (1.86) and protein content (2.04). ECV for inflorescence length, leaf area and stem thickness was observed to be 1.86, 6.60, 3.56 and 4.49 respectively.

Heritability in broad sense was found to be high for all the characters under study. Its value ranged from 85% in fiber content to as high as 99% in plant height, stem thickness, number of leaves per plant, leaf area, inflorescence length,

Table-5: Estimates of range, environmental variance, phenotypic variance, genotypic variance, environmental, phenotypic and genotypic coefficients of variation, heritability (bs) and genetic advance (as% of mean) for different characters in vegetable amaranth (*Amaranthus* spp.)

S. No.	Parameters	Range	Environmental variance (EV)	Phenotypic variance (PV)	Genotypic variance (GV)	Environmental coefficient of variation (ECV)	Phenotypic coefficient of variation (PCV)	Genotypic coefficient of variation (GCV)	Heritability (bs)	Genetic advance (as% of mean)
1.	Days to germination	12.00-23.00	0.99	10.46	9.475	6.21	20.17	19.19	0.90	37.61
2.	Plant height (cm)	59.66-302.99	7.36	2232.38	2225.02	2.49	43.48	43.41	0.99	89.28
3.	Stem thickness (mm)	1.98-23.96	0.31	42.67	42.35	4.49	52.22	52.03	0.99	106.78
4.	No. of branches plant ⁻¹	6.50-31.40	0.80	34.52	33.72	6.57	43.19	42.69	0.97	86.92
5.	No. of leaves plant ⁻¹	50.20-170.33	11.05	1095.91	1084.85	3.27	32.55	32.39	0.99	66.38
6.	Leaf length (cm)	2.69-15.51	0.11	7.99	7.88	3.84	32.71	32.48	0.98	66.45
7.	Leaf area (cm ²)	4.51-68.42	0.74	265.63	264.89	3.56	67.13	67.04	0.99	137.91
8.	Petiole length (cm)	1.81-10.29	0.10	4.20	4.10	7.22	46.76	46.19	0.97	94.02
9.	Days to 50% flowering	15.16-52.22	0.90	42.25	41.34	3.05	20.83	20.60	0.97	41.99
10.	Inflorescence length (cm)	2.32-44.34	1.33	150.29	148.96	6.60	70.08	69.77	0.99	143.09
11.	Lateral spikelet length (cm)	0.45-30.14	0.47	37.38	36.90	11.24	99.78	99.14	0.98	202.93
12.	1000 seed weight (g)	0.72-1.63	0.00	0.05	0.05	7.40	21.61	20.30	0.88	39.29
13.	Leaf yield plant ⁻¹ (g)	6.44-53.82	2.63	104.16	101.53	7.40	46.58	45.99	0.97	93.54
14.	Leaf yield (q ha ⁻¹)	10.73-89.68	7.32	289.32	282.00	7.41	46.60	46.00	0.97	93.57

Table 5 contd...

S. No.	Parameters	Range	Environmental variance (EV)	Phenotypic variance (PV)	Genotypic variance (GV)	Environmental coefficient of variation (ECV)	Phenotypic coefficient of variation (PCV)	Genotypic coefficient of variation (GCV)	Heritability (bs)	Genetic advance (as% of mean)
1.	Dry matter content (%)	7.22-10.30	0.00	0.84	0.835	0.77	10.25	10.22	0.99	21.01
2.	Ascorbic acid content (mg/100g)	39.37-130.70	0.36	314.58	314.21	0.94	27.65	27.65	0.99	56.94
3.	Total chlorophyll content (mg/g)	2.04-4.73	0.04	0.79	0.74	6.25	25.58	24.81	0.94	49.55
4.	Anthocyanin content (mg/100g)	0.01-0.59	0.00	0.05	0.05	1.86	75.71	75.68	0.99	155.86
5.	Fiber content (%)	6.60-9.50	0.11	0.76	0.65	4.05	10.68	9.89	0.85	18.85
6.	Protein content (%)	0.26-1.97	0.00	0.14	0.14	2.04	37.52	37.47	0.99	77.07

dry matter content, ascorbic acid content, anthocyanin content and protein content. Other characters also recorded high heritability viz. leaf length (98%), lateral spikelet length (98%), number of branches per plant (97%), petiole length (97%) days to flowering (97%), leaf yield per plant (97%), yield per hectare (97%), total chlorophyll content (94%), days to germination (90%), 1000 seed weight (88%) and fiber content (85%).

Highest genetic advance as percentage of mean was recorded in lateral spikelet length (202.93) followed by anthocyanin content (155.86), inflorescence length (143.09), and leaf area (137.91) and stem thickness (106.78). Lowest genetic advance as percentage of mean was recorded in fiber content (18.85) followed by dry matter content (21.01), days to germination (37.61), 1000 seed weight (39.29) and days to 50% flowering (41.99). A careful study of results indicates that genotypic coefficients of variation and genetic advance as percentage of mean show a similar trend. Both GCV and genetic advance as percentage of mean are lowest for fiber content and highest for lateral spikelet length and almost complete correspondence was observed between the two parameters for most of the characters although heritability was high in all cases and showed a different trend.

4.4 Correlation coefficient

The correlation coefficients were determined using variances and co variances to obtain relationship among various characters and their relationship with leaf yield plant⁻¹, at both genotypic and phenotypic levels. The genotypic (r_g) and phenotypic (r_p) correlation coefficients among various characters are presented in Table-6.

4.4.1 Days to germination

Days to germination was negatively and significantly correlated with plant height ($r_g = -0.37$, $r_p = -0.35$), stem thickness ($r_g = -0.25$, $r_p = -0.24$), number of

Table-6: Estimates of genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients among different characters in vegetable amaranth (*Amaranthus* spp.)

Parameters	Days to germination	Plant height	Stem thickness	No of branches plant ⁻¹	No of leaves plant ⁻¹	Leaf length	Leaf area	Petiole length	Days to 50% flowering	Inflorescence length	Lateral spikelet length	1000 seed weight	Leaf yield plant ⁻¹	Leaf yield hectare ⁻¹	Dry matter content	Ascorbic acid content	Total chlorophyll content	Anthocyanin content	Fiber content	Protein content
Days to germination	1.00	-0.37**	-0.25*	-0.39**	-0.24*	-0.21	-0.40**	-0.24*	0.19	-0.55**	-0.37**	-0.03	-0.40**	-0.40**	0.22	-0.06	-0.17	0.24*	-0.31*	0.03
Plant height	-0.35**	1.00	0.51**	0.12	-0.16	0.55**	0.52**	0.63**	0.37**	0.71**	0.35**	0.39**	0.74**	0.74**	0.18	0.09	0.34**	-0.41**	0.21	-0.31**
Stem thickness	-0.24*	0.49**	1.00	-0.06	-0.42**	0.52**	0.56*	0.58**	0.24*	0.33**	-0.01	0.50**	0.52**	0.52**	0.18	0.38**	-0.03	0.12	-0.07	0.13
No of branches plant ⁻¹	-0.37**	0.10	-0.05	1.00	0.39**	-0.28*	-0.19	-0.24*	-0.42**	0.27*	0.33**	-0.19	0.50**	0.50**	-0.28*	-0.11	0.24*	-0.48**	0.40**	-0.27*
No of leaves plant ⁻¹	-0.23*	-0.14	-0.40**	0.38**	1.00	-0.26*	-0.38**	-0.38**	-0.43**	0.26*	0.44**	-0.04	0.27**	0.27**	-0.34**	-0.22*	0.26*	-0.38**	0.19	-0.36**
Leaf length	-0.20	0.54**	0.51**	-0.27*	-0.23*	1.00	0.73***	0.87**	0.44**	0.37**	0.12	0.51**	0.33**	0.33**	0.01	0.58**	0.02	-0.02	-0.16	-0.00
Leaf area	-0.37**	0.50**	0.54**	-0.18	-0.37**	0.72***	1.00	0.73**	0.32**	0.46**	0.21	0.35**	0.34**	0.34**	-0.07	0.32**	0.06	0.02	-0.02	0.27*
Petiole length	-0.22*	0.60**	0.57**	-0.23*	-0.36**	0.86**	0.72**	1.00	0.45**	0.30**	0.04	0.49**	0.43**	0.43**	0.05	0.49**	0.11	-0.02	-0.08	0.00
Days to 50% flowering	0.17	0.35**	0.23*	-0.40**	-0.40**	0.43**	0.30**	0.44**	1.00	0.01	-0.14	0.22	0.21	0.21	0.22*	0.37**	0.13	-0.12	-0.33**	-0.19
Inflorescence length	-0.52**	0.70**	0.31**	0.25*	0.24*	0.36**	0.45**	0.29**	0.01	1.00	0.73***	0.39**	0.66**	0.66**	-0.14	-0.17	0.43**	-0.53**	0.45**	-0.14
Lateral spikelet length	-0.36**	0.34**	-0.00	0.31**	0.40**	0.10	0.20	0.03	-0.13	0.72***	1.00	0.26**	0.36**	0.36**	-0.31**	-0.18	0.30**	-0.49**	0.42**	-0.14
1000 seed weight	-0.03	0.37**	0.46**	-0.17	-0.03	0.48**	0.32**	0.44**	0.20	0.36**	0.25**	1.00	0.51**	0.51**	-0.12	0.20	-0.10	-0.04	0.04	0.20
Leaf yield plant ⁻¹	-0.37**	0.73**	0.50**	0.45**	0.26**	0.32**	0.33**	0.42**	0.20	0.64**	0.35**	0.47**	1.00	1.00**	0.18	0.06	0.26*	-0.21	0.15	-0.29**
Leaf yield ha ⁻¹	-0.37**	0.73**	0.50**	0.45**	0.26**	0.32**	0.33**	0.42**	0.20	0.64**	0.35**	0.47**	1.00**	1.00	0.18	0.06	0.26*	-0.21	0.15	-0.29**
Dry matter content	0.20	0.17	0.16	-0.27*	-0.32**	0.01	-0.06	0.04	0.21*	-0.12	-0.30**	-0.11	0.16	0.16	1.00	0.02	-0.21	0.29**	-0.36**	-0.26*
Ascorbic acid content	-0.06	0.07	0.36**	-0.10	-0.20*	0.57**	0.31**	0.48**	0.36**	-0.15	-0.16	0.19	0.05	0.05	0.02	1.00	-0.16	0.19	-0.35**	-0.02
Total chlorophyll	-0.15	0.33**	-0.01	0.23*	0.25*	0.02	0.06	0.10	0.12	0.41**	0.29**	-0.08	0.25*	0.25*	-0.20	-0.15	1.00	-0.71**	0.12	-0.41**
Anthocyanin content	0.22*	-0.40**	0.11	-0.47**	-0.37**	-0.02	0.02	-0.02	-0.11	-0.51**	-0.47**	-0.04	-0.20	-0.20	0.28**	0.18	-0.69**	1.00	-0.26*	0.58**
Fiber content	-0.27*	0.20	-0.06	0.36**	0.17	-0.15	-0.01	-0.07	-0.30**	0.42**	0.39**	0.03	0.13	0.13	-0.33**	-0.32**	0.11	-0.24*	1.00	-0.01
Protein content	0.03	-0.30**	0.11	-0.25*	-0.33**	-0.00	0.25*	0.00	-0.18	-0.12	-0.13	0.19	-0.26**	-0.26**	-0.25*	-0.02	-0.40**	0.56**	-0.00	1.00

*, ** = Significant at 5% and 1% respectively

branches plant⁻¹ ($r_g = -0.39$, $r_p = -0.37$), number of leaves plant⁻¹ ($r_g = -0.24$, $r_p = -0.23$), leaf area ($r_g = -0.40$, $r_p = -0.37$), petiole length ($r_g = -0.24$, $r_p = -0.22$), inflorescence length ($r_g = -0.55$, $r_p = -0.52$), lateral spikelet length ($r_g = -0.37$, $r_p = -0.36$), leaf yield plant⁻¹ ($r_g = -0.40$, $r_p = -0.37$), leaf yield ha⁻¹ ($r_g = -0.40$, $r_p = -0.37$) and fiber content ($r_g = -0.31$, $r_p = -0.27$). However days to germination showed significant positive correlation with anthocyanin content ($r_g = 0.24$, $r_p = 0.22$). It also showed non-significant negative correlation with leaf length ($r_g = -0.21$, $r_p = -0.20$), 1000 seed weight ($r_g = -0.03$, $r_p = -0.03$), ascorbic acid content ($r_g = -0.06$, $r_p = -0.06$), total chlorophyll content ($r_g = -0.17$, $r_p = -0.15$) and non-significant positive correlation with days to 50% flowering ($r_g = 0.19$, $r_p = 0.17$), dry matter content ($r_g = 0.22$, $r_p = 0.20$) and protein content ($r_g = 0.03$, $r_p = 0.03$).

4.4.2 Plant height

Plant height exhibited significant and positive correlation with stem thickness ($r_g = 0.51$, $r_p = 0.49$), leaf length ($r_g = 0.55$, $r_p = 0.54$), leaf area ($r_g = 0.52$, $r_p = 0.50$), petiole length ($r_g = 0.63$, $r_p = 0.60$), days to 50% flowering ($r_g = 0.37$, $r_p = 0.35$), inflorescence length ($r_g = 0.71$, $r_p = 0.70$), lateral spikelet length ($r_g = 0.35$, $r_p = 0.34$), 1000 seed weight ($r_g = 0.39$, $r_p = 0.37$), leaf yield plant⁻¹ ($r_g = 0.74$, $r_p = 0.73$), leaf yield per ha⁻¹ ($r_g = 0.74$, $r_p = 0.73$) and total chlorophyll content ($r_g = 0.34$, $r_p = 0.33$) while it exhibited significant and negative correlation with days to germination ($r_g = -0.37$, $r_p = -0.35$), anthocyanin content ($r_g = -0.41$, $r_p = -0.40$) and protein content ($r_g = -0.31$, $r_p = -0.30$). Plant height exhibited a non-significant positive correlation with number of branches plant⁻¹ ($r_g = 0.12$, $r_p = 0.10$), dry matter content ($r_g = 0.18$, $r_p = 0.17$), ascorbic acid content ($r_g = 0.09$, $r_p = 0.07$) and fiber content ($r_g = 0.21$, $r_p = 0.20$) and negative and non-significant correlation with number of leaves plant⁻¹ ($r_g = -0.16$, $r_p = -0.14$).

4.4.3 Stem thickness

Stem thickness showed significant and positive correlation with plant height ($r_g = 0.51$, $r_p = 0.49$), leaf length ($r_g = 0.52$, $r_p = 0.51$), leaf area ($r_g = 0.56$, $r_p =$

0.54), petiole length ($r_g = 0.58$, $r_p = 0.57$) days to 50% flowering ($r_g = 0.24$, $r_p = 0.23$), inflorescence length ($r_g = 0.33$, $r_p = 0.31$), 1000 seed weight ($r_g = 0.50$, $r_p = 0.46$), leaf yield plant⁻¹ ($r_g = 0.52$, $r_p = 0.50$), leaf yield ha⁻¹ ($r_g = 0.52$, $r_p = 0.50$) and Ascorbic acid content ($r_g = 0.38$, $r_p = 0.36$) and negative and significant correlation with days to germination ($r_g = -0.25$, $r_p = -0.24$) and number of leaves plant⁻¹ ($r_g = -0.42$, $r_p = -0.40$). Non-significant and positive correlation was recorded between stem thickness and dry matter content ($r_g = 0.18$, $r_p = 0.16$), anthocyanin content ($r_g = 0.12$, $r_p = 0.11$), protein content ($r_g = 0.13$, $r_p = 0.11$) while as negative and non-significant correlation was recorded with number of branches plant⁻¹ ($r_g = -0.06$, $r_p = -0.05$), lateral spikelet length ($r_g = -0.01$, $r_p = -0.00$), total chlorophyll content ($r_g = -0.03$, $r_p = -0.01$) and fiber content ($r_g = -0.07$, $r_p = -0.06$).

4.4.4 Number of branches plant⁻¹

Number of branches plant⁻¹ was positively and significantly correlated with number of leaves plant⁻¹ ($r_g = 0.39$, $r_p = 0.38$), inflorescence length ($r_g = 0.27$, $r_p = 0.25$), lateral spikelet length ($r_g = 0.33$, $r_p = 0.31$), leaf yield plant⁻¹ ($r_g = 0.50$, $r_p = 0.45$), leaf yield ha⁻¹ ($r_g = 0.50$, $r_p = 0.45$), total chlorophyll content ($r_g = 0.24$, $r_p = 0.23$) and fiber content ($r_g = 0.40$, $r_p = 0.36$) while it showed positive and non-significant correlation with plant height ($r_g = 0.12$, $r_p = 0.10$). A significant negative correlation was recorded between number of branches plant⁻¹ and days to germination ($r_g = -0.39$, $r_p = -0.37$), leaf length ($r_g = -0.28$, $r_p = -0.27$), petiole length ($r_g = -0.24$, $r_p = -0.23$), days to 50% flowering ($r_g = -0.42$, $r_p = -0.40$), dry matter content ($r_g = -0.28$, $r_p = -0.27$), anthocyanin content ($r_g = -0.48$, $r_p = -0.47$) and protein content ($r_g = -0.27$, $r_p = -0.25$) while it showed negative and non-significant association with stem thickness ($r_g = -0.06$, $r_p = -0.05$), leaf area ($r_g = -0.19$, $r_p = -0.18$), 1000 seed weight ($r_g = -0.19$, $r_p = -0.17$) and ascorbic acid content ($r_g = -0.11$, $r_p = -0.10$).

4.4.5 Number of leaves plant⁻¹

Number of leaves plant⁻¹ was positively and significantly correlated with

number of branches plant⁻¹ ($r_g = 0.39$, $r_p = 0.38$), inflorescence length ($r_g = 0.26$, $r_p = 0.24$), lateral spikelet length ($r_g = 0.44$, $r_p = 0.40$), leaf yield plant⁻¹ ($r_g = 0.27$, $r_p = 0.26$), leaf yield ha⁻¹ ($r_g = 0.27$, $r_p = 0.26$) and total chlorophyll content ($r_g = 0.26$, $r_p = 0.23$) and positive and non-significant correlation with fiber content ($r_g = 0.19$, $r_p = 0.17$). A significant negative correlation of number of leaves plant⁻¹ with days to germination ($r_g = -0.24$, $r_p = -0.23$), stem thickness ($r_g = -0.42$, $r_p = -0.40$), leaf length ($r_g = -0.26$, $r_p = -0.23$), leaf area ($r_g = -0.38$, $r_p = -0.37$), petiole length ($r_g = -0.38$, $r_p = -0.36$), days to flowering ($r_g = -0.43$, $r_p = -0.40$), dry matter content ($r_g = -0.34$, $r_p = -0.32$), ascorbic acid content ($r_g = -0.22$, $r_p = -0.20$), anthocyanin content ($r_g = -0.38$, $r_p = -0.37$) and protein content ($r_g = -0.36$, $r_p = -0.33$) was recorded, while it showed negative and non-significant association plant height ($r_g = -0.16$, $r_p = -0.14$) and 1000 seed weight ($r_g = -0.04$, $r_p = -0.03$).

4.4.6 Leaf length

Leaf length was positively and significantly correlated with plant height ($r_g = 0.55$, $r_p = 0.54$), stem thickness ($r_g = 0.52$, $r_p = 0.51$), leaf area ($r_g = 0.73$, $r_p = 0.72$), petiole length ($r_g = 0.87$, $r_p = 0.86$), days to 50% flowering ($r_g = 0.44$, $r_p = 0.43$), inflorescence length ($r_g = 0.37$, $r_p = 0.36$), 1000 seed weight ($r_g = 0.51$, $r_p = 0.48$), leaf yield plant⁻¹ ($r_g = 0.33$, $r_p = 0.32$), leaf yield ha⁻¹ ($r_g = 0.33$, $r_p = 0.32$) and ascorbic acid content ($r_g = 0.58$, $r_p = 0.57$) while as it showed positive and non-significant correlation with lateral spikelet length ($r_g = 0.12$, $r_p = 0.10$), dry matter content ($r_g = 0.01$, $r_p = 0.01$) and total chlorophyll content ($r_g = 0.02$, $r_p = 0.02$). Leaf length also exhibited significant negative correlation with number of branches plant⁻¹ ($r_g = -0.28$, $r_p = -0.27$) and number of leaves plant⁻¹ ($r_g = -0.26$, $r_p = -0.23$) and non-significant negative correlation with days to germination ($r_g = -0.21$, $r_p = -0.20$), anthocyanin content ($r_g = -0.02$, $r_p = -0.02$), fiber content ($r_g = -0.16$, $r_p = -0.15$) and protein content ($r_g = -0.00$, $r_p = -0.00$).

4.4.7 Leaf area

Leaf area showed significant and positive association with plant height

($r_g = 0.52$, $r_p = 0.50$), stem thickness ($r_g = 0.56$, $r_p = 0.54$), leaf length ($r_g = 0.73$, $r_p = 0.72$), petiole length ($r_g = 0.73$, $r_p = 0.72$), days to 50% flowering ($r_g = 0.32$, $r_p = 0.30$), inflorescence length ($r_g = 0.46$, $r_p = 0.45$), 1000 seed weight ($r_g = 0.35$, $r_p = 0.32$), leaf yield plant⁻¹ ($r_g = 0.34$, $r_p = 0.33$), yield per ha⁻¹ ($r_g = 0.34$, $r_p = 0.33$), ascorbic acid content ($r_g = 0.32$, $r_p = 0.31$) and protein content ($r_g = 0.27$, $r_p = 0.25$) while as it showed non-significant and positive association with lateral spikelet length ($r_g = 0.21$, $r_p = 0.20$), total chlorophyll content ($r_g = 0.06$, $r_p = 0.06$) and anthocyanin content ($r_g = 0.02$, $r_p = 0.02$). Leaf area also showed negative and significant correlation shown with days to germination ($r_g = -0.40$, $r_p = -0.37$) and number of leaves plant⁻¹ ($r_g = -0.38$, $r_p = -0.37$) and negative and non-significant association with number of branches plant⁻¹ ($r_g = -0.19$, $r_p = -0.18$), dry matter content ($r_g = -0.07$, $r_p = -0.06$) and fiber content ($r_g = -0.02$, $r_p = -0.01$).

4.4.8 Petiole length

Petiole length exhibited significant and positive association with plant height ($r_g = 0.63$, $r_p = 0.60$), stem thickness ($r_g = 0.58$, $r_p = 0.57$), leaf length ($r_g = 0.87$, $r_p = 0.86$), leaf area ($r_g = 0.73$, $r_p = 0.72$), days to 50% flowering ($r_g = 0.45$, $r_p = 0.44$), inflorescence length ($r_g = 0.30$, $r_p = 0.29$), 1000 seed weight ($r_g = 0.49$, $r_p = 0.44$), leaf yield plant⁻¹ ($r_g = 0.43$, $r_p = 0.42$), leaf yield ha⁻¹ ($r_g = 0.43$, $r_p = 0.42$) and ascorbic acid content ($r_g = 0.49$, $r_p = 0.48$) while it showed non-significant and positive association with lateral spikelet length ($r_g = 0.04$, $r_p = 0.03$), dry matter content ($r_g = 0.05$, $r_p = 0.04$), total chlorophyll content ($r_g = 0.11$, $r_p = 0.10$), protein content ($r_g = 0.00$, $r_p = 0.00$). Negative and significant correlation of petiole length with days to germination ($r_g = -0.24$, $r_p = -0.22$), number of branches plant⁻¹ ($r_g = -0.24$, $r_p = -0.23$) number of leaves plant⁻¹ ($r_g = -0.38$, $r_p = -0.36$), while as negative and non-significant association was recorded with anthocyanin content ($r_g = -0.02$, $r_p = -0.02$) and fiber content ($r_g = -0.08$, $r_p = -0.07$).

4.4.9 Days to 50% flowering

Days to 50% flowering exhibited significant and positive correlation with

plant height ($r_g = 0.37$, $r_p = 0.35$), stem thickness ($r_g = 0.24$, $r_p = 0.23$), leaf length ($r_g = 0.44$, $r_p = 0.43$), leaf area ($r_g = 0.32$, $r_p = 0.30$), petiole length ($r_g = 0.45$, $r_p = 0.44$), dry matter content ($r_g = 0.22$, $r_p = 0.21$) and ascorbic acid content ($r_g = 0.37$, $r_p = 0.36$) while as it exhibited non-significant and positive association with days to germination ($r_g = 0.19$, $r_p = 0.17$), inflorescence length ($r_g = 0.01$, $r_p = 0.01$), 1000 seed weight ($r_g = 0.22$, $r_p = 0.20$), leaf yield plant⁻¹ ($r_g = 0.21$, $r_p = 0.20$), leaf yield ha⁻¹ ($r_g = 0.21$, $r_p = 0.20$) and total chlorophyll content ($r_g = 0.13$, $r_p = 0.12$). Negative and significant correlation of days to 50% flowering was recorded with number of branches plant⁻¹ ($r_g = -0.42$, $r_p = -0.40$), number of leaves plant⁻¹ ($r_g = -0.43$, $r_p = -0.40$) and fiber content ($r_g = -0.33$, $r_p = -0.30$) while as negative and non-significant association was recorded with lateral spikelet length ($r_g = -0.14$, $r_p = -0.13$), anthocyanin content ($r_g = -0.12$, $r_p = -0.11$) and protein content ($r_g = -0.19$, $r_p = -0.18$).

4.4.10 Inflorescence length

Inflorescence length showed significant and positive association with plant height ($r_g = 0.71$, $r_p = 0.70$), stem thickness ($r_g = 0.33$, $r_p = 0.31$), number of branches plant⁻¹ ($r_g = 0.27$, $r_p = 0.25$), number of leaves plant⁻¹ ($r_g = 0.26$, $r_p = 0.24$), leaf length ($r_g = 0.37$, $r_p = 0.36$), leaf area ($r_g = 0.46$, $r_p = 0.45$), petiole length ($r_g = 0.30$, $r_p = 0.29$), lateral spikelet length ($r_g = 0.73$, $r_p = 0.72$), 1000 seed weight $r_g = 0.39$, $r_p = 0.36$), leaf yield plant⁻¹ ($r_g = 0.66$, $r_p = 0.64$), leaf yield ha⁻¹ ($r_g = 0.66$, $r_p = 0.64$), total chlorophyll content ($r_g = 0.43$, $r_p = 0.41$) and fiber content ($r_g = 0.45$, $r_p = 0.42$); non-significant and positive association with days to 50% flowering ($r_g = 0.01$, $r_p = 0.01$); negative and significant correlation with days to germination ($r_g = -0.55$, $r_p = -0.52$), anthocyanin content ($r_g = -0.53$, $r_p = -0.51$) and negative and non-significant association with dry matter content ($r_g = -0.14$, $r_p = -0.12$), ascorbic acid content ($r_g = -0.17$, $r_p = -0.15$) and protein content ($r_g = -0.14$, $r_p = -0.12$).

4.4.11 Lateral spikelet length

Lateral spikelet length showed significant and positive correlation with

plant height ($r_g = 0.35$, $r_p = 0.34$), number of branches plant^{-1} ($r_g = 0.33$, $r_p = 0.31$), number of leaves plant^{-1} ($r_g = 0.44$, $r_p = 0.40$), inflorescence length ($r_g = 0.73$, $r_p = 0.72$), 1000 seed weight ($r_g = 0.26$, $r_p = 0.25$), leaf yield plant^{-1} ($r_g = 0.36$, $r_p = 0.35$), leaf yield ha^{-1} ($r_g = 0.36$, $r_p = 0.35$), total chlorophyll content ($r_g = 0.30$, $r_p = 0.29$) and fiber content ($r_g = 0.42$, $r_p = 0.39$), while it exhibited non-significant and positive association with leaf length ($r_g = 0.12$, $r_p = 0.10$), leaf area ($r_g = 0.21$, $r_p = 0.20$), petiole length ($r_g = 0.04$, $r_p = 0.03$); negative and significant correlation of with days to germination ($r_g = -0.37$, $r_p = -0.36$), dry matter content ($r_g = -0.31$, $r_p = -0.30$) and anthocyanin content ($r_g = -0.49$, $r_p = -0.47$) while negative and non-significant correlation was recorded with stem thickness ($r_g = -0.01$, $r_p = -0.00$) days to 50% flowering ($r_g = -0.14$, $r_p = -0.13$), ascorbic acid content ($r_g = -0.18$, $r_p = -0.16$) and protein content ($r_g = -0.14$, $r_p = -0.13$).

4.4.12 1000-seed weight

Positive and significant correlation of 1000 seed weight was recorded with plant height ($r_g = 0.39$, $r_p = 0.37$), stem thickness ($r_g = 0.50$, $r_p = 0.46$), leaf length ($r_g = 0.51$, $r_p = 0.48$), leaf area ($r_g = 0.35$, $r_p = 0.32$), petiole length ($r_g = 0.49$, $r_p = 0.44$), inflorescence length ($r_g = 0.39$, $r_p = 0.36$), lateral spikelet length ($r_g = 0.26$, $r_p = 0.25$), leaf yield plant^{-1} ($r_g = 0.51$, $r_p = 0.47$) and leaf yield ha^{-1} ($r_g = 0.51$, $r_p = 0.47$). Non-significant and positive association of 1000- seed weight was recorded with days to 50% flowering ($r_g = 0.22$, $r_p = 0.20$), ascorbic acid content ($r_g = 0.20$, $r_p = 0.19$), fiber content ($r_g = 0.04$, $r_p = 0.03$) and protein content ($r_g = 0.20$, $r_p = 0.19$). 1000 seed weight exhibited negative and non-significant association was shown with days to germination ($r_g = -0.03$, $r_p = -0.03$), number of branches plant^{-1} ($r_g = -0.19$, $r_p = -0.17$), number of leaves plant^{-1} ($r_g = -0.04$, $r_p = -0.03$) dry matter content ($r_g = -0.12$, $r_p = -0.11$), total chlorophyll content ($r_g = -0.10$, $r_p = -0.08$) and anthocyanin content ($r_g = -0.04$, $r_p = -0.04$).

4.4.13 Leaf yield plant^{-1}

Leaf yield plant^{-1} showed significant and positive association with plant

height ($r_g = 0.74$, $r_p = 0.73$), stem thickness ($r_g = 0.52$, $r_p = 0.50$), number of branches plant⁻¹ ($r_g = 0.50$, $r_p = 0.45$), number of leaves plant⁻¹ ($r_g = 0.27$, $r_p = 0.26$), leaf length ($r_g = 0.33$, $r_p = 0.32$), leaf area ($r_g = 0.34$, $r_p = 0.33$), petiole length ($r_g = 0.43$, $r_p = 0.42$), inflorescence length ($r_g = 0.66$, $r_p = 0.64$), lateral spikelet length ($r_g = 0.36$, $r_p = 0.35$), 1000 seed weight ($r_g = 0.51$, $r_p = 0.47$), leaf yield ha⁻¹ ($r_g = 1.00$, $r_p = 1.00$) and total chlorophyll content ($r_g = 0.26$, $r_p = 0.25$) and non-significant and positive association with days to 50% flowering ($r_g = 0.21$, $r_p = 0.20$), dry matter content ($r_g = 0.18$, $r_p = 0.16$), ascorbic acid content ($r_g = 0.06$, $r_p = 0.06$) and fiber content ($r_g = 0.15$, $r_p = 0.13$). Leaf yield plant⁻¹ showed negative and significant correlation with days to germination ($r_g = -0.40$, $r_p = -0.37$) and protein content ($r_g = -0.29$, $r_p = -0.26$) and negative and non-significant association with anthocyanin content ($r_g = -0.21$, $r_p = -0.20$).

4.4.14 Leaf yield ha⁻¹

Leaf yield ha⁻¹ showed significant and positive association with plant height ($r_g = 0.74$, $r_p = 0.73$), stem thickness ($r_g = 0.52$, $r_p = 0.50$), number of branches plant⁻¹ ($r_g = -0.50$, $r_p = -0.45$), number of leaves plant⁻¹ ($r_g = 0.27$, $r_p = 0.26$), leaf length ($r_g = 0.33$, $r_p = 0.32$), leaf area ($r_g = 0.34$, $r_p = 0.33$), petiole length ($r_g = 0.43$, $r_p = 0.42$), inflorescence length ($r_g = 0.66$, $r_p = 0.64$), lateral spikelet length ($r_g = 0.36$, $r_p = 0.35$), 1000 seed weight ($r_g = 0.51$, $r_p = 0.47$), leaf yield plant⁻¹ ($r_g = 1.00$, $r_p = 1.00$) and total chlorophyll content ($r_g = 0.26$, $r_p = 0.25$) and non-significant and positive association with days to 50% flowering ($r_g = 0.21$, $r_p = 0.20$), dry matter content ($r_g = 0.18$, $r_p = 0.16$), ascorbic acid content ($r_g = 0.06$, $r_p = 0.06$) and fiber content ($r_g = 0.15$, $r_p = 0.13$). Leaf yield ha⁻¹ showed negative and significant correlation with days to germination ($r_g = -0.40$, $r_p = -0.37$) and protein content ($r_g = -0.29$, $r_p = -0.26$) and negative and non-significant association with anthocyanin content ($r_g = -0.21$, $r_p = -0.20$).

4.4.15 Dry matter content

Dry matter content exhibited significant and positive association with days

to 50% flowering ($r_g = 0.22$, $r_p = 0.21$) and anthocyanin content ($r_g = 0.29$, $r_p = 0.28$) and non-significant and positive association with days to germination ($r_g = 0.22$, $r_p = 0.20$), plant height ($r_g = 0.18$, $r_p = 0.17$), stem thickness ($r_g = 0.18$, $r_p = 0.16$), leaf length ($r_g = 0.01$, $r_p = 0.01$), petiole length ($r_g = 0.05$, $r_p = 0.04$), leaf yield plant⁻¹ ($r_g = 0.18$, $r_p = 0.16$), leaf yield ha⁻¹ ($r_g = 0.18$, $r_p = 0.16$) and ascorbic acid content ($r_g = 0.02$, $r_p = 0.02$). Negative and significant correlation of dry matter content was shown with number of branches plant⁻¹ ($r_g = -0.28$, $r_p = -0.27$), number of leaves plant⁻¹ ($r_g = -0.34$, $r_p = -0.32$), lateral spikelet length ($r_g = -0.31$, $r_p = -0.30$), fiber content ($r_g = -0.36$, $r_p = -0.33$), protein content ($r_g = -0.26$, $r_p = -0.25$), while as negative and non-significant association was shown with leaf area ($r_g = -0.07$, $r_p = -0.06$), inflorescence length ($r_g = -0.14$, $r_p = -0.12$), 1000 seed weight ($r_g = -0.12$, $r_p = -0.11$) and total chlorophyll content ($r_g = -0.21$, $r_p = -0.20$).

4.4.16 Ascorbic acid content

Ascorbic acid content showed significant and positive correlation with stem thickness ($r_g = 0.38$, $r_p = 0.36$), leaf length ($r_g = 0.58$, $r_p = 0.57$), leaf area ($r_g = 0.32$, $r_p = 0.31$), petiole length ($r_g = 0.49$, $r_p = 0.48$) days to 50% flowering ($r_g = 0.37$, $r_p = 0.36$) and non-significant and positive association with plant height ($r_g = 0.09$, $r_p = 0.07$), 1000 seed weight ($r_g = 0.20$, $r_p = 0.19$), leaf yield plant⁻¹ ($r_g = 0.06$, $r_p = 0.05$), leaf yield ha⁻¹ ($r_g = 0.06$, $r_p = 0.05$), dry matter content ($r_g = 0.02$, $r_p = 0.02$) and anthocyanin content ($r_g = 0.19$, $r_p = 0.18$). Ascorbic acid content exhibited negative and significant correlation was shown with number of leaves plant⁻¹ ($r_g = -0.22$, $r_p = -0.20$) and fiber content ($r_g = -0.35$, $r_p = -0.32$) and while as negative and non-significant association with days to germination ($r_g = -0.06$, $r_p = -0.06$), number of branches plant⁻¹ ($r_g = -0.11$, $r_p = -0.10$), inflorescence length ($r_g = -0.17$, $r_p = -0.15$), lateral spikelet length ($r_g = -0.18$, $r_p = -0.16$) total chlorophyll content ($r_g = -0.16$, $r_p = -0.15$) and protein content ($r_g = -0.02$, $r_p = -0.02$).

4.4.17 Total chlorophyll content

Significant and positive correlation was recorded between total

chlorophyll content and plant height ($r_g = 0.34$, $r_p = 0.33$), number of branches plant⁻¹ ($r_g = 0.24$, $r_p = 0.23$), number of leaves plant⁻¹ ($r_g = 0.26$, $r_p = 0.25$), inflorescence length ($r_g = 0.43$, $r_p = 0.41$), lateral spikelet length ($r_g = 0.30$, $r_p = 0.29$), leaf yield plant⁻¹ ($r_g = 0.26$, $r_p = 0.25$) and leaf yield ha⁻¹ ($r_g = 0.26$, $r_p = 0.25$) and non-significant and positive association of total chlorophyll content with leaf length ($r_g = 0.02$, $r_p = 0.02$), leaf area ($r_g = 0.06$, $r_p = 0.06$), petiole length ($r_g = 0.11$, $r_p = 0.10$), days to 50% flowering ($r_g = 0.13$, $r_p = 0.12$) and fiber content ($r_g = 0.12$, $r_p = 0.11$). Total chlorophyll content exhibited negative and significant correlation with anthocyanin content ($r_g = -0.71$, $r_p = -0.69$) and protein content ($r_g = -0.41$, $r_p = -0.40$) and negative and non-significant association was shown with days to germination ($r_g = -0.17$, $r_p = -0.15$) stem thickness ($r_g = -0.03$, $r_p = -0.01$), 1000 seed weight ($r_g = -0.10$, $r_p = -0.08$), dry matter content ($r_g = -0.21$, $r_p = -0.20$) and ascorbic acid content ($r_g = -0.16$, $r_p = -0.15$).

4.4.18 Anthocyanin content

Anthocyanin content exhibited significant and positive association with days to germination ($r_g = 0.24$, $r_p = 0.22$), dry matter content ($r_g = 0.29$, $r_p = 0.28$) and protein content ($r_g = 0.58$, $r_p = 0.56$) and non-significant and positive association with stem thickness ($r_g = 0.12$, $r_p = 0.11$), leaf area ($r_g = 0.02$, $r_p = 0.02$) and ascorbic acid content ($r_g = 0.19$, $r_p = 0.18$) and negative and significant correlation with plant height ($r_g = -0.41$, $r_p = -0.40$), number of branches plant⁻¹ ($r_g = -0.48$, $r_p = -0.47$), number of leaves plant⁻¹ ($r_g = -0.38$, $r_p = -0.37$), inflorescence length ($r_g = -0.53$, $r_p = -0.51$), lateral spikelet length ($r_g = -0.49$, $r_p = -0.47$), total chlorophyll content ($r_g = -0.71$, $r_p = -0.69$) and fiber content ($r_g = -0.26$, $r_p = -0.24$) and negative and non-significant association with leaf length ($r_g = -0.02$, $r_p = -0.02$), petiole length ($r_g = -0.02$, $r_p = -0.02$), days to 50% flowering ($r_g = -0.12$, $r_p = -0.11$), 1000 seed weight ($r_g = -0.04$, $r_p = -0.04$), leaf yield plant⁻¹ ($r_g = -0.21$, $r_p = -0.20$) and leaf yield ha⁻¹ ($r_g = -0.21$, $r_p = -0.20$).

4.4.19 Fiber content

Fiber content showed significant and positive association with number of branches plant⁻¹ ($r_g = 0.40$, $r_p = 0.36$), inflorescence length ($r_g = 0.45$, $r_p = 0.42$) and lateral spikelet length ($r_g = 0.42$, $r_p = 0.39$); non-significant and positive association with plant height ($r_g = 0.21$, $r_p = 0.20$), number of leaves plant⁻¹ ($r_g = 0.19$, $r_p = 0.17$), 1000 seed weight ($r_g = 0.04$, $r_p = 0.03$), leaf yield plant⁻¹ ($r_g = 0.15$, $r_p = 0.13$), leaf yield ha⁻¹ ($r_g = 0.15$, $r_p = 0.13$) and total chlorophyll content ($r_g = 0.12$, $r_p = 0.11$); negative and significant correlation was shown with days to germination ($r_g = -0.31$, $r_p = -0.27$), days to 50% flowering ($r_g = -0.33$, $r_p = -0.30$), dry matter content ($r_g = -0.36$, $r_p = -0.33$), ascorbic acid content ($r_g = -0.35$, $r_p = -0.32$) and anthocyanin content ($r_g = -0.26$, $r_p = -0.24$) and negative and non-significant association was shown with stem thickness ($r_g = -0.07$, $r_p = -0.06$), leaf length ($r_g = -0.16$, $r_p = -0.15$), leaf area ($r_g = -0.02$, $r_p = -0.01$), petiole length ($r_g = -0.08$, $r_p = -0.07$) and protein content ($r_g = -0.01$, $r_p = -0.00$).

4.4.20 Protein content

Protein content showed significant and positive association with leaf area ($r_g = 0.27$, $r_p = 0.25$) and anthocyanin content ($r_g = 0.58$, $r_p = 0.56$); non-significant and positive association with days to germination ($r_g = 0.03$, $r_p = 0.03$), stem thickness ($r_g = 0.13$, $r_p = 0.11$), petiole length ($r_g = 0.00$, $r_p = 0.00$) and 1000 seed weight ($r_g = 0.20$, $r_p = 0.19$); negative and significant correlation with plant height ($r_g = -0.31$, $r_p = -0.30$), number of branches plant⁻¹ ($r_g = -0.27$, $r_p = -0.25$), number of leaves plant⁻¹ ($r_g = -0.36$, $r_p = -0.33$), leaf yield plant⁻¹ ($r_g = -0.29$, $r_p = -0.26$), leaf yield ha⁻¹ ($r_g = -0.29$, $r_p = -0.26$), dry matter content ($r_g = -0.26$, $r_p = -0.25$) and total chlorophyll content ($r_g = -0.41$, $r_p = -0.40$) and negative and non-significant association was shown with leaf length ($r_g = -0.00$, $r_p = -0.00$), days to 50% flowering ($r_g = -0.19$, $r_p = -0.18$), inflorescence length ($r_g = -0.14$, $r_p = -0.12$), lateral spikelet length ($r_g = -0.14$, $r_p = -0.13$), ascorbic acid content ($r_g = -0.02$, $r_p = -0.02$) and fiber content ($r_g = -0.01$, $r_p = -0.00$).

4.5 Path coefficient

The path coefficient analysis was computed to find out relative direct and indirect contribution of component traits towards leaf yield plant⁻¹. The genotypic correlation coefficients were partitioned into direct and indirect effects of component characters on yield and the results are presented in Table-7. The perusal of table 7 depicts the following results:

4.5.1 Days to germination

Days to germination recorded negative correlation with leaf yield plant⁻¹ (-0.4089) and its direct effect on yield was also negative (-0.0002). Indirect effects of days to germination on yield per plant via plant height, petiole length, inflorescence length, leaf yield ha⁻¹ were negative and those through stem thickness, number of branches plant⁻¹, number of leaves plant⁻¹, leaf length, leaf area, days to 50% flowering, lateral spikelet length, 1000 seed weight, dry matter content, ascorbic acid content, total chlorophyll content, anthocyanin content, fiber content and protein content were positive.

4.5.2 Plant height

Plant height showed positive correlation with leaf yield plant⁻¹ (0.7408) and its direct effect on yield was also positive (0.0005). Indirect effects of plant height on leaf yield plant⁻¹ via days to germination, stem thickness, number of leaves plant⁻¹, leaf area, petiole length, inflorescence length, 1000 seed weight, leaf yield ha⁻¹, dry matter content, ascorbic acid content, total chlorophyll content, fiber content and protein content were positive and those through number of branches plant⁻¹, leaf length, days to 50% flowering, lateral spikelet length and anthocyanin content were negative.

4.5.3 Stem thickness

Stem thickness exhibited positive correlation with leaf yield plant⁻¹ (0.5248) but its direct effect on leaf yield plant⁻¹ was negative (-0.0001). Indirect effects of stem thickness on leaf yield plant⁻¹ via days to germination, plant height,

Table-7: Path coefficient analysis showing direct (diagonal) and indirect (off diagonal) effects of different parameters on yield in in vegetable amaranth (*Amaranthus* spp.)

Parameters	Days to germination	Plant height	Stem thickness	No of branches per plant	No of leaves per plant	Leaf length	Leaf area	Petiole length	Days to 50% flowering	Inflorescence length	Lateral spikelet length	1000-seed weight	Leaf yield (ha ⁻¹)	Dry matter content	Ascorbic acid content	Total chlorophyll content	Anthocyanin content	Fibre content	Protein content
Days to germination	-0.0002	0.0001	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
Plant height	-0.0002	0.0005	0.0003	0.0001	-0.0001	0.0003	0.0003	0.0003	0.0002	0.0004	0.0002	0.0002	0.0004	0.0001	0.0000	0.0002	-0.0002	0.0001	-0.0002
Stem thickness	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
No of branches per plant	0.0001	-0.0001	0.0000	-0.0004	-0.0002	0.0001	0.0001	0.0001	0.0002	-0.0001	-0.0001	0.0001	0.0000	0.0001	0.0000	-0.0001	0.0002	-0.0002	0.0001
No of leaves per plant	0.0000	0.0000	-0.0001	0.0001	-0.0002	-0.0001	-0.0001	-0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	-0.0001	0.0000	0.0001	-0.0001	0.0000	-0.0001
Leaf length	0.0002	-0.0006	-0.0005	0.0003	0.0003	-0.0010	-0.0007	-0.0009	-0.0005	-0.0004	-0.0001	-0.0005	-0.0003	0.0000	-0.0006	0.0000	0.0000	0.0002	0.0000
Leaf area	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Petiole length	-0.0001	0.0003	0.0003	-0.0001	-0.0002	0.0004	0.0003	0.0004	0.0002	0.0001	0.0000	0.0002	0.0002	0.0000	0.0002	0.0001	0.0000	0.0000	0.0000
Days to 50% flowering	0.0000	-0.0001	-0.0001	0.0001	0.0001	-0.0001	-0.0001	-0.0001	-0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0001	0.0000
Inflorescence length	-0.003	0.0004	0.0002	0.0001	0.0001	0.0002	0.0002	0.0001	0.0000	0.0005	0.0004	0.0002	0.0003	-0.0001	-0.0001	0.0002	-0.0003	0.0002	-0.0001
Lateral spikelet length	0.0001	-0.0001	0.0000	-0.0001	-0.0001	0.0000	0.0000	0.0000	0.0000	-0.0002	-0.0002	-0.0001	-0.0001	0.0001	0.0000	-0.0001	0.0001	-0.0001	0.0000
1000 seed weight	0.000	0.0002	0.0002	-0.0001	0.0000	0.0002	0.0002	0.0002	0.0001	0.0002	0.0001	0.0005	0.0002	-0.0001	0.0001	0.0000	0.0000	0.0000	0.0001
Leaf yield hectare ⁻¹	-0.4085	0.7401	0.5144	-0.5010	0.2767	0.3357	0.3397	0.4383	0.2179	0.6681	0.3641	0.5158	0.9991	0.1663	0.0512	0.2576	-0.2010	0.1319	-0.2619
Dry matter content	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ascorbic acid content	0.0000	0.0000	0.0001	0.0000	-0.0001	0.0002	0.0001	0.0002	0.0001	-0.0001	-0.0001	0.0001	0.0000	0.0000	0.0004	-0.0001	0.0001	-0.0001	0.0000
Total chlorophyll	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	-0.001	0.0000	0.0000
Anthocyanin content	0.0001	-0.0001	0.0000	-0.0001	-0.0001	0.0000	0.0000	0.0000	0.0000	-0.0001	-0.0001	0.0000	0.0000	0.0001	0.0000	-0.0002	0.0002	-0.0001	0.0001
Fiber content	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Protein content	0.0000	0.0001	-0.0001	0.0001	0.0001	0.0000	-0.0001	0.0000	0.0001	0.0001	0.0001	-0.0001	0.0001	0.0001	0.0000	0.0002	0.0000	0.0000	-0.0004
Leaf yield plant ⁻¹	-0.4089	0.7408	0.5248	0.5012	0.2769	0.3360	0.3499	0.4387	0.2180	0.6686	0.3644	0.5163	1.0000	0.1663	0.0512	0.2579	-0.2013	0.1321	-0.2623

Residual effect = 0.0001

number of branches plant^{-1} , leaf area, petiole length inflorescence length, lateral spikelet length, 1000 seed weight, leaf yield ha^{-1} , dry matter content, ascorbic acid content, total chlorophyll, anthocyanin content, fiber content were positive and those through number of leaves plant^{-1} , leaf length, days to 50% flowering, and protein content were negative.

4.5.4 Number of branches plant^{-1}

Number of branches plant^{-1} showed positive correlation with leaf yield plant^{-1} (0.5012) but its direct effect on leaf yield plant^{-1} was negative (-0.0004). Indirect effects of number of branches plant^{-1} on leaf yield plant^{-1} via days to germination, plant height, stem thickness, number of leaves plant^{-1} , leaf length, leaf area, days to 50% flowering, inflorescence length, leaf yield ha^{-1} , dry matter content, ascorbic acid content, total chlorophyll, fiber content and protein content were positive and those through petiole length, lateral spikelet length, 1000 seed weight and anthocyanin content were negative.

4.5.5 Number of leaves plant^{-1}

Number of leaves plant^{-1} showed positive correlation with leaf yield plant^{-1} (0.2769) but its direct effect on yield was negative (-0.0002). Indirect effects of number of leaves plant^{-1} on leaf yield plant^{-1} via days to germination, stem thickness, leaf length, leaf area, days to 50% flowering, inflorescence length, 1000 seed weight, leaf yield ha^{-1} , dry matter content, total chlorophyll content, fiber content and protein content were positive and those through plant height, number of branches plant^{-1} , petiole length, lateral spikelet length, ascorbic acid content and anthocyanin content were negative.

4.5.6 Leaf length

Leaf length showed positive correlation with yield per plant (0.3360) but its direct effect on leaf yield plant^{-1} was negative (-0.0010). Indirect effects of leaf length on leaf yield plant^{-1} via days to germination, plant height, stem thickness, number of branches plant^{-1} , leaf area, petiole length, inflorescence length, lateral

spikelet length, 1000 seed weight, leaf yield ha^{-1} , dry matter content, ascorbic acid content, total chlorophyll content, anthocyanin content, fiber content and protein content were positive and those through number of leaves plant^{-1} and days to 50% flowering were negative.

4.5.7 Leaf area

Leaf area exhibited positive correlation with yield per plant (0.3499) and its direct effect on leaf yield plant^{-1} was also positive (0.0001). Indirect effects of leaf area on yield per plant via days to germination, plant height, stem thickness, number of branches per plant, petiole length, inflorescence length, lateral spikelet length, 1000 seed weight, leaf yield ha^{-1} , dry matter content, ascorbic acid content, total chlorophyll content, anthocyanin content, fiber content were positive and those through number of leaves plant^{-1} , leaf length, days to 50% flowering and protein content were negative.

4.5.8 Petiole length

Petiole length recorded positive correlation with leaf yield plant^{-1} (0.4387) and its direct effect on yield was also positive (0.0004). Indirect effects of petiole length on leaf yield plant^{-1} via days to germination, plant height, number of branches plant^{-1} , leaf area, inflorescence length, lateral spikelet length, 1000 seed weight, leaf yield ha^{-1} , dry matter content, ascorbic acid content, total chlorophyll content, anthocyanin content, fiber content and protein content were positive and those through stem thickness, number of leaves plant^{-1} , leaf length, days to 50% flowering were negative.

4.5.9 Days to 50% flowering

Days to 50% flowering showed positive correlation with leaf yield plant^{-1} (0.2180) and its direct effect on leaf yield plant^{-1} was negative (-0.0002). Indirect effects of days to 50% flowering on leaf yield plant^{-1} via days to germination, plant height, stem thickness, number of branches plant^{-1} , number of leaves plant^{-1} , leaf area, petiole length, inflorescence length, lateral spikelet length, 1000 seed

weight, leaf yield ha^{-1} , dry matter content, ascorbic acid content, total chlorophyll content, anthocyanin content, fiber content and protein content were positive and that through leaf length was negative.

4.5.10 Inflorescence length

Inflorescence length showed positive correlation with leaf yield plant^{-1} (0.6686) and its direct effect on leaf yield plant^{-1} was also positive (0.0005). Indirect effects of inflorescence length on leaf yield plant^{-1} via days to germination, plant height, stem thickness, number of leaves per plant, leaf area, petiole length, days to 50% flowering, 1000 seed weight, leaf yield ha^{-1} , dry matter content, total chlorophyll content, fiber content, and protein content were positive and those through number of branches plant^{-1} , leaf length, lateral spikelet length, ascorbic acid content and anthocyanin content were negative.

4.5.11 Lateral spikelet length

Lateral spikelet length showed positive correlation with leaf yield plant^{-1} (0.3644) but its direct effect on leaf yield plant^{-1} was negative (-0.0002). Indirect effects of lateral spikelet length on leaf yield plant^{-1} via days to germination, plant height, stem thickness, number of leaves plant^{-1} , leaf area, petiole length, days to 50% flowering, inflorescence length, 1000 seed weight, leaf yield ha^{-1} , dry matter content, total chlorophyll content, fiber content and protein content were positive and those through number of branches plant^{-1} , leaf length, ascorbic acid content and anthocyanin content were negative.

4.5.12 1000-seed weight

1000 seed weight recorded positive correlation with leaf yield plant^{-1} (0.5163) and its direct effect on leaf yield plant^{-1} was also positive (0.0005). Indirect effects of 1000 seed weight on leaf yield plant^{-1} via days to germination, plant height, stem thickness, number of branches per plant, number of leaves per plant, leaf area, petiole length, days to 50% flowering, inflorescence length, leaf yield hectare^{-1} , dry matter content, ascorbic acid content, total chlorophyll content,

anthocyanin content and fiber content were positive and those through leaf length, lateral spikelet length and protein content were negative.

4.5.13 Leaf yield ha^{-1}

Leaf yield ha^{-1} exhibited positive correlation with leaf yield plant^{-1} (1.000) and its direct effect on yield was also positive (0.9991). Indirect effects of leaf yield ha^{-1} on leaf yield plant^{-1} via days to germination, plant height, stem thickness, number of branches plant^{-1} , number of leaves plant^{-1} , leaf area, petiole length, days to 50% flowering, inflorescence length, 1000 seed weight, dry matter content, ascorbic acid content, total chlorophyll content, anthocyanin content, fiber content and protein content were positive and those through leaf length and lateral spikelet length were negative.

4.5.14 Dry matter content

Dry matter content exhibited positive correlation with leaf yield plant^{-1} (0.1663) and its direct effect on leaf yield plant^{-1} was also positive (0.0000). Indirect effects of dry matter content on leaf yield plant^{-1} via days to germination, plant height, stem thickness, number of branches plant^{-1} , leaf length, leaf area, petiole length, days to 50% flowering, lateral spikelet length, leaf yield ha^{-1} , ascorbic acid content, total chlorophyll content, anthocyanin content, fiber content and protein content were positive and those through number of leaves per plant, inflorescence length and 1000 seed weight were negative.

4.5.15 Ascorbic acid content

Ascorbic acid content showed positive correlation with leaf yield plant^{-1} (0.0512) and its direct effect on leaf yield plant^{-1} was also positive (0.0004). Indirect effects of ascorbic acid content on leaf yield plant^{-1} via days to germination, plant height, stem thickness, number of branches plant^{-1} , number of leaves plant^{-1} , leaf area, petiole length, lateral spikelet length, 1000 seed weight, leaf yield ha^{-1} , dry matter content, total chlorophyll content, anthocyanin content

fiber content and protein content were positive and those through leaf length, days to 50% flowering and inflorescence length were negative.

4.5.16 Total chlorophyll content

Total chlorophyll content exhibited positive correlation with leaf yield plant^{-1} (0.2579) and its direct effect on leaf yield plant^{-1} was also positive (0.0001). Indirect effects of total chlorophyll content on leaf yield plant^{-1} via days to germination, plant height, stem thickness, number of leaves plant^{-1} , leaf length, leaf area, petiole length, days to 50% flowering, inflorescence length, 1000 seed weight, leaf yield ha^{-1} , dry matter content, fiber content and protein content were positive and those through number of branches plant^{-1} , lateral spikelet length, ascorbic acid content and anthocyanin content were negative.

4.5.17 Anthocyanin content

Anthocyanin content showed negative correlation with leaf yield plant^{-1} (-0.2013) but its direct effect on leaf yield plant^{-1} was positive (0.0002). Indirect effects of total anthocyanin content on leaf yield plant^{-1} via days to germination, stem thickness, number of branches plant^{-1} , leaf length, leaf area, petiole length, days to 50% flowering, lateral spikelet length, 1000 seed weight, dry matter content, ascorbic acid content, fiber content and protein content were positive and those through plant height, number of leaves plant^{-1} , inflorescence length, leaf yield ha^{-1} and total chlorophyll content were negative.

4.5.18 Fiber content

Fiber content showed positive correlation with leaf yield plant^{-1} (0.1321) and its direct effect on leaf yield plant^{-1} was also positive (0.0000). Indirect effects of total fiber content on leaf yield plant^{-1} via days to germination, plant height, stem thickness, number of leaves plant^{-1} , leaf length, leaf area, petiole length, days to 50% flowering, inflorescence length, 1000 seed weight, leaf yield ha^{-1} , dry matter content, total chlorophyll content and protein content were positive and

those through number of branches plant^{-1} , lateral spikelet length, ascorbic acid content and anthocyanin content were negative.

4.5.19 Protein content

Protein content showed negative correlation with leaf yield plant^{-1} (-0.2623) and its direct effect on leaf yield plant^{-1} was negative (-0.0004). Indirect effects of protein content on yield per plant via days to germination, stem thickness, number of branches per plant, leaf length, leaf area, petiole length, days to 50% flowering, lateral spikelet length, 1000 seed weight, dry matter content, ascorbic acid content, total chlorophyll content, anthocyanin content and fiber content were positive and those through plant height, number of leaves per plant, inflorescence length and leaf yield ha^{-1} were negative.

Chapter – 5

DISCUSSION

Crop improvement largely depends on the existence of variability and its exploitation by the plant breeder. For this plant breeder needs to identify sources of favorable genes, incorporate them into breeding populations/lines and select for a combination of desirable traits that might result in the isolation of productive genotypes. To achieve these goals, plant breeder needs to know the extent of variability present in a population. Effective evaluation and identification of potentially useful germplasm forms the first and foremost step in a crop improvement programme. The high yielding genotypes with good adaptation and desirable attributes could be directly utilized for general massive hybridization programme.

This improvement in any crop is based on the extent of genetic variation and magnitude of available genetic variability. The proportion of genotypic, environmental variance and their interaction ($G \times E$) can be determined by employing useful biometrical and genetical methods. Some of these parameters include genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV). High value of these coefficients indicates wider diversity. Similarly narrow differences between GCV and PCV reveals low sensitivity to the environmental effects. Another indicator of variability is heritability, which is the ratio of genetic variance to total variance. This is broad sense heritability and gives an idea about that portion of observed variability which is attributable to genetic differences. Heritability estimates supplemented by genetic variance are more meaningful. Heritability is a component in the computation of expected progress which is most meaningful when accompanied by genetic advance.

Genotypic, phenotypic and environmental correlations reveal the degree of association between different characters. Thus it helps to base selection procedure to a required balance when two opposite desirable characters affecting the

principle character are being selected. It also helps to improve different characters simultaneously (Falconer, 1981). The other genetic parameter commonly used is the path analysis as given by Dewey and Lu (1959). Path analysis gives the cause and effect relationship. It critically breaks up different direct and indirect effects which finally make up correlation coefficient.

All these factors help in selection of better parents for the development of commercial variety /hybrid. The results derived from the present investigation are discussed as follows:

5.1 Morphological characterization of genotypes

The characterization results revealed wide range of variation for most of the morphological parameters. Large range of variation for morphological parameters was also reported by Varalakshmi (2004). Most of the genotypes exhibited good early plant vigour with a few exceptions exhibiting very good and poor early plant vigour. An erect plant growth habit was shown by most of the genotypes with a few showing spreading growth habit. Leaf colour exhibited a wide range of variation with green and red as predominant classes. Anindi *et al.* (2012) also observed the similar trend for green leaf colour. Other genotypes had reddish green, pinkish green and yellowish green leaves. Green and red were the predominant classes for inflorescence colour, however pink, yellowish green and reddish green colours were also noticed. Inflorescence compactness was intermediate for most genotypes with a few having dense inflorescences. Genotypes exhibited four classes with respect to stem colour for viz., red, yellowish green, pink and reddish green. Similar results for leaf and stem colour were reported by Wu *et al.* (2004), Anindi *et al.* (2012). Varalakshmi (2004) also observed high variability in case of leaf colour, inflorescence colour and stem colour. Similarly Akaneme and Ani (2013) reported differences between accessions with respect to characters like stem colour, leaf colour. Most of the genotypes had smooth stem surfaces with a few having ridged stem surfaces. Shape of the inflorescence was straight for most of the genotypes with some have

semi drooping inflorescence shapes. Inflorescence spininess was absent in most of the genotypes i.e. they had smooth inflorescences. However a few had spiny and prickly inflorescences. All the genotypes under study had opaque seeds. Black and brown were only classes observed for seed colour. Similar findings were reported by Wu *et al.* (2004) for black and brown seed colour. Akaneme and Ani (2013) also reported similar differences between accessions with respect to characters like seed colour.

5.2 Mean performance of genotypes

Per se performance of the genotypes as depicted in Table 3 revealed that no genotype was superior for all the characters under study. However for days to germination SKAU-A-7 (12.00) and SKAU-A-22 (12.00) followed by SKAU-A-4 (13.00), SKAU-A-11 (13.00) and SKAU-A-19 (13.00); for plant height SKAU-A-7 (302.99 cm) followed by SKAU-A-14 (153.25 cm), SKAU-A-4 (141.17 cm), SKAU-A-22 (136.00 cm) and SKAU-A-10 (133.36 cm); for stem thickness SKAU-A-7 (23.96 mm) followed by SKAU-A-18 (21.90 mm), SKAU-A-21 (21.83 mm), SKAU-A-24 (19.57 mm) and SKAU-A-20 (19.50 mm); for number of branches plant⁻¹ SKAU-A-22 (31.40) followed by SKAU-A-17 (25.13), SKAU-A-10 (22.73), SKAU-A-15 (18.99) and SKAU-A-4 (16.86); for number of leaves plant⁻¹ SKAU-A-4 (170.33) followed by SKAU-A-22 (168.09), SKAU-A-2 (147.58), SKAU-A-6 (139.26) and SKAU-A-21 (138.89); for leaf length SKAU-A-7 (15.50 cm) followed by SKAU-A-14 (12.45 cm), SKAU-A-24 (11.83 cm), SKAU-A-19 (10.67 cm) and SKAU-A-15 (10.64 cm); for leaf area SKAU-A-19 (68.42 cm²) followed by SKAU-A-18 (61.00 cm²), SKAU-A-7 (59.38 cm²), SKAU-A-2 (31.85 cm²) and SKAU-A-9 (31.82 cm²); for petiole length SKAU-A-7 (10.29 cm) followed by SKAU-A-14 (8.14 cm), SKAU-A-24 (7.63 cm), SKAU-A-18 (7.00 cm) and SKAU-A-9 (5.65 cm); for days to 50% flowering SKAU-A-22 (15.17) followed by SKAU-A-1 (26.33), SKAU-A-26 (26.33), SKAU-A-8 (26.78) and SKAU-A-10 (27.33); for inflorescence length SKAU-A-7 (44.34 cm) followed by SKAU-A-4 (39.25 cm), SKAU-A-21 (35.81 cm), SKAU-A-10 (34.30

cm) and SKAU-A-2 (32.97 cm); for lateral spikelet length SKAU-A-4 (30.14 cm) followed by SKAU-A-10 (17.41 cm), SKAU-A-9 (11.65 cm), SKAU-A-21 (10.86 cm) and SKAU-A-2 (8.64 cm); for 1000 seed weight SKAU-A-24 (1.63 g) followed by SKAU-A-7 (1.56 g), SKAU-A-10 (1.31 g), SKAU-A-21 (1.31 g) and SKAU-A-13 (1.28 g); for dry matter content SKAU-A-7 (10.30 per cent) followed by SKAU-A-5 (10.16 per cent), SKAU-A-26 (10.00 per cent), SKAU-A-18 (9.96 per cent), SKAU-A-12 (9.94 per cent) and SKAU-A-27 (9.94 per cent); for ascorbic acid content SKAU-A-15 (130.70 mg/100g) followed by SKAU-A-24 (85.03 mg/100g), SKAU-A-25 (78.72 mg/100g), SKAU-A-7 (78.39 mg/100g) and SKAU-A-14 (75.31 mg/100g); total chlorophyll content SKAU-A-23 (4.73 mg/g) followed by SKAU-A-18 (4.71 mg/g), SKAU-A-13 (4.53 mg/g), SKAU-A-22 (4.42 mg/g) and SKAU-A-21 (4.41 mg/g); for anthocyanin content SKAU-A-3 (0.59 mg/100g) followed by SKAU-A-15 (0.58 mg/100g), SKAU-A-5 (0.57 mg/100g), SKAU-A-11 (0.57 mg/100g), SKAU-A-24 (0.56 mg/100g), SKAU-A-8 (0.56 mg/100g) and SKAU-A-1 (0.56 mg/100g); for fiber content SKAU-A-9 (9.50 per cent) followed by SKAU-A-22 (9.38 per cent), SKAU-A-8 (9.35 per cent), SKAU-A-10 (9.11 per cent) and SKAU-A-7 (9.10 per cent) and for protein content SKAU-A-1 (1.97) followed by SKAU-A-19 (1.97 per cent), SKAU-A-24 (1.85 per cent), SKAU-A-18 (1.26 per cent) and SKAU-A-3 (1.08 per cent) were found superior.

For leaf yield plant⁻¹ SKAU-A-7 (53.82 g) followed by SKAU-A-21 (49.32 g), SKAU-A-4 (29.72 g), SKAU-A-14 (28.95 g) and SKAU-A-20 (27.40 g) were found superior.

The perusal of Table 8 revealed the superior performance of SKAU-A-7 for days to germination, plant height, stem thickness, leaf length, leaf area, petiole length, inflorescence length, leaf yield plant⁻¹, dry matter content, ascorbic acid content and fiber content, SKAU-A-24 for leaf length, petiole length, 1000 seed

Table-8: Best genotypes with respect to different traits based on *per se* performance

S. No.	Traits	Best genotypes
1.	Days to germination	SKAU-A-7 (12.00), SKAU-A-22 (12.00), SKAU-A-4 (13.00), SKAU-A-11 (13.00), SKAU-A-19 (13.00)
2.	Plant height (cm)	SKAU-A-7 (302.99), SKAU-A-14 (153.25), SKAU-A-4 (141.17), SKAU-A-22 (136.00), SKAU-A-10 (133.36)
3.	Stem thickness (mm)	SKAU-A-7 (23.96), SKAU-A-18 (21.90), SKAU-A-21 (21.83), SKAU-A-24 (19.57), SKAU-A-20 (19.50)
4.	No. of branches plant ⁻¹	SKAU-A-22 (31.40), SKAU-A-17 (25.13), SKAU-A-10 (22.73), SKAU-A-15 (18.99), SKAU-A-4 (16.86)
5.	No. of leaves plant ⁻¹	SKAU-A-4 (170.33), SKAU-A-22 (168.09), SKAU-A-2 (147.58), SKAU-A-6 (139.26), SKAU-A-21 (138.89)
6.	Leaf length (cm)	SKAU-A-7 (15.50), SKAU-A-14 (12.45), SKAU-A-24 (11.83), SKAU-A-19 (10.67), SKAU-A-15 (10.64)
7.	Leaf area (cm ²)	SKAU-A-19 (68.42), SKAU-A-18 (61.00), SKAU-A-7 (59.38), SKAU-A-2 (31.85), SKAU-A-9 (31.82)
8.	Petiole length (cm)	SKAU-A-7 (10.29), SKAU-A-14 (8.14), SKAU-A-24 (7.63), SKAU-A-18 (7.00), SKAU-A-9 (5.65)
9.	Days to 50% flowering	SKAU-A-22 (15.17), SKAU-A-1 (26.33), SKAU-A-26 (26.33), SKAU-A-8 (26.78), SKAU-A-10 (27.33)
10.	Inflorescence length (cm)	SKAU-A-7 (44.34), SKAU-A-4 (39.25), SKAU-A-21 (35.81), SKAU-A-10 (34.30), SKAU-A-2 (32.97)

Contd...

Table-8 contd.

S. No.	Traits	Best genotypes
11.	Lateral spikelet length (cm)	SKAU-A-4 (30.14), SKAU-A-10 (17.41), SKAU-A-9 (11.65), SKAU-A-21 (10.86), SKAU-A-2 (8.64)
12.	1000 seed weight (g)	SKAU-A-24 (1.63) SKAU-A-7 (1.56), SKAU-A-10 (1.31), SKAU-A-21 (1.31), SKAU-A-13 (1.28)
13.	Leaf yield plant ⁻¹ (g)	SKAU-A-7 (53.82), SKAU-A-21 (49.32), SKAU-A-4 (29.72), SKAU-A-14 (28.95) SKAU-A-20 (27.40)
14.	Leaf yield (q ha ⁻¹)	SKAU-A-7 (89.68), SKAU-A-21 (82.19), SKAU-A-4 (49.52), SKAU-A-14 (48.24), SKAU-A-20 (45.66)
15.	Dry matter content (%)	SKAU-A-7 (10.30), SKAU-A-5 (10.16), SKAU-A-26 (10.00), SKAU-A-18 (9.96), SKAU-A-12 (9.94). SKAU-A-27 (9.94)
16.	Ascorbic acid content (mg/100g)	SKAU-A-15 (130.70), SKAU-A-24 (85.03), SKAU-A-25 (78.72), SKAU-A-7 (78.39), SKAU-A-14 (75.31)
17.	Total chlorophyll content (mg/g)	SKAU-A-23 (4.73), SKAU-A-18 (4.71), SKAU-A-13 (4.53), SKAU-A-22 (4.42), SKAU-A-21 (4.41)
18.	Anthocyanin content (mg/100g)	SKAU-A-3 (0.59), SKAU-A-15 (0.58), SKAU-A-5 (0.57), SKAU-A-11 (0.57), SKAU-A-24(0.56), SKAU-A-8 (0.56), SKAU-A-1 (0.56)
19.	Fiber content (%)	SKAU-A-9 (9.50), SKAU-A-22 (9.38), SKAU-A-8 (9.35), SKAU-A-10 (9.11), SKAU-A-7 (9.10)
20.	Protein content (%)	SKAU-A-1 (1.97), SKAU-A-19 (1.97), SKAU-A-24 (1.85), SKAU-A-18 (1.26) and SKAU-A-3 (1.08)

Table-9: Six best performing genotypes with respect to maturity, yield attributing and quality traits based on *per se* performance

S. No.	Name of the genotypes	Characters
1.	SKAU-A-7	Days to germination (12.00), Plant height (302.99 cm), Stem thickness (23.96 mm), Leaf length (15.50 cm), Leaf area (59.38 cm ²), Petiole length (10.29 cm), Inflorescence length (44.34 cm), Leaf yield plant ⁻¹ (53.82 g), Dry matter content (10.30 per cent), Ascorbic acid content (78.39 mg/100g), Fiber content (9.10 %)
2.	SKAU-A-24	Leaf length (11.83 cm), Petiole length (7.63 cm), 1000 seed weight (1.63 g), Ascorbic acid content (85.03mg/100g), Anthocyanin content (0.56 mg/100g), Protein content (1.85 per cent).
3.	SKAU-A-18	Leaf area (61.00 cm ²), Petiole length (7.00 cm), Dry matter content (9.96 per cent), Total chlorophyll content (4.71mg/g), Protein content (1.26 per cent).
4.	SKAU-A-22	Number of leaves plant ⁻¹ (168.09), Number of branches plant ⁻¹ (31.40), Days to 50% flowering (15.17), Total chlorophyll content (4.42mg/g), Fiber content (9.38 per cent).
5.	SKAU-A-14	Leaf yield plant ⁻¹ (28.95 g), Leaf length (12.45 cm), Petiole length (8.14 cm), Ascorbic acid content (75.31mg/100g).
6.	SKAU-A-15	Number of branches plant ⁻¹ (18.99), Leaf length (10.64 cm), Ascorbic acid content (130.70 mg/100g), Anthocyanin content (0.58 mg/100g).

weight, ascorbic acid content, anthocyanin content and protein content, SKAU-A-18 for leaf area, petiole length, dry matter content, total chlorophyll content and protein content, SKAU-A-22 for number of leaves plant⁻¹, number of branches plant⁻¹, days to 50% flowering, total chlorophyll content and fiber content, SKAU-A-14 for leaf yield plant⁻¹, leaf length, petiole length, ascorbic acid content and SKAU-15 for number of branches plant⁻¹, leaf length, ascorbic acid content and anthocyanin content. Similar results have been obtained by for leaf yield plant⁻¹, leaf area and dry matter content for best performing genotypes by Revanappa and Madalgeri (1998).

Since no genotype could be identified to have superior performance for all the characters, the genotype with diverse characteristics could be used in a well-planned hybridization programme to select superior performing lines in the successive segregating lines.

5.3 Genetic variability, heritability and genetic advance (as per cent of mean)

The analysis of variance revealed that all the genotypes exhibited highly significant differences for all the traits under study (Table 4). Range values for various characters, 12.00 -23.00 for days to germination, 59.66-302.99 for plant height, 1.98-23.96 for stem thickness, 6.50-31.40 for number of branches plant⁻¹, 50.20-170.33 for number of leaves plant⁻¹, 2.69-15.51 for leaf length, 4.51-68.42 for leaf area, 1.81-10.29 for petiole length, 15.16-52.22 for days to 50% flowering, 2.32-44.34 for inflorescence length, 0.45-30.14 for lateral spikelet length, 0.72-1.63 for 1000 seed weight, 6.44-53.82 for leaf yield plant⁻¹, 10.73-89.68 for leaf yield ha⁻¹, 7.22-10.30 for dry matter content, 39.37-130.70 for ascorbic acid content, 2.04-4.73 for total chlorophyll content, 0.01-0.59 for anthocyanin content, 6.60-9.50 for fiber content and 0.26-1.97 for protein content indicated presence of sufficient genetic variability for all the characters, which is prerequisite for making improvement through selection. Sufficient variability for

number of traits has also been reported by Shukla and Singh, 2003; Varalakshmi, 2003; Dhangra *et al.*, 2015.

Values of range in various characters reflect the amount of phenotypic variability in those characters, but it is not very reliable since it includes genotypic, environmental and genotype $\times$ environmental interaction components and does not reveal as to which character is showing higher degree of variability. Hence, it becomes necessary to split the observed variability into phenotypic coefficient of variation and genotypic coefficient of variation, which ultimately indicates the extent of variability existing for various traits.

The estimates of phenotypic and genotypic coefficients of variation of all the characters studied are presented in (Table 5). Phenotypic coefficients of variation were higher than corresponding genotypic coefficients of variation with slight difference between the values. This indicated that the variability was primarily due to genetic differences and there was little influence of environment in the expression of traits under observation. This was in agreement with the study of Revanappa and Madalageri (1998), Shukla *et al.* (2006) Chattopadhyay *et al.* (2013).

It is evident from the data presented in Table 5 that lateral spikelet length (99.78 and 99.14%), anthocyanin content (75.71 and 75.68%), inflorescence length (70.08 and 69.77%), leaf area (67.13 and 67.04%), stem thickness (52.22 and 52.03%), petiole length (46.76 and 46.19%), leaf yield ha^{-1} (46.60 and 46.00%), leaf yield plant^{-1} (46.58 and 45.99%), plant height (43.48 and 43.41%), number of branches plant^{-1} (43.19 and 42.69%) leaf length (32.71 and 32.48%), number of leaves plant^{-1} (32.55 and 32.39%) recorded high phenotypic and genotypic coefficients of variation, indicating that genotypes had broad genetic base for these characters. The same was observed by Chattopadhyay *et al.* (2013) and Shukla *et al.* (2006) for leaf yield plant^{-1} , Anuja and Kader (2007) and Anuja (2012), for number of leaves plant^{-1} and leaf area, Akaneme and Ani (2013) for plant height, Pan *et al.* (2008) and Hasan *et al.* (2013) for stem thickness, ascorbic

acid content (27.65 and 27.65), total chlorophyll content (25.58 and 24.81), 1000 seed weight (21.61 and 20.30), days to 50% flowering (20.83 and 20.60) and days to germination (20.17 and 19.19) exhibited moderate phenotypic and genotypic coefficients of variation suggesting the existence of moderate variability in the genetic stock studied. Similar findings were reported by Revenappa and Madalgeri (1998) for total chlorophyll content, Sarker *et al.* (2015) for ascorbic acid content. Rest of the traits viz dry matter content (10.25 and 10.22) and fiber content (10.68 and 9.89) showed low phenotypic and genotypic coefficients of variation. These findings were supported by reports of Anuja and Kader (2007) for dry matter content, Shukla *et al.* (2006) for fiber content. Thus these characters were less amenable for improvement through selection.

Characters which possessed moderate to high coefficients of variation suggested that there is better potential for improvement through selection. A wide range of variability along with high estimates of phenotypic and genotypic coefficients of variation further indicates that these attributes would respond well to selection.

The phenotypic and genotypic coefficients of variation do not give a true picture about the extent of inheritance of the character. Therefore, the heritability of a character can be relied upon, as it enables the breeder to decide the extent of selection pressure to be applied under a particular environment, which separates out the environmental influence from the total variability. The estimation of heritability has a greater role to play in determining the effectiveness of selection of a character provided it is considered in conjunction with the predicted genetic advance as suggested by Panse and Sukhatme (1957) and Johnson *et al.* (1955). Furthermore the progress in selection is also directly proportional to the amount of genetic gain. Therefore, the effect of selection is realized more quickly in those characters which have high heritability as well as high genetic advance. The relative amount of heritable portion of variation was, therefore, estimated with the help of heritability estimates and genetic advance.

When high heritability is accompanied with high genetic advance as per cent of mean, it indicates the role of additive gene effects and effectiveness of selection. High heritability with low genetic advance as per cent of mean indicates importance of non-additive gene action where high heritability is exhibited due to favorable influence of environment rather than genotype and the selection for such traits may not be rewarding. Low heritability with high genetic advance as per cent of mean is governed by additive gene effects in which low heritability is exhibited due to high environmental effects and the selection may be effective in such cases. Low heritability coupled with low genetic advance as per cent of mean indicates that character is highly influenced by environmental effects and selection would be ineffective.

Heritability (b.s.) was high for all the characters and ranged from 85 to 99 per cent indicating that the characters are less influenced by environmental effects and that characters are effectively transmitted to the progeny. This suggests the major role of genetic constitution in the expression of a character and thus selection based on phenotypic expression could be relied upon. High heritability was also reported by Varalakshmi and Pratap Reddy (1997) for most of the characters; Chattopadhyay *et al* (2013) for plant height, number of leaves plant⁻¹, stem thickness, leaf yield plant⁻¹; Shukla *et al.* (2006), for number of branches plant⁻¹, leaf area, protein content, ascorbic acid content and fiber content; Akaneme and Ani (2013) for days to 50% flowering; Hasan *et al.* (2013) for leaf length; Anuja and Kader (2007) for petiole length, leaf area, dry matter content Revenappa and Madalgeri (1998) for total chlorophyll content.

High estimate of heritability along with genetic gain (per cent of mean) is more reliable than heritability alone for predicting the effectiveness of selection (Johnson *et al.*, 1955). All the characters except fiber content showed the high estimates of heritability coupled with high genetic advance as per cent of mean, indicating the preponderance of additive gene action for control of these traits. This suggests that real progress in improvement through selection could be made

for yield. These results are in conformity with work of several workers viz. Revenappa and Madalgeri (1998) for leaf yield plant⁻¹, number of leaves plant⁻¹; Shukla *et al.* (2006) for leaf area, ascorbic acid content; Pan *et al.* (2008) for leaf length; Anuja (2012) for plant height, petiole length; Akaneme and Ani (2013) for days to 50% flowering; Mobina *et al.* (2013) for inflorescence length and Salvadora *et al.* (2017) for anthocyanin content.

Leaf yield plant⁻¹ is an important character, which decides the commercial viability of the hybrid/variety. Thus the trait deserves the highest priority in any breeding programme. High heritability along with high genetic advance as per cent of mean for this trait suggested the possibility of selecting high yielding cultivars from the present collection.

5.4 Correlation coefficients

Yield is an ultimate criterion which a plant breeder has always to keep in view for evolving improved cultivars of any crop. However, yield is a polygenic character and highly influenced by environment. Knowledge of the association of quantitative characters specifically for yield and its attributes is of immense practical value during selection. Variability studies provide information on the extent of improvement possible in different characters, but they do not throw light on the extent and nature of relationship existing between various contributing characters and economically important characters. Hence, a knowledge regarding association of various characters among themselves and with economic character is necessary for making indirect selection for improvement of economical characters. Correlation studies pave way to know the association prevailing between highly heritable characters with most economic characters and give better understanding of the contribution of each trait in building up the genetic makeup of the crop. The phenotypic correlations indicate the extent of the observed relationship between two characters. This does not give true genetic picture of the relationship because it indicates both heritability as well as environmental influences. Genotypic correlations provide an estimate of inherent association

between genes controlling any two characters. Hence, it is of greater significance and could be effectively utilized in formulating an effective selection scheme. Perusal of Table-6 indicated that in the present investigation, the estimates of genotypic correlation coefficients were in general higher than phenotypic correlation coefficients showing that masking effect of the environment was little thereby indicating the presence of inherent association between various characters. The nature of genotypic correlation was more or less equal to phenotypic correlation under study. Similar results were reported by Chattopadhyay *et al.* (2013).

The most economically important trait i.e. leaf yield plant⁻¹ showed significant and positive association with plant height ($r_g=0.74$, $r_p=0.73$), stem thickness ($r_g= 0.52$, $r_p= 0.50$), number of branches plant⁻¹ ($r_g= 0.50$, $r_p = 0.45$), number of leaves plant⁻¹ ($r_g= 0.27$, $r_p= 0.26$), leaf length ($r_g= 0.33$, $r_p= 0.32$), leaf area ($r_g= 0.34$, $r_p= 0.33$), petiole length ($r_g= 0.43$, $r_p= 0.42$), inflorescence length ($r_g= 0.66$, $r_p= 0.64$), lateral spikelet length ($r_g= 0.36$, $r_p= 0.35$), 1000 seed weight ($r_g= 0.51$, $r_p= 0.47$), leaf yield ha⁻¹ ($r_g= 1.00$, $r_p= 1.00$) and total chlorophyll content ($r_g= 0.26$, $r_p= 0.25$). These results suggested that selection for these characters is useful for improvement upon leaf yield. These findings were supported by Chattopadhyay *et al.* (2013) for plant height, number of leaves plant⁻¹; stem thickness; Sarker *et al.* (2015) for leaf area, stem thickness; Hasan *et al.* (2013) for leaf length; Shukla *et al.* (2010) for plant height, chlorophyll content; Varalakshmi and Pratap (1997) for plant height, leaf length, and stem thickness; Salvadora *et al.* (2017) for plant height, stem thickness, leaf length; Dhangra *et al.* (2015) for number of leaves; Khurana *et al.* (2013) for number of leaves. Leaf yield plant⁻¹ showed negative and significant correlation with days to germination ($r_g= -0.40$, $r_p= -0.37$) and protein content ($r_g= -0.29$, $r_p= -0.26$). Days to germination was negatively and significantly correlated with number of branches plant⁻¹ ($r_g= -0.39$, $r_p= -0.37$), number of leaves plant⁻¹ ($r_g= -0.24$, $r_p= -0.23$), leaf area ($r_g= -0.40$, $r_p= -0.37$), petiole length ($r_g= -0.24$, $r_p= -0.22$), leaf

yield plant⁻¹ ($r_g = -0.40$, $r_p = -0.37$), leaf yield ha⁻¹ ($r_g = -0.40$, $r_p = -0.37$) and fiber content ($r_g = -0.31$, $r_p = -0.27$). Plant height was found to exhibit significantly positive relationship with leaf yield ha⁻¹ ($r_g = 0.74$, $r_p = 0.73$), stem thickness ($r_g = 0.51$, $r_p = 0.49$), leaf length ($r_g = 0.55$, $r_p = 0.54$), leaf area ($r_g = 0.52$, $r_p = 0.50$). These results were in agreement with Ahmmad *et al.* (2012) for leaf yield ha⁻¹, Shukla *et al.* (2010) for stem thickness, leaf size; Khurrana *et al.* (2013) for leaf length. Stem thickness showed positive and significant association with leaf yield ha⁻¹ ($r_g = 0.51$, $r_p = 0.50$), leaf length ($r_g = 0.52$, $r_p = 0.51$), days to 50% flowering ($r_g = 0.24$, $r_p = 0.23$) which was in agreement with the findings of Ahmmad *et al.* (2012) for yield per ha⁻¹ and Akaneme and Ani (2013) and Hasan *et al.* (2013) for leaf length, days to 50% flowering. Number of branches plant⁻¹ exhibited positive and significant association with number of leaves plant⁻¹ ($r_g = 0.39$, $r_p = 0.38$) which was in agreement with Salvadora *et al.* (2017) and Shukla *et al.* (2010). Number of leaves plant⁻¹ was positively and significantly correlated with number of branches plant⁻¹ ($r_g = 0.39$, $r_p = 0.38$), inflorescence length ($r_g = 0.26$, $r_p = 0.24$), lateral spikelet length ($r_g = 0.44$, $r_p = 0.40$), leaf yield plant⁻¹ ($r_g = 0.27$, $r_p = 0.26$), leaf yield ha⁻¹ ($r_g = 0.27$, $r_p = 0.26$) and total chlorophyll content ($r_g = 0.26$, $r_p = 0.23$). Similar findings were reported by Dhangra *et al.* (2015) for leaf yield ha⁻¹. Leaf length was positively and significantly correlated with stem thickness ($r_g = 0.52$, $r_p = 0.51$), inflorescence length ($r_g = 0.37$, $r_p = 0.36$), days to 50% flowering ($r_g = 0.44$, $r_p = 0.43$), which was in agreement with the findings of Hasan *et al.* (2013) for stem thickness; Akaneme and Ani (2013) for inflorescence length and days to 50% flowering. Leaf area revealed negative correlation with fiber content ($r_g = -0.02$, $r_p = -0.01$) which was similar to the findings of Shukla *et al.* (2010). Petiole length exhibited significant and positive association with leaf length ($r_g = 0.87$, $r_p = 0.86$), leaf area ($r_g = 0.73$, $r_p = 0.72$), days to 50% flowering ($r_g = 0.45$, $r_p = 0.44$), leaf yield plant⁻¹ ($r_g = 0.43$, $r_p = 0.42$), leaf yield ha⁻¹ ($r_g = 0.43$, $r_p = 0.42$) and ascorbic acid content ($r_g = 0.49$, $r_p = 0.48$). Days to 50% flowering exhibited significant and positive correlation with plant height ($r_g = 0.37$, $r_p = 0.35$), stem thickness ($r_g = 0.24$, $r_p = 0.23$), leaf length ($r_g = 0.44$, $r_p = 0.43$), leaf area ($r_g = 0.32$,

$r_p = 0.30$), petiole length ($r_g = 0.45$, $r_p = 0.44$), dry matter content ($r_g = 0.22$, $r_p = 0.21$) and ascorbic acid content ($r_g = 0.37$, $r_p = 0.36$). These results were in agreement with Akaneme and Ani. (2013) for stem thickness and leaf length. Inflorescence length showed significant and positive association with plant height ($r_g = 0.71$, $r_p = 0.70$), stem thickness ($r_g = 0.33$, $r_p = 0.31$), number of branches plant⁻¹ ($r_g = 0.27$, $r_p = 0.25$), number of leaves plant⁻¹ ($r_g = 0.26$, $r_p = 0.24$), leaf length ($r_g = 0.37$, $r_p = 0.36$), leaf area ($r_g = 0.46$, $r_p = 0.45$), lateral spikelet length ($r_g = 0.73$, $r_p = 0.72$), 1000 seed weight $r_g = 0.39$, $r_p = 0.36$), leaf yield plant⁻¹ ($r_g = 0.66$, $r_p = 0.64$), leaf yield ha⁻¹ ($r_g = 0.66$, $r_p = 0.64$), total chlorophyll content ($r_g = 0.43$, $r_p = 0.41$) and fiber content ($r_g = 0.45$, $r_p = 0.42$). These results were in agreement with Shukla *et al.* (2010) for leaf size. Lateral spikelet length showed significant and positive correlation with plant height ($r_g = 0.35$, $r_p = 0.34$), number of branches plant⁻¹ ($r_g = 0.33$, $r_p = 0.31$), number of leaves plant⁻¹ ($r_g = 0.44$, $r_p = 0.40$), inflorescence length ($r_g = 0.73$, $r_p = 0.72$), 1000 seed weight ($r_g = 0.26$, $r_p = 0.25$), leaf yield plant⁻¹ ($r_g = 0.36$, $r_p = 0.35$), leaf yield ha⁻¹ ($r_g = 0.36$, $r_p = 0.35$), total chlorophyll content ($r_g = 0.30$, $r_p = 0.29$) and fiber content ($r_g = 0.42$, $r_p = 0.39$). Positive and significant correlation of 1000 seed weight was recorded with plant height ($r_g = 0.39$, $r_p = 0.37$), stem thickness ($r_g = 0.50$, $r_p = 0.46$), inflorescence length ($r_g = 0.39$, $r_p = 0.36$) and lateral spikelet length ($r_g = 0.26$, $r_p = 0.25$). Dry matter content exhibited significant and positive association with days to 50% flowering ($r_g = 0.22$, $r_p = 0.21$) and anthocyanin content ($r_g = 0.29$, $r_p = 0.29$). Ascorbic acid content showed significant and positive correlation with stem thickness ($r_g = 0.38$, $r_p = 0.36$), leaf length ($r_g = 0.58$, $r_p = 0.57$), leaf area ($r_g = 0.32$, $r_p = 0.31$). These results were in agreement with Shukla *et al.* (2010) for stem thickness. Significant and positive correlation was recorded between total chlorophyll content number of branches plant⁻¹ ($r_g = 0.24$, $r_p = 0.23$), number of leaves plant⁻¹ ($r_g = 0.26$, $r_p = 0.25$), inflorescence length ($r_g = 0.43$, $r_p = 0.41$), lateral spikelet length ($r_g = 0.30$, $r_p = 0.29$), leaf yield plant⁻¹ ($r_g = 0.26$, $r_p = 0.25$) and leaf yield ha⁻¹ ($r_g = 0.26$, $r_p = 0.25$). Similar findings were reported by Shukla *et al.* (2010) for number of branches plant⁻¹ and leaf yield plant⁻¹ ($r_g = 0.26$, $r_p = 0.25$). Anthocyanin content exhibited

significant and positive association with days to germination ($r_g = 0.24$, $r_p = 0.22$), dry matter content ($r_g = 0.29$, $r_p = 0.28$) and protein content ($r_g = 0.58$, $r_p = 0.56$). Fiber content showed significant and positive association with number of branches plant⁻¹ ($r_g = 0.40$, $r_p = 0.36$), inflorescence length ($r_g = 0.45$, $r_p = 0.42$) and lateral spikelet length ($r_g = 0.42$, $r_p = 0.39$). Protein content showed significant and positive association with leaf area ($r_g = 0.27$, $r_p = 0.25$) and anthocyanin content ($r_g = 0.58$, $r_p = 0.56$).

5.5 Path coefficient

Correlation analysis indicates the association pattern of the component traits with yield. It simply represents the overall influence of a particular trait on yield rather than providing cause and effect relationship. It does not give an exact position of the relative importance of direct and indirect effects of various yield attributes. Path coefficient is simply a standardized partial regression coefficient and as such measures the direct influence of one variable upon another variable which permits the separation of correlation coefficients into components of direct and indirect effects.

The path coefficient analysis (Table 7) revealed highest amount of direct positive effect of leaf yield ha⁻¹ (0.9991) followed by plant height (0.0005), inflorescence length (0.0005), 1000 seed weight (0.0005), petiole length (0.0004), ascorbic acid content (0.0004), anthocyanin content (0.0002), leaf area (0.0001), total chlorophyll content (0.0001) and fiber content (0.0000) on leaf yield plant⁻¹. These results were in agreement with the results of Khurana *et al.* (2013) for number of leaves plant⁻¹, plant height; Hasan *et al.* (2013) for number of leaves per plant; Shukla *et al.* (2010) for inflorescence length, plant height, number of leaves per plant. Significant positive genotypic correlation coefficients of plant height, inflorescence length, 1000 seed weight, petiole length, leaf area, total chlorophyll content and fiber content reveal that these traits can be used to develop an optimally reliable selection index for realizing improvements in leaf yield of vegetable amaranth. The direct effect of rest of the component traits viz.

number of days to germination, stem thickness, number of branches plant⁻¹, leaf length days to 50% flowering, lateral spikelet length and protein content were negative. Similar results were reported by Khurrana *et al.* (2013) and Shukla *et al.* (2010) for number of branches plant⁻¹; Hasan *et al.* (2013) for leaf length stem thickness.

In the present study, the value of residual effect was 0.0001 which indicates that the characters chosen for the present study are the main components of yield and the variability in yield is accounted by the characters chosen for present study. Very less residual effect has also been reported by Chattopadhyay *et al.* (2013), Hasan *et al.* (2013).

Chapter – 6

SUMMARY AND CONCLUSION

The present investigation entitled “Morphological Characterization and Variability Studies in Vegetable Amaranth (*Amaranthus* spp.) Under Temperate Conditions” was undertaken to establish morphological characterization, estimate the coefficients of variability, heritability, genetic gain, correlation coefficients and path coefficients in twenty seven genotypes of vegetable amaranth.

The single factor experiment was laid out in randomized complete block design (RCBD) with three replications. The whole experimental area was divided into three blocks each of which was then divided into 27 double lines to represent the 27 treatments. Observations were recorded on eleven descriptor traits viz., early plant vigour, plant growth habit, leaf colour, inflorescence colour, inflorescence compactness, stem colour, stem surface, inflorescence shape, inflorescence spininess, seed transparency and seed colour.

These morphological characters revealed a wide range of variability. Most of the genotypes exhibited good early plant vigour with a few exceptions exhibiting very good and poor early plant vigour. An erect plant growth habit was shown by most of the genotypes with a few showing spreading growth habit. Leaf colour exhibited a wide range of variation with green and red as predominant classes. Others genotypes had reddish green, pinkish green and yellowish green leaves. Green and red were the predominant classes for inflorescence colour, however pink, yellowish green and reddish green colours were also noticed. Inflorescence compactness was intermediate for most genotypes with a few having dense inflorescences. Stem colour exhibited four classes for the genotypes under study viz., red, yellowish green, pink and reddish green. Most of the genotypes had smooth stem surfaces with a few having ridged stem surfaces. Shape of the inflorescence was straight for most of the genotypes with some have semi drooping inflorescence shapes. Inflorescence spininess was absent in

genotypes mostly i.e. they had smooth inflorescences however a few had spiny and prickly inflorescences. All the genotypes under study had opaque seeds and only black and brown colours were observed for seed colour.

Observations were also recorded on twenty quantitative and qualitative characters viz., days to germination, plant height (cm), stem thickness (mm), number of branches per plant⁻¹, number of leaves plant⁻¹, leaf length (cm), leaf area (cm²), petiole length (cm), number of days to 50% flowering, inflorescence length (cm), lateral spikelet length (cm), 1000 seed weight (g), leaf yield plant⁻¹ (g), leaf yield ha⁻¹ (q), dry matter content (%), ascorbic acid (mg/100g), total chlorophyll content (mg/g), anthocyanin (mg/100g), fiber content (%) and protein content (%). The data collected on these characters were subjected to statistical analysis and the results obtained from the investigation are summarized as follows:

Wide range was observed for most of the traits under study. On the basis of mean performance of the genotypes, it was observed that SKAU-A-7 recorded the highest leaf yield plant⁻¹ of 53.82 g followed by SKAU-A-21 (49.32 g), SKAU-A-4 (29.72 g), SKAU-A-14 (28.95 g) and SKAU-A-20 (27.40 g) while SKAU-A-17 recorded lowest yield of 6.44 g followed by SKAU-A-27 (10.54 g), SKAU-A-23 (13.54 g), SKAU-A-1 (13.89 g) and SKAU-A-26 (14.24 g).

Analysis of variance revealed significant differences among genotypes for all the traits studied. The phenotypic and genotypic coefficients of variability ranged from 10.25 - 99.78 and 9.89 - 99.14 respectively. The highest phenotypic and genotypic coefficients of variability were observed for lateral spikelet length (99.78, 99.14) followed by anthocyanin content (75.71, 75.68), inflorescence length (70.08, 69.77), leaf area (67.13, 67.04) and stem thickness (52.22, 52.03). In general the phenotypic and genotypic coefficients of variation were slightly higher than the corresponding phenotypic coefficients of variation, which indicates the minor role of environment in the expression of traits under observation. Heritability (b.s.) was high for all the characters and ranged from 85

to 99 per cent indicating that the characters are less influenced by environmental effects and that characters are effectively transmitted to the progeny. All the characters except fiber content showed the high estimates of heritability coupled with high genetic advance as per cent of mean, indicating the preponderance of additive gene action for control of these traits. The present investigation indicates a great scope of fast improvement in all the traits as these characters in general possessed high estimates of heritability coupled with high genetic advancement.

In the present investigation, the estimates of genotypic correlation coefficients were in general slightly higher than phenotypic correlation coefficients showing that masking effects of the environment was little indicating the presence of inherent association between various characters. Correlation coefficients revealed that the economically important trait i.e. leaf yield plant⁻¹ exhibited significant and positive association with plant height, stem thickness, number of branches plant⁻¹, number of leaves plant⁻¹, leaf length, leaf area, petiole length, inflorescence length, lateral spikelet length, 1000 seed weight and total chlorophyll content both at genotypic and phenotypic levels. Days to 50% flowering, dry matter content, ascorbic acid content and fiber content showed positive but non-significant association with leaf yield plant⁻¹. Leaf yield plant⁻¹ exhibited negative and significant correlation with days to germination and protein content.

The path coefficient analysis made it apparent that the highest amount of direct positive effect on leaf yield plant⁻¹ was recorded via., leaf yield ha⁻¹ followed by plant height, inflorescence length, 1000 seed weight, petiole length, ascorbic acid content, number of leaves plant⁻¹, anthocyanin content, leaf area and total chlorophyll content on leaf yield plant⁻¹.

Based on the findings of present investigation the following conclusions can be drawn:

- i. Characterization on the basis of NBPGR descriptor indicated wide

variability with respect to leaf color, inflorescence color and stem color.

- ii. Analysis of variance indicated that a significant variation existed for various characters under study.
- iii. Correlation studies indicated that characters plant height, number of branches plant⁻¹, number of leaves plant⁻¹, leaf length, leaf area and petiole length should be considered important for improving quantitative traits in vegetable amaranth.
- iv. Path coefficient analysis further suggested that plant height, inflorescence length, petiole length and leaf area had highest direct effects on the leaf yield and should be given due importance by selection for breeding of new cultivars.
- v. *Per se* performance of the experimental material indicated that SKAU-A-7, SKAU-A-18, SKAU-A-24, SKAU-A-14, SKAU-A-22 and SKAU-15 were important with respect to maturity, yield attributing and quality traits.

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CERTIFICATE

Certified that all the corrections/amendments as suggested by External Examiner Dr. Shri Dhar, Principal Scientist, Division of Vegetable Science, ICAR, IARI, New Delhi during Viva-Voice examination held on 29.11.2017 have been incorporated in the manuscript entitled **“Morphological Characterization and Variability Studies in Vegetable Amaranth (*Amaranthus* spp.) under Temperate Conditions”** submitted by **Ms. Labiba Riyaz Shah (Regd. No. 2015-H-99-M)**.

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