Variability studies in Amaranthus (*Amaranthus spp.*)

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Variability studies in Amaranthus
(*Amaranthus spp.)*

A Thesis submitted to the
Orissa University of Agriculture and Technology
in Partial fulfillment of the Requirement for the degree of
Master of Sciences in Agriculture
(Vegetable Science)

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Ex. Prof. and Head **Date:**

CERTIFICATE-I

This is to certify that the thesis entitled **"Variability studies in Amaranthus (*Amaranthus spp*.)"** submitted in partial fulfillment of the requirements for the award of the degree of **MASTERS OF SCIENCE IN AGRICULTURE (VEGETABLE SCIENCE)** to the Orissa University of Agriculture and Technology is a faithful record of *bona fide* and original research work carried out by **Mr. Rosan Kumar Panda** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that the assistance and help received by him from various sources during the course of investigation has been duly acknowledged.

CHAIRMAN
ADVISORY COMMITTEE

CERTIFICATE-II

This is to certify that the thesis entitled **"Variability studies in Amaranthus (*Amaranthus spp*.)"** submitted by **Mr. Rosan Kumar Panda** to the Orissa University of Agriculture and Technology, Bhubaneswar in partial fulfillment of the requirements for the degree of **MASTERS OF SCIENCE IN AGRICULTURE (VEGETABLE SCIENCE)** has been approved by the students' advisory committee and external examiner.

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Date:
Place: **(Rosan Kumar Panda)**

ABSTRACT

Twelve diverse genotypes (germplasms) of Amaranthus were evaluated for genetic parameters taking 13 quantitative characters, maintained in All India Co-ordinated Research Project (AICRP) on Vegetable Crops, Bhubaneswar at Horticulture Research station, following Randomized Block Design having three replications during the kharif season 2014 (July-November).

A wide range of variation was observed for all the 13 characters under study. Genotypes such as 2012/AMVAR-4 (V_4), BHIGARPUR LOCAL (V_{11}) and 2012/AMVAR-2 (V_2) were identified as ideal among the evaluated genotypes. Presence of minimum difference between phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) for all the characters indicated that the phenotypes represent true to the genotypes. High estimates of genotypic coefficient of variation (GCV), heritability and genetic advance as percentage of mean altogether at a glance were observed for the traits like number of inflorescence per plant, leaf: stem ratio, stem weight, yield per plant, leaf weight and plant height suggesting additive gene action for expression of these characters. Hence, these characters may be proved as effective criteria for selection to improve yield in Amaranthus. Correlation studies among the characters revealed that there is a strong inherent association between yield per plant (green yield) with characters like plant height, number of nodes per plant, stem girth, leaf length, leaf area, stem weight and leaf weight both at phenotypic and genotypic levels depicting that these are important correlated characters contributing towards yield (green yield). Path coefficient analysis (genotypic path) of various quantitative traits indicated that stem weight had the maximum positive direct effect followed by leaf weight, while, leaf: stem ratio exhibited the highest negative direct effect on yield of Amaranthus. With the help of D^2 statistics and Tocher's methods the genotypes were grouped into six clusters. Cluster II (two parents) and V (single parent) showed highest inter-cluster distances were the most divergent ones and hybridization involving parents from these two Clusters would be result oriented. Characters like yield per plant, leaf: stem ratio, leaf weight and stem weight predominantly contributed towards genetic divergence among the parents. So, selection of parents differing in these quantitative characters may be useful for developing hybrids in Amaranthus.

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ABBREVIATIONS USED

%	:	Per cent
/	:	Per
@	:	At the rate
C.D.	:	Critical Difference
cm	:	Centimeter
d.f.	:	Degree of freedom
ESS	:	Error sum of square
et al.	:	(*et albeit*) and elsewhere
etc.	:	Etcetera
Even.	:	Evening
g	:	Gram
ha	:	Hectare
Hrs.	:	Hours
i.e.	:	(*Id est.*) that is
Kg	:	Kilogram
km	:	Kilometer
M	:	Meter
m^2	:	Square meter
Max.	:	Maximum
Min.	:	Minimum
mm	:	Millimeter
MSS	:	Mean sum of square
No.	:	Number
R.H.	:	Relative humidity
RSS	:	Replication sum of square
Tss	:	Treatment sum of square
Viz.	:	(*Videlicet*) Namely
°C	:	Degree Celsius
dSM^{-1}	:	deci simon per

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exhibited the highest negative direct effect on yield of Amaranthus. With the help of D^2 statistics and Tocher's methods the genotypes were grouped into six clusters. Cluster II (two parents) and V (single parent) showed highest inter-cluster distances were the most divergent ones and hybridization involving parents from these two Clusters would be result oriented. Characters like yield per plant, leaf: stem ratio, leaf weight and stem weight predominantly contributed towards genetic divergence among the parents. So, selection of parents differing in these quantitative characters may be useful for developing hybrids in Amaranthus.

INTRODUCTION

The word “Amaranth” in Greek means “everlasting”. National Academy of Sciences of the U.S in 1975 elected amaranths as the world’s most promising crops with promising economic value. Amaranth (*Amaranthus spp.*) is a widespread traditional vegetable throughout the tropics and the temperate zone of the world including India. Amaranthus is a herbaceous annual with upright growth habit, cultivated for both its seeds which are used as a grain and its leaves which are used as greens. It is one of the main leafy vegetables in this country and consumed as a pot herb. In India, various domesticated forms of Amaranthus are grown in the southern states of Tamil Nadu, Andhra Pradesh, Karnataka and Kerala, Odisha, West- Bengal and interior areas of North-West hills. Amaranthus is recognized as an easy-to-grow and extremely productive and nutritious vegetable. Unlike other leafy vegetables, vegetable amaranth is cultivated during hot summer months when no other green vegetables are available in the market. The edible amaranth (*Amaranthus spp.*) is one of popular leafy vegetables in the South-East Asia and is becoming increasingly popular in the Asia and elsewhere due to its attractive leaf colour, taste and nutritional value. The vegetable amaranths have been largely ignored by the world of science. Many authors actually labeled them as ‘neglected crops’. Almost universally, the plants have been scorned as a poor people’s resource. The nutritional endowments of amaranths provide evidence that the plants deserve some scientific attention. Lysine and sulphur containing amino acids have been found in their leaves. Many vegetables and cereal grains lack these amino acids. Additionally the leaves are high in carbohydrates, several vitamins including beta-carotene, vitamin - C and minerals such as iron, calcium, manganese and zinc. It also contains high amount of protein, dietary fiber and has been rated equal or superior in taste to spinach and is considerably higher in protein (14 - 30% on dry weight basis). It fits well in multiple and mixed cropping system because of its short duration with high yield potential of edible matter per unit area. It exhibits C_4 type photosynthesis with more efficient photosynthetic ability and has a remarkable capacity of rejuvenation after each cut. Amaranthus has been incorporated into a range of human food products that are primarily targeted at health conscious consumers. It serves as an alternative source of nutrition for vegetarian people in developing countries where the bulk of the population has little access to protein rich food.

Through collection and selection programmers a number of strains have been introduced and acclimatized in various parts of the world, but evaluation studies for yield and its contributing quantitative and qualitative traits are scarce in our country in Amaranthus.

Considering the potentiality of this crop, there is a need to develop varieties suitable for cultivation under specific agro-ecological conditions. A thorough knowledge regarding the amount of genetic variability existing for various characters is essential for initiating the crop improvement programme. With limited variability, much improvement cannot be achieved, hence, the breeders will have to enrich the germplasm or he can restore to create greater variability through hybridization, mutation and polyploidy breeding.

The phenotypic expression of the plant characters is mainly controlled by the genetic makeup of the plant and the environment, in which it is growing. Further, the genetic variance of any quantitative trait is composed of additive variance (heritable) and non-additive variance and include dominance and epistasis (non-allelic interaction). Therefore, it becomes necessary to partition the observed phenotypic variability into its heritable and non-heritable components with suitable parameters such as genotypic and phenotypic coefficient of variation, heritability and genetic advance. Further, genetic advance can be used to predict the efficiency of selection. Yield is a complex character controlled by a large number of contributing characters and their interactions. A study of correlation between different quantitative characters provides an idea of association that could be effectively exploited to formulate selection strategies for improving yield components. For any effective selection programme, it would be desirable to consider the relative magnitude of association of various characters with yield.

Development of productive and potentially ideal type is the main aim of any crop improvement programme. However, present trend exists in the development of hybrid cultivars to boost up the productivity and profitability of farmers. To meet out all the requirements of successful hybrids, it is necessary to be familiar with the detailed genetic structure of germplasm material to be used in hybrid breeding.

The path coefficient technique developed by Wright (1921) helps in estimating direct and indirect contribution of various components in building up the total correlation towards yield. Based on these studies the quantum importance of individual characters is marked to facilitate the selection programme for better gains. Generally diverse plants are expected to give higher hybrid vigour (Harrington, 1940). Hence it necessitates the study of genetic divergence among the existing varieties and germplasm collection for identification of parents for hybridization programme. The information on genetic divergence of various trates particularly those that contribute to yield and quality would be the most useful in planning of the breeding programme. D^2 statistics developed by Mahalanobis (1936) provides a measure of magnitude for divergence between two genotypes under comparision. Grouping of genotypes based on D^2 analysis will be useful in choosing suitable parental lines for heterosis breeding. Such studies are also useful in selection of parents for hybridization to recover superior transgressive segregants. Hence, the present investigation entitled "Variability studies in Amaranthus (Amaranthus spp.)" has been designed with the following objectives to be carried out with a set of varieties and advanced lines.

1. To study the magnitude of genetic variation in the collection.
2. To assess the nature and extent of variability and heritability of character and their expected genetic gain by selection.
3. To investigate the amount of association among different characters with yield through co-relation analysis.
4. To determine the direct and indirect association among yield components through path co-efficient analysis.
5. To compare and contrast the genotypes for component of yield and assess genetic divergence among them based on genetic distance.

REVIEW OF LITERATURES

Amaranthus is a profiteering, short duration, nutritious leafy vegetable. In India lot of variation has been observed in this crop leading to development of several new promising varieties/ lines. As there is every possibility, that the established varieties may lose their importance in course of time, hence to search for new cultivars is a continuous process. Further for crop improvement programme like selection and hybridization, a sound knowledge of nature of character association and genetic divergence in any crop is highly essential. Therefore, reviews relevant to Amaranthus on these aspects have been presented below for interpretation of results.

2.1 Variability and heritability of quantitative traits

Selection of superior genotypes at one stage or the other is most important aspect in any plant improvement programme and the effectiveness of selection is based on the existence of genetic variability within or among the population subjected to selection (Dixit *et al.*, 1971; Swamy Rao, 1972; Tikka *et al.*, 1974). Therefore, a quantitative measure of genetic variability would be extremely significant in breeding for improvement of quantitative traits.

Most of the economically important traits in crop plants are quantitative in nature which are controlled by polygene and also influenced by the environment (Hirachand *et al.*, 1975). The observable quantitative traits are only the phenotype which can be easily assessed but for purpose of selection, it is inadequate since plant is the resultant of genotype and environment which creates difficult to ascertain whether variability is heritable or non-heritable (environmental). This necessitates the partitioning of total variation into two groups such as heritable and non-heritable components as follows:

a) Heritable or genotypic variation. It includes,

i. Additive genetic variance (V_A), which results from additive or average effect of genes and is heritable.

ii. Dominance variance (V_D), which arises from intra-allelic interaction (due to the deviation of the heterozygote Aa from the average of the homozygote AA and aa) and it is also heritable.

b) Non-heritable variation or non-genetic variation

i. Epistatic variance (V_I) which results from the interaction of non-allelic and is referred as inter-allelic interaction.

ii. Environmental variance (V_E) which results from non-genetic factor such as environmental fluctuations, sampling error and difference in the cultural practices.

Besides this classification stated above statistical methods are now available for partitioning of phenotypic variation into genetic and environment components which permit a quantitative assessment of genetic variability and the relative importance of heredity and environment in the expression of quantitative traits.

2.2 Coefficient of variation

Coefficient of variation is defined as the measure of variation and is independent of unit of measurement which is used for comparing different populations. It is provided by the standard deviation expressed as percentage of mean. (Panse and Sukhatme, 1954)

Genotypic coefficient of variation is the genotypic standard deviation expressed as percentage of mean and phenotypic coefficient of variation is expressed as the phenotypic standard deviation expressed as percentage of mean. A slight differences between phenotypic and genotypic standard deviation suggested negligible influence of environment on that character (Choudhary *et al*., 1973).

2.3 Heritability

Heritability is an important parameter of great importance for the plant breeder as its magnitude indicates the accuracy with which a genotype can be recognized by its phenotypic expression. It is estimated as the ratio of genotypic variance to the total phenotypic variance that is due to genetic causes. The term heritability, is also used 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) which are symbolically as follows:

h^2 (narrow sense) = $V_A / (V_G + V_E) = V_A / V_P$

h^2 (broad sense) = $V_G / (V_G + V_E) = V_G / V_P$

But Liang and Walter (1968) defined heritability as the transmission of character from parent to off-spring. Heritability is one of the major properties of a quantitative character. It should be noted that heritability is a property not only of a character but also of a population and the environmental conditions to which the individuals are exposed. Further, variation in quantitative traits occurs due to their degree of heritability. Robinson (1966) grouped the heritability estimates in crop plants into three categories.

i. Low heritability – 5 to 10 percent.
ii. Moderate heritability – 10 to 30 percent.
iii. Higher heritability – 30 to 60 percent.

This classification represents average of heritability estimates over various crop plants, types of population, procedures of determination and environments encountered in different locations and years.

If heritability is 100% the phenotypic performance would be perfect indication of genetic value. However, in this hypothetical situation, the heritability values in itself provide no indication of the amount of genetic progress that would result from selecting the best individuals. Therefore, the utility of heritability is increased when they are used in conjugation with selection differential and the genetic advance is completely predicted as the product of heritability ratio and selection differential (Johnson *et al*., 1955). Randhawa *et al*., (1975) suggested that if the heritability of a character is high, better will be the opportunity for selecting a genetically good individual. Low value of heritability indicates high degree of non-heritable variability (Sharma *et al*., 1966). Further, difference in heritability values also differ greatly depending upon methods used to estimate the parameter (Robinson, 1963) the units for which the variance is considered (Johnson *et al*., 1955) and also the amount of genetic variation in population and environmental condition under which the population is evaluated (Allard, 1960).

Therefore, the most important use of heritability lies in its predictive role, expressing the reliability of the phenotypic value as a guide to the breeding value. It also serves as a useful parameter in predicting genetic advance or response to selection.

2.4 Genetic advance

The heritability alone conveys no identification of the amount of genetic progress that will result from selecting the best individual. But when they are used together with the selection differential, the utility is increased (Tikka *et al*., 1974).

Genetic advance indicates the potentiality of selection at a particular level of selection intensity. The expected genetic advance from selection when expressed as a percentage of mean is the product of

i. the selection differential in terms of phenotypic standard deviation
ii. genotypic co-efficient of variation and
iii. the square root of heritability ratio.

Heritability in narrow sense is the most important tool to estimate expected improvement due to selection or response to selection of genetic advance. Robinson (1963) and Johnson *et al*., (1955) suggested that heritability estimates along with genetic advance were more valuable than the heritability value alone in predicting the response to selection. High heritability does not necessarily mean that the character will show high genetic advance. But the case where the above association exists, additive genes comes into prominence. It is because no genetic advance was due to non-additive genes, whereas additive genes are responsible for high genetic advance.

Genetic variability and heritability in Amaranthus

In a study on Amaranthus, Lohithaswa *et al.* (1996) observed a considerable amount of phenotypic and genotypic variability for plant fresh weight, grain yield followed by stem dry weight, stem girth at collar region and plant height.

Revanappa and Madalgeri (1998) have evaluated 40 genotypes of Amaranthus collected from Tamilnadu and Karnataka. They have reported that the phenotypic coefficient of variability were higher than the genotypic coefficient of variability for all the studied characters. The PCV and GCV were maximum for leaf: stem ratio, number of leaves and fresh weight of leaves while it was minimum for stem girth.

Bhargava *et al.* (2003) observed from a varietal evaluation of Amaranthus, that the phenotypic coefficient of variation (PCV) had higher estimate than corresponding GCV for all the characters though had small differences. The coefficient of variability was high for leaf size and foliage yield while it was lowest for stem diameter.

Rani and Veeraragavathatham (2003) conducted an experiment on genetic variability for green yield in Amaranthus in Tamil Nadu taking 57 lines. They have 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%).

The major components method, i.e. factor analysis indicated that the characteristics such as: plant height, average foliage length and average foliage width, had a significant factor loading with the first factor and these traits are of a crucial importance for genotype variability was observed by Vujacic (2005) in Amaranthus.

According to Shukla *et al.* (2006) the genotypic coefficient of variation (GCV) values ranged from 6.80 to 28.25%. However, the parameters like branches/plant, leaves/plant, plant height and stem diameter showed lowest values of GCV

Anuja and Mohideen (2007) conducted one experiment to study the variability, heritability and genetic advance studies in Amaranthus (*Amaranthus* spp.) involving 100 genotypes in summer and monsoon seasons. Comparison of genotypic and phenotypic co-efficient variation for different traits indicated that the values of PCV were higher as compared to GCV due to the influence of environment. High genotypic co-efficient of variation was observed for number of leaves, yield of greens, root weight, leaf weight, stem weight and leaf area.

Pan *et al.* (2008) observed maximum extent of genetic variability for leaf: stem ratio followed by greens/plot, girth of stem and length of leaf, in a variability study in Amaranthus.

According to Smitha and Krishnakumary (2011) phenotypic coefficient of variation was higher than genotypic coefficient of variation for most of the traits and it ranged from 12.64 to 49.83.

Ahammed *et al.* (2012) observed the highest PCV (87.85%) and GCV (81.67%) for primary branches per plant while the lowest PCV (10.28%) in plant height and the lowest GCV (7.51%) was found in leaf width in a variability study in Amaranthus.

Anuja (2012) conducted an experiment on genetic variability studies in vegetable Amaranthus, for 14 characters in 100 genotypes. She reported that there was a considerable amount of phenotypic and genotypic variability for number of leaves, and leaf weight in both summer and monsoon seasons.

There was significant variability found in the gene pool, evident by a high variation as per cent of mean or coefficient of variation (CV). Principal component analysis revealed that plant height, number of branches/plant, number of leaves/plant, leaf length, leaf width, petiole length, plant weight and leaf weight exhibited 94% of the total variability (Shankar *et al.* 2012).

According to Hasan *et al.* (2013) the differences between GCV and PCV were high for leaf length and stem diameter indicating the vulnerability of traits to environmental influences. High GCV and PCV were observed in leaf weight (77.54 and 80.14 %, respectively).

The values of phenotypic coefficient of variation (PCV) were higher than those of genotypic coefficient of variation (GCV) for all the characters (Khurana *et al.* 2013).

Parveen *et al.* (2014) found that phenotypic coefficients of variation is higher than genotypic coefficients of variation for all the characters and this indicate high influence of environment on the expression of these traits. PCV is highest in the character leaf/ plant, plant in 60 days and lowest in the character branch number/ plant in 90 days. Leaf plant^{-1} in 60 days (51.405) and branch number/plant in 90 days (39.115) showed high estimates of GCV. Length of petiole in 60 days (18.982) and Leaf width in 60 days (18.657) showed moderate estimates of GCV.

Sarker *et al.* (2014) reported high range of variability and high genotypic variance for traits like plant height, leaves/plant, diameter of stem base, leaf area and foliage yield/plot. Close differences between genotypic and phenotypic variances and genotypic and phenotypic coefficient of variations were also observed for all the traits.

Genetic variability studies in related crops

An experiment was conducted by Varalakshmi and Devaraju (2010) to study the genetic variability in Indian spinach (*Baselal alba* L.) taking 11 germplasm lines. They reported that phenotypic coefficient of variation was higher than genotypic coefficient of variation for all the traits studied, indicating environmental influence on expression of these characters.

Chander Parkash (2012) conducted a research on Estimation of genetic variability and implications of direct and indirect effects of different traits on leaf yield in bathua (*Chenopodium album*) among 60 indigenous and exotic germplasm lines. His research results revealed that the phenotypic coefficients of variation were higher than genotypic coefficients of variation for all the characters. The estimates of genotypic coefficient of variation were higher for number of leaves/plant (46.75%), followed by leaf width (47.07%) and leaf yield/plant (46.43%).

Heritability and Genetic advance studies in Amaranthus

Heritability and genetic advance were found high for number of leaves, leaf weight, stem weight, leaf-stem ratio and yield of greens per plant by Varalakshmi and Reddy (1994).

In a study on Amaranthus, Lohithaswa *et al.* (1996) noticed that high heritability coupled with moderate genetic advance for plant height indicating that additive gene effects were operating for these characters and selection pressure could be applied on them for yield improvement. Moderate heritability with moderate genetic advance values were observed for both plant fresh weight, and stem girth at collar region indicating the importance of both additive and non-additive gene actions for these characters.

Revanappa and Madalgeri (1998) reported that heritability in broad sense was high for most of the characters studied but genetic advance was high for green yield per plant (61.07%) and other yield parameters.

High heritability coupled with high genetic advance was noticed for foliage yield (75%), leaf size (74.98%) and leaves/plant (73.43%), indicating the prevalent role of additive gene effects. (Sukla and Singh, 2000)

According to Bhargava *et al.* (2003) heritability values were high ranging from 17.31 to 76.87%. Maximum heritability was observed for leaf size (76.87%) followed by foliage yield (72.22%) and leaves/plant (52.30%). Low heritability was observed for plant height (17.31 %) and branches/plant (17.80%), indicating a major influence of environment. Genetic gain was reported maximum for leaf size (94.63%), followed by foliage yield (70.13%) and number of leaves/plant (37.52%). High heritability coupled with high genetic gain was observed for leaf size, foliage yield and number of leaves/plant indicating a possible role of additive gene effect for the genotypic variance for these characters.

Rani and Veeraragavathatham (2003) noticed high heritability coupled with high genetic advance 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.

According to Shukla *et al.* (2006) found that the values of heritability estimates were high for all the traits in all the cuttings as well as on pooled basis and ranged from 0.89 for branches/plant to 0.98 for foliage yield in Amaranthus. Genetic advance was maximum for foliage yield (42.50%), followed by leaf size (31.02%) and stem diameter (21.13%).

Anuja and Mohideen (2007) reported high heritability coupled with high genetic advance (as per cent of mean) for number of leaves, root length, root weight, leaf weight and stem weight in Amaranthus. Hence, these characters need to be given more importance in selection as these are expected to be controlled by additive genes.

According to Pan *et al.* (2008) heritability along with genetic advance was high for leaf: stem ratio, width of leaf, total yield of greens/plot and length of leaf in Amaranthus.

Smitha and Krishnakumary (2011) reported high heritability and genetic advance for grain yield and plant height in evaluation of the variability and performance of 23 grain amaranth accessions.

Ahammed *et al.* (2012) reported that the heritability estimates in broad sense were higher for leaf weight per plant (91.10%) followed by leaves per plant (86.83%), primary branches per plant (86.42%), stem weight per plant (82.56%) and yield per hectare (78.70%) and lowest in leaf breadth (29.44%). Leaf weight per plant, stem weight per plant and yield per hectare exhibited high value of heritability (91.10%, 82.56% and 78.70%) along with high genetic advance (49.38%, 134.12% and 56.00%), respectively. The lowest value of genetic advance was observed for leaf: stem ratio (0.09%).

High heritability coupled with high genetic advance was observed for plant height, number of leaves, leaf length, leaf width and green yield per plant indicating that additive gene effects were operating for these characters and selection pressure could be applied on them for yield improvement. (Anuja, 2012)

According to Hasan *et al.* (2013) high heritability with high genetic advance as percent of mean was registered for number of leaves, leaf weight and marketable yield which in fact demonstrated the presence of additive gene effects in Amaranthus.

Khurana *et al.* (2013) reported high values of heritability coupled with high genetic gain for the characters like total green yield and leaf area index were obtained indicating the preponderance of additive gene effect and suggested that desired improvement in these characters can be brought through direct selection for these component traits.

Heritability and Genetic advance studies in related crops

Moderate heritability along with high genetic advance for leaf weight and total plant weight, indicating the presence of additive gene effects were reported in Indian spinach (*Baselal alba* L.). (Varalakshmi and Devaraju, 2010).

In Bathua, Chander Parkash (2012) found that the heritability estimates (H^2) were high (>80%) for all the five characters, i.e. plant height, number of leaves/plant, leaf length, leaf width and leaf yield. In spite of high heritability values for all the traits, the expected genetic advance as per cent of mean ranged from 35.86 to 95.01.

2.5 Character association (Correlation)

The most important economic character in crop plant is yield, which is complex one and is dependent on a number of directly or indirectly associated traits. Therefore, knowledge on the nature of association of different attributes with yield is essential. The nature of association between two components may be positive or negative. When any two attributes are positively associated then selection for one will indirectly result in selection of other. When any two attributes are negatively correlated, selection of one will have adverse effect for the selection of the other character. The association between two attributes directly evaluated from the phenotypic correlation which may be due to genetic, environment or both. Thus the utility of correlation studies is enhanced further when phenotypic association is partitioned into genetic and environmental correlation. Pleiotropy and linkage are the genetic causes of association between two characters. The quantitative traits are controlled by polygenes, whose linkage is the cause of genetic correlation. However, genetic correlation resulting from linkage is transient and can be modified by recombination. Pleiotropy refers to the property of certain genes influencing two or more characters. So genetic correlation may be positive or negative depending on pleiotropic effects on the correlated characters and cannot be modified by recombination.

Selection for one character would result in progress for all positively correlated characters. This relation suggests the advantage of a scheme for more than one character at a time (Baha Eldin *et al*., 1958). If negative correlation exists between components of yield, then selection is to be done for intermediate combination for improvement of yield.

Character association in Amaranthus (Correlation studies)

Abbott (1982) conducted an experiment on field evaluation of vegetable amaranth amaranthus spp. taking 20 genotypes in the field at Beltsville, Maryland, USA. He concluded that yield was negatively correlated with leaf: stem ratio (r = -0.56**).

Yield of greens showed highly significant and positive association with plant height, leaf length, leaf breadth, stem girth, leaf weight and stem weight, which indicates the importance of these characters during selection for high yielding genotypes in vegetable amaranth. (Varalakshmi and Reddy, 1994)

Shukla and Singh (2003) conducted an experiment on character association studies in grain amaranth (Amaranthus spp.) taking 66 genotypes grown in Lucknow. They have concluded that the genotypic correlation was generally higher than the corresponding phenotypic correlation. At the phenotypic level, significant and positive association was observed between plant height and number of primary branches per plant, and number of nodes per plant and leaf size. Leaf size was positively associated with all the characters except inflorescence length.

Pan *et al.* (2008) reported that the genotypic correlation coefficients were higher in magnitude than the phenotypic correlation coefficients.

Leaves per plant, stem diameter, stem weight per plant, leaf weight per plant and plant height exhibited highly significant positive correlation with yield per hectare both at genotypic and phenotypic level. (Ahammed *et al.*, 2012)

Shankar *et al.* (2012) reported that yield/plot had a significant positive correlation with leaf length (r = 0.44), leaf width (r = 0.51), stem weight (r = 0.98), leaf weight (r = 0.94), number of leaves/plant and shoot weight (r = 0.98).

In the correlation studies, strong positive association of yield with leaf weight, stem weight and stem diameter was reported by Hasan et al. (2013).

Khurana *et al.* (2013) conducted an experiment for correlation study of quantitative characters and concluded that plant height was positively correlated with number of branches per plant (0.6491), leaf length (0.3381), leaf width (0.41954), number of leaves per plant (0.5254), leaf area index (0.5604), total green yield, while number of leaves per plant was positively correlated with leaf area index (0.9210), total green yield (0.9529). Leaf area index was positively correlated with total green yield (0.9660). The genotypic coefficients of correlation, in general, were high in magnitude than corresponding phenotypic coefficients of correlation indicating that there is an inherent association among the various characters studied and phenotypic expression of correlation was subdued under the influence of environment. Total green yield exhibited highly significant and positive correlation with plant height, number of branches per plant, leaf length, leaf width, number of leaves, and leaf area index both at genotypic and phenotypic levels.

Sarker *et al.* (2014) found significant positive correlation with plant height, leaves per plant, diameter of stem base, fiber content and leaf area.

Hailu *et al.* (2015) from a correlation study reported less value of phenotypic correlation coefficient than the genotypic correlation coefficient in most of the characters. The green leaf yield per plant showed a positive and significant relationship with the majority of the traits except lateral inflorescence which had negative significant association with green leaf yield in Amaranthus.

Correlation studies in related crops

According to Chander Parkash (2012) the genotypic correlation coefficients were in general higher in magnitude than the corresponding phenotypic correlation coefficients. All the characters were positively correlated with leaf yield but significant and positive correlation with leaf yield were shown only by plant height and number of leaves/plant in bathua.

2.6 Path analysis

Yield is a complex trait resulting from direct and indirect effects of several traits operating either in combination or individually. Selection for a trait is one direction may influence another trait by a direct or indirect effect via a third variable. The study of correlation gives only the extent of association among various characters taken in pairs. This extent of association does not imply the cause and effect relationship. Therefore, the path coefficient analysis is used to determine the direct and indirect effects of various plant characters on crop yield.

According to Wright (1921), path coefficient analysis provides a better knowledge of direct and indirect causes of associations and it permits a critical examination of specific forces acting to produce a given correlation and measures the relative importance of each causal factors. This method was first used by Dewey and Lu (1959) in their analysis of seed yield in crested wheat grass. Since then several workers have applied this method for analysis of character association in various crops.

Path analysis in Amaranthus

Ivara (1986) conducted a path analysis study in Amaranthus and reported that the plant weight and harvest index were the best positive indicators of plant yield.

From a path analysis study in grain Amaranthus (*Amaranthus spp*.) Shukla and Singh (2003) reported that the leaf size was indirectly associated with grain yield via plant height and number of inflorescences per plant. Plant height was also indirectly and positively associated with yield via the number of inflorescences per plant and leaf size. Leaf size, plant height and number of inflorescences per plant comprised the major yield components.

Path coefficient analysis of different characters contributing towards total yield of greens revealed that length of leaf and width of leaf have positive direct effect on total yield was reported by Pan *et al.* (2008).

Among the agronomic traits, plant height (0.12), stem diameter (0.21), leaves per plant (0.45) had substantial positive direct effects on foliage yield, while, characters like branches per plant (-1.22), leaf size (-0.27) showed negative direct effect on foliage yield. (Shukla *et al.*, 2010)

According to Hasan *et al.* (2013) the result of path analysis indicated that stem weight had maximum direct effect on marketable yield followed by leaf weight and leaf number in Amaranthus.

In a study on Amaranthus, Khurana *et al.* (2013) reported that the number of leaves per plant had highest (0.4933) positive direct effect on total green yield followed by leaf area index (0.4268), leaf length (0.0986), plant height (0.0915), leaf width (0.0487) and protein content (0.0208). The indirect effect of leaf area index on total green yield was highest (0.4543) in positive direction via number of leaves per plant.

Based on path coefficient values, direct selection through three traits, i.e., leaf area diameter of stem base and leaf weight would significantly improve the foliage yield of vegetable amaranth. (Sarker *et al.*, 2014)

Hailu *et al.* (2015) observed that the maximum positive direct effects were recorded in biomass per plant, leaf area, leaf width and plant height.

Path analysis in related crops

Varalakshmi and Devaraju (2010) noticed that the leaf number had the maximum direct positive effect on total plant weight, followed by leaf length. Indirect effects of other characters through these characters were also seen to be positive. Thus, for yield improvement in Basella, emphasis may be laid on indirect selection through leaf characters like leaf number, leaf length and leaf weight.

From a path analysis study, Chander Parkash (2012) observed that the number of leaves had highest direct effect (0.6279) on leaf yield, followed by leaf length (0.1728) and suggested that direct selection could be made for these characters for improving leaf yield. Further, plant height showed maximum positive indirect effect (0.2084) via number of leaves towards leaf yield hence simultaneous selection for number of leaves/plant and plant height can be made for the improvement of leaf yield in bathua.

2.7 Genetic divergence

Selection of genetically divergent varieties is important in the exploitation of heterosis and in development of transgressive segregates for an efficient breeding programme. The information regarding the nature and magnitude of genetic distance among the genotypes will help the breeder choosing the suitable diverse combinations.

Genetic divergence in Amaranthus

Pan *et al.* (1992) studied the genetic divergence among a set of 45 genotypes of vegetable amaranth (*Amaranthus tricolor* L.) developed from the material collected from indigenous and exotic sources for different characters. The lines/varieties differed significantly for all the characters. Analysis of variance revealed differences among the genotypes for all 10 characters. Using multivariate analysis, the genotypes were grouped into 10 clusters. The number of genotypes in clusters 1 to 10 was 7, 8, 5, 7, 4, 5, 3, 3, 2 and 1, respectively. The intra-cluster value was least in cluster 4 and highest in cluster 8. The inter-cluster value was maximum between clusters 1 and 3, suggesting that the genotypes in these clusters were highly divergent from each other. The genotypes in clusters 4 and 7 were the least divergent at the inter-cluster level. Clustering pattern was not associated with geographic distribution. Cluster 7 had low mean values for leaf-stem ratio and high mean values for diameter of stem, length of lamina and total yield. Cluster 3 had the highest mean value for width of lamina. About 87% of the genetic diversity present in the 45 genotypes occurred in the first 2 canonical roots. Duration of harvest and total yield accounted for most of the variation present.

An experiment on genetic divergence was conducted by Joshi and Rana (1995) in grain amaranth (*Amaranthus hypochondriacus*) evaluating 20 diverse genotypes. On the basis of D^2 analysis, the genotypes were grouped into 9 clusters. These clusters were heterogeneous for geographical origin of the genotypes. Genotypes of cluster II showed the highest grain yield, inflorescence number, leaf length and number of leaves.

Shukla and Singh (2002) studied to assess the genetic diversity of 66 amaranth genotypes for different agronomic traits. The genotypes were grouped into 9 clusters. Cluster VIII had the maximum grain yield and was next to the highest leaf size. Cluster III had the highest number of inflorescence per plant and was next to the highest grain yield. The grain yield in different clusters was greatly influenced by plant height, number of inflorescence and nodes per plant and leaf size. Among the different traits that had the maximum contribution towards divergence was plant height, number of nodes per plant and leaf size.

Hazra *et al.* (2004) conducted an experiment on genetic diversity in grain amaranth genotypes (*Amaranthus spp*.) among 47 genotypes of Indian and exotic origin using the Mahalanobis D^2 statistic. The genotypes were grouped in to 22 clusters. Intra-cluster distance was highest for cluster VII followed by cluster II which included 13 genotypes from different states in India. The highest inter-cluster distance was recorded between cluster XII and XIII followed by cluster VI and XVII. The clustering pattern indicated that the geographic diversity was not necessarily related with genetic diversity. Shoot dry weight, biological yield, terminal panicle number, yield/ plant were identified as potential variability which can be used as parameters while selecting diverse parents in the hybridization programme for yield and quality improvement.

Pandey (2009) evaluated 26 accessions of grain Amaranths (*Amaranthus hypochondriacus*), including both indigenous and exotic introductions. Based on D^2 analysis, the accessions were grouped into eleven clusters. Clusters I, II, and III had seven, four, and three accessions, respectively; clusters VII, VIII, IX and X had only one accession in each case. The accession in cluster V had the greatest divergence, closely followed by those of clusters IV and I. The maximum and minimum divergences were revealed between clusters VIII and XI and between II and VII, respectively.

Pandey and Singh (2011) conducted an experiment on genetic divergence in grain amaranthus (*Amaranthus hypocondriacus* L.) among 98 genotypes for the purpose of identifying more diverse parents which are expected to engender maximum variability. Based on genetic divergence D^2 statistics, genotypes were grouped into 18 clusters in which cluster I contained maximum number of genotypes (42), Cluster II (11), Cluster III (7), Cluster IV and V (5 in each case) and Cluster VI has 4 genotypes. Cluster VII, VIII, IX, X have (3 in each), cluster XI, XII, XIII, XIV (2 in each) and clusters XV, XVI, XVII and XVIII (1in each case). The clustering pattern revealed that there was no relationship between genetic divergence and eco-geographical region. Intra cluster values ranged from 0.00 to 141.86 and cluster XI is most diverse group. The inter cluster values ranged from 133.08 to 1214.59. Maximum divergence was noticed between clusters VIII and XI (1214.59) followed by clusters XI and XV (982.16) and clusters II and XI (938.89).

A study conducted by Shankar *et al.* (2012) consisting 28 accessions of Amaranthus, comprising *A. tricolor*, *A. cruentus*, *A. hybridus* and *A. dubius* classified them into 12 cluster groups at 0.78 Euclidean distances: clusters I, II, III and V were major clusters having 14, 2, 2 and 2 accessions, respectively.

Genetic divergence in related crops

In a research on Chenopodium, Bhargava *et al.* (2007) evaluated 29 germplasm lines for different morphological traits for two test seasons. The traits were analyzed for cluster and principal component analysis. The first four clusters contributed 78.70 % of the variability among the germplasm lines. The first cluster accounted for 39.5% of the variation and had inflorescence/plant, plant height and stem diameter as the traits with largest coefficients, all with positive sign. The characters with greatest positive weight on cluster 2 were branches/plant. All the germplasm lines were grouped into six clusters based on average linkage method.

RESULTS

The experimental results obtained after proper statistical analysis of present investigation "Variability studies in Amaranthus (*Amaranthus spp.*)" conducted during kharif season 2014-15 for 13 characters from 12 diverse genotypes of Amaranthus, are presented under following major heads:

4.1 Analysis of variance
4.2. Mean performance
4.3 Genetic parameters
4.4 Character association analysis
4.5 Path coefficient analysis
4.6 Genetic divergence

4.1 Analysis of Variance

Analysis of variance of twelve different genotypes of Amaranthus for 13 characters is presented in Table 5. The analysis of variance of mean was carried out for various yield and yield contributing traits i.e. plant height(cm), number of nodes per plant, number of leaves per plant, number of inflorescence per plant, stem girth (cm), leaf length (cm), leaf breadth (cm), petiole length (cm), leaf area (cm^2), stem weight (g), leaf weight (g), leaf : stem ratio and yield per plant (g).The data revealed that the treatments significantly differ for all the characters showing that the material under study has sufficient genetic variability.

4.2 Mean performance of genotypes

4.2.1 Mean and range

The mean performance, standard error of variance (SE) and critical difference (CD) are presented in Table 6.

4.2.1.1 Plant height

A wide range of variability ranging from 34.523cm to 70.183cm was noticed with respect to plant height. Highest plant height was recorded in germplasm V_3 (70.183cm) which was closely followed by V_4 (67.827cm), V_7 (65.177cm) and V_2

(61.730cm). Lowest height was observed in V_{10} (34.523cm) followed by V_{12} (39.840cm) in ascending order. The germplasm like V_1 (54.957cm), V_5 (58.147cm) and V_8 (51.763cm) were of medium type.

Table 5. Analysis of variance for 13 quantitative characters studied in Amaranthus germplasm

Sl. No.	Characters	Mean Sum of Square		
		Replication (2)	Genotypes (11)	Error (22)
1.	Plant height(cm)	7.325	376.774**	17.281
2.	Number of nodes per plant	0.582	8.196**	1.313
3.	Number of leaves per plant	11.731	514.216**	14.025
4.	Number of inflorescence per plant	1.336	45.959**	0.748
5.	Stem girth(cm)	0.305	1.458**	0.157
6.	Leaf length(cm)	0.081	1.640**	0.230
7.	Leaf breadth(cm)	0.023	0.462**	0.061
8.	Petiole length(cm)	0.142	1.507**	0.067
9.	Leaf area(cm^2)	1.158	55.032**	6.309
10.	Stem weight(g)	5222.500	267423.468**	3736.306
11.	Leaf weight(g)	1746.333	47717.300**	2377.387
12.	Leaf : stem ratio	0.0004	0.465**	0.002
13.	Yield per plant(g)	12937.333	419466.406**	11940.674

** Significant at 1% level

Figure in the parenthesis indicate degree of freedom of respective sources of variation

4.2.1.2 Number of nodes per plant

A low range of variation from 11.967 to 18.700 was observed among the genotypes for this trait. The germplasm V_4 produced maximum number of nodes per plant (18.700) followed by the germplasm V_{11} (15.900) and V_9 (15.033). Minimum numbers of nodes were observed in V_{10} (11.967).

4.2.1.3 Number of leaves per plant

A significant variation was visualized in number of leaves per plant among the genotypes ranging from 43.667 to 94.233. The germplasm V_{11} recorded the highest number of leaves per plant (94.233) closely followed by V_4 (93.100). The lowest number of leaves per plant (43.667) was observed in V_7. The germplasm like V_2 (70.433), V_9 (72.000), V_{12} (72.067), V_{10} (72.433) and V_8 (76.400) have shown medium value for the character in ascending order.

4.2.1.4 Number of inflorescences per plant

A wide range of variation was observed for number of inflorescence per plant among the genotypes evaluated ranging from 1.233 to 12.267. The highest number of inflorescence per plant (12.267) was recorded in V_3 followed by (10.200) in V_1 whereas the lowest number of inflorescence per plant (1.233) was recorded in V_9 followed by V_{10} (1.367).

4.2.1.5 Stem girth

A narrow range of variation was observed among the twelve germplasm with respect to stem girth. Maximum stem girth (4.870cm) was recorded in V_{11} followed closely by V_4 (4.867cm). However the lowest stem girth (2.567cm) was recorded in V_{10} followed by (3.297cm) in V_6.

4.2.1.6 Leaf length

Leaf length recorded a moderate variation ranging from 9.510cm to 6.573cm. V_4 (9.510cm) recorded the maximum leaf length which is closed followed by V_6 (8.980cm). The lowest value (6.573cm) was recorded in V_{10}. Some of the lines showing medium value for this trait were V_8 (7.503cm), V_{11} (7.537cm), V_{12} (7.733cm) and V_5 (7.887cm) in order.

4.2.1.7 Leaf breadth

A narrow range of variation was observed among the twelve germplasm with respect to leaf breadth. Highest leaf breadth was recorded in V_{10} (5.690cm) closely followed by V_7 (5.637cm). However the lowest leaf breadth (4.433cm) was recorded in V_3 followed by (4.747cm) in V_9.

4.2.1.8 Petiole length

A moderate range of variation was recorded ranging from 4.770cm to 2.747cm among the twelve germplasm for this trait. The maximum value of petiole length was observed in V_9 (4.770cm) closely followed by V_4 (4.667cm). The minimum value of (2.747cm) was recorded in V_2 closely followed by V_{12} (2.840cm) in higher magnitude.

4.2.1.9 Leaf area

The germplasm V_4 recorded the highest leaf area (44.317cm^2) followed by 37.077(cm^2) in V_7. The lowest leaf area (27.360cm^2) was recorded in V_3 followed by (29.993cm^2) in V_{10}. The germplasm like V_1 (34.277cm^2), V_6 (35.417cm^2) and V_5 (35.600cm^2) have shown medium value for the character.

4.2.1.10 Stem weight

A significantly wide range of variation from 102.733g to 1268.133g was noticed with respect to stem weight. The stem weight was maximum for V_4 (1268.133g). Minimum stem weight was observed in V_{10} (102.733g) followed by V_9 (296.867g). However, V_3 (791.233g), V_{11} (760.733g) and V_2 (731.933g) were of medium type.

4.2.1.11 Leaf weight

The maximum leaf weight was observed in V_4 (534.700g) followed by V_8 (506.500g). However the minimum value (142.967g) was recorded in case of V_{10} closely followed by (147.200g) in V_3.

4.2.1.12 Leaf: stem ratio

A significantly wide range of variation was observed among the twelve germplasm with respect to leaf: stem ratio. The highest value (1.399) was recorded in case of V_{10} which was closely followed by (1.302) in V_8. The lowest value (0.184) was observed in V_3. The germplasm like V_5 (0.616), V_7 (0.620) and V_{12} (0.749) have sown medium value for the character.

Table 6. Mean of performance of 12 amaranthus genotypes for 13 characters

Notation	Genotypes	Plant height (cm)	No. of nodes per plant	No. of leaves per plant	No. of inflorescence per plant	Stem girth (cm)	Leaf Length (cm)	Leaf breadth (cm)	Petiole length (cm)	Leaf area (cm^2)	Stem weight (g)	Leaf weight (g)	Leaf : stem ratio	Yield per plant(g)
V_1	2012/AMVAR-1	54.957	14.067	69.067	10.200	3.527	8.147	5.310	3.997	34.277	607.967	341.733	0.559	949.700
V_2	2012/AMVAR-2	61.730	14.433	70.433	9.667	4.017	8.023	5.587	2.747	33.143	731.933	415.867	0.567	1147.800
V_3	2012/AMVAR-3	70.183	14.033	69.600	12.267	3.370	8.240	4.433	4.313	27.360	791.233	147.200	0.184	938.433
V_4	2012/AMVAR-4	67.827	18.700	93.100	5.300	4.867	9.510	5.607	4.667	44.317	1268.133	534.700	0.421	1802.833
V_5	2012/AMVAR-5	58.147	14.567	62.933	8.433	3.540	7.887	5.417	4.557	35.600	648.467	398.467	0.616	1046.933
V_6	2012/AMVAR-6	48.990	14.733	67.033	2.033	3.297	8.980	4.993	3.497	35.417	609.833	239.167	0.390	849.000
V_7	2012/AMVAR-7	65.177	14.933	43.667	4.567	4.663	8.307	5.637	3.277	37.077	548.467	341.433	0.620	889.900
V_8	ARKA SUGUNA	51.763	14.933	76.400	1.467	3.647	7.503	5.457	3.487	33.553	391.567	506.500	1.302	898.067
V_9	ARUN	44.387	15.033	72.000	1.233	3.620	8.240	4.747	4.770	30.630	296.867	377.200	1.287	674.067
V_{10}	UTKAL MAYURI	34.523	11.967	72.433	1.367	2.567	6.573	5.690	3.297	29.993	102.733	142.967	1.399	245.700
V_{11}	BHINGARPUR (LOCAL)	49.160	15.900	94.233	6.167	4.870	7.537	5.407	3.273	32.997	760.933	414.200	0.545	1175.133
V_{12}	SALEPUR (LOCAL)	39.840	12.700	72.067	2.367	4.177	7.733	5.057	2.840	31.113	340.467	255.133	0.749	595.600
	SE(±)	3.394	0.936	3.058	0.707	0.324	0.392	0.202	0.211	2.051	49.909	39.811	0.042	89.221
	CD(0.05)	7.039	1.941	6.342	1.465	0.672	0.812	0.419	0.438	4.253	103.505	82.564	0.086	185.035

4.2.1.13 Yield per plant

The data presented in the table clearly showed distinct variation for yield per plant among the genotypes ranging from 1802.833g to 245.700g. Maximum yield per plant was observed in V_4 (1802.833g) followed by V_{11} (1175.133g) and minimum yield per plant was recorded in V_{10} (245.700g) followed by V_{12} (595.600g).

4.2 Co-efficient of variance (C.V)

The Co-efficient of variance with respect to different characters is presented in Table7, which ranged from 4.69% to 15.96%. The highest variation (15.96%) was noticed in number of inflorescence per plant followed by leaf weight (14.22%) and yield per plant (11.69%). However the lowest variation (4.69%) was recorded in leaf breadth followed by number of leaves per plant (5.21%) and leaf length (5.95%) in ascending order. Therefore, basing on the C.V value, the characters can be grouped into three classes such as:

Low variability (C.V = 5% or less)

Moderate variability (C.V = 5-10%)

High variability (C.V = >10%)

Thus the only trait leaf breadth exhibited low variability. On the contrary, the traits like plant height, number of nodes per plant, number of leaves per plant, leaf length, petiole length, leaf area and leaf: stem ratio recorded moderate variability. Number of inflorescence per plant, stem girth, stem weight, leaf weight and yield per plant exhibited high variability.

4.3 Estimation of genetic parameters

The estimates of genetic parameters *viz.*, phenotypic variance and genotypic variance are presented in table 7. Further, their respective coefficient of variation i.e. PCV and GCV, heritability in broad sense, genetic advance and genetic advance as percentage of mean are presented in Table 8.

Table 7.General mean, range, co-efficient of variation (C.V), genotypic variance, phenotypic variance for 13 quantitative characters in Amaranthus germplasm

Sl. No.	Characters	General Mean	Range	C.V (%)	Genotypic Variance	Phenotypic Variance
1.	Plant height(cm)	53.890	34.523 - 70.183	7.71	119.831	137.113
2.	Number of nodes per plant	14.667	11.967 - 18.700	7.81	2.294	3.608
3.	Number of leaves per plant	71.914	43.667 - 94.233	5.21	166.730	180.756
4.	Number of inflorescence per plant	5.422	1.233 - 12.267	15.96	15.070	15.819
5.	Stem girth(cm)	3.847	2.567 - 4.870	10.32	0.434	0.591
6.	Leaf length(cm)	8.057	6.573 - 9.510	5.95	0.470	0.700
7.	Leaf breadth(cm)	5.278	4.433 - 5.690	4.69	0.134	0.195
8.	Petiole length(cm)	3.727	2.747 - 4.770	6.94	0.480	0.547
9.	Leaf area(cm^2)	33.790	27.360 - 44.317	7.43	16.241	22.551
10.	Stem weight(g)	591.550	102.733 - 1268.133	10.33	87895.719	91632.023
11.	Leaf weight(g)	342.881	142.967 - 534.700	14.22	15113.305	17490.691
12.	Leaf : stem ratio	0.720	0.184 - 1.399	7.08	0.154	0.157
13.	Yield per plant(g)	934.431	245.700 - 1802.833	11.69	135841.906	147782.578

On examining the data in table 8, it was clearly observed that phenotypic variance was higher as compare to the genotypic variance for all the characters under studies. The genotypic variance ranged from 0.134 for leaf breadth to 135841.906 for yield per plant. The phenotypic variance ranged from 0.157 for leaf: stem ratio to 147782.578 for yield per plant. In general all the traits exhibited parallel values between those two variance showing lower value in the former than later.

The perusal of data in Table 8 revealed that the magnitude of phenotypic coefficient of variation (PCV) was greater than the corresponding genotypic coefficient of variation (GCV) for all characters. The PCV was highest (73.352) for number of inflorescence per plant followed by leaf: stem ratio (55.045). Traits like stem weight (51.172), yield per plant (41.140) and leaf weight (38.571) exhibited

Table 8. Genotypic co-efficient of variation (GCV), Phenotypic co-efficient of variation (PCV), Heritability (in broad sense), Genetic advance and GA expressed in % of Mean for 13 quantitative characters studied in Amaranthus

Sl. No.	Characters	Phenotypic co-efficient of variation (PCV)	Genotypic co-efficient of variation (GCV)	Heritability (in broad sense) (%)	Genetic advance	GA Expressed in % of mean
1.	Plant height(cm)	21.728	20.313	87.40	21.08	39.118
2.	Number of nodes per plant	12.950	10.327	63.59	2.48	16.965
3.	Number of leaves per plant	18.695	17.955	92.24	25.54	35.524
4.	Number of inflorescence per plant	73.352	71.595	95.27	7.80	143.953
5.	Stem girth(cm)	19.989	17.120	73.35	1.16	30.204
6.	Leaf length(cm)	10.385	8.509	67.13	1.15	14.362
7.	Leaf breadth(cm)	8.365	6.930	68.63	0.62	11.826
8.	Petiole length (cm)	19.849	18.595	87.76	1.33	35.886
9.	Leaf area(cm^2)	14.053	11.926	72.02	7.04	20.850
10.	Stem weight(g)	51.172	50.117	95.92	598.15	101.116
11.	Leaf weight(g)	38.571	35.853	86.41	253.4	68.656
12.	Leaf : stem ratio	55.045	54.587	98.34	0.802	111.515
13.	Yield per plant(g)	41.140	39.443	91.92	734.94	77.900

moderate value. While, other traits like plant height (21.728), stem girth (19.989), petiole length (19.849), number of leaves per plant (18.695), leaf area (14.053), number of nodes per plant (12.950) and leaf length (10.385) showed lower values having lowest value (8.365) for leaf breadth.

More or less similar trend was observed in the estimate of GCV for all the traits with number of inflorescence per plant having the highest value (71.595) followed by leaf: stem ratio (54.587). The values were moderate in traits like stem weight (50.117), yield per plant (39.443) and leaf weight (35.853). Lower values were observed for traits like plant height (20.313), stem girth (17.120), petiole length (18.595), number of leaves per plant (17.955), leaf area (11.926), number of nodes per plant (10.327) and leaf length (8.509), recording the lowest value (6.930) by leaf breadth.

4.3.1 Heritability

Heritability (broad sense) estimates (Table 8) ranged from 63.59% to 98.34%. Very high heritability above 85% were observed in traits like leaf: stem ratio (98.34%), stem weight (95.92%), number of inflorescence per plant (95.27%), number of leaves per plant (92.24%), yield per plant (91.92%), petiole length (87.76%), plant height (87.40%) and leaf weight (86.41%). High heritability above 60% were observed in rest of traits like stem girth (73.35%), leaf area (72.02%), leaf breadth (68.63%), leaf length (67.13%) and number of nodes per plant (63.59%).

4.3.2 Genetic advance

The genetic advance varied from 0.62 (leaf breadth) to 734.94 (yield per plant). High genetic advance was also observed in stem weight (598.15), leaf weight (253.4), number of leaves per plant (25.54) and plant height (21.08) were also observed. All the remaining characters showed low to very low value for genetic advance, being lowest in leaf breadth (0.62).

The predicted genetic advance expressed as percent of population mean ranged from 143.953% for number of inflorescence per plant to 11.826% for leaf breadth. Highest expected genetic gain by selection was observed in the trait number of inflorescence per plant (143.953%). Other characters showing genetic gain of higher magnitude were leaf: stem ratio (111.515%) followed by stem weight

(101.116%), yield per plant (77.900%) and leaf weight (68.656%) while rest of the traits showed moderate to low value being lowest in leaf breadth (11.826%).

4.4 Character association

Estimates of Phenotypic and Genotypic correlation co-efficient of all pairs of thirteen characters related to fruit yield are presented in Table-9 and Table-10 respectively.

4.4.1 Phenotypic correlation

Yield per plant was positively and significantly correlated with plant height (0.674), number of nodes per plant (0.774), stem girth (0.624), leaf length (0.596), leaf area (0.655), stem weight (0.954) and leaf weight (0.724), whereas it is significantly and negatively correlated with leaf: stem ratio (-0.578). Rests of the characters though have positive association with yield but the values are insignificant.

Plant height was significantly and positively correlated with number of inflorescence per plant (0.671), stem weight (0.736) and yield per plant (0.674) whereas it is positively associated with number of nodes per plant (0.524), stem girth (0.391), leaf length (0.519), petiole length (0.299), leaf area (0.369) and leaf weight (0.277) having insignificant values. On the contrary, it was negatively and significantly correlated with leaf: stem ratio (-0.651). Further this trait exhibited negative association with number of leaves per plant (-0.111) and leaf breadth (-0.028) having insignificant values.

Number of nodes per plant was positively and significantly correlated with leaf area (0.613), stem weight (0.707), leaf weight (0.632) and yield per plant (0.774). Rests of the characters like number of leaves per plant (0.411), number of inflorescence per plant (0.093), stem girth (0.567), leaf length (0.521), leaf breadth (0.143), petiole length (0.329) were positively correlated and leaf: stem ratio (-0.287) was negatively correlated having insignificant values.

Number of leaves per plant was positively correlated with characters like stem girth (0.264), leaf length (0.030), leaf breadth (0.022), petiole length (0.107), leaf area (0.143), stem weight (0.378), leaf weight (0.344), leaf: stem ratio (0.013), yield per plant (0.416) and negatively correlated with number of inflorescence per plant (-0.036) having insignificant values in all cases.

Table 9.Phenotypic correlation co-efficient (r_p) between all pairs of 13 quantitative characters in Amaranthus germplasm

Characters		Number of nodes per plant	Number of leaves per plant	Number of inflorescence per plant	Stem girth (cm)	Leaf length (cm)	Leaf breadth (cm)	Petiole length (cm)	Leaf area (cm^2)	Stem weight (g)	Leaf weight (g)	Leaf : stem ratio	Yield per plant (g)
Plant height(cm)	r_p	0.524	-0.111	0.671*	0.391	0.519	-0.028	0.299	0.369	0.736**	0.277	-0.651*	0.674*
Number of nodes per plant	r_p		0.411	0.093	0.567	0.521	0.143	0.329	0.613*	0.707*	0.632*	-0.287	0.774**
Number of leaves per plant	r_p			-0.036	0.264	0.030	0.022	0.107	0.143	0.378	0.344	0.013	0.416
Number of inflorescence per plant	r_p				0.093	0.140	-0.147	0.178	-0.065	0.529	-0.036	-0.678*	0.404
Stem girth(cm)	r_p					0.295	0.257	-0.091	0.419	0.550	0.556	-0.348	0.624*
Leaf length(cm)	r_p						-0.251	0.390	0.691*	0.639*	0.272	-0.559	0.596*
Leaf breadth(cm)	r_p							-0.337	0.404	0.031	0.335	0.213	0.140
Petiole length(cm)	r_p								0.194	0.296	0.148	-0.076	0.284
Leaf area(cm^2)	r_p									0.580*	0.576*	-0.255	0.655*
Stem weight(g)	r_p										0.483	-0.755**	0.954**
Leaf weight(g)	r_p											0.048	0.724**
Leaf: stem ratio	r_p												-0.578*

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

Number of inflorescence per plant was negatively and significantly correlated with leaf: stem ratio (-0.678). On the other hand it was positively correlated with characters like stem girth (0.093), leaf length (0.140), petiole length (0.178), stem weight (0.529), yield per plant (0.404) and negatively correlated with leaf breadth (-0.147), leaf area (-0.065) and leaf weight (-0.036) having insignificant values.

Stem girth was positively and significantly correlated with yield per plant (0.624), while, it was positively correlated with leaf length (0.295), leaf breadth (0.257), leaf area (0.419), stem weight (0.550), leaf weight (0.556) and negatively correlated with petiole length (-0.091) and leaf: stem ratio (-0.348) with insignificant values.

A significant and positive association was observed for leaf length with leaf area (0.691), stems weight (0.639), yield per plant (0.596), whereas it was insignificantly and positively correlated with petiole length (0.390) and leaf weight (0.272). Characters like leaf breadth (-0.251) and leaf: stem ratio (-0.559) were negatively and insignificantly associated with this parameter.

Leaf breadth was positively correlated with leaf area (0.404), stem weight (0.031), leaf weight (0.335), leaf: stem ratio (0.213), yield per plant (0.140) and negatively correlated with petiole length (-0.337) with insignificant values.

Petiole length was positively correlated with leaf area (0.194), stems weight (0.296), leaf weight (0.148), and yield per plant (0.284) and negatively correlated with leaf: stem ratio (- 0.076), having insignificant values.

Leaf area was significantly and positively correlated to stems weight (0.580), leaf weight (0.576) and yield per plant (0.655). On the other hand, it was negatively and insignificantly correlated with leaf: stem ratio (-0.255).

Stem weight showed a positive and significant correlation with yield per plant (0.954). While, it was negatively and significantly correlated with leaf: stem ratio (-0.755). However this trait exhibited a non-significant positive association with leaf weight (0.483).

Leaf weight was positively correlated with yield per plant (0.724) and leaf: stem ratio (0.048), having significant value in the former.

Leaf: stem ratio showed a negative and significant correlation with yield per plant (-0.578).

4.4.2 Genotypic correlation

The genotypic correlation co-efficient for all the thirteen characters related to yield per plant are presented in Table 10. Perusal of the data in the above cited table indicated that, yield per plant was significantly and positively correlated to plant height (0.765), number of nodes per plant (0.991), stem girth (0.729), leaf length (0.768), leaf area (0.797), stem weight (0.955) and leaf weight (0.696), while significantly but negatively associated to leaf: stem ratio (-0.604). The characters like number of leaves per plant (0.446), number of inflorescence per plant (0.433), leaf breadth (0.242) and petiole length (0.360) were positively associated with yield per plant. But the association was found to be non-significant.

Plant height was significantly and positively correlated with number of nodes per plant (0.600), number of inflorescence per plant (0.671), leaf length (0.675), stem weight (0.812) and yield per plant (0.765) while negatively and significantly correlated with leaf: stem ratio (-0.714). Rest of the characters like stem girth (0.436), petiole length (0.339), leaf area (0.447) and leaf weight (0.335) were positively and number of leaves (-0.149), leaf breadth (-0.033) were negatively associated with this trait having insignificant values.

Number of nodes per plant exhibited significant positive correlation with stem girth (0.776), leaf length (0.883), leaf area (0.899), stem weight (0.885), leaf weight (0.837) and yield per plant (0.991). Insignificant positive association was exhibited by the traits like number of leaves per plant (0.492), number of inflorescence per plant (0.076), leaf breadth (0.179), petiole length (0.550) while insignificant negative association was exhibited by leaf: stem ratio (-0.395).

Table 10.Genotypic correlation co-efficient (r_g) between all pairs of 13 quantitative characters in Amaranthus germplasm

Characters		Number of nodes per plant	Number of leaves per plant	Number of inflorescence per plant	Stem girth (cm)	Leaf length (cm)	Leaf breadth (cm)	Petiole length (cm)	Leaf area (cm^2)	Stem weight (g)	Leaf weight (g)	Leaf : stem ratio	Yield per plant (g)
Plant height(cm)	r_g	0.600*	-0.149	0.705*	0.436	0.675*	-0.033	0.339	0.447	0.812**	0.335	-0.714**	0.765**
Number of nodes per plant	r_g		0.492	0.076	0.776**	0.883**	0.179	0.550	0.899**	0.885**	0.837**	-0.395	0.991**
Number of leaves per plant	r_g			-0.059	0.273	0.061	0.050	0.156	0.172	0.397	0.380	-0.005	0.446
Number of inflorescence per plant	r_g				0.090	0.197	-0.165	0.176	-0.061	0.554	-0.037	-0.705*	0.433
Stem girth(cm)	r_g					0.526	0.273	-0.082	0.672*	0.632*	0.661*	-0.414	0.729**
Leaf length(cm)	r_g						-0.187	0.477	0.622*	0.802**	0.369	-0.668*	0.768**
Leaf breadth(cm)	r_g							-0.374	0.660*	0.083	0.525	0.250	0.242
Petiole length(cm)	r_g								0.252	0.356	0.223	-0.080	0.360
Leaf area(cm^2)	r_g									0.692*	0.721**	-0.294	0.797**
Stem weight(g)	r_g										0.450	-0.774**	0.955**
Leaf weight(g)	r_g											0.056	0.696*
Leaf: stem ratio	r_g												-0.604*

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

Number of leaves per plant was insignificantly and negatively correlated to number of inflorescence per plant (-0.059) and leaf: stem ratio (-0.005). All other characters like stem girth (0.273), leaf length (0.061), leaf breadth (0.050), petiole length (0.156), leaf area (0.0.172), stem weight (0.397), leaf weight (0.380) and yield per plant (0.446) exhibit positive correlation only, with this character.

Number of inflorescence per plant was negatively and significantly associated with leaf: stem ratio (-0.705) while with leaf breadth (-0.165), leaf area (-0.061) and leaf weight (-0.037) it was negatively correlated having insignificant values. Rest of the characters like stem girth (0.090), leaf length (0.197), petiole length (0.176), stem weight (0.554) and yield per plant (0.433) were insignificantly and positively correlated to this trait.

Stem girth was positively and significantly correlated with leaf area (0.672), stem weight (0.632), leaf weight (0.661) and yield per plant (0.729). Characters like leaf length (0.526), leaf breadth (0.273) exhibited positive correlation, while petiole length (-0.082) and leaf: stem ratio (-0.414) exhibited negative correlation with insignificant values with this character.

Leaf length showed a significant and positive correlation with leaf area (0.622), stem weight (0.802) and yield per plant (0.768), whereas it was significantly and negatively associated with leaf: stem ratio (-0.668). Further, this trait showed positive correlation with petiole length (0.477), leaf weight (0.369) and negative association with leaf breadth (-0.187) having insignificant value.

Leaf breadth was positively and significantly correlated to leaf area (0.660). It was insignificantly correlated with the characters like stem weight (0.083), leaf weight (0.525), leaf: stem ratio (0.250), yield per plant (0.242) having positive value, whereas, to leaf length (-0.374) having negatively value.

Petiole length exhibited positive correlation with leaf area (0.252), stem weight (0.356), leaf weight (0.223), yield per plant (0.360) and negative correlation with leaf: stem ratio (-0.080). But all the associations were found to be non-significant.

Leaf area was significantly and positively correlated with characters like stem weight (0.692), leaf weight (0.721) and yield per plant (0.797), while negatively correlated with leaf: stem ratio (-0.294) having insignificant value.

Stem weight was significantly and positively correlated to yield per plant (0.955) and significantly and negatively correlated to leaf; stem ratio (-0.774) while it was positively and insignificantly associated with leaf weight (0.450).

Leaf weight showed positive correlation with yield per plant (0.696) and leaf: stem ratio (0.056) with significant value in the former.

Leaf: stem ratio was significantly and negatively correlated with yield per plant (-0.604).

4.5 Path co-efficient analysis

The path co-efficient analysis was carried out taking 13 quantitative traits in Amaranthus, in order to establish the cause and effect relationship on yield per plant with these characters. The correlations of yield per plant with other characters were partitionised into component of direct and indirect effects that would reflect on the nature of these association and relative importance of the components in determining yield. The genotypic correlation co-efficient was used in path analysis and the results (genotypic path) are presented in Table 11.

Genotypic path analysis Table 11 indicated that stem weight had the highest positive direct effect (0.80425) on yield per plant followed by leaf weight (0.33357). Positive direct effects were also observed for plant height (0.00013), number of leaves per plant (0.00006), petiole length (0.00004), leaf breadth (0.00002) and number of nodes per plant (0.00001). Rest of characters showed negative direct effect being highest in leaf: stem ratio (-0.00014) followed by number of inflorescence per plant (-0.00009), leaf length (-0.00006), stem girth -0.00001) and leaf area (-0.00001).

Stem weight had the highest positive direct effect (0.80425) on yield per plant. These indirect highest effects were mainly resulted by positive indirect effect via leaf weight (0.15025), leaf: stem ratio (0.00011), plant height (0.00010), number of leaves per plant (0.00002), number of nodes per plant (0.00001), leaf breadth (0.00001) and petiole length (0.00001). The indirect effect of stem weight via leaf length (-0.00005), number of inflorescence per plant (-0.00005), stem girth (-0.00001) and leaf area (-0.00001) were in negative direction.

Leaf: stem ratio showed the negative direct effect (-0.00014). The indirect effect of leaf: stem ratio via stem weight (-0.62276), plant height (-0.00009), petiole length (-0.00001), number of nodes per plant(-0.00001) and number of leaves per plant (-0.00001) were in negative direction while rest of the characters like number of inflorescence per plant (0.00007), stem girth (0.00001), leaf length (0.00004), leaf breadth (0.00001), leaf area (0.00001) and leaf weight (0.01868) were found to exert positive indirect effect.

High positive direct effect (0.33357) was observed by leaf weight, which was mainly contributed by indirect positive via plant height (0.00004), number of nodes per plant (0.00001), number of leaves per plant (0.00002), number of inflorescence per plant (0.00001), leaf breadth (0.00001), petiole length (0.00001) and stem weight (0.36225). The indirect effect of leaf weight was in negative direction via stem girth (-0.00001), leaf length (-0.00002), leaf area (0.00001) and leaf: stem ratio (-0.00001).

Plant height showing positive direct effect (0.00013) resulted mainly indirect positive effect via number of nodes per plant (0.00001), petiole length (0.00001), stem weight(0.65307), leaf weight (0.11176) and leaf: stem ratio (0.00010) while for rest of the characters like number of leaves per plant (-0.00001), number of inflorescence per plant (-0.00007), stem girth (-0.00001), leaf length (-0.00004), leaf breadth (-0.00001) and leaf area (-0.00001) the effect was on negative direction.

Other characters such as number of leaves per plant (0.00006), petiole length (0.00004) and leaf breadth (0.00002) showed positive direct effect being lowest in number of nodes per plant (0.00001). The lowest positive direct effect for number of nodes was due to negative indirect effect via number of inflorescence per plant (-0.00001), stem girth (-0.00001), leaf length (-0.00006) and leaf area (-0.00001) in spite of positive indirect effect via other traits for this character.

Table 11.Estimate of direct (diagonal) and indirect effect of component characters on yield in Amaranthus germplasm

Characters	PH	NN	NL	NI	SG	LL	LB	PL	LA	SW	LW	LSR	GCWY
PH	0.00013	0.00001	-0.00001	-0.00007	-0.00001	-0.00004	-0.00001	0.00001	-0.00001	0.65307	0.11176	0.00010	0.765
NN	0.00008	0.00001	0.00003	-0.00001	-0.00001	-0.00006	0.00001	0.00002	-0.00001	0.71172	0.27919	0.00006	0.991
NL	-0.00002	0.00001	0.00006	0.00001	-0.00001	-0.00001	0.00001	0.00001	-0.00001	0.31961	0.12681	0.00001	0.446
NI	0.00009	0.00001	-0.00001	-0.00009	-0.00001	-0.00001	-0.00001	0.00001	0.00001	0.44521	-0.01228	0.00010	0.433
SG	0.00006	0.00001	0.00002	-0.00001	-0.00001	-0.00003	0.00001	-0.00001	-0.00001	0.50806	0.22050	0.00006	0.729
LL	0.00009	0.00001	0.00001	-0.00002	-0.00001	-0.00006	-0.00001	0.00002	-0.00001	0.64476	0.12299	0.00009	0.768
LB	-0.00001	0.00001	0.00001	0.00002	-0.00001	0.00001	0.00002	-0.00001	-0.00001	0.06707	0.17510	-0.00003	0.242
PL	0.00004	0.00001	0.00001	-0.00002	0.00001	-0.00003	-0.00001	0.00004	-0.00001	0.28603	0.07438	0.00001	0.360
LA	0.00006	0.00001	0.00001	0.00001	-0.00001	-0.00004	0.00001	0.00001	-0.00001	0.55652	0.24051	0.00004	0.797
SW	0.00010	0.00001	0.00002	-0.00005	-0.00001	-0.00005	0.00001	0.00001	-0.00001	0.80425	0.15025	0.00011	0.955
LW	0.00004	0.00001	0.00002	0.00001	-0.00001	-0.00002	0.00001	0.00001	-0.00001	0.36225	0.33357	-0.00001	0.696
LSR	-0.00009	-0.00001	-0.00001	0.00007	0.00001	0.00004	0.00001	-0.00001	0.00001	-0.62276	0.01868	-0.00014	-0.604

Figures underlined denoted the Direct Effect
Residual effect = 0.457279

PH = Plant height (cm)
SG = Stem girth (cm)
LA = Leaf area (cm^2)
GCWY = Genotypic correlation with yield
NN = Number of nodes per plant
LL = Leaf length (cm)
SW = Stem weight (g)
NL = Number of leaves per plant
LB = Leaf breadth (cm)
LW = Leaf weight (g)
NI = Number of inflorescence per plant
PL = Petiole length (cm)
LSR = Leaf: stem ratio

The negative direct effect of number of inflorescence per plant (-0.00009) was via the negative indirect effect of number of leaves per plant, stem girth, leaf length, leaf breadth and highest being leaf weight (-0.01228), in spite of positive indirect effect by rest of the characters among which stem weight (0.44521) was higher magnitude.

Leaf area showed negative direct effect (-0.00001), mainly via the negative effect of leaf length (-0.00004), stem girth (-0.00001), in spite of high positive indirect effect via stem weight (0.55652) and leaf weight (0.24051)

From the path analysis, it appeared that stem weight, leaf weight and plant height showed high direct effect on yield per plant in Amaranthus. High indirect effects through these characters were also observed.

4.6 Genetic divergence

4.6.1 Clustering pattern

Twelve genotypes were grouped into six different genetic clusters on the basis of genetic affinity/ diversity as measured by D^2 using Tocher's method, Table 12. Three germplasm each included in Cluster I such as 2012/AMVAR-1(V_1), 2012/AMVAR-2(V_2), 2012/AMVAR-5(V_5) and Cluster III such as 2012/AMVAR-3(V_3), 2012/AMVAR-6(V_6), BHINGARPUR (LOCAL) (V_{11}) were the largest group.

Cluster II and IV were comprised of 2 germplasm each. ARKA SUGUNA (V_8) and ARUN (V_9) were in Cluster II, while, 2012/AMVAR-7 (V_7) and SALEPUR (LOCAL) (V_{12}) in Cluster IV respectively.

Cluster V and VI each having one germplasm each namely 2012/AMVAR-4 (V_4) and UTKAL MAYURI (V_{10}) respectively.

4.6.2 Intra and inter-cluster distances

From the average intra and inter cluster distance presented in Table-13 it is evident that among the multivariate Cluster, Cluster V and VI had the minimum intra-cluster distance (very insignificant value), whereas maximum intra-cluster distance (D^2 =860.487) was observed in Cluster III.

Table 12.Clustering Pattern of 12 Amaranthus germplasm

Cluster No.	Number of Amaranthus	Name of Germplasm (with entry number)
I	3	2012/AMVAR-1(V_1), 2012/AMVAR-2(V_2), 2012/AMVAR-5(V_5)
II	2	ARKA SUGUNA(V_8), ARUN(V_9)
III	3	2012/AMVAR-3(V_3), 2012/AMVAR-6(V_6), BHINGARPUR(LOCAL) (V_{11})
IV	2	2012/AMVAR-7(V_7), SALEPUR(LOCAL) (V_{12})
V	1	2012/AMVAR-4(V_4)
VI	1	UTKAL MAYURI(V_{10})

Table 13.Intra Diagonal and Inter cluster average (D^2) corresponding D ($\sqrt{D^2}$) Values (in parenthesis) among groups

Cluster	I	II	III	IV	V	VI
I	75.018 (8.661)	1459.508 (38.204)	706.329 (26.577)	428.629 (20.703)	2683.723 (51.805)	1193.912 (34.553)
II		107.070 (10.347)	3226.155 (56.799)	870.856 (29.510)	6544.656 (80.899)	529.433 (23.009)
III			860.487 (29.334)	1543.926 (39.293)	1545.109 (39.308)	2791.976 (52.839)
IV				288.372 (16.982)	4575.239 (67.641)	480.543 (21.921)
V					0.000 (0.000)	6537.438 (80.854)
VI						0.000 (0.000)

The average inter-cluster distance indicated that the most divergent Clusters were Cluster II and Cluster V (6544.656) followed by Cluster V and Cluster VI (6537.438), Cluster IV and Cluster V (4575.239) and Cluster II and Cluster III (3226.155) in order.

4.6.3 Characteristics features of six clusters

The cluster means of 13 quantitative characters for groups of Amaranthus germplasm are presented in Table 14.

Cluster I consisting of three Amaranthus germplasm showed the highest value in number of inflorescence per plant (9.433). For rest of the characters moderate expressions were observed.

Cluster II having two germplasm showed the minimum value for the character number of inflorescence per plant (1.350). Rest characters have moderate expressions.

Three germplasm were grouped in Cluster III which were giving lowest values for leaf breadth (4.944) and leaf: stem ratio (0.373).

Cluster IV consisted of two germplasm which were having lowest values for number of leaves per plant (57.867) and petiole length (3.058) but moderate value for various characters under study.

Cluster V with one germplasm having highest values for most of the characters like plant height (67.827), number of nodes per plant (18.700), number of leaves per plant (93.100), stem girth (4.867), leaf length (9.510), petiole length (4.667), leaf area (44.317), stem weight (1268. 133), leaf weight (534.700) and yield per plant (1802.833).

Cluster VI having one germplasm exhibited maximum diversity as it shows the lowest values in plant height (34.523), number of nodes per plant (11.967), stem girth (2.567), leaf length (6.573), leaf area (29.993), stem weight (102.733), leaf weight (142.967) and yield per plant (245.700). In contrary highest value were observed in leaf breadth (5.690) and leaf: stem ratio (1.399) in this cluster.

Table 14.Mean of 13 characters in different clusters of Amaranthus germplasm

Sl. No	Clusters / Characters	I (3)	II (2)	III (3)	IV (2)	V (1)	VI (1)
1.	Plant height(cm)	58.278	48.075	56.111	52.508	67.827**	34.523*
2.	Number of nodes per plant	14.356	14.983	14.889	13.817	18.700**	11.967*
3.	Number of leaves per plant	67.478	74.200	76.956	57.867*	93.100**	72.433
4.	Number of inflorescence per plant	9.433**	1.350*	6.822	3.467	5.300	1.367
5.	Stem girth(cm)	3.694	3.633	3.846	4.420	4.867**	2.567*
6.	Leaf length(cm)	8.019	7.872	8.252	8.020	9.510**	6.573*
7.	Leaf breadth(cm)	5.438	5.102	4.944*	5.347	5.607	5.690**
8.	Petiole length(cm)	3.767	4.128	3.694	3.058*	4.667**	3.297
9.	Leaf area(cm^2)	34.340	32.092	31.924	34.095	44.317**	29.993*
10.	Stem weight(g)	662.789	344.217	720.667	444.467	1268.133**	102.733*
11.	Leaf weight(g)	385.356	441.850	266.856	298.283	534.700**	142.967*
12.	Leaf : stem ratio	0.581	1.294	0.373*	0.685	0.421	1.399**
13.	Yield per plant(g)	1048.144	786.067	987.522	742.750	1802.833**	245.700*

*and ** indicate lowest and highest values

figure in the parenthesis indicate number of cultivars in a cluster.

Table 15. Relative contribution to different characters to genetic divergence in Amaranthus germplasm

Sl. No.	Characters	No. of first rank	% Contribution
1.	Plant height(cm)	0	0.001
2.	Number of nodes per plant	0	0.000
3.	Number of leaves per plant	1	1.515
4.	Number of inflorescence per plant	0	0.000
5.	Stem girth(cm)	0	0.000
6.	Leaf length(cm)	0	0.000
7.	Leaf breadth(cm)	0	0.000
8.	Petiole length(cm)	1	1.515
9.	Leaf area(cm^2)	0	0.000
10.	Stem weight(g)	3	4.545
11.	Leaf weight(g)	13	19.697
12.	Leaf : stem ratio	15	22.727
13.	Yield per plant(g)	33	50.000
Total		66	100

4.6.4 Relative contribution of characters to divergence

The relative contribution of 13 quantitative traits to genetic divergence among the 12 germplasm of Amaranthus was presented in Table-15 by rank average of individual character over all 66 paired combinations.

The character contributing maximum divergence needs greater emphasis for deciding on the cluster for the purpose of selection of parents in respective cluster for hybridization. The number of times, each of the component character appeared first in rank and its respective percent of contribute on towards genetic divergence was analyzed.

Among the yield contributing characters, the maximum contribution towards divergence was made by yield per plant (50.000%) followed by leaf: stem ratio (22.727%) and leaf weight (19.697%) occupying first rank 33, 15 and 13 times respectively. Rests of the characters contributing to the divergence in order were stem weight (4.545%), petiole length (1.515%) and number of leaves per plant (1.515%).

DISCUSSION

The effectiveness of any crop improvement programme involving selection and hybridization depends on the existence of genetic variability among the tested materials (genotypes) and extend to which the characters are heritable (heritability). Therefore, it is a pre-requisite to access the nature and magnitude of variability as one of the basic principles for achieving success in a breeding programme. Further, information on association of various components for the desirable character for selection is of immense importance. The cause and effect relationship among the various correlated characters play an important role subjected to improvement also need attention. In addition to this, computation of the genetic divergence among the selected materials (germplasm) for the character proposed to be improved also having significant importance.

Considering the importance of above factors for improvement in Amaranthus, the present experiment "Variability studies in Amaranthus (*Amaranthus spp*.)" was conducted during the kharif season of year 2014 (July 2014-November 2014) at All India Co-ordinated Research Project on Vegetable Crops (AICRP), Bhubaneswar, to select the superior genotypes, in order to improve their productivity and adoptability, under Bhubaneswar condition of Odisha. The experimental findings of the above study presented in the foregoing chapters have shown some outstanding results which have been discussed and interpreted hereafter.

5.1 Pattern of variation in plant attributes

The nature and magnitude of variability for 13 different quantitative characters are clearly observed in Amaranthus on examining of ANOVA. The value indicates highly significant differences for all the characters under study, there by suggesting existence of large amount of variations among the genotypes. So, there is a scope for considerable improvement in this crop through characters studied such as plant height, number of nodes per plant, number of leaves per plant, number of inflorescence per plant, stem girth, leaf length, leaf breadth, petiole length, leaf area, stem weight, leaf weight, leaf: stem ratio and yield per plant. Similar to the present findings investigation carried out earlier reported wide variation for various characters by Varalakshmi and Reddy (1994), Revanappa and Madalgeri (1998), Anuja and Mohideen (2007), Pan *et al.* (2008), Ahammed *et al.* (2012), Khurana *et al.* (2013), Parveen *et al.* (2014) and Hailu *et al.* (2015) in Amaranthus and Chander Parkash (2012) in Chenopodium.

It may be contemplated from the statistics of range and general mean values of the characters that there is a great deal of variability for each character under study. Further, these statistics quite hopefully provides a strong impetus of selecting genotypes for specific objectives, because of the magnitude and wide spectrum of variations observed in each character among the genotypes under evaluation.

In Amaranthus, yield per plant, stem weight, leaf weight, number of leaves per plant, plant height and leaf size (leaf length, leaf breadth and leaf area) are important characters for selecting ideal genotypes. Among the genotypes evaluated high to moderate values are obtained in 2012/AMVAR-4 (V_4), BHIGARPUR LOCAL (V_{11}), 2012/AMVAR-2 (V_2), 2012/AMVAR-5 (V_5) and 2012/AMVAR-1 (V_1) suggesting suitability of these genotypes for cultivation at Bhubaneswar in Odisha. The information on these characters in the above genotypes showed a parallelism effect indicating that these characters are much interrelated and interdependent. This is in agreement to findings of Revanappa and Madalgeri (1998), Vujacic (2005), Ahammed *et al.* (2012) and Hasan *et al.* (2013) in Amaranthus. Further, the coefficient of variation (C.V) being less than 20% for all the characters studied among the genotypes as such indicates that good precision is maintained in conducting the experiment, which is in consonance the findings of Shankar *et al.* (2012) in Amaranthus.

For understanding a breeding principle in any crop improvement programme two aspects are most important i.e. (i) selection cannot create variability but act only on that which is already in existence, (ii) selection can act effectively only on heritable differences (Allard, 1960). Thus the first and foremost necessity for selection is to ascertain whether the genetic variability for these characters is present in population at significant level or not. Further, the phenotypic mean values are the basis of comparison may fall far short of requirement and may even be misleading as the phenotypic effect sometimes influenced by environment, thereby may not necessarily represent the genotypic values. To avoid this misleading information for the correct interpretation of data, on the sound genetic principle, statistics such as variance and coefficient of variation etc. are to be computed for proper evaluation. The estimates of genetic parameters such as phenotypic and genotypic variance computed here as per method suggested by Burton and Devance (1953) along with the coefficient of variations permits a sound basis to determine the variability components so also to know the relative amount of heritable and non-heritable variation for each of these characters.

From the present study, it is clearly observed that there exists a wide range of phenotypic as well as genotypic variation (Table-7) for the 13 quantitative characters in Amaranthus. The existence of minimum variation between these two parameters indicated that environment has a little effect in expression of these characters in Amaranthus and phenotype truly represents to the genotype. The existence of large genotypic variability for yield per plant, leaf weight, stem weight, number of leaves per plant and plant height etc. indicated that measure part is attributed through its additive interaction instead of dominance and epistatic components and usually favors an effective selection. Lohithaswa *et al.* (1996), Anuja and Mohideen (2007), Anuja (2012) and Sarker *et al.* (2014) observed similar trend for various characters in Amaranthus which is inconformity with the present findings.

In comparing the phenotypic coefficient of variation and genotypic coefficient of variation values (Table-8) it is observed that in general the former values are greater than the later in respect of all the 13 quantitative characters under study and the difference between the two is quite less in some of the characters, suggesting a negligible influence of environment on expression of such characters. This is in agreement with the findings of Revanappa and Madalgeri (1998), Bhargava *et al.* (2003), Anuja and Mohideen (2007), Smitha and Krishnakumary (2011) and Sarker *et al.* (2014) in Amaranthus, Varalakshmi and Devaraju (2010) in Indian spinach and Chander Parkash (2012) in Chenopodium. Further, phenotypic coefficient of variation exhibiting parallelism effect with genotypic coefficient of variation, indicated the phenotypes truly represent the genotypes. In the present study, presence of high to moderate coefficient of variations for number of inflorescence per plant, leaf: stem ratio, stem weight, yield per plant, leaf weight, plant height and number of leaves per plant indicated the presence of good amount of variability among the materials evaluated, so selection for these characters may be quite hopefully used in Amaranthus improvement programme. Revanappa and Madalgeri (1998), Anuja and Mohideen (2007), Pan *et al.* (2008), Ahammed *et al.* (2012), Shankar *et al.* (2012) and Khurana *et al.* (2013) observed the similar trend, which is in agreement with the present findings. Rest of the characters showing low values for this parameter may of least significance for Amaranthus improvement programme.

The heritability which is a major of selection for a particular character in various types of progeny and is index of transmissibility is primarily an interest to a plant breeder. Poehlman and Borthakeer, 1972 opined that the characters not influenced by environment will have high heritability. According to Randhawa *et al*. (1975) higher the heritability value of a character less will be the environmental influence for expression of that character, thereby indicating better opportunity for selecting a genetically good individual. In the present experiment very high to high heritability values above 80% has been obtained for eight characters such as leaf: stem ratio, stem weight, number of inflorescence per plant, number of leaves per plant, yield per plant, petiole length, plant height and leaf weight suggesting that these characters might be highly heritable and less influenced by environment and selecting genotypes on the basis of such characters would be worthwhile in Amaranthus improvement. The results obtained are agreement with the findings of Reddy (1994), Bhargava *et al.* (2003), Shukla *et al.* (2006) and Ahammed *et al.* (2012) in Amaranthus and Chander Parkash (2012) in bathua.

It is suggested by Weber and Moorthy (1952) that information concerning heritability of quantitative characters and their genetic and environmental variances when considered together might be useful for improving the efficiency of selection. Considering the heritability estimates with genotypic coefficient of variation values

(Table-8) it is observed that high values are obtained for both the parameters in case of leaf: stem ratio, stem weight, number of inflorescence per plant, number of leaves per plant, yield per plant and plant height. So, selection may be quite effective based on these characters. Similar results were reported by Revanappa and Madalgeri (1998), Anuja and Mohideen (2007) and Khurana *et al.* (2013) in Amaranthus. On the other hand, deviations were noticed from the findings of previous worker in the present study which is due to difference in genetic stock and environmental variation.

Though the study of heritability estimate is important, their scope is limited since they are estimated in broad sense and are prone to change with change in environment and the testing material. Further, the heritability estimate by itself may not be alone a useful index of genetic potentiality of a character. According to Eswro *et al*. (1963), genetic advance (GA) indicates the potentiality of selection at a particular level of selection intensity. Thus, heritability estimates along with genetic advance are more valuable than heritability alone in predicting the response of selection (Johanson *et al*., 1955; Robinson, 1963). High heritability does not necessarily mean that the character will show high genetic advance, but when such compatible association exist (high heritability and high GA) additive genes come into prominence because no genetic advance is due to non-additive genes. The selection based on a character showing high genetic gain (GA) may be desirable particularly in case of directional selection, when the main aim of the selection is to change the mean value of a character to have better standards. On the other hand, high heritability accompanied with low genetic advance indicates the prominence of non-additive gene effect, suggesting heterosis breeding (hybridization) instead of direct selection. In the present investigation high estimates of heritability coupled with high genetic advance for characters such as number of inflorescence per plant, leaf: stem ratio, stem weight, yield per plant, leaf weight, number of leaves per plant and plant height may be ascribed due to effect of additive genes (Panse and Sukhatme, 1954; Liang and Walter, 1968) may be amenable for selection. The present findings are inconformity with the work of Varalakshmi and Reddy (1994), Revanappa and Madalgeri (1998), Sukla and Singh (2000), Rani and Veeraragavathatham (2003), Anuja and Mohideen (2007), Pan *et al.* (2008), Ahammed *et al.* (2012), Anuja (2012), Hasan *et al.* (2013)

and Khurana *et al.* (2013) in Amaranthus. Considering the three genetic parameters together such as genotypic coefficient of variation, heritability and predicted genetic gain at a glance (Table-8) it is observed that characters like number of inflorescence per plant, leaf: stem ratio, stem weight, yield per plant, leaf weight and plant height showing high to moderate values for the above three important genetic parameters suggested that additive gene action is responsible for expression of these characters. So, direct selection through these characters will be effective in improvement programme of Amaranthus. This is in agreement with the findings of Revanappa and Madalgeri (1998), Anuja and Mohideen (2007) and Khurana *et al.* (2013) in Amaranthus.

5.2 Character association (Correlation study)

In Amaranthus the yield (leaf and stem) is the most economic character. The total yield (green yield) is the ultimate effect of interaction of several quantitative characters that are highly susceptible to change in environment. Hence, selection based on green leaf alone may not be a very sound preposition for effective selection. Among various component characters which directly and positively correlated with yield (green yield) often act as a useful indicator in the selection. Thus, sound knowledge of such association among the various characters particularly in relation to total green yield is a prime importance in planning a successful and effective breeding programme. According to Robinson (1966), correlation studies are helpful in choosing superior genotypes from the phenotypic expression. Thus, after obtaining information on variability, heritability and genetic advance (variation and genetic parameters) available in the present set of germplasm (variety/genotype), attempt has been made to study the inter-relationship of these quantitative traits both at phenotypic and genotypic levels.

The perusal of result (Table-9 and 10) of the present investigation exhibited that the genotypic correlation coefficients showed higher values for most of the variable pairs than the phenotypic correlation coefficients, suggesting that there is a strong inherent association between the various characters studied. Further, as the genotypic correlation coefficients showed a parallel value to the phenotypic correlation coefficients, it may be assumed that there is not much influence of environment in determining the association of these attributing characters with total yield and possibly due to a strong genetical makeup of the evaluated materials (genotypes).

Wigan and Mather (1942, suggested that strong positive association of character with yield may be attributed to linkage and pleiotropy. In the present study, significant positive correlation was observed both at phenotypic and genotypic levels for yield per plant (green yield per plant) with plant height, number of nodes per plant, stem girth, leaf length, leaf area, stem weight and leaf weight. Further, plant height was positively and significantly correlated with number of inflorescence per plant and stem weight. Number of nodes per plant was significantly and positively correlated with leaf area, stem weight and leaf weight. Leaf length was significantly and positively correlated with leaf area and stem weight. Leaf area was also found to be significantly and positively correlated with stem weight and leaf weight. These correlations suggested that selection for these component traits simultaneously will be effective in improving the yield (green yield per plant) in Amaranthus. In case of other pair of characters showing significant negative correlation value and insignificant value either positive or negative at phenotypic and genotypic levels have least importance for effective selection based on these characters. In conformity to the present findings Varalakshmi and Reddy (1994), Shukla and Singh (2003), Pan *et al.* (2008), Ahammed *et al.* (2012), Shankar *et al.* (2012), Hasan et al. (2013), Sarker *et al.* (2014) and Hailu *et al.* (2015) in Amaranthus and Chander Parkash (2012) in bathua reported higher values of genotypic correlation coefficients than phenotypic correlation coefficients and strong and positive association of yield per plant with other variable characters like plant height, number of nodes per plant, stem girth, leaf length, stem weight and leaf weight. Further, Abbott (1982) also reported yield was negatively but significantly correlated with leaf: stem ratio which is inconformity with present finding.

From the above discussion on character association it may be suggested that plant height, number of nodes per plant, stem girth, leaf length, leaf area, stem weight and leaf weight are the important correlated characters contributing towards yield (green yield) in Amaranthus and simultaneous improvement of these traits will be helpful in improvement programme in this crop.

5.3 Direct and indirect effect of characters

Correlation coefficient which measures the association between any two characters may not give a true comprehensive picture in a complex situation. The associations between any two characters which are measured do not exist by themselves alone but are part of complicated pathway in which other traits are also interwoven. The indirect association becomes complex and important due to number of variables in correlation study. In addition to this, the mutual relationship among different characters which may be positive or negative make the situation complicated. In such situation, path coefficient analysis devised by Wright (1921) provides a better knowledge as it reveals direct and indirect causes of association and permits a critical examination of specific forces acting to produce a given correlation and measure the relative importance of each causal factors.

The cause and effect relationships with values of correlation and path coefficient for the components of yield (green yield) at genotypic level of present investigation are presented in Table-11. The genotypic path coefficient analysis exhibited that stem weight had the maximum positive direct effect followed by leaf weight on yield (green yield) of Amaranthus. Further, plant height, number of leaves per plant, petiole length, leaf breadth, number of nodes per plant produced positive direct effects of very lower magnitude. On the other hand, leaf: stem ratio, number of inflorescence per plant, leaf length, stem girth and leaf area had negative direct effects on yield (green yield) being highest in leaf: stem ratio. The low positive or negative direct effect resulted due to cancellation by the respective indirect effects via stem weight, leaf weight and plant height.

The indirect effect of stem weight via leaf weight, leaf: stem ratio and plant height producing a high positive direct effect for these characters. Similarly, leaf weight has the high direct effect which is contributed mainly by the positive indirect effect via stem weight. The findings are in agreement with the findings of Hasan et al. (2013), who reported stem weight had maximum direct effect followed by leaf weight on yield. Further, Khurana *et al.* (2013), Sarker *et al.* (2014) reported highest positive direct effects of plant height and leaf weight respectively on green yield of Amaranthus, as observed in the present investigation.

On the basis of present findings it may be inferred that stem weight and leaf weight are two important yield contributing components in Amaranthus. Further, the correlation coefficients of stem weight, leaf weight (both causal factors) and yield per plant (the effect) being positive and having a little difference with its direct effects explain the true relationship and thus direct selection through stem weight and leaf weight in Amaranthus improvement programme could be effective.

5.4 Genetic divergence

The multivariate analysis based on Mahalonobis' D^2 statistics is being employed as a powerful tool for measuring genetic divergence among the tested genotypes. Ramanujan *et al*. (1974) have categorically suggested the merits of D^2 statistics for genetic grouping of germplasms. In the present investigation, the grouping by multivariate technique has shown good results (Table-12).

Being a numerical estimate the multivariate technique had the added advantage over other criteria of permitting precise comparison among all possible pairs of population in any given group. Since, the estimates are obtained from study of potential parents themselves, the required information is available before deciding parents for future recombination breeding, thus, can be used with advantage.

It is well established that hybrid derivatives from divergent parents are found to be promising, probably because of complementary interaction of divergent genes in the parents taken for cross in the parents. The present study envisaged that Cluster II comprising of two genotypes and Cluster V consisting of one genotype showing highest inter-cluster distance are most divergent clusters. So, promising hybrid derivatives can be obtained by crossing the parents of these two divergent groups.

It was also observed that characters like yield per plant, leaf: stem ratio, leaf weight and stem weight had contributed predominantly towards genetic divergence. So, selection of parents differing in these quantitative traits may be proved useful for heterosis breeding programme in Amaranthus.

SUMMARY AND CONCLUSION

6.1 Summary

The present investigation "Variability studies in Amaranthus (*Amaranthus spp*.)" was undertaken to access the comparative performance, genetic variability, character association, the cause and effect relationship to determine direct and indirect contribution of various characters with most economic character green yield (leaf and stem) through path analysis. In addition to this attempt was also made to access genetic divergence among the genotypes by D^2 statistics to formulate a suitable breeding programme for improvement in Amaranthus. Twelve genotypes (varieties/lines) collected from various sources maintained at All India Co-ordinated Research Project (AICRP) on Vegetable Crops, Bhubaneswar were subjected to evaluation for 13 quantitative characters such as plant height, number of nodes per plant, number of leaves per plant, number of inflorescence per plant, stem girth, leaf length, leaf breadth, petiole length, leaf area, stem weight, leaf weight, leaf: stem ratio and yield per plant. The results of the investigation are summarized below.

1. A wide range of variation was noticed for all the characters as revealed through statistics of range and coefficient of variation. Further, analysis of variance indicated that the 12 genotypes of Amaranthus under study differ significantly among themselves for all the 13 quantitative characters studied.

2. Among the genotypes 2012/AMVAR-4 (V_4), BHIGARPUR LOCAL (V_{11}) and 2012/AMVAR-2 (V_2) are the ideal genotypes for cultivation at Bhubaneswar (Odisha).

3. Presence of minimum difference between phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) for all the characters indicated that the phenotypes represent true to the genotypes. Expression of high to moderate PCV and GCV for characters like number of inflorescence per plant, leaf: stem ratio, stem weight, yield per plant, leaf weight and plant height indicated the presence of good amount of variability among the materials evaluated, so selection for such characters will be helpful in Amaranthus.

4. High heritability (>80%) were observed for eight characters such as leaf: stem ratio, stem weight, number of inflorescence per plant, number of leaves per plant, yield per plant, petiole length, plant height and leaf weight. Moderate to high heritability (60-80%) were observed for rest five characters.

5. Highest genetic advance as percentage of mean was observed in number of inflorescence per plant followed by leaf: stem ratio, stem weight, yield per plant and leaf weight. Rest of the characters showed low to moderate value for this genetic parameter.

6. Considering the three genetic parameters together such as genotypic coefficient of variation (GCV), heritability estimate and genetic advance as percentage of mean altogether at a glance, phenotypic selection for number of inflorescence per plant, leaf: stem ratio, stem weight, yield per plant, leaf weight and plant height may be prove as an effective criteria for selection in Amaranthus since, these characters are due to additive gene effect and less influenced by environment.

7. Genotypic correlation coefficient showing higher value than phenotypic correlation coefficient for most important variable pair of characters influencing green yield suggested that there is a strong inherent association between the various characters studied. Further, plant height, number of nodes per plant, stem girth, leaf length, leaf area, stem weight and leaf weight are the important correlated characters contributing towards yield (green yield) and simultaneous improvement of these traits will be helpful in improvement programme in Amaranthus.

8. Path coefficient analysis (genotypic path) of various quantitative traits indicated that stem weight had the maximum positive direct effect followed by leaf weight on yield of Amaranthus. Whereas, leaf: stem ratio, number of inflorescence per plant and leaf length had negative direct effect on yield.

9. By using D^2 statistics and Tocher's methods the genotypes were grouped into six clusters. Cluster I and III consisting of three genotypes, whereas Cluster II and IV contained two genotypes each. Cluster V and VI were monogenic.

10. Cluster II and V showing highest inter-cluster distance are most divergent Clusters. So, promising hybrid derivatives can be obtained by crossing the parents of these two divergent groups.

11. Characters like yield per plant, leaf: stem ratio, leaf weight and stem weight predominantly contributed towards genetic divergence among the set of evaluated parents. So, selection of parents differing in these quantitative characters may be useful for developing hybrids in Amaranthus.

6.2 Conclusion

From the findings of the present investigation it may be concluded that there exists a wide spectrum of variability among the genotypes for 13 quantitative characters studied. Phenotypic selection based on characters like number of inflorescence per plant, leaf: stem ratio, stem weight, yield per plant, leaf weight and plant height should be considered for improvement of yield (green yield) in Amaranthus. Some of the promising phenotypes producing higher yield such as 2012/AMVAR-4 (V_4), BHIGARPUR LOCAL (V_{11}) and 2012/AMVAR-2 (V_2) are in order of merit for cultivation in Bhubaneswar (Odisha) conditions. Further, plant height, number of nodes per plant, stem girth, leaf length, leaf area, stem weight and leaf weight are the important correlated characters and simultaneous improvement of these characters will be helpful in improvement programme in Amaranthus. Stem weight followed by leaf weight had maximum direct effect on green yield. The most divergent clusters II and V consisting of two and one genotypes each and expected hybridization between germplasms of these two groups may result in highly heterotic hybrids and may produce wide spectrum of variations in the segregating generations. Yield per plant, leaf: stem ratio, leaf weight and stem weight contributing predominantly towards genetic divergence need special attention while designing any crop improvement programme in Amaranthus.

MATERIALS AND METHODS

The present investigation entitled "Variability Studies in Amaranthus (*Amaranthus spp*.)" was carried out during *Kharif*, 2014 at All India Co-ordinated Research Project on Vegetable Crops, HRS, Orissa University of Agriculture and Technology, Bhubaneswar. The investigation was carried to study the genetic variability, correlation, path analysis and D^2 analysis of 12 genotypes of Amaranthus.

3.1 Cropping history of the plot

Prior to the present investigation, detail information on cropping history of the experimental plot was collected & presented in Table-1, for three successive years.

Table 1 Cropping history of the experimental plot

Year	Kharif	Rabi	Summer
2011	Brinjal	Broccoli	Brinjal
2012	Okra	Tomato	Bittergourd
2013	Okra	Tomato	Brinjal

3.2 Soil

A composite soil sample was taken from a depth of 15 cm surface from the experimental field before raising the crop for investigation. The sample was subjected to laboratory analysis to determine the physical and chemical compositions by following various standard methods. It is observed that the soils of experimental plot comes under sandy loam (Sand-75.24%, Silt-14.76%, Clay-10.76%) having pH 7.25. The chemical analysis of soil indicated low nitrogen content (187.5 kg/ha), high in phosphorous content (82.27 kg/ha) and low in potassium content (106.76 kg/ha). The organic carbon content of soil was 1.82% and electrical conductivity was 0.188 dS/m.

Table 2 Methods used for chemical analysis of initial soil of the experimental site

Sl. No.	Constituent	Methods followed
1.	Available nitrogen	Alkaline permanganate method (Subbaiah and Asija,1956)
2.	Available Phosphorus	Olsen method (1954)
3.	Available Potassium	Flame-Photometer using neutral normal ammonium acetate extracts (Jackson,1962)
4.	Organic Carbon	Walkley and Black rapid titration (Page *et al*., 1982)
5.	Soil pH	Blackmans pH meter (Piper,1966) with 1:2.5 soil: water ratio
6.	Electrical Conductivity (EC)	Conductivity Bridge Method

3.3 Geographical location of the experimental plot

Bhubaneswar is located at latitude of 20^0 15' N & 85^0 52' East longitude. It is about 60kms away from Bay of Bengal at an altitude of 25.5 meter above mean sea level (MSL).

3.4 Climate

The experimental site comes under the eighteenth agro-climatic region of the country i.e. Eastern Coastal Plain and is termed as sub-humid characterized by warm moist climate with mild winter.

The average annual rainfall of Bhubaneswar is 1552mm (Based on average of preceding 10 years). Most of the rainfall i.e. 85% is received from July to September. The rainfall code of the place is D_1 E_3 ($B_1A_2B_1$) $C_1D_1E_2$. The average temperature varies from 14^0c in winter to 40^0c in summer & relative humidity varies between 49 or 90% from June to December.

Monthly average meteorological data during cropping season was recorded at meteorological Observatory of Orissa University of Agriculture and Technology Bhubaneswar in Table-3.

Table 3. Meteorological data collected during the experimental period (July14-Nov14)

Month	Temperature(^{0} C)			Rainfall(mm)		Relative Humidity (%)			Wind Velocity	Bright sunshine hour
	Max	Min	Mean	Rainfall in mm	No. of rainy days	Morning	After noon	Mean		
Aug.	32.130	24.700	28.420	53.725	21	92.750	79.250	86.000	5.350	3.375
Sept.	31.880	24.400	28.140	100.58	20	95.200	80.000	87.600	3.980	4.260
Oct.	32.900	23.400	28.150	40.525	8	93.500	64.750	79.125	3.200	6.550
Nov.	30.800	19.100	24.950	0.200	0	89.600	49.600	69.600	2.540	6.600

3.5 Experimental details

(i) Design of Layout : Randomized Block Design (RBD) [Plan Layout Fig. 1]

(ii) Number of Treatments : 12

(iii) Number of Replication : 3

(iv) Total no. of plots : 36

(v) Plot size

a) Length : 3.0 m

b) Width : 2.7 m

c) Area : 8.1 m^2

(vi) Spacing

a) Row to Row : 50 cm

b) Plant to Plant : 20cm

(vii) Number of rows per plot : 6

(viii) Number of plants per row : 15

(ix) Number of plants per plot : 90

(x) Width of the bond separating blocks: 40 cm

(xi) Width of irrigation channel : 100 cm

3.5.1 Field operation and Crop raising

The field was ploughed three times after incorporation of FYM during final land preparation @ 15 tons/ha and leveled properly. Then the individual plots are laid out of scheduled size as per the plan of layout (Fig.1) with required irrigation channel. The seed sowing was done on 2nd August 2014. Six rows were made and seeds were sown in the row. Light irrigation was given with rose cane for the first time in main field.

A fertilizer dose of 50 kg N, 25kg P_2O_5 and 25 kg K_2O per ha were applied. The total amount of phosphorous with 25 kg of nitrogen and 12.5 kg of potash was applied to the soil before sowing. Remaining 25 kg of nitrogen and 12.5 kg of potash was applied in two-splits. Subsequently irrigation was provided in the irrigation channel at an interval of 2-3 days during the cropping season.

Thinning was carried out for the closely germinated plants 7 days after sowing at a spacing of 20cm from plant to plant within the rows thus, accommodating 90plants per plots. Hoeing, weeding and earthing up were done at periodic interval. Manually hoeing followed by weeding, top dressing and earthing up were done followed by irrigation at 15 and 25 days after sowing. Adequate plant protection measures were taken by spraying insecticides and fungicides at periodical intervals to raise the crop successfully. Amaranthus were harvested when they were at tender stage and attained marketable maturity i.e. edible maturity stage.

Design – R.B.D, Plot size – 3.0m X 2.7m, Treatments – 12

Rep-I		Rep-II		Rep-III	
V_9	V_7	V_{12}	V_5	V_1	V_{10}
V_5	V_3	V_8	V_{11}	V_{12}	V_4
V_1	V_{10}	V_6	V_2	V_9	V_7
V_4	V_{12}	V_9	V_{10}	V_3	V_6
V_{11}	V_8	V_3	V_7	V_2	V_5
V_2	V_6	V_1	V_4	V_8	V_{11}

Fig.1 Plan of Layout

3.5.2 Biometric observations

3.5.3 Sampling Technique

Observations on various biometric characters were recorded by selecting randomly ten competitive plants of each cultivar from each plot in a replication which were tagged properly. The border plants were excluded while selecting the sample plants. The observations of these tagged plants were taken time to time.

Characters studied

1. **Plant height (PH)**

   The height of ten sample plants was recorded in cm from the base of the plant to the top of the inflorescence and their mean value were taken for analysis of this character.

2. **Number of nodes per plant (NN)**

   Numbers of nodes were counted along the main stem at the maturity growth stage from ground level to tip of plant.

3. **Number of leaves per plant (NL)**

   This was recorded by counting the number of main countable leaves along the stem.

4. **Number of inflorescences per plant (NI)**

   This was recorded by counting the number of main countable inflorescence along the stem.

5. **Stem girth(SG)**

   The girths at the middle part of the main stem of selected plants were recorded, averaged and expressed in centimeter (cm).

6. **Leaf length(LL)**

   The leaves were selected randomly from different position and their lengths were measured by recording the length starting from the tip of leaves to the base of petiole and expressed in centimeter (cm).

7. **Leaf breadth(LB)**

   The ten randomly selected leaves from different position those were measured for their lengths were also recorded for breadth measured by recording length at the center of each leaf blade and was expressed in centimeter (cm).

8. **Petiole length (PL)**

The ten sample leaves selected for length and breadth measurement were also used for recording petiole length. It was measured by taking the length starting from the top of petiole to the base of attachment with leaf and their mean values were taken for analysis of this character.

9. **Leaf area(LA)**

This was recorded by using the leaf area meter of the selected leaves and was expressed as cm^2.

10. **Stem weight (SW)**

Observation for this character was recorded by taking the fresh weight of total number of stems harvested excluding leaves at marketable harvest in each replication of each plot and the total yield was expressed in terms of gram per plant.

11. **Leaf weight (LW)**

This character was recorded by counting the fresh weight of total number of leaves harvested excluding stem at marketable harvest in each replication of each plot and the total yield was expressed in terms of gram per plant.

12. **Leaf : stem ratio (LSR)**

Observations for this character were recorded by taking the ratio of the fresh weight of total number of leaves to the fresh weight of total number of stems at marketable harvest in each replication of each plot.

13. **Yield per plant(YP)**

This character was recorded by taking the sum of the fresh weight of total number of leaves and the fresh weight of total number of stems at marketable harvest in each replication of each plot.

3.6 Statistical analysis

The data recorded for various characters were subjected to statistical analysis based on their sample means (Gomez and Gomez, 1983). Observations of all the 13 characters were analyzed for variability and other genetic parameters related to fruit yield were taken for character association, path analysis, and genetic divergence study.

Fig.2. Arka Suguna

Fig. 3 Bhingarpur Local

Fig.4 2012/AMVAR-2

Fig. 5 Arun

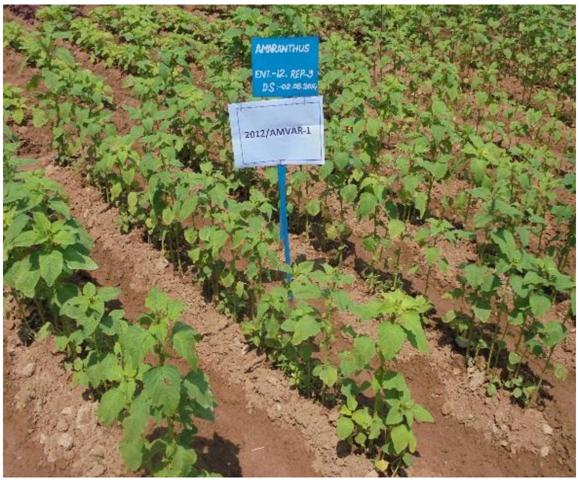

Fig.6 2012/AMVAR-1

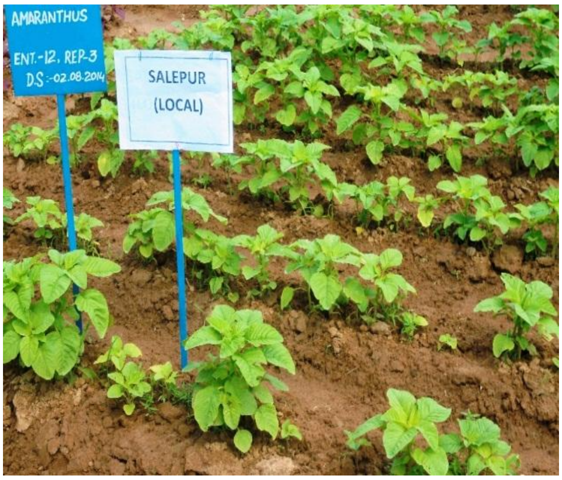

Fig. 7 Salepur Local

Fig.8 Utkal Mayuri

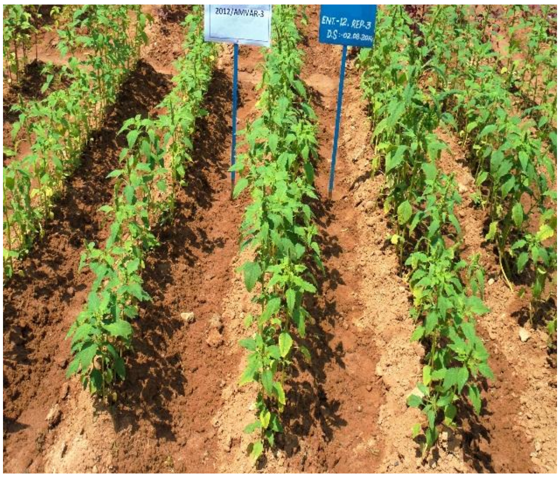

Fig. 9 2012/AMVAR-3

Fig.10 2012/AMVAR-7

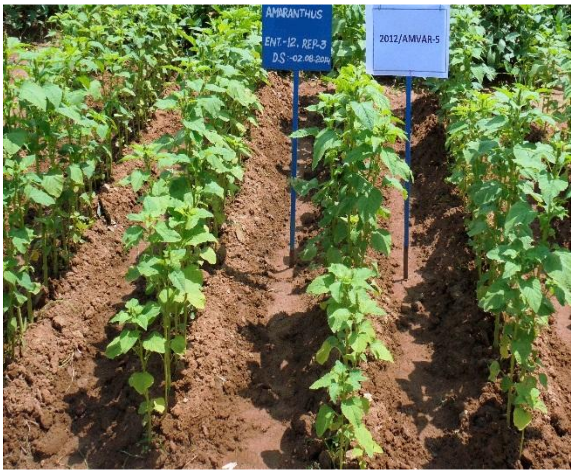

Fig. 11 2012/AMVAR-5

Fig.12 2012/AMVAR-4

Fig. 13 2012/AMVAR-6

Fig.13a Field view of the experimental plot

Fig.13b Field view of the experimental plot

Analysis of variances

The analysis of variances for each of the characters stated was done to find out varietals differences. The analysis was carried out separately for each trait following the procedure of randomized block design analysis (Panse and Sukhatme, 1954).

Analysis of variance was done on basis of following model.

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

Where,

Y_{ij} = Phenotypic observation in the i^{th} genotype and the j^{th} replication

m = General mean

g_i = Effect of the i^{th} genotype/treatment

r_j = Effect of j^{th} replication

e_{ij} = random error associated with i^{th} genotype in j^{th} replication

Table 4.Analysis of variance and expected mean sum of square

Source	Df	MSS	Expected mean sum of square
Replication	(r-1)	M_R	$\sigma^2_e + g\sigma^2_r$
Genotype	(g-1)	M_G	$\sigma^2_e + r\sigma^2_g$
Error	(r-1)(g-1)	M_E	σ^2_e

3.6.1 Mean, Range, Standard error and Critical difference

Sample mean values were calculated for each character by dividing the total by corresponding number of observations, while the highest and lowest values for each character were taken as the range. The S.E. and C.D values were calculated by using the following formula.

Standard error mean (SEM) = $\sqrt{\frac{EMS}{r}}$

Critical difference (C.D) = $\sqrt{\frac{EMS}{r}}$ × t value at error d.f at 5% and 1% level of significance

Where,

r = number of replications,

EMS = Error mean sum of square

3.6.2 Co-efficient of variation

For comparing the variability of two or more than two characters, co-efficient of variation were calculated by using the formula given below:

$$C.V. = \frac{SD}{X} \times 100 = \sqrt{\frac{EMS}{X}} \times 100$$

Where,

S.D. = standard deviation which is the square root of mean square due to error EMS)

X = Experimental mean

From the structure of the analysis of variance

$$\text{Error variance} = \sigma e^2 = M_E$$

$$\text{Genotypic variance} = \sigma^2{}_g = \frac{M_g - M_E}{r}$$

$$\text{Phenotypic variance} = \sigma^2{}_p = \frac{M_g}{r} = \frac{\sigma_g^2 + \sigma_g^e}{r}$$

The genotypic co-efficient of variation (GCV) and the phenotypic co-efficient of variation (PCV) were calculated by the formula given by Burton (1952).

$$GCV = \frac{\text{Genotypic standard deviation}}{\text{Grand mean}} \text{ X } 100$$

$$PCV = \frac{\text{Phenotypic standard deviation}}{\text{Grand mean}} \text{ X } 100$$

3.7.3 Heritability (broad sense)

The heritability estimates were used to measure the degree of correspondence between phenotypic value and breeding value. It is worked out by using the formula suggested by Lush (1949) and Burton and Devance (1953) and expressed in percentage according to Weber and Moorthy (1952).

$$h^2 \text{ (broad sense)} = \frac{\text{Genotypic variance}}{\text{Phenotypic variance}}$$

$$h^2 \text{ (broad sense in percentage)} = \frac{\text{Genotypic variance}}{\text{Phenotypic variance}} \times 100$$

3.7.4 Expected genetic advance

Genetic advance was estimated as per the formula suggested by Johnson *et al* (1995).

$$GA = K.\ h^2\sigma_p$$

Where,

K = Selection differential in standard units (which is 2.06 per 5% selection intensity).

h^2 = Heritability in broad sense

σ_p = Phenotypic standard deviation

$$\text{GA expressed as percentage of mean} = \frac{GA}{Mean} \times 100$$

3.7.5 Estimation of correlation co-efficient

Simple correlation co-efficient were computed at phenotypic and genotypic levels between pairs of 12 important characters that contribute to total plant yield using the following formula.

$$\text{Genotypic correlation } (r_g) = \frac{\sigma_g(xy)}{\sigma_g(x)} \times \sigma_g(y)$$

$$\text{Phenotypic correlation } (r_p) = \frac{\sigma_p(xy)}{\sigma_p(x)} \times \sigma_p(y)$$

Where,

σ_g (xy) = Genotypic co-variance between the two traits x and y.

σ_p (xy) = Phenotypic co-variance between the two traits x and y.

σ_g (x) and σ_g (y) = Genotypic standard deviation for x and y respectively.

σ_p (x) and σ_p (y) = Phenotypic standard deviation for x and y respectively.

The estimated values were compared with the table value at (n - 2) and at 5% and 1% levels of significance in order of test the significance of correlation coefficients at phenotypic and genotypic level.

3.7.6 Path co-efficient analysis

The cause and effect relationship among the various correlated characters are determined by path co-efficient analysis. Path co-efficient were standardized by partial regression coefficients which individually provide a measure of direct effect of the casual factors on the effect variable. These permit partitioning of the correlation between casual factors and the effect of variables into components of direct and indirect effect and thus give a better picture of the association of the casual factors with the effect variable.

In the present investigation total yield per plant was taken as the effect with other characters like plant height, number of nodes per plant, number of leaves per plant, number of inflorescence per plant, stem girth, leaf length, leaf breadth, petiole length, leaf area, stem weight, leaf weight and leaf : stem ratio related to this as the casual factor.

The path coefficients were obtained by solving the following the simultaneous equations which give the basic relationship between correlations and path coefficients in a system of correlated causes. (Dewey and Lu, 1959)

$$r_{112} = r_{11}p_{112} + r_{12}p_{112} + r_{13}p_{112} + \ldots\ldots + r_{111}p_{1112}$$

$$r_{212} = r_{21}p_{112} + r_{22}p_{112} + r_{23}p_{112} + \ldots\ldots + r_{211}p_{1112}$$

$$r_{312} = r_{31}p_{112} + r_{32}p_{112} + r_{33}p_{112} + \ldots\ldots + r_{311}p_{1112}$$

$$r_{1112} = r_{111}p_{112} + r_{112}p_{212} + r_{113}p_{312} + \ldots\ldots + p_{1112}$$

Where, r_{ij} is the coefficient of correlation between i^{th} and j^{th} characters and p_{qi} is the path coefficient (direct effect of i^{th} character total yield per plant (1, 2).

The solutions for path coefficients, direct and indirect effects of the casual factors were estimated as the values of the individual terms of the above equations in R.H.S.

The coefficient of determination (R^2) and the residual effect ($p_{12.R}$) were calculated as follows:

$$I = p^2_{12.R} + \sum p_{iy} r_{iy}$$

$$R^2 = \sum p_{iy} r_{iy}$$

$$= p_{112} r_{112} + p_{212} r_{212} + p_{312} r_{312} + \ldots\ldots\ldots\ldots + p_{1112} r_{1112}$$

$$P_{12.R} = \sqrt{I - R^2}$$

The path analysis at the genotypic level with the same cause and effect relationship was computed using the genotypic correlations as stated earlier.

3.7.7 Genetic divergence

Mahalanobis' (1928) generalized distance, D^2 statistics was used for computing genetic divergence as described by (Rao, 1952). The original measurements were transformed to standardized uncorrelated variables by pivotal condensation (Rao, 1952). The divergence between any two varieties was obtained as the sum of squares of the difference in the values of the corresponding transformed values (V_{ij})

$$D^2_{jk} = \sum^n_{i=1} Y_i j - Y_i k$$

Gives the D^2 between J^{th} and K^{th} germplasm for 'n' characters. The all possible 66 pairs of D^2 were calculated from the 12 varieties using the formula n (n - 1) / 2.

Following Tocher's method as described by Rao (1952), the genotypes were grouped into clusters. The criterion of grouping was that any two genotypes belonging to the same cluster should have a smaller D^2 value than those between genotypes belong to different clusters. Inter and intra-cluster distances were determined and represented.

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