Characterisation and evaluation of amaranthus (*Amaranthus spp*. L.) genotypes for leaf yield

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By

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CERTIFICATE-I

This is to certify that the thesis entitled **"Characterisation and evaluation of amaranthus (*Amaranthus spp.* L.) genotypes for leaf yield"** submitted in partial fulfilment of the requirements for the award of the degree of **MASTER OF SCIENCE IN AGRICULTURE (VEGETABLE SCIENCE)** to the Odisha University of Agriculture and Technology is a faithful record of *bona fide* and original research work carried out by **Suravi Garnaik, Adm. No. 191222602** 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 her from various sources during the course of investigation has been duly acknowledged.

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CERTIFICATE-II

This is to certify that the thesis entitled **"Characterisation and evaluation of amaranthus (*Amaranthus spp.* L.) genotypes for leaf yield"** submitted by **Suravi Garnaik, Adm. No. 191222602** to the Odisha University of Agriculture and Technology, Bhubaneswar in partial fulfilment of the requirements for the award of the degree of **MASTER OF SCIENCE IN AGRICULTURE (VEGETABLE SCIENCE)** has been approved by the students' advisory committee and external examiner.

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ABSTRACT

The present investigation entitled, **"Characterization and evaluation of Amaranthus (*Amaranthus spp.* L.) genotypes for leaf yield''** was carried out at research plot of Central Horticultural Experiment Station, ICAR-Indian Institute of Horticultural Research, Bhubaneswar, Odisha, India during *rabi*, 2020-2021. The objectives of the investigation were characterization and evaluation of vegetable amaranthus germplasm for *per se* performance. The other objectives were estimation of nature and extent of genetic variability, character association, path analysis of green leaf yield and yield attributing traits as well as divergence study for future crop improvement programme of vegetable amaranthus. Thirty germplasm of vegetable amaranthus were studied by adopting randomized block design replicated twice. Important traits on vegetative growth, green leaf yield and yield attributing traits as well as leaf quality attributes were recorded and analyzed statistically.

The results on morphological characterization of vegetable amaranthus germplasm showed dominance of short plant height (100.00%) with upright growth habit (90.00%) having pink stem (43.33%), purplish red petiole colour pigmentation (43.33%), ovate leaf shape (66.67%), green colour leaves (53.33%) without any blotch in leaves (83.33%). These findings will be utilized towards development of new superior genotypes in vegetable amaranthus improvement programme. Results revealed that germplasm *viz.*, ACCESSION-48 (611.02), ACCESSION-45 (598.25), ACCESSION-276 (595.43), ACCESSION-65 (591.25), ACCESSION-204 (575.40), ACCESSION-248 (573.17), ACCESSION-287 (568.82) and ACCESSION-268 (561.50) for green leaf yield (qha^{-1}) were identified as superior genotypes on the basis of *per se* performance. Traits *viz.,* leaf length (90.20% and 54.61%), leaf breadth (92.60% and 65.37%), stem girth (91.60% and 58.14%), petiole length (88.50% and 49.70%), leaf area (98.10% and 117.76%), leaf : stem ratio (85.40% and 53.31%), leaf weight (90.80% and 51.89%), green yield plant^{-1} (96.30% and 60.06 %), green yield plot^{-1} (96.30% and 60.07%) and green yield ha^{-1} (96.60% and 60.58 %) revealed both higher heritability and genetic advance as % mean suggesting that these traits are controlled by additive gene actions. So, there is enormous scope for direct selection of these traits in vegetable amaranthus. Green leaf yield plant^{-1} revealed highly significant positive association with plant height (0.490 and 0.533), number of leaves plant^{-1} (0.693 and 0.765), leaf length (0.553 and 0.583), leaf breadth (0.660 and 0.706), stem girth (0.553 and 0.610), leaf weight (0.894 and 0.914), leaf area (0.505 and 0.518) and leaf to stem ratio (0.570 and 0.573) both at phenotypic and genotypic level, respectively. Similarly, path analysis studies showed maximum direct effect on green leaf yield plant^{-1} was by leaf weight (0.532), number of leaves plant^{-1} (0.369) and leaf: stem ratio (0.221). All the 30 tested genotypes were grouped into seven diverse clusters through Tocher's method. Being most divergent, expected hybridization between these parent(s) *viz.,* cluster VI (ACCESSION-65 and ACCESSION-204) with either cluster VII (ACCESSION-8) or cluster III (ACCESSION-40) might result in producing desirable recombinants with maximum exploitation of heterosis either at F_1 stage or new segregants in segregating generation in future vegetable amaranthus improvement programme.

Based on overall findings of the present investigation, ACCESSION-48, ACCESSION-45, ACCESSION-276, ACCESSION-65, ACCESSION-204, ACCESSION-248, ACCESSION-287 and ACCESSION-268 being identified as superior genotypes on the basis of *per se* performance may be recommended for cultivation. Direct selection through traits *viz.,* plant height, number of leaves plant^{-1}, leaf length, leaf breadth, leaf weight, stem girth, stem weight, leaf weight, leaf: stem ratio and green leaf plant^{-1} will be very effective for improvement of vegetable amaranthus. Green leaf yield plant^{-1}, leaf area and stem weight are important parameters contributing more towards green leaf yield hectare^{-1} in vegetable amaranthus. Therefore, simultaneous improvement of these traits will be highly helpful in improvement of vegetable amaranthus.

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LIST OF ABBREVIATIONS

@	:	At the rate
cm	:	Centimeter
cm^2	:	Centimeter square
C.V.	:	Coefficient of variation
C.D.	:	Critical Difference
°	:	Degree
°C	:	Degree Celsius
d.f.	:	Degree of freedom
SSe	:	Error sum of square
et al.	:	And others
Fig.	:	Figure
GA	:	Genetic advance
GCV	:	Genotypic co-efficient of variation
SSg	:	Genotypic sum of square
g	:	Gram
>	:	Greater than
ha	:	Hectare
h^2	:	Heritability
hr.	:	Hour
i.e.	:	(Id est.) that is
Kg	:	Kilogram
Min.	:	Minimum
Viz.	:	Namely
No.	:	Number
/	:	Per
%	:	Per cent
km	:	Kilometer
<	:	Less than
Max.	:	Maximum
MSS	:	Mean sum of square
m	:	Meter
mm	:	Millimeter
PCV	:	Phenotypic co-efficient of variation
R.H.	:	Relative humidity
SSr	:	Replication sum of square
σ	:	Sigma
SEm	:	Standard error of mean
M^2	:	Square meter

INTRODUCTION

Amaranthus (*Amaranthus spp.* L.) is a cosmopolitan genus of annual or short-lived perennial plants (Dorling, 2008). The genus name "Amaranthus" comes from Greek word "amarantos" which means "immortal" or "everlasting" in view of fact that its flower last for long time (Rezwana *et al.*, 2017). According to Rezwana *et al.* (2017), the crop, amaranthus believed to be originated from Central and South America. Since the centuries amaranthus species are being cultivated as leafy vegetables, characterized by a high degree of diversity having broad adaptability to different agro ecological conditions (Katiyar *et al.*, 2000 and Snezana *et al.*, 2012).

In India amaranthus is widely cultivated for both grains and greens in highly diverse areas from tropical low land to the elevation of 3500 m in the Himalayas and in South Indian hills (Yadav and Mina, 2019). In India various domesticated forms of amaranthus are grown in Tamil Nadu, Andhra Pradesh, Karnataka, Kerala, Odisha, West Bengal and interior areas of North-West hills. It is one of the cheapest leafy vegetables in tropical and sub-tropical parts of the country.

Amaranthus is a fast growing, easy to grow annual having quick rejuvenation capacity after each harvest with high yield of edible matter unit area^{-1} in limited time making it suitable for kitchen gardening as well as commercial cultivation. Being a short duration crop fits well to both multiple and mixed cropping systems. The C-4 cycle photosynthetic pathway of the crop assures high photosynthetic activity and water use efficiency under high temperatures and high radiation intensity making it ideal for abiotic stress conditions under changing climate. Being a C4 plant makes potent for very high production (Rana *et al.*, 2005). The characteristics in amaranthus enable them to grow rapidly. They are accounted as highly productive plants. The leaves and tender stem of amaranthus are used as vegetable (Mobina *et al.*, 2014). It is a summer crop and grown successfully in hot summer season and humid conditions of *kharif* season in India.

Almost universally, amaranthus has been scorned as poor people's resource (Akaneme and Ani, 2013). The vegetable amaranthus substantially contribute to the nutritional well-being of rural people by providing the essential nutrients required for body growth and development and for prevention of diseases associated with nutritional deficiencies. It is a highly nutritious super food rich in protein, carbohydrates, dietary fibres, calcium, iron, manganese, zinc, vitamin- A, vitamin- C, vitamin-K, riboflavin, niacin, vitamin-B_6 and folate which enable the crop to combat mal-nutrition. Tender stems and leaves contains on an average as moisture (85.70 %), carbohydrates (6.30 g), protein (4.0 g), fat (0.50 g), calcium (397.0 mg), phosphorus (83.0 mg), iron (25.5mg), vitamin A (9200IU), and vitamin C (99 mg), (Rai and Yadav, 2005). Due to their nutritional superiority, amaranthus have been suggested as alternative source of rich protein leafy vegetables feeding those overpopulated and undernourished areas (Dhangrah *et al.*, 2015). Lysine and sulphur containing amino acids have been found in their leaves which many vegetables and cereal grains lack. ICMR recommends consumption of 125g of leafy vegetables alone out of 300 g of vegetables day^{-1} head^{-1} (Hazra and Som, 1999). In recent few years' amaranthus has been rediscovered as a promising food crop mainly due to its resistance to heat, drought, diseases and pests, and the high nutritional value of both seeds and leaves (Jangde *et al.*, 2017). It can be used as food, fodder and medicine in various pharmaceutical and cosmetic products (Prakash and Pal, 1991; Shukla *et al.*, 2003).

Vegetable amaranthus being very perishable in nature doesn't stand storage for more than a day under room temperature which restricts its export potential. The low productivity of amaranthus is due to negligence in proper cultivation and management practices, lack of advance technologies and less human interference and exploitation of this vegetable. A number of strains have been introduced and acclimatized in various parts of the world through collection and selection, but evaluation studies for yield and its contributing quantitative and qualitative traits are scarce in India.

Considering the potentiality of this crop, there is a need of development of suitable varieties for cultivation under specific agro-ecological conditions. A thorough knowledge regarding the amount of genetic variability existing for various characters followed by effective selection by adapting different breeding methodology is essential for initiating the crop improvement programme.

The phenotypic expression of the plant characters is primarily governed by genetic makeup of the genotype, environment and their interaction effects. Further, the genetic variance of any quantitative trait is composed of additive variance (heritable) and non-additive variance which 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.

The development of a new cultivars involves breeding of cultivars with desired traits *viz.,* economic yield and yield attributing traits, tolerance / resistance to both biotic and abiotic stresses, quality attributes etc. In order to achieve this goal, it is highly essential to estimate the nature and extent of genetic variability of the said germplasm, their character association, path analysis and diversity study etc. Further, adequate characterization of gene bank accessions is highly essential in order to facilitates the utilization of germplasm by plant breeders and evaluation helps revealing the potentially useful variability for further use in genetic enhancement of crops *i.e.,* characterization and evaluation of genetic resources can provide breeders with valuable information on effective utilization of genetic resources for the breeding programmes for further improvements.

Keeping these facts in view, the present investigation entitled, **"Characterization and evaluation of Amaranthus (*Amaranthus spp.*) genotypes for leaf yield"** is being proposed and will be undertaken with the following objectives:

1. Morphological characterization of amaranthus genotypes
2. Identification of superior amaranthus genotype(s) for green leaf yield
3. Estimation of nature and extent of genetic variability among the tested genotypes
4. Estimation of correlation coefficient and path analysis of the tested genotypes
5. Divergence study of tested amaranthus genotypes

REVIEW OF LITERATURE

Vegetable amaranthus (*Amranthus spp.*), a very popular leafy vegetables of tropical regions, belonging to the family Amranthaceae having chromosome number, 2n=32 or 34. The crop is native to India or Indo-Chinese region (Dewan *et al.,* 2017). The centres of diversity of amaranthus are Central and South America, India and SE Asia while secondary centre of diversity has been reported in West Africa (Grubben, 1997). Amaranthus leaves are very rich in inexpensive sources of dietary fibres, proteins, vitamins and a wide range of minerals (Shukla *et al.,* 2006). Still under Indian sub-continent conditions, amaranthus is grown as under-exploited vegetable crops grown during warm seasons, primary due to low productivity of the crop, unavailability of HYVs, lack of proper production technologies etc., varietal adaptability to environmental fluctuations is important for the stabilization of crop production both over regions and years (Dewan *et al.*, 2017). In general, adaptability is measured in terms of phenotypic stability of a genotype over several environments (Tomkins and Shipe, 1997).

Performance of any genotype primarily depends upon the genetic makeup of the genotype, environments and their interaction effects. Hence, location specific research is not only highly essential to identify the suitable genotype(s) for a specific region or locality but also utilization of that specific genotype (s) for further crop improvement programmes. The development of a new cultivar involves breeding of cultivars with desired traits *viz.,* economic yield and yield attributing traits, tolerance / resistance to both biotic and abiotic stresses, quality attributes etc. Supposing to obtain this goal, it is highly essential to estimate the nature and extent of genetic variability of the said germplasm, their character association, path analysis and diversity study etc. Further, adequate characterization of gene bank accessions is highly essential in order to facilitates the utilization of germplasm by plant breeders and evaluation helps revealing the potentially useful variability for further use in genetic enhancement of crops *i.e.,* characterization and evaluation of genetic resources can provide breeders with valuable information on effective utilization of genetic resources for the breeding programmes for further improvements. Amaranthus is a cross-pollinated crop and shows wide range of genetic variability. Hence, collection and evaluation of germplasm including landraces offer considerable scope to pick out suitable genotypes for any specific region (Mandal *et al.,* 2010).

Keeping these facts in view, the present investigation entitled, **"Characterization and evaluation of Amaranthus (*Amaranthus spp.*) genotypes for leaf yield"** was undertaken at experimental plot of CHES-IIHR (ICAR), Bhubaneswar during summer season of 2020. The objective of the investigation was morphological characterization of amaranthus germplasm, estimation of nature and extent of genetic variability, character association, direct & indirect path for leaf yield and clustering analysis for future improvement programme.

In the present chapter, "Review of Literature" emphasis have been given for critical reviewed of various aspects of the present investigation on the following subheadings, *viz*.,

- 2.1. Morphological characterization
- 2.2. Mean performance of amaranthus genotypes
- 2.3. Variability study (Range, mean, PCV, GCV, heritability & genetic Advance)
  - 2.3.1. Range and general mean
  - 2.3.2. PCV and GCV
  - 2.3.3. Heritability and genetic advance
- 2.4. Correlation coefficient analysis
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  - 2.6.3. Cluster mean and % of contribution towards divergence

2.1. Morphological Characterization

Morphological and physiological characterization is a traditional and general approach for the determination of genetic diversity as well as variations (Hien *et al*., 2007). However, they play crucial role in the selection and utilization of proper parents in breeding programme. Moreover, yield and yield contributing traits are very helpful through which overall performance of genotypes could be determined.

Characterization and evaluation of genetic resources can provide breeders with valuable information for effective utilization of genetic resources for improvement of the programme as per the breeding objectives. Collection and evaluation of germplasm including wild types, wild relatives, local landraces, absolute varieties etc. offer ample scope to identify suitable types for a particular region (Shah *et al.*, 2018).

Gherase *et al.* (2020) reported significant differences for the traits like diameter of the bush, the length of the panicle, as well as the number of main branches in amaranthus. The genotypes had different types of the inflorescences, thus 9.10% were semi-drooping, completely drooping 36.50% and straight inflorescences 54.40%. The colour of the inflorescence also had variations from light green to dark pink.

Celine *et al.* (2007) evaluated 89 diverse genotypes of amaranthus collected from different parts of Kerala during September to December, 2004 at College of Agriculture, Vellayani, Thiruvananthapuram. Exceptional variability for yield, quality and resistance to leaf blight was noticed. The plant height ranged from 13.3 cm for Am-15 to 81.1 cm for Am-83 taken down at flowering. The length of leaf lamina was maximum for Am 67 (21.1 cm) followed by Am 21 (20.8 cm) and Am 37 (20.8 cm) whereas it was shortest for Am 24 (7.4 cm). The yield ranged from 120 to 1132.5 g plant^{-1}. The highest yield was recorded in Am 88 followed by Am 7 and Am 86 while, lowest yield in Am 27 (120 g plant^{-1}). The top yielders' genotypes belonged to *A. dubius*. Leaf blight disease scored on a 0-4 scale revealed that the highest incidence 2.60 was in Am-1. The genotypes belonging to *A. dubius* were free from disease incidences. Am-37 (*A. hypochondriacus*) was also resistant. All the *A. tricolor* accessions were susceptible to varying levels. The analysis of quality parameters like b-carotene, vitamin C, protein, oxalate and nitrate also showed variability. Am-5 had the maximum b-carotene content of 4655.50 µg 100 g^{-1} while Am-90 had the minimum. Am 58 (151.20 mg 100 g^{-1}) recorded highest vitamin C whereas Am-91 had maximum protein content (3.50%). Oxalate was minimum in Am 90 (0.60 %) and maximum in Am-76 (2.10%). nitrate content varied from 0.04 % to 1.60 %.

Shah *et al.* (2018) reported wide range of variations for most of the morphological parameters in *Amranthus spp.* under Jammu & Kashmir conditions. Most of the genotypes exhibited good early plant vigour with a few exceptions, exhibiting very good and poor early plant vigour. Erect growth habit was dominant in the germplasm with a few showing spreading growth habits. Leaf colour exhibited a wide range of variations with green and red as predominant classes. Green and red were the prominent classes for inflorescence colour, however, pink, yellowish green and reddish green colours were also noticed. Genotypes exhibited four classes with respect to stem colour *viz.,* red, yellowish green, pink and reddish green.

Ray (2019) evaluated 50 germplasm of vegetable amaranthus at CHES-IIHR, Bhubaneswar, Odisha. He characterized 50 genotypes of vegetables on the basis of leaf colour, stem colour, petiole colour, leaf shape and multi-cut ability. Results on characterization of vegetable amaranthus indicated dominance of 48.00% as green leaf colour followed by yellowish green colour (18.00%) while dominance of 56.00% as light green stem colour followed by 12.00% as purple stem colour. Similarly, out of 13 types of petiole coloured observed in the germplasm, light green colour was dominated (56.00%) followed by green colour (12.00%). On the other hand, out of five different types of leaf shape, the population was dominated by ovate and broad ovate shaped leaves (34.00% each) followed by elliptic shaped (22.00%). The evaluated vegetable amaranthus germplasm also showed 40.00% as multi-cut type while 60.00% as non-multi-cut types of genotypes.

2.2 Mean performances of amaranthus genotypes

Shukla and Singh (2003) evaluated 10 high yielding and pure breeding lines of vegetable amaranthus, namely, AV-35, AV-45, AV-35/1, AV-63, AV-64, AV-77, AV-151, AV-N-3, AV-190 and AV-76 at NBRI, Lucknow from 1997-98 to 2001-2002. The analysis of variance for stability revealed that the mean square due to genotypes was significant for foliage yield, indicating the presence of substantial genetic variations among the genotypes. They also reported that the environment plays a major role in foliage yield. The genotype, AV-190 (264.88 q ha^{-1}) was most ideal for foliage yield as well as adaptability to wide range of climatic conditions.

Shukla *et al.* (2006) tested 29 genotypes of vegetable amaranthus (*Amaranthus tricolor* L.) for different leaf yield and its nine contributing morphological and quality traits. They reported that the genotypes, AV-38 (5.06 kg $plot^{-1}$) and AV-31 (5.04 kg $plot^{-1}$) revealed highest leaf yield followed by AV-30 (4.78 kg $plot^{-1}$) and AV-23 (4.70 kg $plot^{-1}$). On the other hand, Gimplinger *et al.* (2007) while studying two important genotypes of amaranthus (*Amaranthus hypocondriacus* L. and *Amaranthus cruentus* L.) reported that average harvested leaf yields varied from 2200 to 3000 kg ha^{-1} without significant differences between the two evaluated genotypes.

Priya *et al.* (2007) estimated 60 diverse strains of amaranthus and observed variability among strains for all the traits studied. The highest yield was noted from accession A-57 (304.50 g $plant^{-1}$) followed by A-53 while lowest yield was found in NBPGR accession, A-9.

Pan *et al.* (2008) estimated direct and indirect effect of quality traits on foliage yield in 39 distinct genotypes of vegetable amaranthus (*Amaranthus tricolor* L.). On the basis of yield performance, the red leaved line, HAAMTH-48 (3.15 kg $plot^{-1}$, 35.00 t ha^{-1}) performed the best followed by the red leaved line, HAAMTH-21(3.11 kg $plot^{-1}$, 34.50 t ha^{-1}) and the green leaved line, HAAMTH-29 (3.00 kg $plot^{-1}$, 33.30 t ha^{-1}) respectively. These three lines also out yielded the released varieties of vegetable amaranthus *viz.*, Pusa Lal Chauli (2.05 kg $plot^{-1}$, 22.78 t ha^{-1}) and Pusa Kirti (2.28 kg $plot^{-1}$, 25.33 t ha^{-1}).

Celini *et al.* (2011) studied 32 accessions of *Amaranthus dubius* Mart. ex. Thell. They reported that the accession, AD-23 had highest yield (382.00 g $plant^{-1}$) which was closely followed by AD-13 and AD-18.

Mandal *et al.* (2012) estimated 17 cultivars of amaranthus having four improved varieties and 13 local types and observed a vast range of variations for yield (55.80 to 303.90 q ha^{-1}). Among the cultivars, Bankura collection-3 (303.90 q ha^{-1}) and Bolpur collection-1 (287.00 q ha^{-1}) produced highest yield followed by Pusa Kirti (283.50 q ha^{-1}).

Tejaswini *et al.* (2017) while evaluating 27 genotypes including 25 germplasm lines and two checks of amaranthus (*Amaranthus tricolor* L) observed highly significant differences among the genotypes for 19 traits under study. Taking into account mean performance of the genotypes, five genotypes *viz.*, IC-522214, IC-536718, IC-536712, IC-536699 and IC-536728 were identified as promising genotypes under Hyderabad situations. Similarly, Dewan *et al.* (2017) while working with 20 germplasm of stem amaranthus at Dhaka, Bangladesh conditions identified germplasm of G-08 and G-18 for higher individual leaf yield and G-07 for higher individual stem weight.

2.3. Variability study (Range, mean, PCV, GCV, heritability and genetic Advance)

In general, crop improvement primarily depends on the presence of genetic variability in the population followed by effective selection. Therefore, knowledge of both nature and extent of genetic variability in the population in terms of quantitative and qualitative traits are essential for improvement of any crop. The variability in the population can be estimated by various parameters like range, mean, genotypic and phenotypic coefficient of variations *i.e*. GCV and PCV together with heritability and genetic advance (GA) / genetic gain (GG). In general, agronomic traits are quantitative in nature and interact with environment under study, so partitioning the traits into genotypic, phenotypic and environmental effects are essential to find out the additive or heritable portion of variability (Sarker *et al.*, 2015).

According to Faruk *et al.* (2009) and Kaiser *et al.* (2011) evaluation of genetic variability among accessions of a species is the first step to design a breeding programme. This enables plant breeders to select the accessions or the particular plant trait to incorporate in a breeding programme.

2.3.1. Range and General mean

In any crop improvement programme, the variability in the population will very much essential for further improvement. The first step in the nature and extent of genetic variability study in a population will depend on the range and general mean of the traits to be targeted for selection for improvement. Range is measure as the difference between the lowest and highest value of observations of a particular trait in the population. Higher differences simply indicate the wide scope for selection of that trait in future crop improvement programme. Hence, in a variability study, the ranges of various traits provide scope for selection, which the breeder will target. On the other hand, general mean indicates the quantification of a particular trait in the population to be selected. In general, traits having higher general mean values are more useful in crop improvement programme.

Varalakshmi *et al.* (2004) estimated 46 amaranthus genotypes during the *kharif* season. The genotype showed a wide range of variability in plant height (31.00 to 81.50 cm), length of basal lateral branches (2.30 to 103.00 cm), length of top branches (5.00 to 58.3 cm), leaf width (3.00 to 12.00 cm), petiole length (3.00 to 9.00

cm), inflorescence length (5.00 to 50.00 cm), inflorescence lateral length (2.50 to 32.60 cm), length of auxiliary branches (0.20 to 5.00 cm) and days to 50% flowering (29.00 to 69.00). Similar presence of considerable amount of genetic variability in amaranthus was also observed by Vyas *et al.* (2006).

Oboh (2007) reported wide range of variability in almost all quantitative traits studied, ranging from 74.30 to 181.00 cm for plant height, 13.90 to 29.40 cm for leaf length and 7.00 to 12.40 cm for leaf width among 16 accessions of *Amaranthus hybrid* L.

Pan *et al.* (2008) evaluated 24 indigenously fetched germplasm of vegetable amaranthus (*Amaranthus tricolor* L.) for all the nine quantitative characters. The maximum extent of genetic variability was manifested by leaf: stem ratio followed by total green leaf yield plot^{-1}, girth of stem and length of leaf.

Joshi *et al.* (2011) observed wide range of variability in plant height (46.00 to 149.00 cm), number of branches (5.50 to 20.50), leaf length (10.00 to 24.50 cm), leaf width (5.20 to 12.70 cm), petiole length (5.70 to 12.70 cm), leaf weight plant^{-1} (7.00 to 119.00 g), stem weight plant^{-1} (28.00 to 975.00 g) and seed yield plant^{-1} (6.00 to 58.00 g) in accessions of vegetable amaranthus.

Akaneme and Ani (2013) evaluated five genotypes of *Amranthus hybridus* at University of Nigeria, Nigeria. They reported wide variability for different quantitative traits under study. Plant height varied from 147.25 cm to 228.10 cm whereas days to 50% flowering from 25.00 days (Accession no.1) days from the earliest to 66.00 days (Accession no.3).

Dhangrah *et al.* (2015) studied the genetic variability of 22 genotypes of vegetable amaranthus under West Bengal conditions. They reported wide variations among the traits studied varied from minimum of 0.27 to 1.74 (fresh leaf: stem ratio) to 55.80 to 300.20 q ha^{-1} (green yield).

2.3.2 PCV and GCV

Coefficient of variation is described as the measure of variations and measured as ratio of standard deviation to the mean and is expressed in percentage. GCV is the genotypic standard deviation expressed as percentage of mean, while PCV is expressed as the phenotypic standard deviation expressed as percentage of mean. A slight difference between PCV and GCV suggested negligible influence of environment on that character. Mahmood *et al.* (2013) explained that, if PCV values were much higher than GCV values, in such situations it indicates the high involvement of environmental factors or what called the contribution of non-additive gene effects (Habtamu *et al.,* 2011). Thus, breeding objectives may not be achieved, if such traits are selected because of the low proportion of additive gene effects.

Bharghava *et al.* (2003) observed higher estimates of PCV over corresponding GCV for most of the characters studied in amaranthus. They also reported higher PCV and GCV for the traits like leaf size and foliage yield while that of lowest in stem diameter. Similarly, under Tamil Nadu conditions while evaluating 57 lines of amaranthus, Rani and Veeraragavathatham (2003) reported higher PCV and GCV for green yield plant^{-1} (84.66% and 81.53%) followed by stem weight plant^{-1} (76.04% and 75.08%), leaf weight plant^{-1} (58.77% and 55.70%) and number of leaves plant^{-1} (57.22% and 54.69%).

Shukla *et al.* (2006) reported lowest values of GCV in traits *viz.,* branches plant^{-1}, leaves plant^{-1}, plant height and stem diameter in amaranthus. Similarly, Anuja and Mohideen (2007) while working with 100 genotypes in amaranthus reported that invariably PCV were higher than GCV for all traits under study. They reported higher GCV for traits *viz.,* number of leaves plant^{-1}, yield of greens, root weight, leaf weight, stem weight and leaf area.

Ahammed *et al.* (2012) reported highest PCV (87.85%) and GCV (81.67%) in primary branches plant^{-1} while that of lowest PCV (10.28%) for plant height and GCV (7.51%) for leaf width of vegetable amaranthus. Hasan *et al.* (2013) observed high GCV and PCV for leaf weight (77.54% and 80.14%) and dry weight without rind (74.42% and 74.47%), respectively in amaranthus. Invariably, PCV was higher than those of GCV for all the characters.

Patial *et al.* (2014) studied 22 genotypes of amaranthus and found relatively low differences between the PCV and GCV showing lesser impact of environmental factors on the expression of the traits under study. Similarly, Vujacic *et al.* (2014) evaluated 10 amaranthus genotypes and reported significant variability among the traits under study.

Akaneme and Ani (2013) estimated five genotypes of *Amranthus hybridus* at University of Nigeria, Nigeria. They reported that invariably the estimates PCV of different traits were higher than corresponding GCV values, highest being recorded by plant height (225.626% and 53.577%) and days to 50% flowering (133.925% to 107.029%).

Dhangrah *et al.* (2015) studied the genetic variability of 22 genotypes of vegetable amaranthus under West Bengal conditions. They reported high PCV and GCV (>30%) for plant weight, stem fresh weight, leaf fresh weight, leaf: stem ratio (fresh) and green foliage yield. Similarly, Abe *et al.* (2015) assessed 32 amaranthus germplasms and reported wide range of variability with highly significant differences in phenotypic characteristics. Similarly, Diwan *et al.* (2017) observed high magnitude of GCV and PCV in amaranthus for traits *viz.*, leaf weight (35.01% and 35.63%), leaf length (19.69% and 24.50%) and internodal length (18.46% and 22.99%), thereby suggesting the substantial improvement of amaranthus through simple selections for these traits.

2.3.3 Heritability and genetic advance (GA)

The extent to which variability of a particular trait is transferred to the progeny is considered as its heritability. Thus, heritability is for assessing the genetic variance over total variance of a particular character. According to Lush (1949) heritability treated as "portion of observed variance for which differences in heritability is responsible". On the other hand, Robinson *et al*. (1966) defined heritability in broad sense as "the ratio of total variance to total phenotypic variance". Heritability is usually expressed in percentage. Therefore, heritability is the heritable of phenotypic variance- a good index of character transmission from parents to their progenies. It has been suggested by Johnson *et al*. (1955) that heritability estimates would provide more appropriate information when studied together with GA as compared to heritability studies alone. Similarly, Allard (1960) suggested that traits having low-inheritance should not be considered as they are masked by environmental impacts.

Heritability always emphasizes the selection of genetic traits, which may be in broad sense that reflects the functioning of genotypes or in narrow sense which is that part of the observed variance caused by additive genetic variance which actually guides the plant breeders in selecting individuals from segregating generations to improve effectively. As a whole, estimation of heritability is necessary for planning any crop improvement programme based on the technique of selection.

Similarly, GA is even more useful in estimating nature of transmission of traits. In general, GA is directly linked to heritability due to selection of a specific trait. GA is the improvement over the parental population in the mean genotypic value of the selected plants, which is a measure of genetic gain under selection. The GA as % of mean estimates provide more definitive details on the efficiency of selection in improving a character, as its estimate is based on heritability phenotypic standard deviation and selection intensity. Hence, estimates of heritability along with GA are two important parameters for selection of traits in crop improvement programme.

In crop improvement programme, the success of GA under selection mainly depends upon three major factors *viz.*, genetic variability, heritability and selection intensity. High value of GA indicates the nature of gene action as additive while non-additive gene action with low values of GA.

Bhargava *et al.* (2003) observed higher heritability in amaranthus for traits *viz.*, leaf size (76.87%), foliage yield (72.27%) and number of leaves plant^{-1} (52.30%). They also reported low heritability for traits like plant height (17.31%) and number of branches plant^{-1} (17.80%), indicating a major impact of environmental factors on the expressions of these traits. The study also showed high heritability with high GA as % mean for traits like leaf size, foliage yield and number of leaves plant^{-1}, thus suggesting a possible role of additive gene effect for the genotypic variance for these traits.

Rani and Veeraragavathatham (2003) reported high heritability coupled with high GA for green yield plant^{-1} (92.56% and 161.36%), stem weight plant^{-1} (97.00% and152.40%), leaf number plant^{-1} (91.31% and107.65%) and leaf weight plant^{-1} (89.94% and 108.77%), plant height (85.93% and 44.37%), leaf length (82.68% and 47.80%), leaf breadth (74.26% and45.72%) and stem girth (73.33% and 47.87%) in amaranthus which suggested additive gene effects. Similarly, Shukla *et al.* (2006) reported high heritability estimates for all the traits along with highest expected GA as % of mean for ascorbic acid (57.48%) followed by foliage yield (48.30%) and leaf size (29.51%) in amaranthus.

Anuja and Mohideen (2007) while working with 100 genotypes of amaranthus observed high heritability coupled with high GA as % of mean for traits *viz.,* number of leaves, root length, root weight, leaf weight and stem weight. On the other hand, Pan *et al.* (2008) recorded high heritability for traits *viz.,* leaf stem ratio, width of leaf, length of leaf, days to 1st clipping, number of clipping, girth of stem and total yield of greens plot^{-1}. Similar reports of high heritability coupled with high GA as % mean was reported in traits *viz.,* leaf weight plant^{-1} (91.10% and 49.38%, stem weight plant^{-1} (82.56% and 134.12%) and yield ha^{-1} (78.70% and 56.00%), respectively by Ahammed *et al.* (2013). Therefore, traits with high heritability as well as high GA indicate that there is prevalence of additive gene action in their inheritance. Thus, selection for such traits can easily be done (Rajib and Jagatpati, 2011).

Hasan *et al.* (2013) assessed 17 strains of stem amaranthus and recorded high heritability coupled with high GA as % of mean for number of leaves, leaf weight and marketable yield while Patial *et al.* (2014) worked on 22 genotypes of amaranthus also observed high heritability coupled with high GA as % mean for yield plant^{-1}, days to maturity, days to seed fill, harvest index, panicle girth and seed yield plant^{-1}, which indicated the presence of additive gene effects.

Dhangrah *et al.* (2015) while studying the genetic variability of 22 genotypes of vegetable amaranthus under West Bengal conditions, reported high to moderate estimates of heritability along with high to moderate estimates of GA as % mean for plant weight, stem fresh weight, leaf fresh weight, leaf: stem ratio (fresh) and green foliage yield suggesting the predominance of additive gene action for the expression of the traits, hence simple selection will be more effective.

Sarker *et al.* (2015) reported highest heritability along with high GA as % mean in traits *viz.,* leaf area (99.86% and 95.83%), shoot weight (99.71% and 61.01%), shoot: root ratio (96.83% and 149.10%), stem base diameter (99.71% and 63.40%) and biological yield (99.99% and 60.16%) in amaranthus under Bangladesh conditions.

Similar results also reported by Diwan *et al.* (2017) who observed high estimates of heritability along with high GA as % mean for traits like number of leaves plant^{-1}(76.20% and 20.60%), leaf width (78.10% and 25.70%) and leaf weight

(96.60% and 71.20%) in amaranthus. They suggested that the heritability might be due to additive gene effects and selection may be very effective in these traits for improvement in amaranths.

According to Adeniji (2018) heritability estimates were low for leaves plant^{-1}, marketable yield, non-marketable foliage yield, fresh weight of leaves and leaf dry weight in amaranthus. High heritability estimates were recorded for leaf width (70.00%) and plant height (60%). Phenotypic traits having very high heritability indicates relatively small contribution of the environment factors to the phenotype and selection for such characters could be fairly easy due to high additive effect. In addition, medium heritability estimates were recorded for branches plant^{-1}and plant height. While leaves plant^{-1}, marketable foliage yield, non-marketable foliage yield, fresh weight of leaves and leaf dry weight had low heritability estimates.

2.4 Correlation coefficient

In general, genetic variability studies provide information on the extent of crop improvement in various traits. But they do not throw any light on the extent and nature of relationship existing between various traits. Therefore, for rational approach towards the improvement of most complex trait in crop plant, yield, proper selection has to be made for various components of yield, as yield of a crop plant is governed by many genes. Genetic correlations between two traits arise because of linkage, pleiotropy or developmentally induced functional relationship. Therefore, study of character association of various traits with yield, will play a vital role in proper selection of a superior genotype in crop improvement programme. In general, many of the yields attributing traits are interacted in both desirable and undesirable directions as well. Hence, knowledge of correlations between traits can help effectively to avoiding inversely related compensation effects at the time of phenotypic selection processes. Usually, when the results of correlation showed closeness between at phenotypic and genotypic levels, that indicates the lesser influence of environmental factors in the expression of the trait and presence of strong inherent association among the traits.

Pan *et al.* (2008) estimated 24 indigenously collected germplasm of *Amaranthus tricolor* L. including two released varieties. They observed that GCV were higher in magnitude than PCV which suggest strong inherent relationship between the traits. They also reported that the total yield of greens plot^{-1} was positively and significantly correlated with duration of harvest. Thus, selection for duration of harvest in positive direction could results in substantial improvement in total yield of greens in vegetable amaranthus. Among the agronomic traits, plant height and number of inflorescences exhibited significant positive association with foliage yield, while chlorophyll a, chlorophyll b, carotenoid, fibre and ascorbic acid were positively correlated with foliage yield.

Similarly, Aruna (2009) estimate the character associations of various traits of vegetable amaranthus with six genotypes and 30 F_1 crosses. The character association between leaf yields of greens with weight of leaves was significantly highest with both at genotypic and phenotypic level.

Varalakshmi *et al.* (2010) reported that plant weight was significantly and positively associated with number of branches plant^{-1}, number of leaves plant^{-1}, leaf weight and stem weight in amaranthus. They also observed higher significant and positive correlation of green yield with leaf weight, stem weight and plant height, whereas, leaf: stem ratio showed negative association with green yield in hundred genotypes of vegetable amaranthus.

In amaranthus, leaves plant^{-1}, stem diameter, stem weight plant^{-1}, leaf weight plant^{-1}and plant height exhibited highly significant positive correlation with yield hectare^{-1} both at genotypic and phenotypic level (Ahammed *et al.*, 2012). Similarly, Navangburuka and Denton (2012) and Arif *et al.* (2013) reported that leaf yield plot^{-1} had strong positive association with leaf width, stem girth and leaf stem ratio.

Akaneme and Ani (2013) studied five accessions of the *Amaranthus hybridus* L. and reported that days to 50% flowering were positively correlated with leaf length and stem diameter. The association between many pairs of characters were positive and highly significant ($P<0.01$). The highly significant and positive correlation ($P <0.01$) recorded between 500 seed weight and leaf width; 500 seed weight and hypocotyls length; leaf width.

Correlation studies on stem amaranthus (*Amaranthus tricolor* L.) conducted by Hasan *et al.* (2013) revealed that green yield had strong positive association with leaf weight (0.780 and 0.774), stem weight (0.999 and 0.998), stem diameter (0.602

and 0.594), dry weight with rind (0.611 and 0.610), and dry weight without rind (0.754 and 0.764) at both genotypic and phenotypic level, respectively.

According to Kendre *et al.* (2013) higher fresh stem weight and number of leaves plant^{-1} must be taken into account in the selection yardstick for increasing leaf yield (kg) plot^{-1} as they studied that fresh stem weight followed by number of leaves plant^{-1} showed high positive and direct effect and had significant positive correlation with leaf yield (kg) plot^{-1}.

Khurana *et al.* (2013) reported that the number of leaves plant^{-1} had highest (0.4933) positive direct effect on total green yield followed by leaf area index (04268), 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 plant^{-1}.

Patial *et al.* (2014) studied 22 genotypes of amaranthus and found that harvest index was positively correlated with days to maturity. In a study for genotypic variability by Sarker *et al.* (2014) in 30 vegetable amaranthus genotypes found that there was significant positive correlation of leaf yield with plant height, leaves plant^{-1}, diameter of stem base, fibre content and leaf area. Similarly, Yadav *et al.* (2014) revealed that seed yield plant^{-1} showed highly significant positive correlation with days to 80% maturity and plant height and significant positive correlation with days to 50% flowering. Inflorescence length had significant positive correlation with lateral spikelet length in amaranthus.

Abe *et al.* (2015) reported positive association of plant height with fresh biomass and dry biomass. Yield plant^{-1} showed a moderate positive correlation with leaf width, leaf length, leaf area, leaf area index and plant height, and a strong correlation with fresh biomass and dry biomass. On the other hand, Hailu *et al.,* (2015) worked out correlation study and reported about less value of phenotypic correlation coefficient than the genotypic correlation coefficient in most of the characters. The green leaf yield plant^{-1} 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.

Dhangrah *et al.* (2015) observed higher genotypic correlation than their corresponding phenotypic correlation there by suggesting strong inherent association between various traits in vegetable amaranthus. Green yield was found positively and significantly correlated with leaf number, leaf length: width ratio, plant weight, stem and leaf fresh weights. They also suggested that indirect selection of these traits would be helpful for identifying high yielding genotypes for growing in a particular region. On the other hand, Sarker *et al.* (2015) observed that biological yield of amaranthus had positive and significant correlation with leaf area (0.326), shoot weight (0.999), shoot: root weight (0.454) and stem base diameter (0.368). Similarly, stem base diameter had a significant positive association with leaf area (0.597) and shoot weight (0.365).

Tejaswini *et al.* (2017) while evaluating 27 genotypes including 25 germplasm lines and two checks of amaranthus (*Amaranthus tricolor* L) observed positive and significant correlation of leaf yield with leaf weight plant^{-1}(0.935, 0.974 and 0.953), leaf stem (0.845, 0.866 and 0.871), leaf breadth (0.774, 0.823 and 0.771) at 30, 60 and 90 days after sowing, respectively.

Adeniji (2018) observed that number of branches plant^{-1} recorded negative and significant correlation coefficient with leaf width. This indicated that phenotypic improvement in the number of branches will not complement leaf width among the genotypes. The leaves plant^{-1} recorded positive and significant correlation coefficient with marketable foliage yield, non-marketable foliage yield and leaf fresh weight.

Sagar *et al.* (2018) studied the correlation coefficients of various traits of vegetable amaranthus with 25 genotypes. They reported that foliage yield plant^{-1} was significantly and positively correlated with number of leaves plant^{-1} (0.987) followed by stem girth (0.696), number of branches plant^{-1} (0.631), number of spikes plant^{-1} (0.629), spike length (0.566) and leaf area (0.355) at genotypic level. This suggests the possibility of simultaneous improvement of these traits in improving total foliage yield plant^{-1}.

2.5 Path analysis

Yield of any crop is a complex trait which results from direct and indirect effects of several characters operating either in combination or individually. Selection for a trait in one direction may influence another trait by a direct or indirect effect *via* a third variable factor. Therefore, knowledge on the nature of association of different attributes with yield is essential. So, for determining the direct and indirect effects of various plant characters on crop yield the path coefficient analysis is carried out.

Path coefficient analysis is an efficient statistical technique specially designed to quantify the interrelationship of different components and their direct and indirect effects on yield. Through this technique yield contributing characters and specific traits producing a given correlation can be categorized (Islam *et al.,* 2010).

Pan *et al.* (2008) estimated path coefficient analysis of quality traits on foliage yield in 39 distinct cultivars of vegetable amaranthus (*Amaranthus tricolor* L.). The analysis of different characters contributing towards total yield of greens revealed that the duration of harvest had maximum direct effect on total yield. The indirect effect of duration of harvest *via* number of clipping was maximum and positive.

Aruna (2009) estimate the path analysis of various traits of vegetable amaranthus with six genotypes and 30 F_1 crosses. Results on path analysis indicated that both leaf and stem weight had higher and direct contribution to green yield. Similarly, Shukla *et al.* (2010) reported plant height (0.12), stem diameter (0.21), number of leaves plant^{-1} (0.45) had significant positive direct effects on foliage yield while negative direct effect by number of branches plant^{-1} (-1.22), leaf size (-0.27) with foliage yield in amaranthus.

Khurana *et al*. (2013) studied on the agronomic traits of amaranthus and found that the number of leaves plant^{-1} had highest (0.493) positive direct effect on total green yield followed by leaf area index (0.427), leaf length (0.099), plant height (0.092), leaf width (0.049) and protein content (0.021). The indirect effect of leaf area index on total green yield was highest (0.454) in positive direction *via* number of leaves plant^{-1}.

Path analysis studies on stem amaranthus (*Amaranthus tricolor* L.) conducted by Hasan *et al.* (2013) reported that stem weight (0.951) had maximum direct effect on marketable yield followed by leaf weight (0.090), leaf number (0.004) and dry weight without rind (0.007). 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 amaranthus (Sarker *et al.*, 2014).

Hailu *et al.* (2015) estimated 36 germplasm accessions of amaranthus and revealed that the maximum positive direct effects were recorded in biomass plant^{-1}, plant height, leaf area and leaf width. Tejaswini *et al.* (2017) while evaluating 27 genotypes including 25 germplasm lines and two checks of amaranthus (*Amaranthus tricolor* L.) observed that leaf yield had positive and direct effect with leaf weight plant^{-1} followed by leaf: stem ratio, leaf length, leaf width, protein content and ascorbic acid content of leaves.

Jangde *et al.* (2017) reported highest positive direct effects for fresh stem weight of plant (1.100) followed by dry leaf weight (0.766), petiole length (0.686), leaf length (0.519), harvest index % (0.344), leaf area (0.050) and number of leaves plant^{-1} (0.014) whereas the leaf stem ratio (-0.781), dry stem weight (-0.741), plant fresh weight (- 0.524), plant height (-0.355), stem base diameter (-0.306), number of leaves plant^{-1} (-0.073), leaf width (-0.065), fresh leaf weight (-0.037) showed maximum negative direct effects on leaf yield kg plot^{-1}.

2.6. Genetic divergence

In general, selection of genetically distinct divergent genotypes as parents is highly essential not only for exploitation of hybrid vigour towards development of F_1 hybrid(s) but also development of high yielding variety(s) as transgressive segregants in any crop improvement programme. Therefore, to study the nature and magnitude of genetic divergence among the tested genotypes will help the plant breeder for choosing the suitable diverse combinations.

2.6.1 Clustering analysis

Anuja (2011) studied the genetic divergence of 100 genotypes of amaranthus belonging to *A. tricolor, A. blitum, A. tricolor var. triistis* and *A.dubius.* On the basis of D^2 analysis, 100 genotypes were grouped into 09 clusters. Cluster I had maximum 655 genotypes followed by cluster II, IV with seven genotypes, cluster AV and VIII with five genotypes each, cluster IV with four genotypes each, cluster VI and VII with three genotypes each and cluster IX with one genotype. The genotypes chosen from the same eco-geographical origin were found scattered in different cluster indicating the non-existences of relationship between genetic diversity and geographical origin.

Akther *et al.* (2013) computed seventeen genotypes of amaranthus that fell into 4 different clusters. According to the study maximum number of genotypes (6) were included in cluster (IV) followed by cluster III (5) and cluster II (5), and the minimum number was in cluster I (1). The genotypes within the same cluster, although formed specific clusters, but were collected from different places, which indicated the geographical distribution and genetic divergence and did not follow the same trend.

Ahammed *et al.* (2013) estimated the genetic divergence among 22 genotypes of stem amaranthus using D^2 analysis at Ghazipur, Bangladesh. The genotypes were grouped into four clusters. Cluster I, II, III and IV composed of two, four, seven and nine genotypes in succession. No relationship was found between divergence and geographical distribution of the genotypes. Similarly, Akaneme and Ani (2013) on evaluating five accessions of the *Amaranthus hybridus* revealed, accessions were distributed into 2 clusters. Cluster I comprising accessions 3 and 5 and cluster II comprising accessions 1, 2 and 4.

Kujur *et al.* (2017) studied the extent of genetic divergence that exist for the yield and yield contributing traits of 25 genotypes of kheda bhaji (*Amranthus dubius* Mart.) using Mahalanobis D^2 analysis. They grouped the 25 genotypes into five distinct clusters. The distribution pattern indicated that the maximum numbers of genotypes (7) were included in Cluster I and V followed by cluster IV (6) and cluster-II (4) and the minimum number was in cluster III (1).

An experiment was conducted by Kumar *et al.* (2019) to identify the extent of genetic divergence that exist for the yield and yield contributing characters of 25 genotypes of Amaranthus (*Amaranthus spp*.) using D^2 analysis. Analysis of variance showed significant difference among the genotypes for most of the traits studied. The genotypes under study fell into 5 clusters. The distribution pattern indicated that the maximum numbers of six genotypes each were included in cluster IV and cluster V each followed by five genotypes in cluster II and cluster III and three genotypes in cluster I.

2.6.2 Inter and intracluster distance

Anuja (2011) studied the genetic divergence of 100 genotypes of amaranthus belonging top *A. tricolor, A. blitum, A. tricolor var. triistis* and *A. dubius.* On the basis of D^2 analysis, 100 genotypes were grouped into 09 clusters. The intra cluster generalized distance ranged from 1.899 to 10.569. Cluster VI showed minimum intra cluster distance (1.899) and maximum by cluster III (10.569). Minimum inter cluster distance was observed between cluster I and II (9.60) while maximum between VII and IX (31.855) followed by cluster II and IX (29.268). Similarly, Akther *et al.* (2013) grouped seventeen genotypes of amaranthus into four different clusters. The highest inter cluster distance was observed between IV and I (50.75) followed by the distance between cluster II and I (36.24) showing wide diversity among the groups. The lowest intercluster distance was observed between clusters III and II (9.85) suggesting a close relationship among the genotypes of these two clusters.

Ahammed *et al.* (2013) estimated the genetic divergence among 22 genotypes of stem amaranthus into four clusters. Maximum inter cluster distance was observed between cluster I and III (12.326) while minimum of 3.526 between cluster I and II. The crosses between the genotypes of cluster I with that of cluster III and cluster II with cluster III would exhibit high heterosis and also likely to produce new recombinants with desirable traits in stem amaranthus. Similarly, Kujur *et al.* (2017) grouped the 25 genotypes of *Amranthus dubius* Mart. into five distinct clusters. The inter cluster distance varied from 0.000 to 3.157. the maximum intra cluster distance was shown by cluster I (3.157) followed by cluster IV (2.482), cluster II (2.390), cluster V (1.871) and cluster III (0.000) which indicate distance within the cluster. Kumar *et al.* (2019) identified five diverged clusters by analyzing 25 genotypes of Amaranthus. The intra cluster D^2 values ranged from 1.849 (cluster III) to 2.345 (cluster V). The intra cluster distance was observed highest in cluster V (2.345) followed by cluster IV (2.284), cluster I (2.050), cluster II (1.954) and was recorded the lowest in cluster III (1.849), which indicate distance within the cluster. However, the inter cluster D^2 values varied from clusters II and V (2.523) to clusters II and III (6.370). The maximum inter cluster distance was observed between the clusters II and III (6.370) followed by cluster III and IV (6.272), cluster I and IV (5.314) cluster III and V (4.795), cluster I and III (4.625), cluster I and II (4.278), cluster I and V (3.818), cluster II and IV (2.880), cluster IV and V (2.800) and the minimum inter cluster observed between cluster II and V (2.523).

2.6.3 Cluster mean values and % of contribution

Shukla and Singh (2002) while studying genetic diversity of 66 amaranthus, grouped into nine clusters on the basis of Mahalanobis D^2 analysis. Cluster VIII had the maximum yield and leaf size while cluster III had highest number of inflorescence plant^{-1} followed by yield. They also reported maximum contribution towards divergence was plant height, number of nodes plant^{-1} and leaf size. Similarly, Anuja (2011) reported maximum contribution by number of leaves plant^{-1} (14.73%) followed by leaf weight (13.43%) whereas minimum by root length (3.43%) and leaf area (3.29%) towards the yield of greens while studying 100 genotypes of amaranthus.

Ahammed *et al.* (2013) while studying the genetic divergence among 22 genotypes of stem amaranthus, reported that number of leaves plant^{-1}, petiole length, stem diameter, leaf weight plant^{-1}and stem weight plant^{-1}, leaf width, petiole length and 1000 seed weight showed maximum contribution to the total divergence.

Kujur *et al.* (2017) grouped the 25 genotypes of *Amranthus dubius* Mart. into five distinct clusters. They reported that traits like test weight of seed contributes highest (42.95%) to divergence followed by leaf length (17.11%), dry matter % (13.42%), plant height (12.75%), fibre content (2.68%), petiole length (1.34), number of leaves plant^{-1} (1.00%), root length (1.00%), yield kg plot^{-1}(1.00%) days to 50% flowering and duration (0.33%) contributed maximum towards genetic divergence. Hence, these traits could be given the importance for selection of genotypes for further crop improvement programme.

Akther *et al.* (2013) studied 17 genotypes of amaranths distributed into 4 clusters. Maximum number of genotypes (6) was included in cluster (IV) followed by cluster III (5) and cluster II (5), and the minimum number was in cluster I (1). The highest inter cluster distance was observed between IV and I, followed by the distance between cluster II and I showing wide diversity among the groups. The lowest intercluster distance was observed between clusters III and II suggesting a close relationship among the genotypes of these two clusters.

MATERIALS AND METHODS

The present investigation entitled **"Characterisation and evaluation of Amaranthus (*Amaranthus spp.* L.) genotypes for leaf yield''** was carried out at research plot of Central Horticultural Experiment Station, ICAR-Indian Institute of Horticultural Research, Aiginia Bhubaneswar, Odisha, India during *rabi*, 2020-2021. The objectives of the present investigation were characterization and evaluation of germplasm of vegetable amaranthus for *per se* performance. The other objectives were estimation of nature and extent of genetic variability, character association, path analysis of leaf yield and yielding attributes as well as divergence study for future crop improvement programme of vegetable amaranthus.

The details of materials used and methods adopted for conducting the experiment are described in the present chapter "Materials and Methods" with relevant information supported by tables, figures, photographs etc. as per the requirement.

3.1 Cropping history of the plot

Prior to the present investigation, detailed information on cropping history of the experimental plot was collected and presented in Table 1.

Table 1. Cropping history of the experimental plot

Year	***Kharif***	***Rabi***	**Summer**
2018	Fallow	Brinjal	Chilli
2019	Fallow	Amaranthus	Fallow
2020	Fallow	Amaranthus	Fallow

3.2 Soil

A composite of soil sample was collected from five places randomly from 15 cm depth from the experimental field before raising the crop for the investigation. The collected soil samples were mixed thoroughly and a composite sample of 500g size was made to analysis the soil property. The physiochemical analysis of the soil has been shown in Table 2.

Table 2. Soil status of experiment field

Sl. No.	Particulars	Analytical Value	Classification	Methods
I Mechanical analysis				
1	Sand (%)	82.44%	loam	International pipette method (Black, 1965)
2	Silt (%)	3.80%		
3	Clay (%)	13.76%		
II Chemical analysis				
1	Organic carbon (%)	0.22-0.24	Low organic matter	Walkley and Black's method (Black, 1965)
2	Available N (kgha^{-1})	<200kgha^{-1}	Low	Modified kjeldahl method (Piper, 1966)
3	Available P_2O_5 (kgha^{-1})	10-15 kgha^{-1}	Medium	Olsen method (Olsen, 1954)
4	Available K2O (kgha^{-1})	150-200 kgha^{-1}	Medium	Flame photometer (Jackson,1973)
5	Soil pH	4.8-5.2	Highly acidic	Carbon electrode pH meter method (Piper, 1966)

3.3 Geographical location of the experimental site

Khurdha district is situated in the eastern part of Odisha state between latitude 190 40" to 200 25" North latitude and 840 55" to 860 5" East longitude covering an area of 2,813 sq. kms. It is situated at an altitude of 25.50 m above mean sea level and about 60 kilometres away from Bay of Bengal. It is surrounded by Ganjam district in the south, Cuttack district in north, Nayagarh district in the west and Puri district in east.

3.4 Climate

The geographical location of the experimental site comes under the 18thagro-climatic region of the state i.e. East and South Eastern coastal plain according to Centre for Environmental Studies, Forest and Environment Department, Government of Odisha. It is termed as sub-humid, characterized by warm moist climate with mild winter. The average temperature varies from 9.5°**C** in winter to 41.4°**C** in summer and relative humidity varies between 49.00% or 90.00% from May to November. Based on average of preceding ten years rainfall data, the average annual rainfall of Bhubaneswar is 1552 mm. Most of the rainfall (85%) is received from July to September.

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

Table 3. Meteorological data collected during the experimental period (Oct - Feb)

Month	Temperature (°C)			Rainfall (mm)		Relative Humidity (%)			Wind speed km/hr	Bright sunshine hour
	Max	Min	Mean	Rainfall (mm)	No. of rainy days	Max	Min	Mean		
Year - 2020										
Oct.	31.9	24.4	28.2	247.6	13	95	76	85.5	0.5	4.7
Nov.	31.4	19.6	25.5	5.6	1	90	53	71.5	1.0	6.5
Dec.	29.8	14.3	22.1	0.0	0	94	41	67.5	1.8	6.5
Year - 2021										
Jan.	30.5	16.3	23.4	0.0	0	93	39	66	2.6	4.2
Feb.	32.8	15.3	24.1	0.0	0	92	28	60	2.9	7.0

3.5 Experimental details

Experimental Design	:	Randomized Block Design (RBD)
Number of replications	:	2 (Two)
Number of treatments	:	30 genotypes
Season of experimentation	:	*Rabi*, 2020-21
Spacing	:	30 cm × 10 cm
Total no. of plots	:	30
Plot size	:	3.0 m × 1.0 m
No. of rows per plot	:	10
No. of plants per row	:	10
No. of plants per plot	:	100
Width of bund separating blocks	:	1 m
Width of irrigation channel	:	30 cm

Table 4. Source of vegetable amaranthus germplasm

Genotypes		Source	Genotypes		Source
V_1	ACCESSION-65	NBPGR, Kerala	V_{16}	ACCESSION-48	Odisha local
V_2	ACCESSION-2	Odisha local	V_{17}	ACCESSION-202	NE Collections
V_3	ACCESSION-6		V_{18}	ACCESSION-204	
V_4	ACCESSION-8		V_{19}	ACCESSION-205	
V_5	ACCESSION-13		V_{20}	ACCESSION-231	
V_6	ACCESSION-19		V_{21}	ACCESSION-237	
V_7	ACCESSION-26		V_{22}	ACCESSION-247	
V_8	ACCESSION-32		V_{23}	ACCESSION-248	
V_9	ACCESSION-37		V_{24}	ACCESSION-250	Odisha local
V_{10}	ACCESSION-38		V_{25}	ACCESSION-287	
V_{11}	ACCESSION-39		V_{26}	ACCESSION-288	
V_{12}	ACCESSION-40		V_{27}	ACCESSION-258	
V_{13}	ACCESSION-41		V_{28}	ACCESSION-263	
V_{14}	ACCESSION-43		V_{29}	ACCESSION-268	
V_{15}	ACCESSION-45		V_{30}	ACCESSION-276	

Replication I		Replication II	
V_{30}	V_{26}	V_{26}	V_{29}
V_{11}	V_{03}	V_{02}	V_{10}
V_{06}	V_{10}	V_{06}	V_{13}
V_{16}	V_{14}	V_{09}	V_{04}
V_{13}	V_{09}	V_{28}	V_{11}
V_{01}	V_{22}	V_{14}	V_{25}
V_{19}	V_{29}	V_{24}	V_{27}
V_{15}	V_{04}	V_{07}	V_{01}
V_{05}	V_{18}	V_{19}	V_{18}
V_{17}	V_{25}	V_{05}	V_{30}
V_{07}	V_{12}	V_{16}	V_{15}
V_{23}	V_{08}	V_{20}	V_{23}
V_{28}	V_{21}	V_{21}	V_{03}
V_{20}	V_{24}	V_{08}	V_{12}
V_{02}	V_{27}	V_{17}	V_{22}

Fig. 1. Layout of research plot

Fig.2. Field view of the experimental plot

3.6 Morphological characterization

The morphological observations on Plant height, Plant growth, Stem colour, Petiole length, Petiole colour, Leaf colour, Presence of blotch in leaf, Leaf shape, Prominence of leaf veins, Inflorescence colour and Presence of axillary inflorescence traits of 30 genotypes of vegetable amaranthus at different stages of plant growth were recorded as per the plant minimal descriptor of Grain Amaranthus (*Amaranthus spp.* L.) excluding ornamental or vegetable varieties) by Protection of Plant varieties and Farmer's Rights Authority, Government of India.

3.7 Field operations

The experimental field was brought to a fine tilth by ploughing twice followed by proper levelling with incorporation of FYM @ 15 t ha^{-1} before final land preparation. Then individual plots were designed as per the plan of layout. The seed sowing was done on 16^{th} December 2020 at the depth of 1-2 cm with required spacing. Light irrigation was given with rose cane for the first time in main field. Subsequently light irrigation was given to raise a good crop of amaranthus. Standard package of practices was adapted uniformly to all the 30 tested genotypes of vegetable amaranthus to raise a good crop. Thinning was carried out after seven days of sowing for the closely germinated plants at a spacing of 10cm from plant to plant. Manually hoeing, 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. For control of stem borer application of Phorate @ 10kg ha^{-1} was applied during crop stand. Amaranthus were harvested when they were at tender stage (marketable maturity) i.e. edible stage.

3.8 Biometric observations

3.8.1 Sampling techniques

The observations of both qualitative and quantitative traits were recorded on ten randomly selected plants, leaving the border plants, from each plot of both the replications which were tagged properly. The observations of these tagged plants were recorded from time to time.

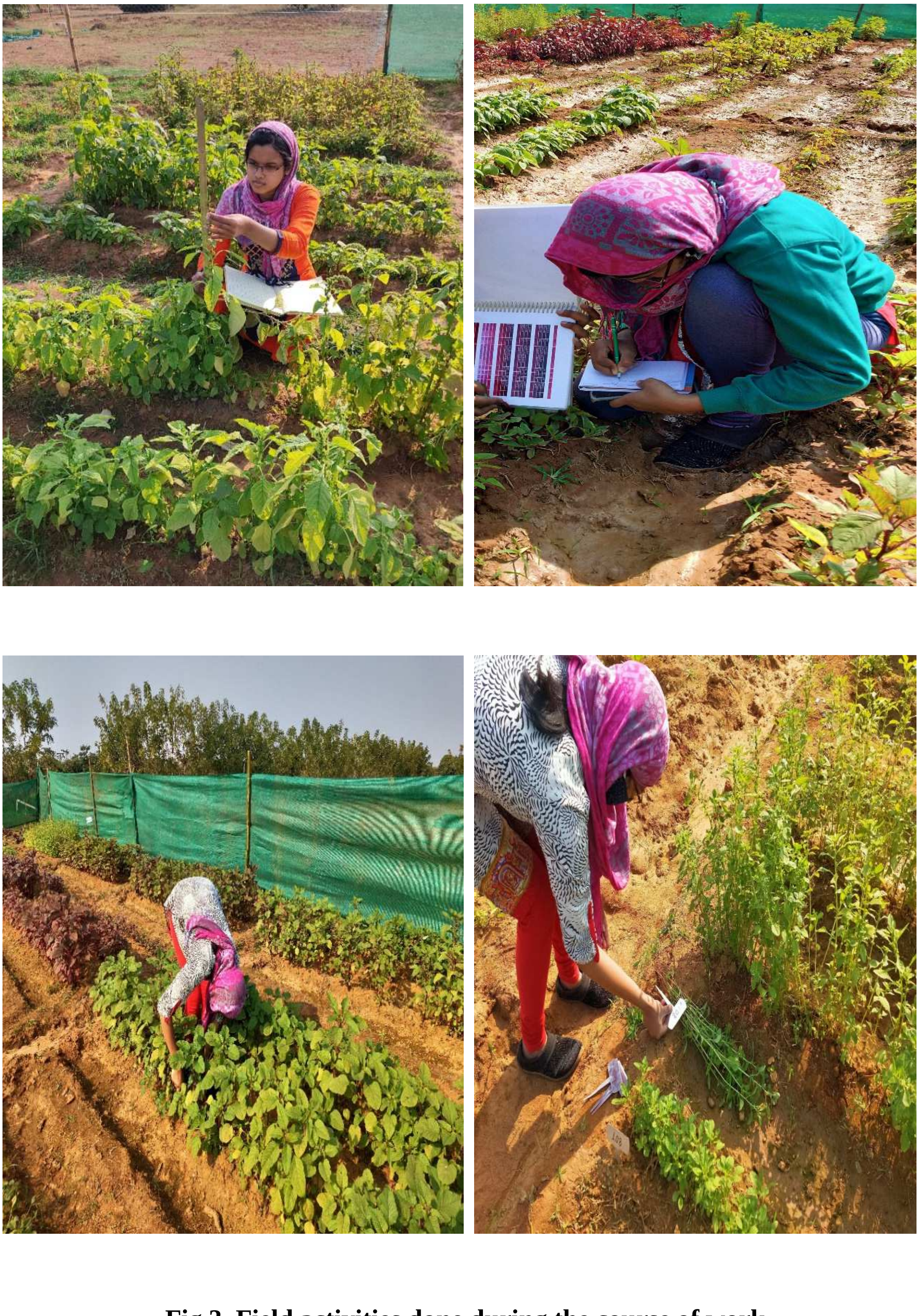

Fig.3. Field activities done during the course of work

Fig.4. Laboratory activities done during the course of work

Fig.5. ACCESSION-48

Fig.6. ACCESSION-45

Fig.7. ACCESSION-276

Fig.8. ACCESSION-65

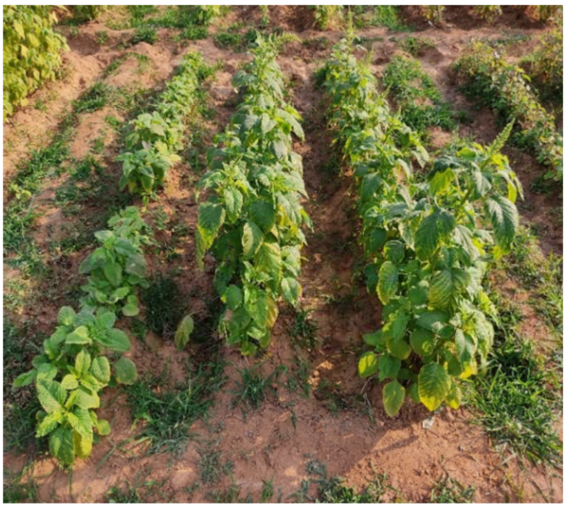

Fig.9. ACCESSION-204

Fig.10. ACCESSION-248

3.8.2 Characters studied

1. Plant growth

The circumference of tagged plant spread was measured horizontally in cm in the east-west and north-south directions and the mean of five plants were calculated separately.

2. Plant height

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

3. Number of nodes plant^{-1}

This character was recorded at the maturity growth stage by counting the number of nodes along the main stem from ground level to tip of plant.

4. Number of leaves plant^{-1}

The numbers of main countable leaves along the stem were taken into consideration to record this character.

5. Number of inflorescences plant^{-1}

The numbers of main countable inflorescence along the stem were taken into consideration to record this character.

6. Leaf length

Three leaves were selected randomly each from top, middle and bottom position of the selected plants. Their lengths were measured by recording the length starting from the tip of leaves to the base of petiole, averaged and expressed in centimetre (cm).

7. Leaf breadth

The leaves that were selected for measurement of lengths from the tagged plants were also taken for computing breadth. The breadth was measured by recording length at the centre of each leaf blade, averaged and was expressed in centimetre (cm).

8. Leaf thickness

The leaves that were selected for measurement of lengths and breadths from the tagged plants were also taken for measuring the leaf thickness using a Vernier caliper.

9. Stem girth

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

10. Petiole length

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

11. Colour of leaf, stem and inflorescence

Colour of leaf, stem and inflorescence of the crop were taken from leaf colour chart, stem colour chart and inflorescence colour chart.

12. Stem weight

For this character, fresh weight of total number of stems harvested excluding leaves at marketable harvest was taken in each replication of each plot and the total yield was expressed in terms of gram plant^{-1}.

13. Leaf weight

Observation for this trait was estimated 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 plant^{-1}.

14. Leaf area

The leaf area meter was used on the selected leaves to record the leaf area and was expressed as cm^2.

15. Leaf: stem ratio

The ratio of the fresh weight of total number of leaves to the fresh weight of total number of stem were taken at marketable harvest in each replication of each plot were recorded for this character.

16. Leaf yield plant^{-1}

To record this character, sum of the fresh weight of total number of leaves and the fresh weight of total number of stems at marketable harvest was taken in each replication of each plot.

17. Quality parameters

The following procedures were used for estimating the biochemical constituents:

a) TSS -The TSS of amaranthus sample was measured from the lowest range of Refractometer from 0-32.

Procedure: 7 to 10 amaranthus leaves were crushed in mortar and pestle to extract the filtrate juice. A drop of the sample was put on the glass of refractometer prism and covered gently with the lid to measure the TSS against the light.

b) Ascorbic acid (mg /100 g) -Ascorbic acid content of amaranthus leaves was estimated by volumetric method (Sadasivam and Balasubramanian, 1987).

Dye solution: It was prepared by taking a 200 ml volumetric flask in which 42 mg of sodium bicarbonate was dissolved in distilled water, to which 52 mg of 2-6 dichlorophenol indophenol was added and the volume was made up to 200 ml by adding distilled water.

Standard Stock solution: It was made by dissolving 100 mg ascorbic acid in 100 ml of 4% oxalic acid solution and 10 ml of this stock solution was diluted to 100 ml with 4% oxalic acid to get the working standard of 100 mg per ml.

Procedure: 5 ml of the working standard solution was pipetted into a 100 ml conical flask. Into it 10 ml of 4% oxalic acid was added. The contents were titrated against the dye (V_1ml) until a pink end point appeared. The amaranthus sample (5g) was extracted in 4% oxalic acid and the volume was made up to 100 ml. Then the contents were centrifuged. 5 ml of this supernatant was pipetted out and to it 10 ml of 4% oxalic acid was added and titrated against the dye (V_2 ml). The following formula was then used for calculation of ascorbic acid content.

Ascorbic acid (mg/100 g) = (0.5 mg ÷ V1) × (V2 ÷ 5ml) × (100ml ÷ Wt. of the sample) × 100

c) Sugar content -The total sugar content in amaranthus leaves was determined with the following procedures.

Determination of total sugar: 10 ml of filtrate juice amaranthus leaves was taken in a 250 ml of conical flask. 5 ml of 1N HCl was added followed by addition of distilled water. The content was heated for 4-5 minutes, followed by cooling for 30 minutes in a water bath for complete inversion. The content was then transferred to 250 ml conical flask & 2-3 drops of Phenolphthalein indicator was added & titrated against 1N NaOH solution taken in a burette. The end point was marked by appearance of light pink colour. Now the non-reducing sugar present in fruits is converted into reducing sugar. The whole content is then transferred to a burette. 5 ml each of Fehling's A & B are taken in 250 ml conical flask, followed by addition of 40 ml distilled water and then heated over the flame. When 1^{st} bubble appears 1-2 drops of Methylene blue was added and titrated till the end point comes to brick-red colour.

% of Total sugar = Dilution Factor (0.05) × 100 × 100 Titrate value × volume of sample

3.9 Statistical analysis

3.9.1 Analysis of variance

For finding out the varietal differences, analysis of variance for each asserted trait was done. For carrying out the analysis for each character, randomized block design analysis procedure was followed (Panse and Sukhatme, 1954).

The following model was used for carrying out analysis of variance.

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

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 and j^{th} replication

Table 5. Analysis of variance and expected mean sum of square

Source	Df	MSS	Expected mean sum of squares
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

3.9.2 Mean, Range, Standard Error and Critical Differences

The total was divided by the respective number of observations to calculate the sample mean values for each trait, while the highest and lowest values for each trait were taken as the range. The following formula was used to calculate S.E. and C.D. values.

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

Critical difference (C.D.) = $\sqrt{2EMS/r}$ × t value at error d.f. at 5% and 1% levels of significance

Where,

r = number of replications

EMS = Error mean sum of square

3.9.3 Co-efficient of variation

Co-efficient of variation was calculated for comparing the variability of two or more than traits by using the following formula:

$$C.V. = S.D./ X \times 100 = \sqrt{EMS}/ X \times 100$$

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

Error variance = $\sigma e^2 = M_E$

Genotypic variance = $\sigma^2{}_g = M_G - M_e / r$

Phenotypic variance = $\sigma^2{}_p = M_G / r = \sigma^2{}_g + \sigma^2{}_e / r$

The genotypic co-efficient of variation (GCV) and the phenotypic co-efficient of variation (PCV) were calculated by the formula given by Burton (1953).

GCV = Genotypic standard deviation / Grand mean × 100

PCV = Phenotypic standard deviation / Grand mean × 100

3.9.4 Heritability (broad sense)

To measure the degree of correspondence, heritability estimates between phenotypic value and breeding value were used. For this the formula given by Lush (1949) and Burton and Devance (1953) is used and expressed in percentage according to Weber and Moorty (1952).

h^2 (broad sense) = Genotypic variance / Phenotypic variance

h^2 (broad sense in percentage) = Genotypic variance /Phenotypic variance × 100

3.9.5 Expected genetic advance

Estimation of genetic advance was carried out 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

GA expressed as percentage of mean = GA / Mean × 100

3.9.6 Estimation of correlation co-efficient

Simple correlation coefficients between pairs of 12 important traits contributing to green yield plant $^{-1}$ were calculated at phenotypic and genotypic levels using the formula given below.

Genotypic correlation (r_g) = $\sigma_g(xy) / \sigma_g(x) \times \sigma_g(y)$

Phenotypic correlation (r_p) = $\sigma_p(xy) / \sigma_p(x) \times \sigma_p(y)$

Where,

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

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

$\sigma_g(x)$ and $\sigma_g(y)$ = Genotypic standard deviation for x and y respectively.

$\sigma_p(x)$ and $\sigma_p(y)$ = 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 to test the significance of correlation coefficients at phenotypic and genotypic level.

3.9.7 Path co-efficient analysis

The path coefficient analysis is used to determine the cause and effect relationships among the various traits that are correlated. Path coefficients are standardized partial regression coefficients which individually provide a measure of direct effect of the causal factors on the effect variable. These permit partitioning of the correlation between causal factors and the effect of variables, into components of direct and indirect effect and thus give a closure idea of the association of the causal factors with the effect variable.

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

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

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

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

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

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 on fruit yield per plant (1, 2)}.

The solutions for path coefficients, direct and indirect effects of the causal 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:

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

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

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

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

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

3.9.8 Genetic divergence

Genetic divergence was computed using Mahalanobis (1928) generalized distance, D^2 statistic as suggested by Rao (1952). The original measurements were transformed to standardized uncorrelated variables by crucial 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})

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

It gives the D^2 between j^{th} and k^{th} genotypes for 'n' characters. The genotypes were grouped into clusters following Tocher's method as suggested by Rao (1952). The grouping was done on the basis of the criteria that any two genotypes belonging to the same cluster should have a smaller D^2 value than those between genotypes belonging to different clusters. Inter and intra-cluster distances were determined and represented.

RESULTS

The present investigation entitled, **“Characterization and evaluation of Amaranthus (*Amaranthus spp.* L.) genotypes for leaf yield’’** was carried out at research plot of Central Horticultural Experiment Station, ICAR-Indian Institute of Horticultural Research, Bhubaneswar, Odisha, India, during *rabi*, 2020-2021. The objectives of the present investigation were characterization and evaluation of germplasm of vegetable amaranthus for *per se* performance. The other objectives were estimation of nature and extent of genetic variability, character association, path analysis of leaf yield and leaf yield attributing traits as well as divergence studies for future crop improvement programme of vegetable amaranthus.

In the present chapter “Results”, salient findings recorded on various aspects of morphological characterization, mean performances, genetic variability, character associations, path analysis and divergence studies among the 30 tested genotypes of vegetable amaranthus were analysed scientifically and presented with suitable tables, as per the requirements. For effective interpretation of salient findings of the present investigation, results are presented in the following sub-headings *i.e.*,

4.1 Morphological characterization

4.2 Mean performance of 30 genotypes of vegetable amaranthus

4.3 Genetic variability

4.4 Correlation coefficient

4.5 Path analysis

4.6 Genetic divergence

4.1 Morphological characterization

A perusal of Table 6 revealed wide variations for different morphological traits among the 30 evaluated genotypes of vegetable amaranthus.

Characterisation of plant growth of genotypes of vegetable amaranthus showed dominance of short plant (100.00 cm) with upright growth habit of 90.00%, while only 10.00% genotypes showed semi-spreading growth habit. In the study no genotype has spreading growth habit.

Regarding characterization of stem colour of vegetable amaranthus showed dominance of pink (43.33%) closely followed by yellowish green colour (33.33%). On the other hand, the evaluated genotype showed 6.67% each as stem colour in the form of purplish pink, greenish red and reddish brown. The result showed only 3.33% having yellowish pink stem colour. Purplish red petiole colour was dominant (43.33%) in the present study, followed by yellowish green (33.33%) then purplish pink, greenish red and reddish brown (6.67%) each and yellowish pink petiole (3.33%). Similarly, the results revealed dominance of short petiole (<14.00cm) (100.00%) than medium (14.00-17.00cm) and long petiole length (>17.00cm) (0.00% each), respectively.

Characterisation of leaf colour varied widely and five different leaf colours were observed. However, green leaf colour was dominated among the tested genotypes (53.33%) followed by green with purple blotch (16.67%), purplish green (13.33%), purple (10.00%) and greenish purple (6.67%). The results also revealed dominance of absence of blotch in leaves (83.33%) over presence of blotch in leaves (16.67%).

Characterisation of leaf shape of vegetable amaranthus showed dominance of ovate leaf shape (66.67%) and rhombate-ovate leaves (20.00%). The result also showed presence of 6.67% obovate leaf shape followed by lanceolate and elliptical (3.33%) shape each. The results showed prominence of smooth leaf veins among all the tested genotypes. Rugose type was absent in present study.

Regarding characterization of inflorescence colour, the germplasm was dominated by green colour (53.33%) followed by purplish green (20.00%), pink (16.67%) and purplish pink (3.33%) only. The result showed presence of 100% axillary inflorescence among the tested genotypes.

Table 6. Morphological characterisation of 30 genotypes of vegetable amaranthus

Sl. No.	The traits/descriptor	Class or scale of descriptor		No. of genotypes	Distribution by classes of descriptor (%)
I. According to DUS guidelines					
1	Plant height	1.	Short (<150 cm)	30	100.00
		2.	Medium (150-200 cm)	0	0.00
		3.	Tall (>200 cm)	0	0.00
2	Stem colour	1.	Pink (*Red-Purple 67A*)	13	43.33
		2.	Yellowish green (*Yellowish-green 150C*)	10	33.33
		3.	Red (*Red group 54A*)	2	6.67
		Others			
			Greenish red	2	6.67
			Purplish pink	2	6.67
			Yellowish pink	1	3.33
3	Petiole length	1.	Short (<14 cm)	30	100.00
		2.	Medium (14 -17 cm)	0	0.00
		3.	Long (>17 cm)	0	0.00
4	Leaf colour	1.	Green	16	53.33
		2.	Purple (*Red purple group 67 A*)	3	10.00
		Others			
			Green with purple blotch	5	16.67
			Greenish purple	2	6.67
			Purplish green	4	13.33
5	Presence of blotch in leaf	1.	Absent	25	83.33
		2.	Present	5	16.67
6	Inflorescence colour	1.	Green	16	53.33
		2.	Yellowish green (*Yellow green group 145C*)	2	6.67
		3.	Pink (*Red-Purple61B, N66A, 67A*)	5	16.67
		4.	Light yellow	0	0.00
		5.	Yellow (Yellow group 2C, 10	0	0.00

Contd……

Sl. No.	The traits/descriptor	Class or scale of descriptor		No. of genotypes	Distribution by classes of descriptor (%)
			A)		
		6.	Orange (Orange group 23A, 24A)	0	0.00
		7.	Pinkish green	0	0.00
		8.	Purple	0	0.00
		9.	Red (Red group51B)	0	0.00
		10.	Reddish green	0	0.00
		Others			
			Purplish green	6	20.00
			Purplish pink	1	3.33
II. Others					
1	Plant growth	1.	Upright	27	90.00
		2.	Semi- spreading	3	10.00
		3.	Spreading	0	0.00
2	Petiole colour	1.	Purplish red	13	43.33
		2.	Yellowish green	10	33.33
		3.	Purplish pink	2	6.67
		4.	Greenish red	2	6.67
		5.	Reddish brown	2	6.67
		6.	Yellowish pink	1	3.33
3	Leaf shape	1.	ovate	20	66.67
		2.	Obovate	2	6.67
		3.	Rhombate-ovate	6	20.00
		4.	Lanceolate	1	3.33
		5.	Elliptical	1	3.33
		6.	Cuneate	0	0.00
4	Prominence of leaf veins	1.	Smooth	30	100.00
		2.	Rugose	0	0.00
5	Presence of axillary inflorescence	1.	Present	30	100.00
		2.	Absent	0	0.00

Table 7. Qualitative parameters of 30 vegetable amaranthus germplasm.

Sl. No.	Genotypes	Plant growth	Plant height	Stem colour	Petiole colour	Petiole length	Leaf shape	Leaf colour	Presence of blotch in leaf	Prominence of leaf veins	Inflorescence colour	Presence of axillary inflorescence
1	ACCESSION-2	Semi- spreading	Short	Pink	Purplish red	Short	ovate	Green	Absent	Smooth	Green	Present
2	ACCESSION-6	Upright	Short	Pink	Purplish red	Short	ovate	Green with purple blotch	Present	Smooth	Green	Present
3	ACCESSION-8	Semi- spreading	Short	Yellowish green	Yellowish green	Short	Obovate	Green	Absent	Smooth	Yellowish green	Present
4	ACCESSION-13	Upright	Short	Yellowish green	Yellowish green	Short	ovate	Green	Absent	Smooth	Green	Present
5	ACCESSION-19	Upright	Short	Pink	Purplish red	Short	ovate	Greenish purple	Absent	Smooth	Purplish green	Present
6	ACCESSION-26	Upright	Short	Yellowish green	Yellowish green	Short	ovate	Green	Absent	Smooth	Green	Present
7	ACCESSION-32	Upright	Short	Yellowish green	Yellowish green	Short	ovate	Green with purple blotch	Present	Smooth	Green	Present
8	ACCESSION-37	Upright	Short	Pink	Purplish red	Short	Rhombate-ovate	Purplish green	Absent	Smooth	Pink	Present
9	ACCESSION-38	Upright	Short	Yellowish green	Yellowish green	Short	Rhombate-ovate	Green	Absent	Smooth	Green	Present
10	ACCESSION-39	Upright	Short	Yellowish green	Yellowish green	Short	ovate	Green	Absent	Smooth	Green	Present
11	ACCESSION-40	Upright	Short	Pink	Purplish red	Short	ovate	Green with purple blotch	Present	Smooth	Pink	Present
12	ACCESSION-41	Upright	Short	Pink	Purplish red	Short	ovate	Green with purple blotch	Present	Smooth	Purplish green	Present
13	ACCESSION-43	Upright	Short	Pink	Purplish red	Short	ovate	Green	Absent	Smooth	Green	Present
14	ACCESSION-45	Upright	Short	Pink	Purplish red	Short	ovate	Green with purple blotch	Present	Smooth	Pink	Present
15	ACCESSION-48	Upright	Short	Pink	Purplish red	Short	ovate	Green	Absent	Smooth	Green	Present

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Sl. No.	Genotypes	Plant growth	Plant height	Stem colour	Petiole colour	Petiole length	Leaf shape	Leaf colour	Presence of blotch in leaf	Prominence of leaf veins	Inflorescence colour	Presence of axillary inflorescence
16	ACCESSION-65	Upright	Short	Purplish pink	Purplish pink	Short	ovate	Purplish green	Absent	Smooth	Purplish pink	Present
17	ACCESSION-202	Upright	Short	Yellowish green	Yellowish green	Short	Rhombate-ovate	Green	Absent	Smooth	Green	Present
18	ACCESSION-204	Upright	Short	Yellowish green	Yellowish green	Short	ovate	Green	Absent	Smooth	Green	Present
19	ACCESSION-205	Upright	Short	Greenish red	Greenish red	Short	ovate	Green	Absent	Smooth	Purplish green	Present
20	ACCESSION-231	Upright	Short	Red	Reddish brown	Short	Rhombate-ovate	Purplish green	Absent	Smooth	Purplish green	Present
21	ACCESSION-237	Upright	Short	Pink	Purplish red	Short	ovate	Greenish purple	Absent	Smooth	Green	Present
22	ACCESSION-247	Upright	Short	Yellowish green	Yellowish green	Short	ovate	Green	Absent	Smooth	Green	Present
23	ACCESSION-248	Upright	Short	Pink	Purplish red	Short	ovate	Purple	Absent	Smooth	Pink	Present
24	ACCESSION-250	Upright	Short	Greenish red	Greenish red	Short	ovate	Green	Absent	Smooth	Green	Present
25	ACCESSION-258	Semi- spreading	Short	Yellowish pink	Yellowish pink	Short	Obovate	Green	Absent	Smooth	Yellowish green	Present
26	ACCESSION-263	Upright	Short	Red	Reddish brown	Short	Lanceolate	Purplish green	Absent	Smooth	Purplish green	Present
27	ACCESSION-268	Upright	Short	Purplish pink	Purplish pink	Short	ovate	Green	Absent	Smooth	Green	Present
28	ACCESSION-276	Upright	Short	Pink	Purplish red	Short	Rhombate-ovate	Purple	Absent	Smooth	Pink	Present
29	ACCESSION-287	Upright	Short	Yellowish green	Yellowish green	Short	Rhombate-ovate	Green	Absent	Smooth	Green	Present
30	ACCESSION-288	Upright	Short	Pink	Purplish red	Short	Elliptical	Purple	Absent	Smooth	Purplish green	Present

4.2 Mean performance of 30 vegetable amaranthus genotypes

4.2.1 Analysis of variance

Table 8. Analysis of variance for 18 characters studied in vegetable amaranthus germplasm.

Sl. No.	Characters	Mean Sum of Square		
		Replication (1)	Genotypes (29)	Error (29)
1	Plant height (cm)	0.294	14543.39**	1024.09
2	Nodes plant $^{-1}$	8.067	526.93**	100.93
3	Leaves plant^{-1}	25.938	2868.82**	302.08
4	Leaf length (cm)	0.171	310.21**	15.97
5	Leaf breadth (cm)	0.020	233.21**	8.90
6	Leaf thickness (mm)	0.003	0.24**	0.02
7	Stem girth (mm)	3.725	768.78**	33.69
8	Petiole length (cm)	0.542	125.41**	7.67
9	Stem weight (g)	0.082	142.53**	8.70
10	Leaf weight (g)	0.333	68.33**	3.31
11	Leaf Area (cm^2)	17.227	21788.39**	204.59
12	Leaf: Stem ratio	0.002	1.44**	0.11
13	TSS (%)	0.000	14.13**	1.20
14	Ascorbic acid (mg 100g^{-1})	2.904	13276.87**	1276.74
15	Total sugar (%)	0.134	0.27	0.26
16	Green yield plant^{-1} (g)	215.083	90978.76**	1733.36
17	Green yield plot^{-1} (kg)	2.147	910.48**	17.36
18	Green yield (q ha^{-1})	3481.426	1028766.10**	17630.71

4.2.2. Mean performance of 30 vegetable amaranthus genotypes

Results on plant height of vegetable amaranthus revealed significant variations among the 30 genotypes evaluated ranging from 34.80 cm (ACCESSION-38) to 112.25 cm (ACCESSION-204) with a mean plant height of 74.07 cm. Significantly longest plants were observed in genotype, ACCESSION-204 than rest of the tested genotypes. However, the results also revealed significantly higher plant height of 93.55 cm by the genotype, ACCESSION-287 closely followed by ACCESSION-250 (91.30 cm), ACCESSION-8 (90.40 cm), ACCESSION-45 (88.95 cm), ACCESSION-65 (88.55 cm), ACCESSION-19 (84.50 cm), ACCESSION-268 (83.00 cm) and ACCESSION-248 (82.70 cm) where *statistical parity* were observed.

Results on number of nodes plant^{-1} significantly varied from 10.00 (ACCESSION-263) to 25.50 (ACCESSION-41 &ACCESSION-204) with a mean value of 19.97. Significantly highest number of nodes plant^{-1}was recorded by ACCESSION-41 and ACCESSION-204 (25.50) than rest of the tested genotypes except ACCESSION-8 &ACCESSION-237 (23.00) and ACCESSION-40 and ACCESSION-45 (22.50) where *statistical parity* were observed.

Regarding number of leaves plant^{-1} in vegetable amaranthus, the results showed significant differences among the tested genotypes which varied from 31.46 (ACCESSION-39) to 57.55 (ACCESSION-43) with an average value of 41.11. The genotype, ACCESSION-43 recorded significantly highest number of leaves plant^{-1} (57.55) than rest of the tested genotypes, except ACCESSION-45 (51.19) which was *statistically at par.*

The result showed significant variation among the 30 tested genotypes for leaf length which varied from 3.30 cm (ACCESSION-258) to 13.25 cm (ACCESSION-65) with a mean leaf length of 8.07cm. The genotype ACCESSION-65 produced significantly longest leaf (13.25 cm) followed by ACCESSION-204 (12.75 cm) than rest of the other genotypes.

Similarly, results on leaf breadth of vegetable amaranthus varied significantly from 2.20 cm (ACCESSION-258) to 9.65 cm (ACCESSION-202) with a mean leaf breadth of 5.97. The genotype ACCESSION-202 recorded significantly maximum leaf breadth of 9.65 cm than rest of the tested genotype except ACCESSION-250 (8.75cm), ACCESSION-65 (8.70cm) and ACCESSION-204 (8.65 cm) which were *statistically at par* with each other.

Table 9. Mean performance of 30 vegetable amaranthus germplasm for 18 characters.

Name of germplasms	Plant height (cm)	Nodes plant^{-1}	Leaves plant^{-1}	Leaf length (cm)	Leaf breadth (cm)	Leaf thickness (mm)	Stem girth (mm)	Petiole length (cm)	Stem weight (g)	Leaf weight (g)	Leaf Area (cm^2)	Leaf: Stem ratio	TSS (%)	Ascorbic acid (mg 100g^{-1})	Total sugar (%)	Green yield plant^{-1} (g)	Green yield plot^{-1} (kg)	Green yield (q ha^{-1})
ACCESSION-2	71.70	20.00	38.21	8.50	4.85	0.30	11.35	5.30	5.63	4.34	33.44	0.78	4.90	91.05	1.99	123.34	12.34	411.12
ACCESSION-6	51.70	19.00	41.73	7.25	4.75	0.20	11.17	5.75	8.76	3.54	18.95	0.40	4.70	71.43	1.89	114.06	11.41	380.19
ACCESSION-8	90.40	23.00	33.28	7.75	5.50	0.30	10.45	5.50	5.41	2.65	16.98	0.49	3.30	96.95	1.87	55.26	5.53	184.21
ACCESSION-13	81.20	20.00	39.63	7.05	5.25	0.30	8.54	6.10	5.32	2.76	33.74	0.52	3.55	54.53	1.87	106.15	10.62	353.84
ACCESSION-19	84.50	20.00	42.82	6.65	6.80	0.35	9.31	5.10	7.51	4.52	52.05	0.61	4.55	47.17	1.96	149.80	14.98	499.34
ACCESSION-26	43.95	21.00	38.84	7.25	6.60	0.35	9.12	4.30	6.49	3.54	44.28	0.55	4.05	67.70	1.96	104.80	10.48	349.33
ACCESSION-32	74.70	20.00	41.08	7.90	5.20	0.35	9.60	5.70	6.22	4.35	38.46	0.71	4.75	68.58	1.96	126.65	12.67	424.17
ACCESSION-37	56.80	20.50	50.90	6.80	6.40	0.35	10.19	6.05	5.51	3.17	33.88	0.58	4.40	58.69	1.89	120.06	12.01	400.21
ACCESSION-38	34.80	20.00	35.15	4.20	2.25	0.40	12.51	4.65	9.95	3.06	20.25	0.31	4.10	53.76	1.98	106.54	10.66	355.14
ACCESSION-39	55.80	14.00	31.46	7.30	5.35	0.20	10.05	3.75	8.36	2.03	21.92	0.24	4.00	70.41	1.93	69.50	6.95	231.67
ACCESSION-40	67.50	22.50	32.61	4.80	3.00	0.20	7.96	6.40	7.22	2.08	16.97	0.29	4.65	69.16	1.99	60.88	6.09	202.93
ACCESSION-41	69.00	25.50	32.16	7.40	4.70	0.30	13.82	7.30	8.59	2.55	27.88	0.30	5.00	82.20	1.98	89.45	8.95	298.17
ACCESSION-43	77.85	20.00	57.55	8.30	6.80	0.30	11.64	6.75	7.07	3.31	16.85	0.48	4.70	91.70	2.00	151.15	15.12	503.84
ACCESSION-45	88.95	22.50	51.19	8.35	8.05	0.25	15.68	6.30	7.80	4.72	33.35	0.61	4.90	76.13	1.97	179.48	17.95	598.25
ACCESSION-48	69.30	21.00	49.69	6.45	8.30	0.35	19.02	6.60	9.85	4.94	37.16	0.50	3.80	68.03	1.89	183.31	18.33	611.02
ACCESSION-65	88.55	19.00	47.69	13.25	8.70	0.40	12.86	5.25	6.47	5.01	91.79	0.78	4.10	51.98	2.23	177.38	17.74	591.25
ACCESSION-202	81.10	20.00	49.81	10.40	9.65	0.30	10.71	6.50	5.82	4.44	68.33	0.77	4.40	57.95	1.96	163.10	16.31	579.15
ACCESSION-204	112.25	25.50	46.38	12.75	8.65	0.35	19.56	8.20	9.06	4.97	73.00	0.55	4.65	54.60	1.92	172.12	17.21	575.40

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Name of germplasms	Plant height (cm)	Nodes plant^{-1}	Leaves plant^{-1}	Leaf length (cm)	Leaf breadth (cm)	Leaf thickness (mm)	Stem girth (mm)	Petiole length (cm)	Stem weight (g)	Leaf weight (g)	Leaf Area (cm^2)	Leaf: Stem ratio	TSS (%)	Ascorbic acid (mg 100g^{-1})	Total sugar (%)	Green yield plant^{-1} (g)	Green yield plot^{-1} (kg)	Green yield (q ha^{-1})
ACCESSION-205	59.65	16.00	34.44	9.20	4.75	0.35	9.63	5.10	4.76	3.52	28.25	0.74	3.65	64.13	1.85	91.80	9.18	306.00
ACCESSION-231	74.55	17.50	31.90	5.85	3.80	0.30	12.13	2.70	9.31	3.74	11.94	0.40	4.00	69.46	1.96	101.25	10.13	337.50
ACCESSION-237	73.25	23.00	49.38	11.10	8.10	0.40	22.37	8.20	9.41	4.53	52.40	0.49	5.05	79.73	1.98	167.70	16.81	558.98
ACCESSION-247	64.60	18.00	34.52	5.30	3.20	0.20	7.72	3.95	8.63	2.12	14.04	0.25	4.40	67.09	1.98	70.91	7.09	236.37
ACCESSION-248	82.70	18.50	39.18	8.85	6.40	0.35	11.89	6.05	8.69	5.68	25.86	0.66	4.00	58.83	2.04	171.95	17.20	573.17
ACCESSION-250	91.30	21.00	46.02	9.40	8.75	0.35	12.80	5.65	7.80	4.91	29.07	0.63	4.50	47.68	1.89	166.15	16.62	553.84
ACCESSION-258	77.05	19.50	33.32	3.30	2.20	0.25	5.29	2.35	5.52	4.12	6.62	0.75	3.40	98.46	1.94	136.50	13.65	455.00
ACCESSION-263	68.65	10.00	42.96	7.25	4.00	0.25	14.15	2.35	8.99	4.81	15.57	0.54	4.00	48.83	2.01	156.89	15.69	522.95
ACCESSION-268	83.00	20.00	43.16	9.25	6.20	0.35	13.99	5.95	8.40	5.21	21.86	0.62	4.70	85.69	1.99	168.45	16.85	561.50
ACCESSION-276	80.75	20.50	39.11	11.35	6.65	0.20	15.49	6.85	9.53	5.66	37.68	0.60	4.30	54.35	1.94	178.63	17.87	595.43
ACCESSION-287	93.55	21.50	44.10	9.85	7.65	0.27	11.41	5.55	8.81	5.17	51.49	0.59	5.00	49.86	1.96	170.65	17.07	568.82
ACCESSION-288	72.85	20.00	35.21	9.05	6.45	0.40	11.83	6.45	8.49	4.74	28.92	0.56	4.80	82.23	1.97	126.52	12.65	421.72
General Mean	74.07	19.97	41.11	8.07	5.97	0.31	12.07	5.56	7.64	4.00	33.43	0.54	4.34	67.94	1.96	132.01	13.20	441.35
C.D.	12.15	3.82	6.60	1.52	1.13	0.06	2.20	1.05	1.12	0.69	5.43	0.13	0.42	13.57	-	15.81	1.58	50.43
SE(m)	4.13	1.30	2.24	0.52	0.39	0.02	0.75	0.36	0.38	0.23	1.85	0.04	0.14	4.61	0.07	5.37	0.54	17.14
SE(d)	5.94	1.87	3.23	0.74	0.55	0.03	1.08	0.51	0.55	0.34	2.66	0.06	0.20	6.64	0.09	7.73	0.77	24.66
C.V.	8.02	9.34	7.85	9.20	9.29	8.78	8.93	9.26	7.17	8.44	7.95	11.58	4.68	9.77	4.82	5.86	5.86	5.57

Regarding leaf thickness of vegetable amaranthus the results indicated significant variation which varied from 0.20mm (ACCESSION-6, ACCESSION-39, ACCESSION-40, ACCESSION-247, ACCESSION-276) to 0.40mm (ACCESSION-38, ACCESSION-65, ACCESSION-237, and ACCESSION-288) with mean thickness of 0.31 mm. Significantly thickest leaf was recorded in ACCESSION-38, ACCESSION-65, ACCESSION-237, ACCESSION-288 (0.40mm) and were *statistically at par* with ACCESSION-19, ACCESSION-26, ACCESSION-32, ACCESSION-37, ACCESSION-48, ACCESSION-204, ACCESSION-205, ACCESSION-248, ACCESSION-250, ACCESSION-268 (0.35mm).

Regarding stem girth of vegetable amaranthus, the results showed significantly highest stem girth of 22.37mm by the genotype ACCESSION-237 while that of lowest recorded in genotype, ACCESSION-258 (5.29 mm).

Similarly, petiole length of vegetable amaranthus indicated significant variations among the tested genotypes which varied from 2.35 cm (ACCESSION-258 and ACCESSION-263) to 8.20 cm (ACCESSION-204 and ACCESSION-237) with a mean value of 5.56 cm. Both the genotypes, ACCESSION-204 and ACCESSION-237 recorded longest petiole of 8.20 cm than the rest of the tested genotypes except ACCESSION-41 (7.30 cm) which was *statistically at par* with the highest value.

Results on stem weight of vegetable amaranthus also revealed significant variations among the tested genotypes which varied from 4.76 g (ACCESSION-205) to 9.95 g (ACCESSION-38) with a mean stem weight of 7.64 g. The genotype, ACCESSION-38 recorded significantly heaviest stem of 9.95 g than rest of the tested genotypes. However, *statistical parity* was observed among the genotypes ACCESSION-48 (9.85g), ACCESSION-276 (9.53g), ACCESSION-237 (9.41g), ACCESSION-231 (9.31g), ACCESSION-204 (9.06g) and ACCESSION-263 (8.99 g).

Similarly, the results also showed significant variations among the genotypes for leaf weight which varied from 2.03 g (ACCESSION-39) to 5.68 g (ACCESSION-248) with a mean leaf weight of 4.00 g. Significantly heaviest leaves were produced by the genotypes ACCESSION-248 (5.68g) closely followed by ACCESSION-276 (5.66 g), ACCESSION-268 (5.21g), ACCESSION-287 (5.17g) and ACCESSION-65 (5.01g) which were *statistically at par* with each other.

Results on leaf area of vegetable amaranthus genotypes varied significantly ranging from 6.62 cm^2 (ACCESSION-258) to 91.79 cm^2 (ACCESSION-65) with a mean value of 33.43 cm^2. The results also showed leaf area above 40 cm^2 were ACCESSION-204 (73.00), ACCESSION-202 (68.33), ACCESSION-19 (52.05), ACCESSION-237 (52.40), ACCESSION-287 (51.49) and ACCESSION-26 (44.28).

The ratio of leaf: stem in vegetable amaranthus also showed significant variation among the tested genotypes ranging from 0.24 (ACCESSION-39) to 0.78 (ACCESSION-2 &ACCESSION-65) with a mean ratio of 0.54. Significant highest leaf: stem ratio was recorded in ACCESSION-2 and ACCESSION-65 (0.78) and was *statistically at par* with ACCESSION-202 (0.77), ACCESSION-258 (0.75), ACCESSION-205 (0.74), ACCESSION-32 (0.71) and ACCESSION-248 (0.66).

Results on TSS of vegetable amaranthus leaves indicated significant variations among the tested genotypes ranging from 3.30 (ACCESSION-8) to 5.05 (ACCESSION-237) with a mean value of 4.34. The genotype ACCESSION-237 recorded significantly highest TSS of 5.05 than rest of the tested genotypes. However, *statistical parity* were observed among genotypes *viz.*, ACCESSION-41 & ACCESSION-287 (5.00), ACCESSION-2 & ACCESSION-45 (4.90), ACCESSION-288 (4.80), ACCESSION-32 (4.75), ACCESSION-6 & ACCESSION-43 & ACCESSION-268 (4.70) and ACCESSION-40 & ACCESSION-204 (4.65).

Results data on ascorbic acid content of vegetable amaranthus leaves showed significant variations ranging from 47.17 mg100g^{-1}(ACCESSION-19) to 98.46 mg 100g^{-1}(ACCESSION-258) with a mean value of 67.94mg 100g^{-1}. The genotype ACCESSION-258 recorded significantly highest ascorbic acid in leaves (98.46mg 100g^{-1}) and was *statistically at par* with ACCESSION-8 (96.95), ACCESSION-43 (91.70), ACCESSION-2(91.05) and ACCESSION-268 (85.69).

Regarding total sugar content of vegetable amaranthus leaves varied significantly ranging from 1.85 % (ACCESSION-205) to 2.23 % (ACCESSION-65) with a mean value of 1.96%.

Green yield $plant^{-1}$ showed significant variations among the tested genotypes ranging from 55.26g (ACCESSION-8) to 183.31g (ACCESSION-48) with a mean yield of 132.01g. Significantly highest green yield $plant^{-1}$ was produced by the genotype, ACCESSION-48 (183.31g) than the rest of the tested genotypes. However, *statistical parity* were observed among the other genotypes with highest value *viz.*,ACCESSION-45(179.48g), ACCESSION-276 (178.63g), ACCESSION-65 (177.38g), ACCESSION-204(172.12g), ACCESSION-248(171.95g), ACCESSION-287 (170.65g), ACCESSION-268 (168.45g) and ACCESSION-237 (167.70g).

Regarding green yield plot^{-1} of 3 m^2 area, the result showed significant variation ranging from 5.53 kgplot^{-1}(ACCESSION-8) to 18.33 kgplot^{-1}(ACCESSION-48) with a mean value of 13.20 kgplot^{-1}. Significantly highest per plot green yield were recorded by genotypes ACCESSION-48 (18.33) and was *statistically at par* with genotypes, ACCESSION-45 (17.95), ACCESSION-276 (17.87), ACCESSION-65(17.74), ACCESSION-204(17.21), ACCESSION-248 (17.20), ACCESSION-287 (17.07), ACCESSION-268 (16.85) and ACCESSION-237 (16.81).

A persual of table 9 on total green yield hectare^{-1} of vegetable amaranthus showed significant variations ranging from 184.21 (ACCESSION-8) to 611.02 (ACCESSION-48) with a mean yield of 441.35. Significantly highest green yield ha^{-1} was recorded in genotype, ACCESSION-48 (611.02) than rest of the tested genotypes. However *statistical parity* were observed among the tested genotypes with the highest value *viz.*, ACCESSION-276 (595.43), ACCESSION-268 (591.50), ACCESSION-45 (598.25), ACCESSION-65 (591.25), ACCESSION-202 (579.15), ACCESSION-204 (575.40), ACCESSION-248 (573.17) and ACCESSION-287 (568.82).

4.3 Genetic variability

Results data presented in table no. 10 showed wide variations among the tested 30 genotypes of amaranthus for 18 traits. The result showed wide variations among the 18 traits which varied from 0.20mm to 0.40mm (leaf thickness) to 184.21 q ha^{-1} to 611.02 q ha^{-1} (green yield). Results on range of 18 traits also showed that the difference between minimum to maximum value varies from 1.21 times (total sugar %) to maximum 13.87 times (leaf area). The traits showing more than three times differences between minimum to maximum were *viz.*, leaf area (13.87 times), length (4.57 times), leaf breadth (4.39 times), stem girth (4.23 times), petiole length (3.49 times), green yield plant^{-1}& green yield hectare^{-1} (3.32 times), green yield plot^{-1}(3.31 times), leaf: stem ratio (3.25 times), plant height (3.22 times).

Regarding general mean of 18 characters studied the result also showed wide variations among the traits ranging from 0.31 (leaf thickness) to 441.35 (green yield ha^{-1}).

Results presented in table 10 revealed wide variations among the traits for both PCV and GCV. Invariably, estimates of PCV were higher than corresponding GCV for all the 18 traits under study. Higher PCV and GCV (>20%) were recorded for the traits viz. plant height 22.18 and 20.61, leaf length 29.39 and 27.91, leaf breadth 34.25 and 32.97, leaf thickness 22.00 and 20.17, stem girth 30.81 and 29.49, petiole length 27.27 and 25.65, leaf weight 27.76 and 26.44, leaf area 58.25 and 57.71, leaf: stem ratio 30.30 and 28.00, ascorbic acid content 23.32 and 21.17, green yield $plant^{-1}$30.29 and 29.71, green yield $plot^{-1}$ 30.29 and 29.72 and green yield $hectare^{-1}$ 30.43 and 29.92, respectively. On the other hand, lower PCV and GCV were observed (<20%) in traits number of nodes $plant^{-1}$16.48 and 13.57, number of leaves $plant^{-1}$17.98 and 16.18, TSS 11.84 and 10.87, total sugar 4.89 and 0.85, respectively. The data also showed the closeness between PCV and GCV for the trait (within 10%) *viz.*, plant height, leaf length, leaf breadth, stem girth, petiole length, stem weight, leaf weight, leaf area, leaf: stem ratio, TSS, green yield $plant^{-1}$, green yield $plot^{-1}$, green yield $hectare^{-1}$.

Regarding heritability among the 18 traits of amaranthus revealed wide variations ranging from 3.00% (total sugar) to 96.60% (green yield $hectare^{-1}$). The result also showed that most of the traits except number of nodes $plant^{-1}$ and total sugar content showed more than 80.00% heritability.

Regarding genetic advance as % of mean, the result also showed wide variations ranging from 0.30 (total sugar) to 117.76 (leaf area). The traits showing higher genetic advance as % of mean (>30%) were leaf area (117.76), leaf breadth (65.37), green yield $hectare^{-1}$ (60.58), green yield $plot^{-1}$ (60.07) , green yield $plant^{-1}$ (60.06), stem girth (58.14), leaf length (54.61), leaf: stem ratio (53.31), leaf weight (51.89), petiole length (49.70), ascorbic acid content (39.60), plant height (39.57), stem weight (38.51) and leaf thickness (38.10). The results also showed the traits *viz.*, leaf length (90.20% and 54.61%), leaf breadth (92.60% and 65.37%), stem girth (91.60% and 58.14%), petiole length (88.50% and 49.70%), leaf area (98.10% and 117.76%), leaf : stem ratio (85.40% and 53.31%), leaf weight (90.80% and 51.89%), green yield $plant^{-1}$ (96.30% and 60.06 %), green yield $plot^{-1}$ (96.30% and 60.07%) and green yield ha^{-1} (96.60% and 60.58 %) of high heritability coupled with genetic advance expressed in % of mean.

Table 10. Range, General mean, phenotypic co-efficient of variation (PCV), genotypic co-efficient of variation (GCV), heritability (in broad sense), genetic advance (GA) and GA expressed in % of Mean for 18 characters in vegetable amaranthus germplasm.

Characters	Range	General mean	Phenotypic co-efficient of variation (PCV)	Genotypic co-efficient of variation (GCV)	Heritability (in broad sense) (%)	Genetic advance	GA expressed in % of Mean
Plant height (cm)	34.80 - 112.25	74.07	22.12	20.61	86.80	29.31	39.57
Nodes plant $^{-1}$	10.00 - 25.50	19.97	16.48	13.57	68.10	4.60	23.03
Leaves plant $^{-1}$	31.46 - 57.55	41.11	17.98	16.18	80.90	12.33	29.99
Leaf length (cm)	3.30 - 13.25	8.07	29.39	27.91	90.20	4.41	54.61
Leaf breadth (cm)	2.20 - 9.65	5.97	34.25	32.97	92.60	3.90	65.37
Leaf thickness (mm)	0.20 - 0.40	0.31	22.00	20.17	84.10	0.12	38.10
Stem girth (mm)	5.29 - 22.37	12.07	30.81	29.49	91.60	7.02	58.14
Petiole length (cm)	2.35 - 8.20	5.56	27.27	25.65	88.50	2.76	49.70
Stem weight (g)	4.76 - 9.95	7.64	21.13	19.87	88.50	2.94	38.51
Leaf weight (g)	2.03 - 5.68	4.00	27.76	26.44	90.80	2.08	51.89
Leaf Area (cm^2)	6.62 - 91.79	33.43	58.25	57.71	98.10	39.37	117.76
Leaf: Stem ratio	0.24 - 0.78	0.54	30.30	28.00	85.40	0.29	53.31
TSS (%)	3.30 - 5.05	4.34	11.84	10.87	84.30	0.89	20.56
Ascorbic acid (mg $100g^{-1}$)	47.17 - 98.46	67.94	23.32	21.17	82.50	26.91	39.60
Total sugar (%)	1.85 - 2.23	1.96	4.89	0.85	03.00	0.01	0.30
Green yield plant $^{-1}$ (g)	55.26 - 183.31	132.01	30.29	29.71	96.30	79.28	60.06
Green yield plot $^{-1}$ (kg)	5.53 - 18.33	13.20	30.29	29.72	96.30	7.93	60.07
Green yield (q ha^{-1})	184.21 - 611.02	441.35	30.43	29.92	96.60	267.37	60.58

4.4 Correlation coefficient

Results on characters association between all pairs of 18 traits in vegetable amaranthus showed significant to highly significant effect for most of the traits.

The results revealed highly significant positive correlation of green yield plant^{-1} with plant height (0.490 and 0.533), number of leavesplant^{-1} (0.693 and 0.765), leaf length (0.553 and 0.583), leaf breadth (0.660 and 0.706), stem girth (0.553 and 0.610), leaf weight (0.894 and 0.914), leaf area (0.505 and 0.518) and leaf: stem ratio (0.570 and 0.573) both at phenotypic and genotypic level, respectively. Similarly, significant positive correlation with green yield plant^{-1} was recorded with stem weight (0.275 and 0.313) and TSS (0.265 and 0.292). However, the traits *viz.*, leaf thickness (0.283) and petiole length (0.304) showed significant positive association with yield at phenotypic level only while highly significant positive correlation at genotypic level (0.355 and 0.338), respectively. The trait ascorbic acid content of leaf showed significantly negative correlation with green yield plant^{-1} (-0.269) at phenotypic level and highly negative significant at genotypic level (-0.332).

Total sugar content of vegetable amaranthus leaves showed highly significant association with number of leaves plant^{-1} (0.862), leaf length (0.971), leaf breadth (0.464), leaf thickness (0.519), stem weight (0.848), leaf weight (0.910), leaf area (0.903), leaf: stem ratio (0.727), TSS (0.948) at genotypic level only. The total sugar was also highly significant and negatively correlated with ascorbic acid content (-0.507) and number of nodes plant^{-1} (-0.665) at genotypic level only. Similarly, the total sugar content of the leaves showed significant positive association with stem girth (0.296) while negative association with petiole length (-0.276).

Results on character association of ascorbic acid content of vegetable amaranthus leaves showed significant and negative correlation at genotypic level with leaf length (-0.259), stem weight (-0.261) and leaf weight (-0.307). However, the trait was highly significant and negatively correlated with leaf area (-0.424 and -0.476) whereas, significant and negatively correlated with leaf breadth (-0.274 and -0.280) both at phenotypic and genotypic level.

Table 11. Phenotypic correlation co-efficient and genotypic correlation co-efficient (in parenthesis) between all pairs of 18 characters in vegetable amaranthus germplasm.

Traits	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	**1.000** (**1.000**)	0.306* (0.416**)	0.322* (0.339**)	0.531** (0.608**)	0.520** (0.577**)	0.038 (0.102)	0.282* (0.294*)	0.324* (0.374**)	-0.031 (-0.038)	0.483** (0.557**)	0.392** (0.440**)	0.385** (0.456**)	0.129 (0.157)	-0.067 (-0.063)	0.123 (0.243)	0.490** (0.533**)
2		**1.000** (**1.000**)	0.133 (0.229)	0.177 (0.243)	0.282* (0.399**)	0.224 (0.241)	0.270* (0.326*)	0.670** (0.790**)	-0.003 (0.020)	0.029 (0.021)	0.295* (0.344**)	-0.010 (-0.039)	0.378** (0.397**)	0.200 (0.250)	-0.036 (-0.665**)	0.086 (0.110)
3			**1.000** (**1.000**)	0.423** (0.506**)	0.705** (0.761**)	0.241 (0.332**)	0.441** (0.500**)	0.421** (0.499**)	0.017 (0.011)	0.427** (0.489**)	0.462** (0.502**)	0.334** (0.399**)	0.306* (0.389**)	-0.196 (-0.177)	0.055 (0.862**)	0.693** (0.765**)
4				**1.000** (**1.000**)	0.749** (0.802**)	0.298* (0.337**)	0.515** (0.597**)	0.535** (0.589**)	0.034 (0.062)	0.558** (0.611**)	0.718** (0.774**)	0.434** (0.481**)	0.301* (0.346**)	-0.224 (-0.259*)	0.217 (0.971**)	0.553** (0.583**)
5					**1.000** (**1.000**)	0.352** (0.398**)	0.518** (0.561**)	0.549** (0.629**)	0.046 (0.038)	0.538** (0.608**)	0.730** (0.763**)	0.389** (0.469**)	0.282* (0.310*)	-0.274* (-0.280*)	0.063 (0.464**)	0.660** (0.706**)
6						**1.000** (**1.000**)	0.304* (0.345**)	0.282* (0.276*)	-0.041 (-0.076)	0.328* (0.382**)	0.424** (0.452**)	0.336** (0.426**)	0.016 (0.049)	-0.093 (-0.129)	0.176 (0.519**)	0.283* (0.355**)
7							**1.000** (**1.000**)	0.546** (0.584**)	0.572** (0.640**)	0.461** (0.523**)	0.359** (0.385**)	-0.025 (-0.017)	0.319* (0.380**)	-0.098 (-0.082)	0.058 (0.296*)	0.553** (0.610**)
8								**1.000** (**1.000**)	0.107 (0.136)	0.196 (0.212)	0.441** (0.457**)	0.040 (0.040)	0.478** (0.565**)	0.015 (0.014)	-0.058 (-0.276*)	0.304* (0.338**)
9									**1.000** (**1.000**)	0.259* (0.270*)	-0.067 (-0.079)	-0.511** (-0.512**)	0.311* (0.344**)	-0.200 (-0.261*)	0.067 (0.848**)	0.275* (0.313*)
10										**1.000** (**1.000**)	0.430** (0.450**)	0.681** (0.677**)	0.193 (0.218)	-0.225 (-0.307*)	0.147 (0.910**)	0.894** (0.914**)
11											**1.000** (**1.000**)	0.429** (0.469**)	0.230 (0.254)	-0.424** (-0.476**)	0.250 (0.903**)	0.505** (0.518**)
12												**1.000** (**1.000**)	-0.067 (-0.068)	-0.036 (-0.078)	0.094 (0.727**)	0.570** (0.573**)
13													**1.000** (**1.000**)	0.024 (0.014)	0.176 (0.948**)	0.265* (0.292*)
14														**1.000** (**1.000**)	-0.040 (-0.507**)	-0.269* (-0.332**)
15															**1.000** (**1.000**)	0.198 (1.343**)

&**Significant at 5% & 1% respectively

1. Plant height (cm), **2.**Nodes plant^{-1}, **3.**Leaves/plant, **4.**Leaf length (cm), **5.**Leaf breadth (cm), **6.**Leaf thickness (mm), **7.**Stem girth (mm), **8.**Petiole length (cm), **9.**Stem weight (g), **10.**Leaf weight (g), **11.**Leaf area, **12.**Leaf: stem ratio, **13.**TSS (%), **14.**Ascorbic acid (mg 100 g^{-1}), **15.**Total sugar (%), **16.**Green yield plant^{-1} (g)

Regarding TSS of vegetable amaranthus leaves highly significant positive correlation were observed with number of nodes plant^{-1} (0.378 and 0.397) and petiole length (0.478 and 0.565) both at phenotypic and genotypic level, respectively. On the other hand, significant positive correlations were observed at phenotypic level with number of leaves plant^{-1} (0.306), leaf length (0.301), leaf breadth (0.282), stem girth (0.319), stem weight (0.311) while, highly significant positive correlation at genotypic level (0.389, 0.346, 0.310 and 0.344), respectively.

Leaf: stem ratio of vegetable amaranthus showed highly significant and positive correlation with plant height (0.385 and 0.456), number of leaves plant^{-1} (0.334 and 0.399), leaf length (0.434 and 0.481), leaf breadth (0.389 and 0.469), leaf thickness (0.336 and 0.426), leaf weight (0.681 and 0.677), and leaf area (0.429 and 0.469). Similarly, negative correlation with stem weight (-0.511 and -0.512), both at phenotypic and genotypic level respectively.

In vegetable amaranthus leaf area play very crucial role towards crop improvement. The present study revealed highly significant and positive correlation of leaf area with important leaf yield attributing traits *viz.*, plant height (0.392 and 0.440), number of leaves plant^{-1} (0.462 and 0.502), leaf length (0.718 and 0.774), leaf breadth (0.730 and 0.763), leaf thickness (0.424 and 0.452), stem girth (0.359 and 0.385), petiole length (0.441 and 0.457) and leaf weight (0.430 and 0.450) both at phenotypic and genotypic level, respectively. However, leaf area was significantly and positively correlated with number of nodes plant^{-1} at phenotypic level (0.295) while highly significant at genotypic level (0.344).

Character association of leaf weight of vegetable amaranthus showed highly significant and positive effect with plant height (0.483 and 0.557), number of leaves plant^{-1} (0.427 and 0.489), leaf length (0.558 and 0.611), leaf breadth (0.538 and 0.608) and stem girth (0.461 and 0.523) at phenotypic and genotypic level, respectively. However, leaf weight was significantly and positively correlated with stem weight both at phenotypic and genotypic level (0.259 and 0.270) whereas, with leaf thickness at phenotypic level (0.328). On the other hand, leaf weight was highly significant and positively correlated with leaf thickness at genotypic level (0.382).

Similarly, stem weight was highly significant and positively correlated with stem girth only (0.572 and 0.640) at phenotypic and genotypic level, respectively.

Results on character association between petiole length with other traits showed highly significant and positive correlation *viz.,* number of nodes plant^{-1} (0.670 and 0.790), number of leaves plant^{-1} (0.421 and 0.499), leaf length (0.535 and 0.589), leaf breadth (0.549 and 0.629) and stem girth (0.546 and 0.584) at both phenotypic and genotypic level, respectively. On the other hand, petiole length was significant and positively correlated with leaf thickness at both phenotypic (0.282) and genotypic (0.276) level. Whereas, significant and positive correlation with plant height at phenotypic level (0.324) and highly significant at genotypic level (0.374) was observed.

Regarding correlation of stem girth of vegetable amaranthus showed highly significant correlation with number of leaves plant^{-1} (0.441 and 0.500), leaf length (0.515 and 0.597), and leaf breadth (0.518 and 0.561) at both phenotypic and genotypic level, respectively. However, stem girth was significant and positively correlated with both plant height (0.282& 0.294), and number of nodes plant^{-1} (0.270 and 0.326) at both phenotypic and genotypic level, respectively. Similarly, stem girth was significant and positively correlated at phenotypic level (0.304) while highly significant at genotypic level (0.345).

Character association between leaf thickness with traits *viz.,* number of leaves plant^{-1} (0.332), leaf length (0.337) and leaf breadth (0.398) showed highly significant correlation at genotypic level only. However, leaf thickness showed at phenotypic level significant effect with leaf length (0.298) and highly significant effect with leaf breadth (0.352).

The study also showed highly significant and positive correlation of leaf breadth with plant height (0.520 and 0.577), number of leaves plant^{-1} (0.705 and 0.761), and leaf length (0.749 and 0.802) at both phenotypic and genotypic level, respectively. However, leaf breadth showed significant positive association with number of nodesplant^{-1} (0.282) at phenotypic level and highly significant at genotypic level (0.399).

Leaf length of vegetable amaranthus showed highly significant association with plant height (0.531 and 0.608) as well as leaves plant^{-1} (0.423 and 0.506) both at phenotypic and genotypic level, respectively. Similarly, results on character association between number of leaves plant^{-1} with plant height showed significant positive effect at phenotypic level (0.322) and highly significant positive effect at genotypic level (0.339). On the other hand, number of nodesplant^{-1} the result showed similar effect of significantly positive correlation with plant height at phenotypic level (0.306) and highly significant at genotypic level (0.416).

4.5 Path analysis

Result data on phenotypic path analysis presented in table 12 showed wide variations among the 15 traits towards green yield plant^{-1}.

Plant height had direct positive effect (0.018) and indirect effect *via* nodes plant^{-1} (0.008), number of leaves plant^{-1} (0.119), leaf breadth (0.020), stem girth (0.014), petiole length (0.011), leaf weight (0.257), leaf area (0.018), leaf: stem ratio (0.085), ascorbic acid (0.002) and total sugar (0.012). However, plant height, had negatively indirect effect *via* leaf length (-0.055), leaf thickness (-0.004), stem weight (-0.007) and TSS (-0.007).

Number of nodes plant^{-1} showed direct positive effect with yield (0.026) and indirect effect *via* number of leaves plant^{-1} (0.049), leaf breadth (0.011), stem girth (0.013), petiole length (0.024), leaf weight (0.016) and leaf area (0.013), while negatively indirect effect *via* leaf length (-0.018), leaf thickness (-0.022), stem weight (-0.001), leaf: stem ratio (-0.002), TSS (-0.020), ascorbic acid (-0.004) and total sugar (-0.004).

Regarding number of leaves plant^{-1} the result showed direct positive effect with yield (0.369) and indirect positive effect *via* leaf breadth (0.027), stem girth (0.022), petiole length (0.015), stem weight (0.004), leaf weight (0.227), leaf area (0.021), leaf: stem ratio (0.074), ascorbic acid (0.004) and total sugar (0.005) while negative indirect effect *via* leaf length (-0.044), leaf thickness (-0.024) and TSS (-0.016).

Leaf thickness of vegetable amaranthus showed negative direct effect (-0.097) and indirect effect *via* stem weight (-0.009) and TSS (-0.001). Similarly, leaf thickness showed positive indirect effect through stem girth (0.015), petiole length (0.010), leaf weight (0.175), leaf area (0.019), leaf: stem ratio (0.074), ascorbic acid (0.002) and total sugar (0.017).

Results on stem girth showed direct positive effect (0.049) and indirect effect *via* petiole length (0.019), stem weight (0.126), leaf weight (0.245), leaf area (0.016), ascorbic acid (0.002) and total sugar (0.006). Similarly, negative indirect effect *via* leaf: stem ratio (-0.006) and TSS (-0.017).

Path analysis of petiole length with green yield in vegetable amaranthus showed direct positive effect (0.035) and indirect effect *via* stem weight (0.023), leaf weight (0.104), leaf area (0.020) and leaf: stem ratio (0.009). on the other hand, negative indirect effect *via* TSS (-0.026) and total sugar (-0.006).

Table 12. Phenotypic estimate of direct (diagonal in bold) and indirect effect of component characters on yield in vegetable amaranthus germplasm.

Traits	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	**0.018**	0.008	0.119	-0.055	0.020	-0.004	0.014	0.011	-0.007	0.257	0.018	0.085	-0.007	0.002	0.012	0.490**
2		**0.026**	0.049	-0.018	0.011	-0.022	0.013	0.024	-0.001	0.016	0.013	-0.002	-0.020	-0.004	-0.004	0.086
3			**0.369**	-0.044	0.027	-0.024	0.022	0.015	0.004	0.227	0.021	0.074	-0.016	0.004	0.005	0.693**
4				**-0.104**	0.029	-0.029	0.025	0.019	0.008	0.297	0.032	0.096	-0.016	0.005	0.021	0.553**
5					**0.039**	-0.034	0.026	0.019	0.010	0.286	0.033	0.086	-0.015	0.006	0.006	0.660**
6						**-0.097**	0.015	0.010	-0.009	0.175	0.019	0.074	-0.001	0.002	0.017	0.283*
7							**0.049**	0.019	0.126	0.245	0.016	-0.006	-0.017	0.002	0.006	0.553**
8								**0.035**	0.023	0.104	0.020	0.009	-0.026	0.000	-0.006	0.304*
9									**0.220**	0.138	-0.003	-0.113	-0.017	0.004	0.007	0.275*
10										**0.532**	0.019	0.150	-0.010	0.005	0.014	0.894**
11											**0.045**	0.095	-0.012	0.009	0.024	0.505**
12												**0.221**	0.004	0.001	0.009	0.570**
13													**-0.054**	-0.001	0.017	0.265*
14														**-0.022**	-0.004	-0.269*
15															**0.096**	0.198

&**Significant at 5% & 1% respectively (RESIDUAL EFFECT = 0.2439)

1.Plant height (cm), **2.**Nodes plant^{-1}, **3.**Leaves/plant, **4.**Leaf length (cm), **5.**Leaf breadth (cm), **6.**Leaf thickness (mm), **7.**Stem girth (mm), **8.**Petiole length (cm), **9.**Stem weight (g), **10.**Leaf weight (g), **11.**Leaf area, **12.**Leaf: stem ratio, **13.**TSS (%), **14.**Ascorbic acid (mg 100^{-1}), **15.**Total sugar (%), **16.**Green yield plant^{-1} (g)

Leaf weight showed positive direct effect with yield (0.532) and indirect effect *via* leaf area (0.019), leaf: stem ratio (0.150), ascorbic acid (0.005) and total sugar (0.014), while negative indirect effect *via* TSS (-0.010).

Regarding leaf area the result showed positive direct effect with green yield plant^{-1} (0.045) and indirect effect *via* leaf: stem ratio (0.095), ascorbic acid (0.009) and total sugar (0.024) while, negative effect *via* TSS (-0.012). Similarly, leaf: stem ratio of vegetable amaranthus showed direct positive effect with green yield plant^{-1}(0.221) and indirect effect *via* TSS (0.004), ascorbic acid (0.001) and total sugar (0.009).

On the other hand, TSS of vegetable amaranthus leaves showed negative direct effect with yield (-0.054) and indirect effect *via* ascorbic acid (-0.001), while positive indirect effect *via* total sugar (0.017). Similarly, ascorbic acid content of vegetable amaranthus leaves showed negative direct effect (-0.022) and indirect effect *via* total sugar (-0.004). The total sugar content of vegetable amaranthus leaves showed positive direct effect (0.096) with yield.

4.6 Genetic divergence

The results presented in Table 13 showed grouping of 30 vegetable amaranthus genotypes into seven clusters by adopting Mahalanobis D^2 statistics. Among the seven clusters both cluster I and cluster II consisted of 12 numbers of genotypes followed by cluster VI with two genotypes while rest of the clusters have single genotype.

Table 13. Clustering Pattern of 30 vegetable amaranthus germplasm.

Cluster No.	Number of Amaranthus	Name of Germplasm (member)
I	12	ACCESSION-2, ACCESSION-6, ACCESSION-13, ACCESSION-26, ACCESSION-32, ACCESSION-37, ACCESSION-39, ACCESSION-41, ACCESSION-205, ACCESSION-231, ACCESSION-247, ACCESSION-288
II	12	ACCESSION-19, ACCESSION-43, ACCESSION-45, ACCESSION-48, ACCESSION-202, ACCESSION-237, ACCESSION-248, ACCESSION-250, ACCESSION-263, ACCESSION-268, ACCESSION-276, ACCESSION-287
III	1	ACCESSION-40
IV	1	ACCESSION-258
V	1	ACCESSION-38
VI	2	ACCESSION-65, ACCESSION-204
VII	1	ACCESSION-8

Regarding inter and intra cluster distance among seven clusters, the result showed wide variations with inter cluster distance which varied from 174.45 between cluster VII and cluster III to 1622.85 between cluster VII and cluster VI with maximum inter-cluster distance of 1622.85 between cluster VI with cluster VII, followed by cluster VI with cluster III (1591.22), cluster VI with cluster IV (1542.94), cluster VI with cluster V (1153.30), cluster VI with cluster I (929.93). The result also showed the cluster VI having two genotypes namely ACCESSION-65 and ACCESSION-204 showing higher inter cluster distance with rest of the clusters.

Table 14. Inter and intra cluster distance of 30 vegetable amaranthus germplasm.

Cluster	I	II	III	IV	V	VI	VII
I	120.33	346.77	204.47	228.91	307.41	929.93	327.92
II		198.37	730.20	572.76	354.92	562.22	907.75
III			0.00	217.33	516.25	1591.22	174.45
IV				0.00	366.98	1542.94	297.41
V					0.00	1150.30	912.98
VI						160.42	1622.85
VII							0.00

Similarly, the results also showed intra cluster distance ranging from 0.00 (cluster III, IV, V & VII) to 198.37 (cluster II). Maximum intra cluster distance was observed in cluster II (198.37) closely followed by cluster VI (160.42) and cluster I (120.33).

Results on cluster mean showed wide variations among the clusters for 16 traits. Invariably, the result showed cluster VI revealed highest green yield plant^{-1} (174.75 g), plant height (100.40 cm), leaf area (82.39 cm^2), number of leaves plant^{-1} (47.03), stem girth (16.21 mm), leaf length (13.00 cm), leaf breadth (8.67 cm), petiole length (6.73 cm), leaf weight (4.99 g) and total sugar (2.07 %) while, second highest for leaf: stem ratio (0.66) and leaf thickness (0.38 mm) and third rank for number of nodes plant^{-1} (22.25), stem weight (7.76 g) and TSS (4.38%) (Table 15).

On the other hand, cluster VII showed first rank for nodes plant^{-1} (23.00), second rank for ascorbic acid (96.95 mg 100g^{-1}) and plant height (90.40 cm), whereas, third rank for the traits of leaf length (7.75 cm) and leaf breadth (5.50 cm).

Table 15. Mean of 18 characters in different clusters of amaranthus germplasm.

Sl. No.	**Clusters** / **Characters**	**I** (12)	**II** (12)	**III** (1)	**IV** (1)	**V** (1)	**VI** (2)	**VII** (1)
1	Plant height (cm)	64.71	81.24	67.50	77.05	34.80	100.40	90.40
2	Nodes plant $^{-1}$	19.29	19.83	22.50	19.50	20.00	22.25	23.00
3	Leaves plant^{-1}	37.50	46.25	32.61	33.32	35.15	47.03	33.28
4	Leaf length (cm)	7.40	8.93	4.80	3.30	4.20	13.00	7.75
5	Leaf breadth (cm)	5.11	7.28	3.00	2.20	2.25	8.67	5.50
6	Leaf thickness (mm)	0.30	0.31	0.20	0.25	0.40	0.38	0.30
7	Stem girth (mm)	10.43	14.04	7.96	5.29	12.51	16.21	10.45
8	Petiole length (cm)	5.20	5.99	6.40	2.35	4.65	6.73	5.50
9	Stem weight (g)	7.17	8.30	7.22	5.52	9.95	7.76	5.41
10	Leaf weight (g)	3.36	4.82	2.08	4.12	3.06	4.99	2.65
11	Leaf Area (cm^2)	27.97	36.80	16.97	6.62	20.25	82.39	16.98
12	Leaf: Stem ratio	0.50	0.59	0.29	0.75	0.31	0.66	0.49
13	TSS (%)	4.35	4.49	4.65	3.40	4.10	4.38	3.30
14	Ascorbic acid (mg 100g^{-1})	70.62	63.83	69.16	98.46	53.76	53.29	96.95
15	Total sugar (%)	1.93	1.96	1.99	1.94	1.98	2.07	1.87
16	Green yield plant^{-1} (g)	103.71	167.27	60.88	136.50	106.54	174.75	55.26

Regarding mean data of cluster V showed higher values for the traits *viz.,* stem weight (9.95 g), leaf thickness (0.04 mm) and third rank for stem girth (12.51 mm) with total sugar (1.98 %). On the other hand, cluster III showed highest values for TSS (4.65%) while second rank for the traits *viz.,* number of nodesplant^{-1} (22.50), petiole length (6.40cm) and total sugar (1.99%). The cluster means of cluster I rank third for the traits *viz.,* ascorbic acid (70.62 mg 100g^{-1}), number of leaves plant^{-1} (37.50) and leaf area (27.97 cm^2).

Regarding relative contribution of different traits to genetic divergence in vegetable amaranthus showed that green yield plant^{-1} contributed to maximum extent towards genetic divergence (51.03%) followed by leaf area (36.09%). Similarly, stem weight contributed (3.22%), while, leaf weight and ascorbic acid content (1.84%) each, TSS (1.15%) and stem girth, leaf: stem ratio and total sugar contributed (0.69%) each. Similarly, both plant height and leaf thickness contributed 0.23% each while leaf breadth 0.46% towards genetic divergence in vegetable amaranthus (Table 16).

Table 16. Relative contribution of different characters to genetic divergence in vegetable amaranthus germplasm.

Sl. No.	Character	No. of First Rank	% Contribution
1	Plant height (cm)	1	0.23 %
2	Nodes plant $^{-1}$	0	0.00 %
3	Leaves plant^{-1}	0	0.00 %
4	Leaf length (cm)	0	0.00 %
5	Leaf breadth (cm)	2	0.46 %
6	Leaf thickness (mm)	1	0.23 %
7	Stem girth (mm)	3	0.69 %
8	Petiole length (cm)	8	1.84 %
9	Stem weight (g)	14	3.22 %
10	Leaf weight (g)	8	1.84 %
11	Leaf Area (cm^2)	157	36.09 %
12	Leaf: Stem ratio	3	0.69 %
13	TSS (%)	5	1.15 %
14	Ascorbic acid (mg 100g^{-1})	8	1.84 %
15	Total sugar (%)	3	0.69 %
16	Green yield plant^{-1} (g)	222	51.03 %
Total		435	100 %

DISCUSSION

The present investigation entitled, **"Characterization and evaluation of Amaranthus (*Amaranthus spp.* L.) genotypes for leaf yield''** was carried out at research plot of Central Horticultural Experiment Station, ICAR-Indian Institute of Horticultural Research, Aiginia, Bhubaneswar, Odisha, India, during *rabi*, 2020-2021. The objectives of the present investigation were characterization and evaluation of germplasm of vegetable amaranthus for *per se* performance. The other objectives were estimation of nature and extent of genetic variability, character association, path analysis of leaf yield and yielding attributes as well as divergence study for future crop improvement programme of vegetable amaranthus.

In the present chapter entitled, "Discussion", interpretation of salient significant findings with respect to different observations recorded at various stages of vegetable amaranthus was analysed scientifically with the other earlier established scientific views available at regional, national and international levels. For the effective interpretation of salient significant findings, discussions are presented in the following sub-headings *i.e.*,

5.1 Morphological characterization

5.2 Mean performance of 30 genotypes of vegetable amaranthus

5.3 Genetic variability

5.4 Correlation coefficient

5.5 Path analysis

5.6 Genetic divergence

5.1 Morphological characterization

In general, morphological characterization is treated as one of the most useful techniques for estimation of genetic diversity among the different genotypes (Dhatt *et al*., 2017). For the development of new variety as per the breeding objectives of any crop species, there is urgency in proper collection, evaluation, conservation and utilization of germplasm. In the present investigation, several morphological characters were studied at different stages of vegetable amaranthus crop for proper identification which are discussed below.

The results on morphological characterization presented in table 6 of vegetative growth (*viz.*, plant height and plant growth habit) in vegetable amaranthus showed dominance of short plant height (100.00%) with upright growth habit (90.00%) while semi-spreading as 10.00%. Similar reports of wide variations in different growth habit of amaranthus germplasm were also suggested by Shah *et al.* (2018). Gerrano *et al.* (2017) also observed dominance of erect growth habit in vegetable amaranthus population.

Results on stem colour of collected vegetable amaranthus also showed wide variations. The results showed dominance of pink (43.33%) closely followed by yellowish green colour (33.33%). On the other hand, the evaluated genotype showed 6.67% each as stem colour in the form of purplish pink, greenish red and reddish brown. The result showed only 3.33% having yellowish pink stem colour. Purplish red petiole colour was dominant (43.33%) followed by yellowish green (33.33%) then purplish pink, greenish red and reddish brown (6.67%) each and yellowish pink petiole (3.33%). Similarly, the results revealed dominance of short petiole (<14.00cm) (100.00%) than medium (14.00-17.00cm) and long petiole length (>17.00cm) (0.00% each), respectively. Similar reports of variations in stem colouration in amaranthus have also been reported by Shah *et al.* (2018) and Ray (2019) in vegetable amaranthus.

Results on characterization of leaf colour of vegetable amaranthus showed wide variations among the tested genotypes. The present study showed five different colours of leaves *viz.*, green (53.33%), green with purple blotch (16.67%), greenish purple (6.67%), purplish green (13.33%) and purple (10.00%). Regarding presence of blotch in leaves, the results revealed dominance of absence of blotch in leaves (83.33%) over presence of blotch in leaves (16.67%). Similar reports of dominance of green coloured leaves in vegetable amaranthus have also been reported by several scientists (Gerrano *et al.*, 2017; Shah *et al.,* 2018 and Ray, 2019). The population also showed prominence of smooth leaf veins (100.00%). This result is in agreement with the findings of Gerrano *et al.* (2017).

Characterisation of leaf shape of vegetable amaranthus showed dominance of ovate leaf shape (66.67%), followed by rhombate-ovate leaves (20.00%). The result also showed presence of 6.67% obovate leaf shape followed by lanceolate and elliptical (3.33%) shape each. Gerrano *et al.* (2017) also observed dominance of elliptical leaf shape in vegetable amaranthus population.

Regarding inflorescence colour of vegetable amaranthus, the results showed wide variations in colour, dominated by green colour (53.33%) followed by yellowish green (6.67%), purplish green (20.00%), pink (16.67%) and purplish pink (3.33%). The results of present study corroborate the findings of Shah *et al.* (2018) and Gherase *et al.* (2020) in vegetable amaranthus.

Presence of axillary inflorescence is treated as an important trait related to seed production of vegetable amaranthus. In the present investigation, all the evaluated genotypes showed the presence of axillary inflorescence. None of the genotype showed absence of axillary inflorescence.

The overall results on characterization of 30 evaluated genotypes of vegetable amaranthus showed the dominance of short plant (100.00%) with upright growth habit (90.00%), short petiole length (100.00%) having purplish red petiole (43.33%) and stem colour (43.33%) pigmentation, ovate leaf shape (66.67%) with smooth leaf surface (100.00%), green leaf colour (53.33%) without any blotch in leaves (83.33%), green inflorescence colour (53.33%) with presence of axillary inflorescence (100.00%). These distinct variations in morphological traits of vegetable amaranthus, observed in the present study might be due to genetic makeup of the concerned genotypes and their interaction effects with other environmental factors. Similar reports on morphological variations in vegetable amaranthus have also been reported earlier by several scientists in different proportions in vegetable amaranthus (Shah *et al.*, 2018; Ray, 2019 and Gherase *et al.*, 2020).

5.2 Mean performance of 30 vegetable amaranthus genotypes

5.2.1 Analysis of variance for 30 vegetable amaranthus genotypes

The *per se* performances of 30 genotypes of vegetable amaranthus was carried out by Analysis of Variance for 18 different traits. The degree of experimental precision during the investigation was around 10.00% for all the traits under study which varied from 4.68% (TSS) to 11.58% (leaf: stem ratio) indicating the least influence of environmental factors during the field experimentation (Table 8). Similar observations have also been reported by several scientists in vegetable amaranthus (Tejaswini *et al.*, 2017; Shahiba *et. al.*, 2020 and Agadi *et al.*, 2021).

5.2.2 Vegetative growth parameters

Significant variations were recorded for vegetative growth parameters *viz.*, plant height and number of nodes plant^{-1} in all the genotypes of vegetable amaranthus ranging from 34.80 cm (ACCESSION-38) to 112.25 cm (ACCESSION-204) and 10.00 cm (ACCESSION-63) to 25.50 cm (ACCESSION-41 and ACCESSION-204), respectively.

The genotype, ACCESSION-204 (112.25 cm) recorded significantly tallest plants than rest of the genotypes. However, the genotype *viz*., ACCESSION- 287 (93.55 cm), ACCESSION-255 (91.30 cm), ACCESSION- 8 (90.40 cm), ACCESSION-45 (88.95 cm), ACCESSION-65 (88.50 cm), ACCESSION- 19 (84.50 cm), ACCESSION-268 (83.00 cm) and ACCESSION-248 (82.70 cm) where *statistical parity* were observed. Significantly highest number of nodes plant^{-1} was recorded by ACCESSION-41 and ACCESSION-204 and was *statistically at par* with ACCESSION-8 (23.00), ACCESSION-237 (23.00), ACCESSION-40 (22.50) and ACCESSION-45 (22.50).

Results on overall performance of 30 vegetable amaranthus genotypes revealed that, ACCESSION-8, ACCESSION-45 and ACCESSION-204 recorded significantly higher values for both plant height and number of nodes plant^{-1} under study. The variations on growth parameters of amaranthus as observed in the present study might be due to genetic makeup of the genotype and their interaction effects of a given set of environmental condition. Similar reports of significant differences in plant height have also been reported by Tejaswini *et al.* (2017) and Rashad *et al*. (2020) in vegetable amaranthus.

5.2.3 Leaf yield attributing parameters

In general, among the green leaf yield attributing traits, *viz.*, number of leaves plant^{-1}, leaf length, leaf breadth, leaf thickness, stem girth, petiole length, stem weight, leaf area and leaf: stem ratio play vital role towards the productivity of vegetable amaranthus crop. Consequently, these green leaf yield attributing traits must be considered carefully for selection of superior genotype(s) under a specific set of environmental conditions. Results revealed significant differences in number of leaves plant^{-1}, ranging from 31.46 (ACCESSION-39) to 57.55 (ACCESSION-43). Significantly highest number of leaves plant^{-1} was recorded in ACCESSION-43 (57.55) and was *statistically at par* with ACCESSION-45 (51.19). Similar reports of significant variations among the genotypes of vegetable amaranthus have also been reported by several workers (Mobina *et al.*, 2014, Tejaswini *et al.*, 2017 and Rashad *et al*., 2020).

Results on leaf length, leaf breadth, leaf thickness and leaf area of vegetable amaranthus revealed significantly higher values in the genotypes *viz.*, ACCESSION-65 (13.25 cm, 8.70 cm, 0.40 mm, 91.79 cm^2) and ACCESSION-204 (12.75 cm, 8.65 cm, 0.35 mm, 73.00 cm^2), respectively. However, significantly highest leaf, length leaf thickness and leaf area were recorded in ACCESSION-65 (13.25 cm^2, 0.04 mm and 91.79 cm^2) while leaf breadth (9.65 cm) by ACCESSION-202. On the other hand, the genotype, ACCESSION-258 showed lowest leaf length (3.30 cm), leaf breadth (2.20 cm) and leaf area (6.62 cm^2) while, ACCESSION-247 recorded lowest leaf thickness (0.20 mm). Similar observations of significant variations were reported in leaf length and breadth among the genotypes of vegetable amaranthus have been reported by Tejaswini *et al.* (2017) and Shahiba *et al.* (2020).

Regarding results on stem girth and petiole length of vegetable amaranthus, the results showed significantly highest values by ACCESSION-237 (22.37 mm and 8.20 cm) while minimum by ACCESSION-258 (5.29 mm and 2.35 cm), respectively. However, ACCESSION-204 also recorded longest petiole (8.20 cm). These results are in agreement with the findings of Rashad *et al*. (2020) and Shahiba *et al.* (2020).

In vegetable amaranthus, traits like stem weight, leaf weight and leaf: stem ratio play very crucial role towards the improvement of green leaf yield. The result of the present study revealed significantly highest stem weight of 9.95 g by ACCESSION-38 and was *statistically at par* with ACCESSION-48 (9.85 g), ACCESSION-276 (9.53 g), ACCESSION-237 (9.41 g), ACCESSION-231 (9.31 g), ACCESSION-204 (9.06 g), and ACCESSION-263 (8.99 g). On the other hand, significantly highest leaf weight (5.68 g) was recorded by ACCESSION-248, closely followed by ACCESSION-276 (5.66 g), ACCESSION-268 (5.21), ACCESSION-287 (5.17 g) and ACCESSION-65 (5.01 g). Similarly, leaf: stem ratio, the result revealed significantly highest values of 0.78 by ACCESSION-65 and ACCESSION-2 and was *statistically at par* with ACCESSION-32 ACCESSION-202, ACCESSION-205, ACCESSION-248 and ACCESSION-258. The findings of present investigation are in agreement with Hasan *et al.* (2013) and Dhangrah *et al.* (2015) for leaf weight in vegetable amaranthus. Similar reports significant variations among the genotypes for leaf: stem ratio was also observed by Tejaswini *et al.* (2017) and Shahiba et al. (2020) in vegetable amaranthus.

It may be concluded that vegetable amaranthus genotypes, *viz.*, ACCESSION-65, ACCESSION-204, ACCESSION-268 and ACCESSION-276 were identified as relatively superior type with respect to various green leaf yield attributing traits. These results of present study are in agreement with findings of Selvaraj (2004), Pan *et al.* (2008), Jangde (2016), Tejaswini *et al.* (2017) and Shahiba *et al.* (2020).

5.2.4 Leaf quality parameters

Results on leaf quality parameters *viz.*, TSS, ascorbic acid and total sugar revealed significant differences among the tested genotypes except total sugar content in leaves.

Significantly highest TSS of 5.05% was recorded by ACCESSION-237 and was *statistically at par* with ACCESSION-41 (5.00%), ACCESSION-287 (5.00%), ACCESSION-2 (4.90%), ACCESSION-45 (4.90%), ACCESSION-288 (4.80%), ACCESSION-32 (4.75%), ACCESSION-43 (4.70%), ACCESSION-268 (4.70%), ACCESSION-40 (4.65%) and ACCESSION-204 (4.65%). On the other hand, the leaves of genotype, ACCESSION-258 recorded significantly highest ascorbic acid content of leaves (mg $100g^{-1}$) as 98.46 and were *statistically at par* with ACCESSION-8 (96.95), ACCESSION-43 (91.70), ACCESSION-2 (91.05) and ACCESSION-268 (85.69). The results on total sugar content of amaranthus leaves were non-significant among the tested genotypes. However, highest value of 2.23% was observed by ACCESSION-65 while lowest of 1.85% in ACCESSION-205.

The overall findings on leaf quality of vegetable amaranthus revealed that, genotypes *viz.*, ACCESSION-2, ACCESSION-43 and ACCESSION-268 produced significantly better leaf quality. The findings of present study corroborated with reports of Tejaswini *et al.* (2017).

5.2.5 Leaf yield parameters

Results of green yield plant^{-1}, green yield plot^{-1} and green yield ha^{-1} presented in table 10, revealed significant variations among tested genotypes ranging from 55.26 g, 5.53 kg and 184.21 q in ACCESSION-8 to 183.31g, 18.33 kg and 611.02 q in ACCESSION-48. However, the genotypes *viz.*, ACCESSION-45 (179.48 g, 17.95 kg and 598.25 q), ACCESSION-65 (177.38 g, 17.74 kg and 591.25 q), ACCESSION-204 (172.12g, 17.21 kg and 575.40 q), ACCESSION-248 (171.95 g, 17.20 kg and 573.17 q), ACCESSION-268 (168.45 g, 16.85 kg and 561.50 q), ACCESSION-276 (178.63 g, 17.87 kg and 595.43 q) and ACCESSION-287 (170.65 g, 17.07 kg, 568.82 q) were *statistically at par* with the highest values, respectively.

Thus, on the basis of *per se* performance, it may be concluded that the better performing genotypes of vegetable amaranthus identified germplasm *viz.*, ACCESSION-48, ACCESSION-45, ACCESSION-276, ACCESSION-65, ACCESSION-204, ACCESSION-248, ACCESSION-287 and ACCESSION-268. Significantly better performances of these identified genotypes might be due to inheritance of major green leaf yield contributing traits with high heritability coupled with high GA as % mean *viz.,* leaf length (90.20% and 54.61%), leaf breadth (92.60% and 65.37%), stem girth (91.60% and 58.14%), petiole length (88.50% and 49.70%), leaf area (98.10% and 117.76%), leaf : stem ratio (85.40% and 53.31%), leaf weight (90.80% and 51.89%), green yield plant^{-1} (96.30% and 60.06 %), green yield plot^{-1} (96.30% and 60.07%) and green yield ha^{-1}(96.60% and 60.58 %)as observed in the present investigation (Table 10). Further, the present study also revealed highly significant and positive correlation of plant height (0.490 & 0.533), number of leaves plant^{-1} (0.693 & 0.765), leaf length (0.553 & 0.583), leaf breadth (0.660 &0.706), stem girth (0.553 & 0.610), leaf weight (0.894 & 0.914), leaf area (0.505& 0.518) and leaf: stem ratio (0.570 &0.573) both at phenotypic and genotypic level, respectively, as well as direct path by leaf weight (0.532), number of leaves plant^{-1} (0.186) and leaf: stem ratio (0.221) on total green leaf yield plant^{-1} which was observed to be higher, as evidenced in the present investigation. Similar observations of higher green leaf yield plant^{-1} by different genotypes of vegetable amaranthus under different agro-climatic conditions have also been reported by Chattopadhyay *et al.* (2013); Hailu *et al.* (2015) and Tejaswini *et al.* (2017).

5.3 Genetic variability

In crop improvement programme, the presence of nature and extent of genetic variability will play crucial role for subsequent selection or isolation of superior types. In general, wider will be the genetic variability, effective will be the selection. Therefore, it is very essential to study the genetic variability for subsequent crop improvement programme. As a whole, the study of genetic variability includes the range, general mean, PCV, GCV, heritability and GA as % of mean of different traits of a particular crop population. The range value of a particular trait simply indicates the extent of genetic variability present in the population whereas general mean will indicate the quantification of that particular trait, which will be useful for subsequent selection programme. On the other hand, both PCV and GCV estimates will provide a firm base to assess various components of particular traits like heritable as well as non-heritable portion (Burton and Devenace, 1953). Estimates of heritability of a trait indicate the heritable portion to be transmitted to progeny while GA indicates the % of gain of a particular trait in the future progeny.

Results of present investigation (Table 10) showed wide genetic variability in ranges for 18 quantitative traits under study. The range of different traits between minimum and maximum values varied from 0.20 to 0.40 mm in leaf thickness to maximum of 184.21 to 611.02 qha^{-1} total green yield. Similarly, the % of difference between minimum and maximum of a particular trait varied minimum from 2.00 times (leaf thickness) to maximum of 13.87 times (leaf area). The traits showing wide differences between maximum and minimum (> 3 times) *viz.*, plant height (3.23), leaf length (4.02), leaf breadth (4.39), stem girth (4.23), petiole length (3.49), leaf area (13.87), leaf: stem ratio (3.25), green yield plant^{-1}, plot^{-1} and hectare^{-1} (3.32, 3.31 and 3.32, respectively) etc., there by suggesting enormous scope for selection of these traits in future vegetable amaranthus improvement programme. Similar reports of wide ranges of different traits in vegetable amaranthus have also been reported by several scientists (Vyas *et al.*, 2006; Oboh, 2007; Pan *et al.*, 2008; Joshi *et al.*, 2011; Akaneme and Ani, 2015, Shahiba *et al.*, 2020 and Agadi *et al.*, 2021).

Results also showed wide range of variations for general mean values of 18 traits studied in vegetable amaranthus ranging from 0.31 mm (leaf thickness) to 441.35 qha^{-1} (green leaf yield hectare^{-1}). The traits *viz.*, leaf thickness (0.31), leaf:

stem ratio (0.54), total sugar content of leaves (1.96), leaf weight (4.00), TSS (4.34), petiole length (5.56), leaf breadth (5.97), stem weight (7.64), leaf length (8.07), stem girth (12.07), green yield plot^{-1}(13.20), number of nodes plant^{-1} (19.97), leaf area (33.43) and number of leaves plant^{-1} (41.11) showed less than 50 values. On the other hand, traits *viz.,* ascorbic acid content of leaves (67.94), plant height (74.07), green yield plant^{-1} (132.01) and green yield hectare^{-1} (441.35) showed more than 50 values in the present investigation. Hence, it may be concluded from the present investigation that, due to presence of wide variability among the traits, there will be enormous scope for selection in vegetable amaranthus improvement. The results of present investigation are similar to the observations of Varalakshmi *et al.* (2004), Vyas *et al.* (2006), Oboh (2007), Joshi *et al.* (2011) and Dhangrah *et al.* (2015) in vegetable amaranthus.

The study also revealed that difference between PCV and GCV was less (< 10.00%) in traits *viz.,* plant height, leaf length, leaf breadth, leaf thickness, stem girth, petiole length, stem weight, leaf weight, leaf area, leaf: stem ratio, TSS, green yield plant^{-1}, green yield plot^{-1} and green yield ha^{-1} which suggested more prevalence of genetic governance of these traits with least influenced by the concerned environment towards phenotypic expression of such traits. Therefore, simple phenotypic selection would be very effective in improvement of vegetable amaranthus. The results of present investigations are in agreement with findings of Hasan *et al.* (2013), Dhangrah *et al.* (2015), Diwan *et al.* (2017) and Agadi *et al.* (2021) in vegetable amaranthus.

Similarly, relatively wide variations were observed between PCV and GCV for the traits *viz.,* number of node plant^{-1}, number of leaves plant^{-1} and ascorbic acid content of the leaves, indicating the influence of environmental factors for expression of these traits. Hence, phenotypic selection of these traits may not be effective for development of superior types in vegetable amaranthus improvement programme. Similar reports have also been reported by Rani and Veeraragavathatham (2003) and Anuja and Mohideen (2007).

The results of present investigation also showed relatively higher estimates (>20.00 %) for both PCV and GCV for traits *viz.,* plant height (22.12 and 20.61), leaf length (29.39 and 27.91), leaf breadth (34.25 and 32.97), leaf thickness (22.00 and 20.17), stem girth (30.81 and 29.49), petiole length (27.27 and 25.65), leaf weight

(27.76 and 26.44), leaf area (58.25 and 57.71), leaf : stem ratio (30.30 and 28.00), ascorbic acid content of leaves (23.32 and 21.17), green yield plant^{-1} (30.29 and 29.71), green yield plot^{-1}(30.29 and 29.72) and green yield ha^{-1}(30.43 and 29.92), respectively, there by suggesting better scope of improvement through selection. The results of present study are in agreement with the findings of Ahammed *et al.* (2012), Hasan *et al.* (2013), Dhangrah *et al.* (2015), Diwan *et al.* (2017) and Agadi *et al.* (2021).

It has been reported that estimates of both PCV and GCV does not portioned the extent of heritable and non-heritable components of any particular character. Hence, for proper estimation of heritable component of a particular trait, it is also essential to estimate heritability in broad sense, which includes both additive and non-additive gene effects. As a general rule, higher estimates of heritability of a particular trait simply indicate the transfer of more heritable portion of that character, hence more stable under various environmental conditions thereby, creating better opportunity for effective selection of a desirable superior genotype. On the other hand, high GA /GG indicate the additive gene action. Therefore, it has been suggested that consideration of both high heritability along with high GA as % mean would be more effective tool for selecting superior genotype(s) rather consideration of heritability of the character alone. The results of present investigation revealed wide range of heritability varying from merely 3.00 % (total sugar content of leaves) to 98.10% (leaf area). The result also showed very high heritability (>80.00%) for traits *viz.,* number of leaves plant^{-1}(80.90%), ascorbic acid content (82.50%), leaf thickness (84.10%), TSS (84.30%), leaf : stem ratio (85.40%), plant height (86.80%), leaf length (90.20%), petiole length (88.50%), stem weight (88.50%), leaf weight (90.80%), leaf breadth (92.60), stem girth (91.60%), green yield plant^{-1} (96.30%), green yield plot^{-1} (96.30%), green yield ha^{-1}(96.60%) and leaf area (98.10%). Therefore, selection of genotypes on basis of above cited traits would be more beneficial. The results of present study are in agreement with the findings of Shukla *et al.* (2006) and Pan *et al.* (2008) for leaf breadth, leaf length, leaf: stem ratio, stem girth and green yield plot^{-1}; Diwan *et al.* (2017) for leaf weight, stem weight, petiole length and number of leaves plant^{-1} and Adeniji (2018) leaf breadth and plant height in vegetable amaranthus.

Johnson *et al*. (1955) suggested that to increase the effectiveness in phenotypic selection, both heritability and GA as % of mean should be considered simultaneously in crop improvement programme. The results of present investigation showed high heritability with high GA as % of mean (>40%) for traits *viz.,* leaf length (90.20% and 54.61%), leaf breadth (92.60% and 65.37%), stem girth (91.60% and 58.14%), petiole length (88.50% and 49.70%), leaf area (98.10% and 117.76%), leaf : stem ratio (85.40% and 53.31%), leaf weight (90.80% and 51.89%), green yield plant^{-1}(96.30% and 60.06 %), green yield plot^{-1}(96.30% and 60.07%) and green yield ha^{-1} (96.60% and 60.58 %). These results imply additive gene effects in expression of the abovementioned traits. Therefore, simple phenotypic selection would improve these traits in subsequent generations of vegetable amaranthus improvement programme. Similarly, the results of present study also revealed traits having high heritability coupled with low GA for number of nodes plant^{-1}(67.80% and 23.03%), TSS (84.50% and 20.56% and total sugar content (3.00% and 0.03%) implies that some improvement through selection can also be possible in future generation. However, low or high GA is indicative of non-additive gene action (dominance and epistasis). Similar observations in amaranthus breeding programme have also been reported by several scientists earlier in vegetable amaranthus (Anuja and Mohideen, 2007; Pan *et al.,* 2008; Hasan *et al.,* 2013; Patial *et al.,* 2014; Dhangrah *et al.,* 2015; Sarker et *al.,*2015; Diwan *et al.,* 2017 and Jangde *et al.,* 2018).

5.4 Correlation coefficient of green leaf yield and yield attributing traits

Green leaf yield of vegetable amaranthus being a complex trait is controlled by polygene and hence subjected to various environmental factors for full expressions. Therefore, selection of a superior genotype (s) on the basis of phenotypic selection may not be always true to type in crop improvement programme. Hence, as suggested by Robinson *et al.* (1966), the effectiveness of the phenotypic selection may further improve with the study of character associations between yields with other yield attributing traits. Therefore, it is suggested that along with genetic variability study of various traits of a given population, it is also essential to study the character association both at genotypic and phenotypic level for an effective phenotypic selection programme.

In the present investigation, results of correlation study presented in Table 11 revealed significant associations among 18 traits, where both phenotypic and genotypic correlations exhibited almost similar trends. The results also showed that invariably the estimates of genotypic correlations were higher than the corresponding phenotypic correlations, thereby suggesting the inherited association between these trait pairs in vegetable amaranthus. Similarly, the results also revealed the close association between both genotypic and phenotypic levels, thus suggesting that there was least influence of environmental factors towards estimating the association of these leaf yield attributing traits with green leaf yield plant^{-1} in vegetable amaranthus. This might be due to a strong genetic makeup of evaluated genotypes of amaranthus. The results of present investigation are well corroborated with the findings of Pan e*t al.* (2008) and Hasan *et al.* (2013) in vegetable amaranthus.

The results present study revealed significant phenotypic correlation which varied from (-) 0.003 (between stem weight with number of nodes plant^{-1}) to 0.894 (between green leaf yield plant^{-1} with leaf weight) while that of genotypic correlation varied from (-) 0.017 (between leaf: stem ratio with stem girth) to 0.914 (between green yield plant^{-1} with leaf weight). Results also indicated that out of 120 estimates of phenotypic correlations with green leaf yield plant^{-1}, only 70 estimates were found significant including 66 positive and four in negative direction, whereas 88 estimates were significant including 78 positive and ten were in negative direction at genotypic level. The results also revealed that out of 70 significant, 23 were significant at 5% while 47 at 1% level at phenotypic level whereas 13 and 75 at 5% and 1% at genotypic level, respectively. Similar significant correlations of green leaf yield with other traits in vegetable amaranthus have also been reported by several scientists in vegetable amaranthus (Aruna, 2009; Varalakshmi *et al.,* 2010; Ahammed *et al.,* 2012; Yadav *et al.,* 2014; Abe *et al.,* 2015, Sarkar *et al.,* 2015, Tejaswini *et al.,* 2017 and Sagar *et al.,* 2018).

Results on character association with green yield plant^{-1} in vegetable amaranthus revealed highly significant positive association with plant height (0.490 and 0.533), number of leaves plant^{-1} (0.693 and 0.765), leaf length (0.553 and 0.583), leaf breadth (0.660 and 0.706), stem girth (0.553 and 0.610), leaf weight (0.894 and 0.914), leaf area (0.505 and 0.518) and leaf: stem ratio (0.570 and 0.573) both at phenotypic and genotypic level, respectively. Similarly, significant positive association with green yield plant^{-1} with traits like leaf thickness (0.283). Petiole length (0.304) and stem weight (0.275) at phenotypic level while highly significant positive association with leaf thickness (0.355) and petiole length (0.338) at genotypic level. However, stem weight showed significant positive association with green yield plant^{-1} (0.275 and 0.313) and TSS (0.265 and 0.292) at both phenotypic and genotypic level, respectively. This investigation was in compliance with Varalakshmi and Reddy (1994) who reported that leaf yield plot^{-1} had strong positive association with leaf width, stem girth and leaf stem ratio. The results of present investigations are well in agreement with the findings of several scientists in vegetable amaranthus (Sarker *et al.*, 2014; Hailu *et al.*, 2015; Sarker *et al.*, 2015; Tejaswini *et al.*, 2017 and Sagar *et al.*, 2018).

Plant height of vegetable amaranthus showed highly significant positive association with number of leaf length (0.531 and 0.608) leaf breadth (0.520 and 0.577), leaf weight (0.483 and 0.557), leaf area (0.392 and 0.440), leaf: stem ratio (0.385 and 0.456) at both phenotypic and genotypic level while significant positive association number nodes plant^{-1}(0.322), stem girth (0.282) and petiole length (0.324) at phenotypic level whereas highly significant positive association with leaf length (0.339) and petiole length (0.374) at genotypic level. Thus, the results showed that simultaneous improvement of these traits will be very effective in development of new genotype(s) in vegetable amaranthus. Similar reports are in conformity with Sagar *et al.* (2018) for leaf area in amaranthus.

Results also showed highly significant association of number of leaves plant^{-1} with leaf length (0.423 and 0.506), leaf breadth (0.705 and 0.761), stem girth (0.441 and 0.500), petiole length (0.421 and 0.499), leaf weight (0.427 and 0.489), leaf area (0.462 and 0.502) and leaf stem ratio (0.334 and 0.399) at both phenotypic and genotypic level . Similar observation with character associations were also reported by Sagar *et al.* (2018) and Adeniji (2018).

Overall results on character association of present investigation indicated that direct selection of the traits *viz.*, plant height, number of leaves plant^{-1}, leaf length, leaf breadth, leaf thickness, stem girth, petiole length, stem weight, leaf weight, leaf area, leaf: stem ratio, TSS and total sugar content may lead to the development of high yielding genotypes in vegetable amaranthus. Similar reports suggesting that positive increase in the traits will accelerate the yield potential of vegetable amaranthus are in agreement by the findings of Shukla *et al.* (2010); Hasan *et al.* (2013); Khurana *et al*. (2013); Dhangrah *et al.* (2015); and Sagar *et al.* (2018). Therefore, it may be concluded from correlation study that simultaneous improvement of these traits will be highly useful in green leaf yield improvement in vegetable amaranthus.

5.5 Path analysis of green leaf yield and yield attributing traits

Yield of any crop is treated as a complex trait and controlled by polygene, therefore, usually influenced significantly by various environmental factors including different stresses. Thus, in order to increase the yield of a crop, it is essential to estimate the relative contribution of all other important yield attributing traits which may contribute either directly or indirectly alone or in combination with other traits. Therefore, it is highly essential to study direct and indirect effects of various traits towards expression of yield plant^{-1} through path analysis.

Results on path analysis of green leaf yield plant^{-1} of vegetable amaranthus with other 16 important traits were studied at phenotypic level. The results revealed that maximum direct effect on green leaf yield plant^{-1} was observed with leaf weight (0.532) closely followed by number of leaves plant^{-1}(0.369), leaf: stem ratio (0.221) and stem weight (0.220). The results of present investigation are in agreement with the findings of Hasan *et al.* (2013) and Khurana *et al*. (2013) for leaf weight whereas Shukla *et al.* (2010) for number of leaves plant^{-1}. Similar reports of direct positive effects on green leaf yield plant^{-1} by leaf: ratio (Aktheruzzaman *et al*., 2013, and Tejaswini *et al.*, 2017); leaf length and leaf width (Hasan *et al.*, 2013 and Chattopadhyay *et al.*, *2013*) as well as leaf width (Hailu *et al.,* 2015 and Tejaswini *et al.*, 2017).

On the other hand, leaf length (-0.104) and leaf thickness (-0.097) showed negative direct effect with green leaf yield plant^{-1} in vegetable amaranthus. Similar reports were also reported by Shukla *et al.* (2010) and Hasan *et al.* (2013).

Some other traits *viz.*, plant height (0.018), number of node plant^{-1} (0.369), leaf breadth (0.039), stem girth (0.049), petiole length (0.035), leaf area (0.045), TSS (-0.054), ascorbic acid (-0.022) and total sugar content of leaves (0.096) exhibited low positive or negative direct effect of green leaf yield plant^{-1}in vegetable amaranthus. Similarly, Shukla *et al.* (2010) reported negative direct effect by leaf size with foliage yield and in amaranthus.

Maximum positive indirect effects on green leaf yield plant^{-1}in vegetable amaranthus exhibited by leaf weight *via* plant height (0.257), number of leaves plant^{-1} (0.227), leaf length (0.297), leaf breadth (0.286), stem girth (0.245), petiole length (0.104), stem weight (0.138) and leaf: stem ratio *via* leaf weight (0.150). On the other hand, maximum negative indirect effects on green leaf yield plant^{-1}in vegetable amaranthus exhibited by leaf: stem ratio *via* stem weight (-0.138). Interestingly those traits which recorded direct positive effect on green leaf yield plant^{-1} in vegetable amaranthus had indirect positive effect *via* each other. Hence, they don't affect each other adversely. Therefore, proper selection would be beneficial for improving for green leaf yield plant^{-1}in vegetable amaranthus. Similar findings were also reported by Aruna (2009) for indirect effect in leaf weight *via* stem weight in vegetable amaranthus.

The residual value of 0.2439 recorded in the present study demonstrated that the effect of the remaining traits other than those studied had relatively less effects.

Thus, from the present investigation (Table 12), it can be inferred that the traits *viz.*, leaf weight, number of leaves plant^{-1}, leaf: stem ratio and stem weight showed direct positive effect on green leaf yield plant^{-1}. Hence, these traits should be considered for selection to improve green leaf yield plant^{-1} in vegetable amaranthus. This was the main cause of desirable positive association of leaf weight, number of leaves plant^{-1}, leaf: stem ratio and stem weight with total green leaf yield plant^{-1}. If the direct effects of traits are positive and high, better selection is possible for future improvements of vegetable amaranthus in the next generation. Hence, these traits should be considered for selection to improvement of green leaf yield in vegetable amaranthus. The observations of the present study *i.e.* positive direct effects were similar to the findings of Aktheruzzaman *et al.* (2013); Chattopadhyay *et al.* (2013); Khurana *et al.* (2013); Hailu *et al.* (2015) and Tejaswini *et al.* (2017) in vegetable amaranthus.

5.6 Genetic divergence

Study of genetic diversity is one of the important tools for suitably isolating the genotypes based on their genetic makeup by adopting Mahalanobis D^2 Statistics. The study of D^2 analysis will be very helpful of identification of distinct diverse parents for either development of F_1 hybrid (s) or desirable genotype(s) in subsequent segregating population. The results on D^2 analysis of 30 genotypes of vegetable amaranthus for 16 traits are presented in Table 13 to 16.

5.6.1 D^2 clustering

The cluster derived using Tocher's method was grouped into seven different clusters. Both cluster I and II were found to be the largest groups with 12 genotypes each. The next cluster was cluster VI having two genotypes namely, ACCESSION-65 and ACCESSION-204. On the other hand, cluster-III (ACCESSION-40), IV (ACCESSION-258), V (ACCESSION-38) and VII (ACCESSION-8).

Results of the present investigation on cluster patterns of tested genotypes clearly stipulated that there was no distinct relationship between geographical diversity with genetical diversity. These clusters of present study were grouped regardless of geographic divergence, thus specifying non-parallelism between geographical and genetic diversity (Rana *et al.*, 2005; Anuja, 2011; Akther *et al.*, 2013; Ahammed *et al.,* 2013 and Kujur *et al.*, 2017).This might be due to presence of other forces such as genetic stock, genetic drift, spontaneous mutation or variations, selection either by natural or artificial means etc. (Bhattacharjee *et al.,* 2019). Therefore, the parental selection should be made on the basis of their genetic distance in any specific population not with their geographical diversity. Siddique (2010) and Kumar *et al.* (2019) also reported similar observations in vegetable amaranthus.

Similarly, out of 30 genotypes, both cluster-I and II have 12 genotypes in each as evidenced from the study indicating the less divergence among the genotypes of the clusters. Similar results were also reported by various workers in vegetable amaranthus (Anuja, 2011; Akther *et al.*, 2013; Akaneme and Ani, 2013; Kujur *et al.*, 2017 and Kumar *et al.*, 2019).

5.6.2 Intra and inter cluster divergence

Both intra and inter cluster distance is treated as index of genetic diversity among the clusters of different genotypes (Akther *et al.*, 2013). Results of present study revealed that invariably, inter cluster distance showing relatively higher values as compared to intra cluster distance, thereby suggesting presence of considerable amount of genetic diversity among 30 tested genotypes of vegetable amaranthus. Similarly, out of seven intra cluster distance, cluster II recorded highest average D^2 value (198.37) closely followed by cluster VI (160.42) and cluster I (120.33). The results showed that genotypes in cluster II and VI were relatively more diverse than genotypes of other clusters. Thus, genotypes from these clusters could be used as parental line for developing hybrid through heterosis breeding programme due to their higher mean performance within the group. On the other hand, least intra cluster distance was observed for cluster IV (0.00), cluster V (0.00) and cluster VII (0.00) due to the single genotype present in these clusters (Table 14).

Results on inter cluster distance ranging from 204.47 (cluster I and III) to 1622.85 (cluster VI and VII). Results also showed highest inter-cluster distance of 1622.85 (cluster VI and VII) closely followed by 1591.22 (cluster VI and III), 1542.94 (cluster VI and IV), 1150.30 (cluster VI and V), 929.93 (cluster VI and I) and 912.98 (cluster VII and V). Invariably, cluster VI showed higher inter cluster values with all the other clusters ranging from 562.22 (cluster II) to 1622.85 (cluster VII). Thus, it may be concluded that crosses involving any genotype of cluster VI (ACCESSION-65 and ACCESSION-204) with cluster VII (ACCESSION-8), cluster III (ACCESSION-40) or cluster IV (ACCESSION-258) may produce desirable gene recombinants with more exploitation of hybrid vigour in future vegetable amaranthus improvement programme. However, green leaf yield potential of the parents should also be considered. Similar observations were also reported by Anuja (2011), Akther *et al.* (2013), Ahammed *et al.* (2013) and Kujur *et al.* (2017) in vegetable amaranthus. It has also been established that selection of diverged parent material likely to produce either higher hybrid vigour or having a more desirable genetic recombination (Siddique, 2010; Ahammed *et al.*, 2013; Kujur *et al.*, 2017 and Kumar *et al.*, 2019).

5.6.3 Relative contribution of different traits towards genetic diversity

The results on relative % of contribution of 16 green leaf yield attributing parameters towards diversity (Table 16) indicated that out of 16 traits, three major traits were contributing towards genetic divergence namely green leaf yield plant^{-1}, leaf area and stem weight. The traits *viz.*, green leaf yield plant^{-1} (51.03%), leaf area (36.09%), stem weight (3.22%), petiole length, leaf weight and ascorbic acid content of leaves (1.84% each). Similar results on contribution towards genetic divergence were also reported in vegetable amaranthus by several scientists (Ahammed *et al.*, 2013, Kujur *et al.*, 2017 and Akther *et al.*, 2013).

Thus, traits contributing more towards genetic diversity such as green leaf yield plant^{-1}, leaf area and stem weight etc. in vegetable amaranthus should be considered as critical selection parameters for improvement.

5.6.4 Characterization of D^2 based on clusters

The results on cluster means of 30 genotypes of vegetable amaranthus grouped into seven clusters (Table 15) revealed that cluster VI has the highest mean value for green yield plant^{-1} (174.75 g), plant height (100.40 cm), leaf area (82.39 cm^2), number of leaves plant^{-1} (47.03), stem girth (16.21 mm), leaf length (13.00 cm), leaf breadth (8.67 cm), petiole length (6.73 cm), leaf weight (4.99 g) and total sugar (2.07 %) while, second highest for leaf: stem ratio (0.66) and leaf thickness (0.38 mm) and third rank for nodesplant^{-1} (22.25), stem weight (7.76 g) and TSS (4.38%). The second best cluster II has higher value for green yield plant^{-1} (167.27g), leaves plant^{-1} (46.25), leaf area (36.80 cm^2), stem girth (14.04 mm), leaf length (8.93 cm), stem weight (8.30 g), leaf breadth (7.28 cm), leaf weight (4.82 g), TSS (4.49%), third in rank for the traits *viz.*, plant height (81.24 cm), petiole length (5.99 cm), leaf: stem ratio (0.59) and leaf thickness (0.31 mm). The results of present investigation are in agreement with the findings of Ahammed *et al.* (2013).

Thus, from the results of present investigation, it may be concluded that the selection of suitable genotype from cluster VI may produce new genotype(s) having more green yield plant^{-1}, plant height, leaf area, number of leaves plant^{-1}, stem girth, leaf length, leaf breadth, petiole length, leaf weight, total sugar with relatively higher leaf: stem ratio, leaf thickness, number of nodes plant^{-1}, stem weight and TSS. Inter-crossing among genotypes with outstanding mean performance for their characters would prove to be effective for further crop improvement programme in vegetable amaranthus. Similar results on contribution towards genetic divergence were also reported in vegetable amaranthus by several scientists (Shukla and Singh, 2002; Anuja, 2011; Ahammed *et al.*, 2013 and Kujur *et al.*, 2017).

SUMMARY AND CONCLUSION

The present investigation entitled, **"Characterization and evaluation of Amaranthus (*Amaranthus spp.* L.) genotypes for leaf yield"** was undertaken at research plot of Central Horticultural Experiment Station, ICAR-Indian Institute of Horticultural Research, Aiginia Bhubaneswar, Odisha, India during *rabi*, 2020-2021. The objective of present investigation were characterization and evaluation of vegetable amaranthus germplasm for *per se* performance along with estimation of nature and extent of genetic variability, character association, path analysis of green leaf yield and yield attributing traits as well as divergence study for future crop improvement programme of vegetable amaranthus. Thirty germplasm of vegetable amaranthus were studied by adopting RBD replicated twice. Important traits on vegetative growth, green leaf yield and yield attributing traits as well as leaf quality attributes were carefully accessed during the investigation. The details of significant findings of the present study are summarized below.

- ❖ Results on morphological characterization of vegetative growth (*viz.*, plant height and plant growth habit) showed dominance of short plant height (100.00%) with upright growth habit (90.00%) while semi-spreading as 10.00%.
- ❖ Characterization of stem and petiole colour showed dominance of pink in stem (43.33%) while purplish red in petiole pigmentation (43.33%) with dominance of short petiole (<14.00cm) (100.00%).
- ❖ Characterization of leaf shape of vegetable amaranthus showed wide variations varying from elliptical / lanceolate shape (3.33%) to ovate shape (66.67%). Similarly, five different colours of leaves were observed in the germplasm, dominated by green (53.33%) followed by green with purple blotch (16.67%). The germplasm showed dominance of absence of blotch in leaves (83.33%). Similarly, inflorescence colour of vegetable amaranthus showed dominance of green colour (53.33%) with the presence of axillary inflorescence (100.00%).
- ❖ Plant height of vegetable amaranthus varied significantly ranging from 34.80 cm (ACCESSION-38) to 112.25 cm (ACCESSION-204) with a mean plant height of 74.07cm.

- Significantly highest nodes plant^{-1}was recorded by ACCESSION-41 and ACCESSION-204 (25.50) except ACCESSION-8 (23.00), ACCESSION-40 (22.50), ACCESSION-45 (22.50) and ACCESSION-237 (23.00) which were *statistically at par.* On the other hand, ACCESSION-43 recorded significantly highest number of leaves plant^{-1} (57.55) and was *statistically at par* with ACCESSION-45 (51.19).

- Significantly longest leaf was recorded in ACCESSION-65 (13.25 cm) closely followed by ACCESSION-204 (12.75 cm) than rest of the other genotypes. On the other hand, ACCESSION-202 recorded significantly maximum leaf breadth (9.65 cm) than rest of the tested genotype except ACCESSION-65 (8.70 cm), ACCESSION-204 (8.65 cm) and ACCESSION-250 (8.75cm) which were *statistically at par* with each other. Similarly, significantly thickest leaves were produced by ACCESSION-38, ACCESSION-65, ACCESSION-237, and ACCESSION-288 (0.40 mm).

- The genotype, ACCESSION-237 revealed significantly maximum stem girth of 22.37mm than rest of the tested genotypes. Similarly, significantly longest petiole was recorded by ACCESSION-204 and ACCESSION-237 (8.20 cm) and was *statistically at par* with ACCESSION-41(7.30 cm). On the other hand, heaviest stem was recorded in ACCESSION-38 (9.95 g) with a mean stem weight of 7.64 g.

- The genotype, ACCESSION-548 (5.68 g) showed significantly heaviest leaves and was *statistically at par* with ACCESSION-65 (5.01g). The genotype, ACCESSION-65 also produced significantly highest leaf area (91.79 cm^2).

- The leaf: stem ratio in vegetable amaranthus was significantly highest in ACCESSION-2 and ACCESSION-65 (0.78) among the tested genotypes and was *statistically at par* with ACCESSION-32 (0.71), ACCESSION-202 (0.77), ACCESSION-205 (0.74), ACCESSION-248 (0.66) and ACCESSION-258 (0.75).

- Significantly highest TSS of 5.05% was recorded by ACCESSION-237 and was *statistically at par* with ACCESSION-41, ACCESSION-287, ACCESSION-2, ACCESSION-45, ACCESSION-288, ACCESSION-32, ACCESSION-43, ACCESSION-268, ACCESSION-40, ACCESSION-204 (4.65% to 5.00%). On the other hand, the leaves of genotype, ACCESSION-258 recorded significantly highest ascorbic acid content of leaves (mg $100g^{-1}$) as 98.46 and were *statistically at par* with ACCESSION-8, ACCESSION-43, ACCESSION-2 and ACCESSION-268 (85.69 to 96.95). The results on total sugar content of amaranthus leaves were non-significant among the tested genotypes.

- ❖ Significant highest green leaf yield ($plant^{-1}$, $plot^{-1}$ and ha^{-1}) was recorded by genotype, ACCESSION-65 (183.31g, 18.33 kg and 611.02 q) and *statistical* parity were observed with other genotypes *viz.,*ACCESSION-45 (179.48 g, 17.95 kg and 598.25 q), ACCESSION-65 (177.38 g, 17.74 kg and 591.25 q), ACCESSION-204 (172.12g, 17.21 kg and 575.40 q), ACCESSION-248 (171.95 g, 17.20 kg and 573.17 q), ACCESSION-268 (168.45 g, 16.85 kg and 561.50 q), ACCESSION-276 (178.63 g, 17.87 kg and 595.43 q) and ACCESSION-287 (170.65 g, 17.07 kg, 568.82 q).

- ❖ Results on ranges of different traits between minimum and maximum values varied from 0.20 to 0.40 mm in leaf thickness to maximum of 184.21 to 611.02 qha^{-1} total green yield. On the other hand, general means of 18 traits varied widely ranging from 0.31 mm (leaf thickness) to 441.35 qha^{-1} (green leaf yield ha^{-1}).

- ❖ Similarly, results revealed estimates of PCV were higher than corresponding GCV for all the 18 traits under study. Higher PCV and GCV (>20%) were recorded for the traits *viz.,* plant height, leaf length, leaf breadth, leaf thickness, stem girth, petiole length, leaf weight leaf area, leaf: stem ratio, ascorbic acid content, green yield $plant^{-1}$, green yield $plot^{-1}$ and green $yieldhectar^{e-1}$, respectively.

- ❖ Results on heritability showed that most of the traits except nodes $plant^{-1}$ and total sugar content showed more than 80% heritability with green yield $hectare^{-1}$ being highest (97%) while maximum GA as % mean in leaf area (117.76)

- ❖ High heritability coupled with high GA as % of mean were observed in vegetable amaranthus for the traits *viz.,* leaf length (90.20% and 54.61%), leaf breadth (92.60% and 65.37%), stem girth (91.60% and 58.14%), petiole length (88.50% and 49.70%), leaf area (98.10% and 117.76%), leaf : stem ratio (85.40% and 53.31%), leaf weight (90.80% and 51.89%), green yield $plant^{-1}$ (96.30% and 60.06 %), green yield $plot^{-1}$ (96.30% and 60.07%) and green yield ha^{-1} (96.60% and 60.58 %), respectively.

- Results on characters association between all pairs of 18 traits in vegetable amaranthus showed significant to highly significant effect for most of the traits.

- The results revealed highly significant positive correlation of green leaf yield plant^{-1} with plant height (0.490 and 0.533), leavesplant^{-1} (0.693 and 0.765), leaf length (0.553 and 0.583), leaf breadth (0.660 and 0.706), stem girth (0.553 and 0.610), leaf weight (0.894 and 0.914), leaf area (0.505 and 0.518) and leaf: stem ratio (0.570 and 0.573), respectively. Similarly, significant positive correlation with green yield plant $^{-1}$ was recorded with stem weight (0.275 and 0.313) and TSS (0.265 and 0.292). However, the traits *viz*., leaf thickness (0.283), petiole length (0.304), showed significant positive association with yield at phenotypic level only while, highly significant positive correlation at genotypic level (0.355, 0.338), respectively.

- Results on path analysis towards green yield plant^{-1} revealed maximum direct positive effect with green leaf yield plant^{-1} *via* leaf weight (0.532) closely followed by number of leaves plant^{-1} (0.369) and leaf: stem ratio (0.221) whereas, maximum indirect positive effect was observed for green yield plant^{-1} by leaf breadth *via* leaf weight (0.286).

- The residual value of 0.2439 recorded in the present study demonstrated that the effect of the remaining traits other than those studied had relatively less effects.

- The results regarding D^2 analysis showed grouping of 30 vegetable amaranthus genotypes into seven clusters by adopting Mahalanobis D^2 statistics. Among the seven clusters both cluster I and cluster II consisted of 12 numbers of genotypes followed by cluster VI with two genotypes while rest of the clusters have single genotype.

- The results showed maximum inter-cluster distance exhibited between cluster VII and cluster VI (1622.85) and maximum intra-cluster distance in cluster II (198.37) in the present study of vegetable amaranthus.

- The result also revealed that the cluster VI having two genotypes namely, ACCESSION-65 and ACCESSION-204 showing higher inter-cluster distance with rest of the clusters.

- ❖ Results on cluster mean showed that cluster VI, invariably revealed highest plant height (100.40 cm), leaves plant^{-1} (47.03), leaf length (13.00 cm), leaf breadth (8.67 cm), stem girth (16.21 mm), petiole length (6.73 cm), leaf weight (4.99 g), leaf area (82.39 cm^2), total sugar (2.07 %) and green yield plant^{-1} (174.75 g). Similarly, cluster II proved to be the second best cluster of higher mean values with second highest, leaves plant^{-1} (46.25), leaf length (8.93 cm), leaf breadth (7.28 cm), stem girth (14.04 mm), stem weight (8.30 g), leaf weight (4.82 g), leaf area (36.80 cm^2), TSS (4.49%) with green yield plant^{-1} (167.27g).

- ❖ Regarding relative contribution of different traits to genetic divergence in vegetable amaranthus showed that green yield plant^{-1} contributed to maximum extent towards genetic divergence (51.03%) followed by leaf area (36.09%).

CONCLUSION

In crop improvement programme, characterization of germplasm followed by effective selection for green leaf yield in vegetable amaranthus, a location specific research is very much essential due impact of not only the genetic constitution of the genotypes but also their interactions with a particular set of environmental factors. In the present investigation, all possible efforts have also been made for an effective morphological characterization of collected germplasm of vegetable amaranthus followed by isolation of superior genotype(s) on the basis of *per se* performance. Emphasis has also been made for estimation of genetic variability, character association, path analysis and clustering of genotypes for future crop improvement in vegetable amaranthus. The following conclusions are made from the present investigation:

- ❖ Morphological characterization of vegetable amaranthus germplasm showed dominance of short plant height (100.00%) with upright growth habit (90.00%) having pink (43.33%) stem and purplish red petiole colour pigmentation, ovate leaf shape (66.67%), green leaf colours (53.33%) without any blotch in leaves (83.33%). Germplasm showed 100.00% presence of axillary inflorescence with dominance of green colour (53.33%).

- ❖ On the basis of *per se* performance, ACCESSION-48, ACCESSION-45, ACCESSION-276, ACCESSION-65, ACCESSION-204, ACCESSION-248, ACCESSION-287 and ACCESSION-268 were identified as superior genotypes for cultivation under Bhubaneswar, Odisha conditions.

- Direct selection through traits *viz.*, plant height, number of leaves plant^{-1}, leaf length, leaf breadth, leaf weight, stem girth, stem weight, leaf weight, leaf: stem ratio and green leaf plant^{-1} will be very effective for improvement of vegetable amaranthus.

- Green leaf yield plant^{-1}, leaf area and stem weight are important parameters contributing more towards green leaf yield hectare^{-1} in vegetable amaranthus. Therefore, simultaneous improvement of these traits will be highly helpful in improvement of vegetable amaranthus.

- Direct selection will be very effective *via* the important traits *viz,* leaf weight, number of leaves plant^{-1}, leaf: stem ratio in crop improvement of vegetable amaranthus.

- Being most divergent, cluster VI (ACCESSION-65 and ACCESSION-204) and cluster VII (ACCESSION-8), hence, expected hybridization between these parent(s) might result in producing desirable recombinants with maximum exploitation of heterosis either at F_1 stage or new segregants in segregating generation in future vegetable amaranthus improvement programme.

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