GENOTYPE X ENVIRONMENT INTERACTION IN THE FIELD PERFORMANCE OF STEM AMARANTH

(*Amaranthus tricolor* L.)

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CERTIFICATE

This is to certify that thesis entitled, "Genotype x Environment interaction in the field performance of stem amaranth (Amaranthus tricolor L.)" submitted to the faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of ***MASTER OF SCIENCE IN GENETICS AND PLANT BREEDING****, embodies the result of a piece of bona fide research work carried out by Md. Noor Nabi Dewan, Registration No: 13-05778 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has been duly been acknowledged by him.

Dated: December, 2014
Place: Dhaka, Bangladesh

(Dr. Md. Sarowar Hossain)
Professor
Supervisor

Dedicated

to

My Beloved Parents

Some commonly used abbreviations

Full word	Abbreviations	Full word	Abbreviations
Agricultural	*Agril.*	Milligram(s)	mg
Agriculture	*Agric.*	Milli mole	mM
And others	*et al.*	Nitrate	NO_3
Applied	*App.*	Number	No.
Bangladesh Agricultural Research Council	BARC	Murashige and Skoog	MS
Bangladesh Agricultural Research Institute	BARI	Nanometre	nm
Bangladesh Bureau of Statistics	BBS	Nitric Acid	HNO_3
Biology	*Biol.*	Nutrition	*Nutr.*
Calcium ion	Ca^{2+}	Perchloric Acid	$HClO_4$
Centimeter	Cm	Percentage	%
Chlorine ion	Cl^-	Plant Genetic Resource Centre	PGRC
Chlorophyll	Chl	Phenotypic variance	$\boldsymbol{\sigma}_p^2$
Days after transplanting	DAT	Percentage of coefficient of variation	CV%
Decisiemens per meter	dS/m	Parts per million	ppm
Degrees of freedom	df	Phenotypic coefficient of variation	PCV
Environment	*Environ.*	Physiology	*Physiol.*
Environmental variance	$\boldsymbol{\sigma}_e^2$	Physiology	*Physiol.*
Etcetera	etc.	Research and resource	*Res.*
Food and Agriculture Organization	FAO	Review	*Rev.*
Gram	gm	Science	*Sci.*
Genotype	G	Soil Resource Development Institute	SRDI
Genetic advance	GA	Sher-e-Bangla Agricultural University	SAU
Genotypic coefficient of variation	GCV	Serial	Sl.
Genotype number	GN.	Standard Error	SE
Genotypic variance	$\boldsymbol{\sigma}_g^2$	Sodium ion	Na^+
Horticulture	*Hort.*	Tons per hectare	t/ha
Heritability in broad sense	h^2_b	Technology	*Technol.*
International	*Intl.*	That is	i.e.
Journal	*J.*	Ton	T
Kilogram	Kg	Videlicet (namely)	viz.
Liter	L	United States of America	U.S.A.
Milligram per liter	mg/L	Ultraviolet	UV

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GENOTYPE X ENVIRONMENT INTERACTION IN THE FIELD PERFORMANCE OF STEM AMARANTH (*Amaranthus tricolor* L.)

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ABSTRACT

A research was carried out to find genotype x environment interaction effects on the field performance of 20 germplasm of Stem amaranth at Genetics Farm, Sher-e-Bangla Agricultural University, Dhaka during the period from November, 2013 to May 2014. The experiment was laid out in the Randomized Complete Block Design with three replications. Data were recorded on plant height (cm), no. of leaves per plant, leaf length (cm), leaf breadth (cm), individual stem diameter (mm), individual leaf weight (gm), individual stem weight (gm), marketable stem weight (gm), days to first flowering, no. of seed per plant, yield (Kg/ha) at three environments. G-18 was the tallest with non significant S^2di value (10.5) and G-9 was the shortest (2.22). G-20 produced most number of leaves with non significant S^2di value (2.59) and G-01 was the least (11.56**). G-02 produced the lengthiest leaf with significant S^2di value (16.09**) and G-09 was the shortest (0.09). G-01 produced the lengthiest leaf breadth with non significant S^2di value (0.38) and G-15 was the shortest (0.46). G-01 showed the thickest stem diameter with non significant S^2di value (1.63) and G-09 was the least (0.19). G-01 was the highest individual leaf weight with significant S^2di value (46.08**) and G-15 was the least (2.84). G-01 was the highest individual stem weight with non significant S^2di value (15.13) and G-09 was the least (48.09). G-01 produced the highest marketable stem weight with non significant S^2di value (451.59) and G-09 was the least (39.77). G-03 was the earliest first flowering and with non significant S^2di value (8.71) and G-09 was the latest (1.06). G-07 produced the highest number of seed per plant with significant S^2di value (11773806.62**) and G-05 was the least (260802.7). G-01 was the highest yield producing with non significant S^2di value (7821.539) and G-09 was the least (688.8164). Based on stable responses considering the higher yield character G-08 and G-18, for higher individual leaf weight G-07 and G-11, for higher individual stem weight G-18, for lesser dry weight of stem G-14 and G-18 and for early days to first flowering G-03 and G-16 genotypes could be selected for effective use in breeding program.

Chapter 1

Introduction

CHAPTER I

INTRODUCTION

Bangladesh is an agro based country where the Amaranth (*Amaranthus sp.*) is an important vegetable. Amaranth is the herbaceous plant of the genus *Amaranthus*, family *Amaranthaceae*, native to the India or Indo-Chinese region. The centers of diversity for amaranths are Central and South America, India and South East Asia and the secondary centers of diversity has been reported in West Africa (Grubben, 1997). The tender leaves and stems, rich in vitamin A and C, calcium and iron, are considered as vegetable. Two predominant types are grown; the leafy type can be cultivated throughout the year but its production is high during winter months. The stem type is a vegetable primarily of the summer.

The amaranth is a cross pollinated vegetable crop. It has chromosome number 2n=32 or 34; under the genus *Amaranthus* (Muthukrishnan *et al.* 1989). *Amaranthus sp.* is erect, annual and up to 1.5 m tall. Leaves are elliptical to lanceolate or brad ovate, dark green, light green or red. Clusters of flowers are axillary, often globose, with a reduced terminal spike, but are well developed. Fruit dehiscent, seeds are black, relatively large (Palada and Chang, 2008). The harvested amaranth is 50-80% edible (Oke, 1980). Amaranth leaves are rich and inexpensive source of dietary fibre, protein, vitamins and a wide range of minerals (Shukla *et al.* 2006).

This vegetable crop is well suited to the agro climatic condition of Bangladesh which can supplement to the shortage of vegetable production. The fresh tender leaves and stem of amaranth are delicious when cooked like other fresh vegetables. It is relished as vegetable soup, cooked by boiling and mixing with condiments. The seeds have various uses, as on ingredient in making sweet rolls, crepes, granola cereal, pancakes, cookies, crackers etc. Its lysine content is nearly three times higher than corn and nearly twice than that of wheat (Muthukrishnan *et al.* 1989).

Amaranth is grown mainly during summer and rainy season in Bangladesh. The amaranth is an important and popular vegetable as it can be grown quickly and it is nutritious. The last documented area under this crop in Bangladesh is 25485 acres with production of 67358 tons having yield of 4.5 t/ha only (Anonymous, 2012), which is very low. The low yield is attributed to the use of low yielding varieties and inefficient method of culture. Total vegetable production in our country is about 1500 thousand tons per year. Out of which 70% is produced in Rabi season and 30% in kharif season (Anonymous, 2012).

Amaranth may be an important vegetable to cope up with the present malnutrition situation of the country. Environmentally stable varieties with high yield are must needed for securing sustainable crop production by farmers. High yielding stable varieties may give more gross return to the farmers. Thus the farmers will be encouraged and the national economy will be strengthened. Though it is a very common crop, very limited attempt had been made for genetic improvement of this crop. An understanding of the nature and magnitude of variability among the genetic stocks is of prime importance to the breeder. Varietal adaptability to environmental fluctuations is important for the stabilization of crop production both over regions and years. Adaptability is the ability of a genotype to exhibit relatively stable performance in different environments. Adaptability is measured in terms of phenotypic stability of a genotype over several environments (Tomkins and Shipe, 1997).

Stability refers to constancy in performance of a variety for general cultivation over a wide range of environments. Stability analysis helps in the identification of location specific and widely adaptable genotype and it can be performed with both parental as well as segregating populations (Admassu *et al.* 2008).Gene–

environment interaction (or genotype–environment interaction or G x E) is the phenotypic effect of interactions between genes and the environment. Study of genotype-environment interaction is important for improving accuracy and precision in the assessment of both genetic and environmental influences. Amaranth is an environmental sensitive crop. Stable genotypes are required to secure sustainable crop production.

The heritability of a population is the proportion of observable differences between individuals that is due to genetic differences. Factors including genetics, environment and random chance can all contribute to the variation between individuals in their observable characteristics (in their phenotypes). Heritability thus analyzes the relative contributions of differences in genetic and non-genetic factors to the total phenotypic variance in a population. Genetically stable varieties ensure the stable production and stable production ensures the profit of the farmers. In the present context, the field performances on different parameters at different sowing dates may be the indicators of the stability of amaranth varieties. Stable varieties provide almost the same performance as those are genetically boosted up to provide the additive performance. Identification of those stable varieties could help the farmers and researchers to exploit those in further crop production and in research field. Selection of best genotypes adapted to the wide range of environment specifically suitable for each of the growing seasons may help to improve the selection efficiency as well as the productivity of amaranth in this country. Therefore, to identify stable varieties or genotypes over different environments, study of genotype x environment (GXE) interactions is very important in breeding point of view (Eberhart and Russell, 1966).

For evolving better and stable varieties for yield and its components, it is necessary to screen the available genotypes over a wide range of agro climatic conditions for their commercial exploitation or effective utilization in breeding program. Gene expression is subject to modification by the environment; therefore, genotypic expression of the phenotype is environmentally dependent (Kang, 1998).

The development of new cultivars involves breeding of cultivars with desired characteristics such as high economic yield, tolerance or resistance to biotic and a biotic stresses, traits that add value to the product, and the stability of these traits in target environments. Inconsistent genotypic responses to environmental factors such as temperature, soil moisture, soil type or fertility level from location to location and year to year are the functions of genotype environment (GE) interactions. Genotypes x environment interactions have been defined as the failure of genotypes to achieve the same relative performance in different environments (Baker, 1988).

It has been emphasized that the study of individual yield components can lead to simplification in genetic explanation of yield stability and hence, it is valuable to breeders in prediction and determination of environmental effects. It is important to identify the stable genotypes under different growing seasons which have great significance to the plant breeders for improvement of this crop. In a view of the above circumstances, a study was undertaken with the following objectives:

1. To identify the environmentally stable genotypes of amaranth.
2. To assess the heritability of yield contributing characters of different genotypes.
3. To select the most promising genotypes for future breeding program.

Chapter 2

Review of literature

CHAPTER II

REVIEW OF LITERATURE

The review of literature includes reports of amaranth and other related crops studied by several investigators, which appears pertinent in understanding the problem and which may help in the explanation and interpretation of results of the present study. In this section, an attempt has been made to review the available information at home and abroad on adaptability, genotype-environment interaction and stability of different yield and yield contributing characters of different amaranth genotypes.

Shudhir *et al.* (2003) studied ten high yielding, pure bred genotypes of vegetable amaranth (*Amaranthus tricolor*; AV-35, AV-45, AV-35/1, AV-63, AV-64, AV-77, AV-151, AV-N-3, AV-190 and AV-76) to check the stability of foliage yield in vegetable amaranth (*Amaranthus tricolor* L.) in different locations. The analysis of variance for stability revealed that mean square due to genotypes was significant for foliage yield, indicating substantial genetic variations among the genotypes. G x E interaction was significant. The foliage yield recorded over five years showed that AV-190 was the most promising, recording a mean yield of 264.88+or-12.15 q/ha, followed by AV-45 (mean=254.77+or-10.51 q/ha) and AV-77 (mean=194.64+or-10.12 q/ha). AV-190 and AV-45 exhibited stable yield performance over the years. Only AV-190 had the highest foliage yield, regression coefficient (b=1) and non-significant deviation from regression, indicating that this genotype was the most adaptable and stable to varying environments. AV-45 was also promising and stable in low responsive environments.

Tyagi *et al.* (2006) studied 40 indigenous and exotic genotypes of soybean during spring and rainy season of 2005 and 2006 to check the genotype x environment interaction and stability of those genotypes for yield and its component in soybean (*Glycine max* L.). This study showed the presence of

GE interactions among the 12 soybean genotypes and their yield components. High yielding genotypes with broad adaptation and some genotypes with specific adaptation were identified. Among the cultivars used in this study, MACS-47, showed higher mean seed yield and was found to be stable over the environments and therefore; could be used in the breeding program for the development of high yielding stable genotypes over environments for future use.

An experiment was conducted by Mashark *et al.* in 2007 to determine the importance of genotype by environment interaction (GE) in late maturing lowland maize varieties to determine yield stability of the genotypes. Seven out of the nine genotypes were stable, when bi values alone were considered. When the bi values and the deviations from regression (S^2di) were considered, (GH24 x 1368) x 5012 and (GH22 x 1368) x 5012 were the most stable, but when coefficient of determination was added to the bi value and S^2di, GH132-28 was the most stable genotype.

Aina *et al.* (2007) studied twenty genotypes of cassava across eight different locations in Nigeria in order to identify stable and adaptable genotypes, determine the magnitude of G x E interaction and to identify the factors contributing to the G x E interaction pattern. Significant variation for genotypes (G), environment (E) and GEI were observed for storage root yield. Genotype 4(2) 1425 and 91/02324 were found to be stable and adaptable. 96/0326 was found to be unstable but high yielding, while 96/0590 was highly stable but low yielding. Genotypes 96/0529 and 96/0860 were specifically adapted to Zaria and 96/0191 was adapted to Ibadan. Ibadan and Mokwa were relatively stable environments but Mallamadori was highly unstable.

Fifteen maize genotypes were tested by Admassu *et al.* (2008) at nine different locations to determine stable genotypes for grain yield. There was considerable variation among genotypes and environments for yield. Genotypes 30H-83, BH-540, AMH-800, and BHQP-543 were found to be stable for grain yield. The first two Interaction Principle Component axis (IPCA1 and IPCA2) were significant (p<0.01) and cumulatively contributed 70.27% of the total genotype by environmental interaction. The coefficient of determination (R2) for genotypes 30H83 was as high as 0.92, confirming its high predictability to stability. Among the genotypes, the highest fruit yield was obtained from genotype 30H83 and BH-541 (8.98 and 8.05 t ha-1) across environments. Clustering of AMMI estimate values grouped genotypes into four clusters and the environment into three clusters. Environment Goffa was unique as it is grouped differently from all other environments.

Dhanapal *et al.* (2009) studied optimization of sowing dates of two cultivars (Suvarna and K-432) on growth and yield of grain amaranth. The highest grain yield (944 kg/ha) obtained with Suvarna was significantly higher than K-432 (505 kg/ha). Maximum seed yield of 937 kg/ha recorded with July first fortnight sowing was superior to other sowing periods except the June second fortnight sowing (906 kg/ha). The Suvarna cultivar sown during first fortnight of July showed the highest seed yield of 1301 kg/ha which was significantly superior to other treatments except that which was sown at June second fortnight sowing.

Balestre *et al.* (2009) conducted an experiment and evaluated the phenotypic and genotypic stability and adaptability of maize hybrids using the additive main effect and multiplicative interaction (AMMI) and genotype x genotype-environment interaction (GGE) biplot models. They found that, GGE bi-plot method to be superior to the AMMI 1 graph, due to more retention of GE and G + GE in the graph analysis. However, based on cross-validation results, the GGE bi-plot was less accurate than the AMMI 1 graph, inferring that the quantity of GE or G + GE retained the graph analysis alone is not a good parameter for choice of stabilities and adaptabilities parameter comparing AMMI and GGE analysis.

Yarnia *et al.* (2010) studied sowing dates and density evaluation of amaranth (cv. Koniz). The results showed that delay in sowing reduced plant height at least 13.02 up to 33.17%, the number of inflorescence per plant from 23.35 to 56.69%, number of seeds per plant from 22.75 to 71.44%, grain yield per plant from 5.09 to 92.78% and yield from 27.41 to 79.88%, plant biomass from 39.34 to 79.91%. Increasing plant density led to increase the number of inflorescence per plant up to 56.69% and reduced the number of seeds per plant up to 63.74% but the yield per area unit increased in low density and decreased in very high density (40 plant/ m^2). Interaction between delay sowing and increasing plant density decreased leaf area at least 19.63 up to 97.15%, oil in seeds from 22.20 up to 98.26%, shoots oil from 34.38 to 93.81%, seed protein content from 2.99 to 92.23%, shoot protein from 3.74% up to 65.81%. Therefore, early sowing dates with low density increased growth period and reduced competition, so increased production potential of amaranth.

Nargis *et al.* (2010) studied seven genotypes of jute (O-9897, O-72, A-1749, O-4, SDLT2, JRO-524 and A-4582) at three different sowing dates (1st March, 1st April & 1st May) to check the genotype environment x interaction for fiber and seed yield. Genotype x environment interaction was highly significant for number of pods per plant, which indicated significant differences in the response of genotypes to changes in environments for this character. The varieties O-9897, JRO-524 and A-4582 showed stability for number of pods per plant under environmental fluctuation. The genotype A-4582 reflected stability to poor environment for the concerned character.

Islam (2000) stated that genotype-environment interaction of dry bean under five cultural environments showed highly significant ($P<0.001$) genotypic mean differences and genotype x environment interactions in five traits.

Varalakshmi *et al.* (2011) studied genotype x environment interactions for some quantitative characters in grain amaranth (*Amaranthus hypochondriacus* L.). Stability analysis of variance in grain amaranth showed significant differences among the genotypes for days to 50% flowering, plant height and number of spikelets/panicle indicating the presence of variability among the genotypes. Significant linear component against pooled deviation for days to 50% flowering, plant height and yield/plant indicated that the major component for differences in stability was due to linear regression and the performance can be predicted with some reliance under different environments. Among the 20 genotypes tested for stability of performance, no single genotype possessed ideal characteristics of a stable genotype for all the traits over the eight environments tested. However, regarding the grain yield/plant, IIHR-11, IIHR-22 and IIHR-46 were found to be responsive ($b<1.0$) over the environments, hence more adaptable to normal growing conditions.

García *et al.* (2011) studied genotype × environment interaction and analyzed stability of five genotypes of amaranth (*Amaranthus* spp.). Study of interaction G × E indicated that the evaluated materials tended to behave differently in the various localities and evaluated population densities.

Talukder *et al.* (2012a) studied thirty two hybrids of maize to assess the genotype x environment interaction and stability for grain yield, days to tasseling, days to silking, plant height and ear height across five different locations. Significant variation for genotypes (G), environment (E) and GEI were observed for the character yield. The environment Gazipur and Hathazari were poor; but Jessore, Jamalpur and Burihat were rich for hybrid maize production. Burihat of Rangpur was found highly suitable for hybrid maize cultivation followed by Jamalpur and Jessore. Among the hybrids 981, 827K and Elite were higher yielder as well as stable over all the environments. Pac 999 Super, Prince, Pioneer, BMS 08-1 and 740 were highly stable with moderate yield potentiality. Sunshine was the highest yielder but responsive to environment. C6485 was the most stable variety but not good yielder.

Uddin *et al.* (2011) studied twenty six hybrids of maize to check the genotype x environment interaction and stability for grain yield, days to silking, plant height and days to maturity across six different locations. Significant variation for genotypes (G), environment (E) and GEI were observed for the character yield. In this case Gazipur, Hathazari and Jamalpur were poor, but Jessore, Barisal and Rangpur were rich for hybrid maize production. 981, Pinacale, BHM-5, 980 and 999 were stable across the environment. 980 and 999 were found promising across locations.

Talukder *et al.* (2012b) studied twelve genotypes of barley to assess the genotype x environment interaction and stability for grain yield, days to heading, days to maturity, plant height, number of tillers per plant, spike length, number of grains per spike, 1000 grains weight across three locations. Significant variation for genotypes (G), environment (E) and GEI were observed for the character yield. The environment Barisal was poor; but Gazipur and Ishurdi were rich for barley production. The genotypes E5 and E11 were higher yielder as well as stable over all environments. E2 and E4 were highly stable with moderate yield potentiality. E1 was the highest yielder but responsive to environment.

Chapter 3

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

3.1 Experimental site

The experiment was conducted at the Research Farm of the Sher-e-Bangla Agricultural University in three successive sowing dates with Seventy days interval during November 2013 to May 2014 on 20 genotypes of amaranth. The location of the experimental site was situated at **23^0 74'** N latitude and **90^0 35'** E longitude with an elevation of 8.6 meter from the sea level.

3.2 Soil and Climate

The Experimental site is situated in the subtropical climate zone, characterized by heavy rainfall during the month of May to September and scanty rainfall during rest of the year. There were three sowing dates as different environment. First sowing was done in 5th November, second sowing was done in 15th January and third sowing was done in 25thMarch. During the first sowing time average temperature was 28.66^o C, average relative humidity was 86.4 %, monthly rainfall was 36.54 mm, during the second sowing time average temperature was 29.72^oC, average relative humidity was 84.83%, monthly rainfall was 143.76 mm, during the third sowing time average temperature was 29.81 ^{o}C, average relative humidity was 88.65%, monthly rainfall was 243.92 mm (Appendix 1). The soil was clay loam in texture and olive gray with common fine to medium distinct dark yellowish brown mottles. The pH was 5.47 to 5.63 and organic carbon content is 0.82% (Appendix 1).

3.3 Plant materials

Total twenty genotypes were used in the experiment. All genotypes are collected from Bangladesh Agricultural Research Institute. (Plate1. Some of the Amaranth genotypes used in the research work). List of 20 amaranth genotypes used in the research work are presented in Table 01.

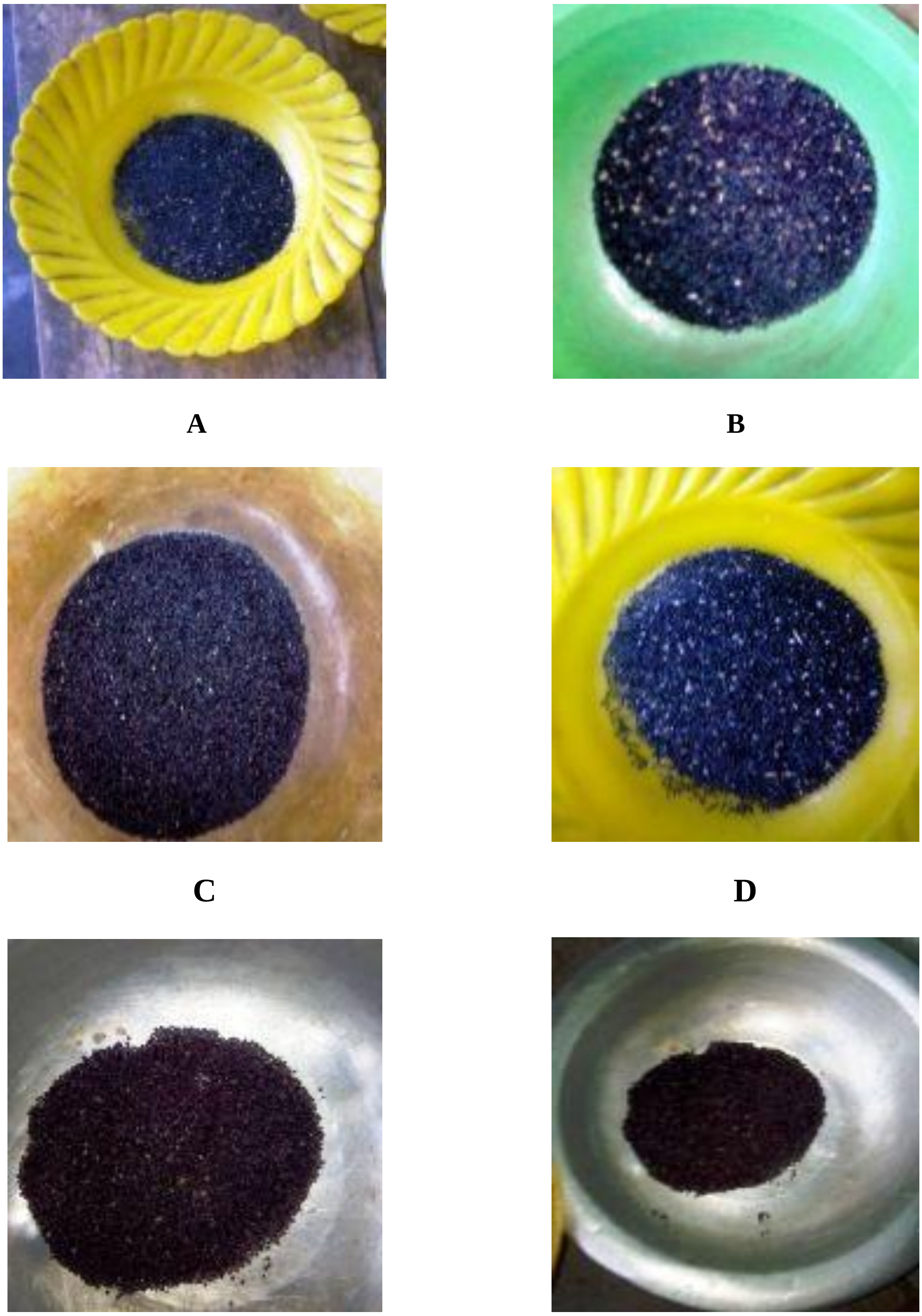

Plate 1. Some of the Amaranth genotypes used in the research work.

A. BD-7402, B. BD-7412, C. BD-10218, D-7777, E-9941, F-7365

Table 01. List of 20 amaranth genotypes used in the research work.

Sl. No.	Variety Name	Source
G1	BD- 10205	BARI, Gazipur
G2	BD-7393	BARI, Gazipur
G3	BD-10207	BARI, Gazipur
G4	BD-10203	BARI, Gazipur
G5	BD-7402	BARI, Gazipur
G6	BD-7404	BARI, Gazipur
G7	BD-7412	BARI, Gazipur
G8	BD-10192	BARI, Gazipur
G9	BD-10191	BARI, Gazipur
G10	BD-9941	BARI, Gazipur
G11	BARI data -1	BARI, Gazipur
G12	BARI data-2	BARI, Gazipur
G13	BD-7777	BARI, Gazipur
G14	BD-7392	BARI, Gazipur
G15	BD-7365	BARI, Gazipur
G16	BD-10220	BARI, Gazipur
G17	BD-7387	BARI, Gazipur
G18	BD-10221	BARI, Gazipur
G19	BD-10223	BARI, Gazipur.
G20	BD-10218	BARI, Gazipur

3.4 Design and layout

Randomized Complete Block Design (RCBD) was the experimental design for conducting the experiment. Three replications were done for each three sowing dates or seasons. Twenty genotypes of amaranth was the treatment for each season. The interval between two successive seasons was seventy days. The unit plot size was

1m x 1m. Each unit plot was separated by 0.5m and block to block distance was also 0.5m. The treatments (genotypes) were randomly distributed within the replication.

3.5 Preparation of land

The experimental plot was first opened by disc plough. Following discing the land was ploughed twice by tractor tiller followed by leveling. The clods were broken and weeds were removed from the field to obtain a desirable tilth. The basal doses of manures and fertilizers were mixed into the soil during the final land preparation. Irrigation and drainage channels were prepared around the plots as per design.

3.6 Manure and fertilizer

The entire quantity of cowdung and TSP were applied during land preparation. Those were mixed with the soil of the individual plots by spading and this was a week before of sowing seeds. Urea & Murate of Potash (MP) were top dressed in three equal splits. The first, second and third top dressing were done at 15 days, 21 days & 28 days after sowings respectively.

3.7 Seed Sowing

After land preparation, the seeds were sown in line. The lines were made by the use of tiner. Line to line distance was 20cm and five lines were made per plot. Twenty plants were retained per line in case of every plot.

3.8 Raising of seedlings

Seeds of all the twenty genotypes were first allowed to soak water for 24 hours. The seeds were sown in line. Within four to seven days seeds were germinated. Light irrigation was given in case when it was needed. Intensive care was taken for production of healthy seedlings. (Plate 3. Growing conditions of some amaranth genotypes in different season)

3.9 Intercultural operation

Intercultural operations were done as necessary during the growing period for proper growth and development of the plants.

Mulching

Mulching was done to conserve the soil moisture and for the proper development of roots. This was done by crushing the earth crust by the use of Hand Hoe.

Weeding

Routine weeding were done to keep the field free from weeds and to pulverize the soil.

Irrigation and drainage

Irrigation was applied as and when required.

Harvesting

To get data for the parameters of field performance of amaranth genotypes for the evaluation of genotype x environment interaction 5 (five) plants were harvested at random from each plot at marketable stage of the plant.

3.10 Data recorded

Five plants were selected randomly from each plot for recording data at the marketable stage of the plant. Then the harvested plants were measured either by manually or by using many devices to get data for different parameters respectively. The mean value of 5 (five) harvested plant was taken for each

A

B

C

Plate 2. Growing conditions of some amaranth genotypes in different seasons.

A. First season, B. Second season, C. Third season parameter.

The following characters were studied for measuring the field performance of amaranth genotypes:

Plant height (cm): The stem height was measured in centimeter on the ground level to the tip of the stem.

No. of leaves: The leaf number was counted manually.

Leaf length (cm): The leaf length was measured in centimeter on the node of the petiole of the tip of the leaf.

Leaf breadth (cm): The leaf breadth length was measured in centimeter through scale.

Individual stem diameter (mm): The Stem diameter was measured in millimeter through digital slide calipers.

Individual leaf weight (gm): The Individual Leaf weight was measured in gm & total 5 stem leaves were averaged by 5.

Individual stem weight (gm): The Individual Stem weight was taken in gm. The leaves were excluded while taking the Individual Stem Weight.

Marketable stem weight (gm): The Marketable stem weight was calculated in gm having some fresh leaves and stem weight.

Days to first flowering: The number of days after the sowing date was counted when the flower was bloomed in the plot.

No. of seed per plant: The seed number is counted which is got from each individual plant.

Yield (Kg/ha): The yield was got from the data of marketable weight by multiplying those as per hectare of land.

3.11 Stability analysis

The analysis of variance (ANOVA) was used and the G-E interaction was estimated by the AMMI model (Zobel *et al.* 1988; Duarte and Zimmermann, 1991). In this procedure, the contribution of each genotype and each environment to the G-E interaction is assessed by use of the bi-plot graph display in which yield means are plotted against the scores of the first principle component of the interaction (IPCA 1). The computational program for AMMI analysis is supplied by Duarte and Zimmermann (1991). The stability parameters, regression coefficient (bi) and deviation from regression (S^2di) were estimated according to Eberhart and Russel's (1966) model. Significance of differences among bi value and unity was tested by t-test, between S^2di and zero by F-test.

The statistical approaches suggested by Eberhart and Russel (1966) were followed for genotype x environment interaction and estimating stability parameters. According to them, a stable genotype may be considered as one having high mean, average linear regression (bi=1) to environments of varying levels of productivity and deviation from regression as close to zero. According to Panwar e*t al.* (1995), during data analysis, seasons are considered as separate environment in each season. Luthra *et al.* (1974) recommended Eberhart and Russel's for stability analysis considered its simplicity.

Eberhart and Russel's (1966) used the following models to study the stability of genotypes under different environments,

Yij = m + biIj + Sij (i = 1, 2………g and j = 1, 2……….e)

Where,

M = Overall mean

Yij =Mean of the i^{th} genotype over all the environments

bi = The regression coefficient of the i^{th} genotype on the environmental index which measures the response of these genotype to varying environments.

Ij = The environmental index which is defined as the deviation of the mean of all the genotypes at a given environment from the overall mean, i.e.

Ij = $\bar{Y}$.j – $\bar{Y}$...... ($\bar{Y}$.j= mean of the i^{th} genotype in the jth environment, $\bar{Y}$ = overall mean)

The regression coefficient (bi) was calculated for each genotype as follows

bi = [$\sum$ j Yij Ij / I^2]

Where, $\sum$ Yij Ij is the sum of product of environmental index (Ij) with the corresponding mean of that genotype of each environment.

$\sum \delta^2$ ij= [δ^2 vi – bi $\sum$ YijIj] which is the variance of mean over different environments with regard to individual genotypes.

δ^2vi = [$\sum$ jYij^2 – Yi^2/e]

Where, e = no. of environment and Yi = sum of the i^{th} genotype over environments.

Mean square deviation (S^2di) from linear regression was calculated using the following formula-

S^2di = [$\sum$ j δ^2ij/(e-2) – S^2e/r]

Where, S^2e = estimated pooled error and r = no. of replication

The phenotypic index (Ram *et al.* 1970) has been introduced in the Eberhart and Russel's model for easy interpretation and quick conclusion. The formula of phenotypic index (Pi) is given below,

Pi = $\bar{Y}$i.- $\bar{Y}\ldots$

Where,

$\bar{Y}$i = mean of the ith genotype over environment,

$\bar{Y}$ = overall mean

The hypothesis is that there is no response of genotype to different environment (Ho: bi = 1) and there is no deviation from regression (Ho: S^2di = 1) were tested approximately by the F test.

H_o; bi = 1, $F = \frac{\text{M.S. due to regression}}{Error\ M.S.}$

H_o: S^2di = 0, $F = \frac{\text{M.S. due to deviation}}{.pooled\ Error\ M.S.}$

The individual genotypic response i.e. regression coefficient (bi) was tested by 't'- test using the standard error of the corresponding bi value against the hypothesis. The individual deviations from linear regression tested by F-test using pooled error and S^2di did not differ significantly from zero in the genotypes.

t=$|\frac{1-bi}{\text{SE(b)}}|$, $SE_{(b)}=\sqrt{\frac{MS\ due\ to\ pooled\ deviation}{\sum il2j}}$ and

$$F = [\sum \delta^2 ij/(n-2)]/Pooled\ error$$

Additive Main Effects Multiplicative Interaction (AMMI) model

A recent extension of principal components, aimed specifically at the analysis of genotype-environment interactions, has led to the development of the so called Additive Main Effects, Multiplicative Interaction (AMMI) model (Zobel *et al.* 1990). AMMI is a two-stage model, used to separate the additive effects of genotypes and environments, is followed by the multiplicative principal components analysis to extract the pattern from the remaining genotype-environment interaction portion of the ANOVA table.

Essentially this means stripping out the additive effects of genotypes and environments from the two-way genotype-environment table, and then conducting a principal components analysis on the residuals. The resulting statistical model is therefore a hybrid of these two models, which yields at least squares analysis (Zobel *et al.* 1990). In this way the interaction is described in terms of differential sensitivity to the most discriminating environmental variables that can be constructed (Yau, 1995). No measured environmental variables enter the model. Because environmental variables and genotypic sensitivities are estimated from the data, AMMI is a bilinear model: given the Column parameters the model is linear in the row parameters, and given the row parameters it is linear in the column parameters (Yau, 1995).

The first axis represented that environmental variable which accounts for the largest amount of interaction, and which therefore discriminates most effectively between the genotypes, and so on down. An AMMI analysis generates a clutch of models, variously designated AMMIO, AMMI1, and AMMI2 up to AMMIF, depending on the number of axes retained. AMMIO fits only the additive main effects of genotypes and environments and retains none of the interaction principal component axes (IPCA). AMMII fits the additive effects from AMMIO plus those genotype-environment interactions associated with the first principal component axis (IPCA1), sweeping the remainder into the residual item of the analysis; and so on for AMMO up to AMMIF, the full model, which retains all the axes. The descriptive value of AMMI is enhanced by the use of biplots. The AMMI biplot is developed by placing both genotype and environment means on the x axis or abscissa, and the respective eigenvectors on the Y 'axis or ordinate (Zobel *et al.* 1990). Genotypes (or environments) which appear almost on a perpendicular line have similar means, while those falling almost on a horizontal line have similar interaction patterns.

Genotypes (Or environments) with large first principal component axis scores (either plus or minus) have high interactions, those with values close to zero have small interactions. The expected value for any particular genotype-environment combination may also be calculated from the biplot. Thus for AMMI1, the additive part is derived from AMMIO and is simply the genotype mean plus the environmental mean minus the grand mean. The appropriate interaction is the genotype score on the first axis multiplied by the corresponding environmental score. These two parts are then summed to give the expected value of the AMMII model (Zobel *et al.* 1990). In many instances these values supply a more accurate estimate of the true mean, and as such they may have greater predictive value than the treatment means (Gauch and Zobel, 1996).

AMMI partitions a noise-good residual from the interaction df, while error control is achieved by discarding this residual. The early or large eigen values selectively capture pattern, while the late or small eigen values selectively recover noise. To assess those benefits accruing from AMMI, two kinds of accuracy must be distinguished, namely postdictive and predictive (Gauch and Zobel, 1996). Usually postdictive and predictive criteria diagnose different AMMI models, with the former retaining more IPCA axes than the latter. The choice of appropriate model should reflect agricultural research priorities, because the most accurate post dictive model differs from the best predictive model. Gauch and Zobel (1996) suggests that, since yield trials are not conducted to determine what has already happened, but to improve future yields on farmers' fields, a predictive model is more suitable.

Chapter 4

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Combined analysis of variance

Results of combined analysis of variance of eleven characters viz. plant height (cm), no. of leaves per plant, leaf length (cm), leaf breadth (cm), individual stem diameter (mm), individual leaf weight (gm), individual stem weight (gm), marketable stem weight (gm), days to first flowering, no. of seed per plant, yield (Kg/ha), of twenty genotypes at three environments are presented in Table 2. Highly significant mean sum of squares due to environments (linear) indicated the difference between the environments.

4.2 Stability analysis for different characters of 20 amaranth genotypes

Eberhart and Russel (1966) emphasized the need of both linear (bi) and non-linear (S^2di) components of genotype x environment interactions in judging the phenotypic stability of a genotype. In this model, regression coefficient (bi) is considered as response and the deviation from regression (S^2di) as the parameter of stability. Relatively low value of bi around 1 will mean less responsive to the environmental change and therefore, more adaptive. If however, bi is negative, the genotype may be grown only in poor environment. Deviation from regression (S^2di), if significantly different from zero, will invalidate the linear prediction. If S^2di is non-significant, the performances of genotypes for a given environment may be predicted. Therefore, a genotype whose performance for a given environment can be predicted i.e., $S^2di \approx 0$ is said to be stable genotype. Results of stability and response of the genotypes under different environments according to Eberhart and Russel are presented characterwise.

Table 02. Combined analysis of variance including the partitioning of the G X E Interaction of 11 characters of the Amaranth under three seasons

Source of variation	df	Mean sum of squares					
		Plant Height (cm)	**No. of Leaves per Plant**	**Leaf Length (cm)**	**Leaf Breadth (cm)**	**Individual Stem Diameter (mm)**	**Individual Leaf Weight (gm)**
Genotypes (G)	19	1759.69**	314.58**	8.291**	2.249**	47.303**	897.789**
Environment (E)	2	11518.1**	291.350**	35.53**	39.864**	50.216**	2461.65**
Interaction G X E	38	151.432**	311.625**	6.59**	1.682**	15.165**	432.881**
AMMI component 1	20	56.88	160.106	2.898	0.791	5.619	199.628
AMMI Component 2	18	43.36	41.396	1.419	0.305	4.428	82.81
G X E (Linear)	19	49	167.405	1.606	0.561	5.899	201.763
Pool deviation	19	51.95	40.3451	2.789	0.560	4.211	86.824
Pooled Error	118	2.218	1.655	0.6459	0.125	0.306	2.198

*P<0.05, **P<0.01 (Tested against pooled error)

Table 02. Cont'd

Source of variation	df	Mean sum of squares				
		Individual Stem Weight (gm)	Marketable Stem Weight (gm)	Days to First Flowering	No. of Seed per Plant	Yield (Kg/ha)
Genotypes (G)	19	12315.1**	16890.3**	316.071**	75798600**	675249000**
Environment (E)	2	4498.38**	11032.7**	714.606**	5071980**	442507000**
Interaction G X E	38	2841.70**	4198.85**	37.71**	3665040**	168027000**
AMMI component 1	20	1062.69	1481.14	12.153	59286800	59286800
AMMI Component 2	18	818.949	1309.04	13.032	52367000	52367000
G X E (Linear)	19	815.17	1535.33	12.663	61461600	61461600
Pool deviation	19	1079.3	1263.91	12.478	50556400	50556400
Pooled Error	118	5.522	8.178	0.336	394368	330909

*P<0.05, **P<0.01 (Tested against pooled error)

4.2.1. Plant Height (cm)

The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for plant height are presented in Table 3. The positive and negative environmental index (Ij) reflects the good or favorable and poor or unfavorable environments for this character, respectively.

The environmental mean and genotypic mean ranged from 63.2 to 90.84 and 37 (G-09) to 96.14 (G-18), respectively. Thirteen genotypes namely G-02, G-03, G-04, G-05, G-06, G-07, G-14, G-15, G-16, G-17, G-18, G-19 and G-20 showed positive phenotypic index while the other genotypes had negative phenotypic index. Positive phenotypic index represented the desirability of production of plants with higher plant height and negative represented the undesirability of production of plants with higher plant height among the genotypes.

The season I possess the negative environmental index (Ij) while season II and season III possess the positive environmental index (Ij). Thus the season I was poor and the season II & season II was considered as good environment for the production of plants with higher plant height. (Plate3. Plant height of different Amaranth genotypes)

The regression coefficient (bi) values of these genotypes ranged from 0.228 to 1.671. These differences in bi values indicated that all the genotypes respond differently to different environments. The regression coefficient (bi) of one genotype namely G-20 was significantly different from unity which indicated high responsiveness of these genotypes across the environments.

Ten genotypes namely G-03, G-04, G-05, G-06, G-09, G-07, G-14, G-15, G-17 and G-18 possess low value of bi around 1. These genotypes are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of plant height character. If the bi value is negative, the genotype may be grown only in poor environment. Here there was no.

Table 03. Stability analysis for Plant Height (cm) of 20 genotypes of amaranth in three seasons

Genotypes	Environments				Phenotypic Index (P_i)	(b_i)	S^2di
	Season I	Season II	Season III	Overall Mean			
G-01	52.03	62.80	90.90	68.58	-9.01	1.373	79.33**
G-02	62.60	78.07	109.40	83.34	5.75	1.660	775.55**
G-03	83.87	88.63	101.50	91.34	13.75	0.624	15.56*
G-04	66.40	83.23	91.50	80.38	2.79	0.916	4.94
G-05	75.83	79.73	98.13	84.57	6.98	0.718	47.41**
G-06	63.63	80.23	93.97	79.28	1.69	1.096	0.130
G-07	77.87	84.50	99.30	87.22	9.63	0.759	17.52*
G-08	44.10	82.10	75.83	67.34	-10.25	1.208	256.69**
G-09	26.97	38.97	45.07	37	-40.59	0.660	2.22
G-10	38.63	68.80	66.37	57.93	-19.66	1.047	139.15**
G-11	53.67	75.63	84.97	71.42	-6.17	1.145	12.71
G-12	47.83	70.83	78.70	65.79	-11.80	1.134	19.21*
G-13	47.17	79.50	75.47	67.38	-10.21	1.073	169.07**
G-14	66.10	76.40	91.50	78	0.41	0.907	10.47
G-15	78.13	81.53	99.63	86.43	8.84	0.752	51.99**
G-16	90.57	88.23	97.37	92.06	14.47	0.228	23.12*
G-17	73	83.40	98.63	85.01	7.42	0.915	10.63
G-18	87.70	94.27	106.50	96.14	18.55	0.667	10.50
G-19	62.50	90.77	108.50	87.26	9.67	1.671	3.88
G-20	65.30	86.9	103.50	85.23	7.64	1.382*	0.01
Mean	63.2	78.73	90.84	77.59			
En. Index (I_j)	-14.39	1.14	13.25				
LSD (0.05)				3.08			

Plate 3. Plant height of some amaranth genotypes used in the research work.

genotype which possesses the negative bi value. So, there was no specific genotype which may be grown only in poor environment.

When the S^2di value of a genotype tends to zero i.e. S^2di≈0, then that genotype is said to be stable genotype. In this case, the S^2di value of G-04, G-06, G-09, G-11, G-14, G-17, G-18, G-19 and G-20 tends to near zero. So, these genotypes could be called as stable genotypes. Deviation from regression (S^2di) of the genotypes G-01, G-02, G-03, G-05, G-07, G-08, G-10, G-12, G-13, G-15 and G-16 was significantly different from zero. So, linear prediction of these ten genotypes was not possible. These genotypes are unstable for plant height character.

Among the twenty genotypes, G-18 could be considered as tallest genotype and this genotype was stable. This was due to highest positive Pi value (18.55), positive non significant bi value (0.667) which tends to 1 and non significant S^2di value (10.5).

Among the twenty genotypes G-9 could be considered as the shortest genotype and this was stable. This was due to highest negative Pi value (-40.59), positive non significant bi value (0.66) which tends to 1 and non significant S^2di value (2.22).

Considering the Pi, bi and S^2di, it was evident that all the genotypes showed different response to adaptability under differential conditions and the genotypes G-04, G-06 were the genotypes with higher plant height and stable across all environmental conditions. These genotypes had positive index and non significant bi value and non significant S^2di value which was desirable for this trait. Similar kind of result was found by Varalakshmi *et al.* (2011) and Yarnia *et al.* (2010) in amaranth.

4.2.2. No. of leaves per Plant

The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for number of leaves per plant are presented in Table 4.

The environmental mean and genotypic mean ranged from 36.35 to 40.45 and 29.33 (G-1) to 49.89 (G-20), respectively. Nine genotypes namely G-02, G-05, G-06, G-09, G-10, G-11, G-13, G-15 and G-20 showed positive phenotypic index while the other genotypes had negative phenotypic index. Positive phenotypic index represented the desirability of production of plants with more number of leaves and negative represented the undesirability of production of plants with more number of leaves among the genotypes.

The season I possess the negative environmental index (Ij) while season II and season III possess the positive environmental index (Ij). Thus the season I was poor and the season II & season II was considered as good environment for the production of plants with more number of leaves.

The regression coefficient (bi) values of these genotypes ranged from -10.033 to 6.94. These differences in bi values indicated that all the genotypes respond differently to different environments. The regression coefficient (bi) of any genotype was not significantly different from unity which indicated there is no high responsiveness of any genotype across the environments for the character under studied. Four genotypes namely G-01, G-07, G-13, and G-18 possess low value of bi around 1. These genotypes are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of number of leaves character.

Among the genotypes G-02, G-09, G-10, G-15 and G-20 possess negative bi value so these may be grown only in poor environment. The S^2di value of G-05, G-08, G-11, G-12, G-13, G-15, G-17, G-18, G-19 and G-20 tends to near zero. So, these genotypes could be called as stable genotypes. Deviation from regression (S^2di) of the genotypes G-01, G-02, G-03, G-04, G-06, G-07, G-09,

Table 04. Stability analysis for No. of Leaves per Plant of 20 genotypes of amaranth in three seasons

Genotyps	**Environments**				**Phenotypic Index (P_i)**	**(b_i)**	**S^2di**
	Season I	**Season II**	**Season III**	**Overall Mean**			
G-01	25	32	28	28.33	-8.54	1.262	10.46**
G-02	44	47.33	32.67	41.33	4.46	-1.627	94.47**
G-03	15	45.67	40.67	34.11	-3.76	7.94	25.53**
G-04	23.33	36	46	35.11	-1.76	3.913	22.28**
G-05	45	46.67	46	45.89	9.02	0.223	0.40
G-06	50.33	36	61.67	49.33	10.46	0.470	318.74**
G-07	28	28.33	39	31.78	-7.09	1.825	44.44**
G-08	25.67	41	39.67	35.44	-3.43	3.756	6.28
G-09	67	42.33	20	43.11	4.24	-10.033	117.79**
G-10	51.67	32.67	34	39.44	0.57	-4.706	9.86
G-11	31.67	43	41	38.56	1.69	1.611	6.99
G-12	26	35	40	34.67	-3.20	4.147	4.46
G-13	36	45	42	41	4.13	0.843	9.01
G-14	24	30.33	41	31.78	-5.09	4.380	34.646**
G-15	53.33	39.33	40	44.22	7.35	-2.519	4.46
G-16	24	47	45	38.67	-0.20	5.634	15.48**
G-17	26	44	44	38	-0.87	4.665	4.70
G-18	27.67	33.33	36	32.33	-6.54	1.903	1.04
G-19	30.67	39	39.33	36.33	-2.54	2.214	0.62
G-20	62.67	44	43	49.89	11.02	-5	2.59
Mean	36.35	39.80	40.45	36.87			
En. Index (I_j)	-0.52	2.93	3.58				
LSD(0.05)				2.15			

G-14 and G-16 was significantly different from zero. So, linear prediction of these nine genotypes was not possible. These genotypes are unstable for number of leaves character.

Among the twenty genotypes, G-20 could be considered as the most number of leaves producer genotype and this genotype was stable under poor environment. This was due to highest positive Pi value (11.02), negative non significant bi value (-5) and non significant S^2di value (2.59).

Among the twenty genotypes G-01 could be considered as the least number of leaves producer genotype and this was unstable. This was due to highest negative Pi value (-9.54), positive non significant bi value (1.162) which tends to 1 and significant S^2di value (11.56**).

Considering the Pi, bi and S^2di, it was evident that all the genotypes showed different response to adaptability under differential conditions and the genotype G-13 was the genotype with more number of leaves and stable across all environmental conditions. This genotype showed positive index and non significant bi value and non significant S^2di value which was desirable for this trait. Voltas *et al.* (2002) found similar kind of result considering the number of leaves per plant in barley.

4.2.3. Leaf Length (cm)

The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for leaf length are presented in Table 5.

The environmental mean and genotypic mean ranged from 22.98 to 24.38 and 21.88 (G-09) to 25.62 (G-02), respectively. Twelve genotypes namely G-01, G-02, G-04, G-05, G-06, G-07, G-08, G-13, G-14, G-16, G18 and G-19 showed positive phenotypic index while the other genotypes had negative phenotypic index. Positive phenotypic index represented the desirability of production of

Table 05. Stability analysis for Leaf Length (cm) of 20 genotypes of amaranth in three seasons

Genotypes	**Environments**				**Phenotypic Index (P_i)**	**(b_i)**	**S^2di**
	Season I	**Season II**	**Season III**	**Overall Mean**			
G-01	24.53	24.43	22.73	23.90	0.04	1.300	0.04
G-02	22.93	28.7	25.23	25.62	1.76	0.801	16.09**
G-03	24.10	23.73	23.43	23.76	-0.10	0.338	0.09
G-04	25.83	25.73	23.90	25.16	1.30	1.400	0.05
G-05	24	25.60	23.17	24.26	0.40	1.321	0.99
G-06	25.13	24.63	23.33	24.37	0.51	1.126	0.23
G-07	27.50	23.57	23.50	24.86	1	1.269	8.58**
G-08	24.2	24.07	23.50	23.92	0.06	0.464	0.02
G-09	22.47	22.2	20.97	21.88	-1.98	1.003	0.09
G-10	23.53	23.67	20.60	22.60	-1.26	2.248	0.02
G-11	23.83	24.23	23.20	23.76	-0.10	0.648	0.05
G-12	22.27	22.17	22.63	22.36	-1.50	0.00	0.317*
G-13	23.30	24.97	24.07	24.11	0.25	0.155	1.36
G-14	27.17	23	25.20	25.12	1.26	-0.351	8.54**
G-15	24.17	23.67	20.60	22.81	-1.05	2.445	0.38
G-16	24.57	27.20	20.50	24.09	0.23	4.186	2.03
G-17	25.17	20.9	23.50	23.19	-0.67	-0.619	8.79**
G-18	24.17	26	22.33	24.17	0.31	2.169	1.15
G-19	22.67	25.77	23.20	23.88	0.02	0.955	4.41**
G-20	23.07	23.37	23.97	23.47	-0.39	-0.541	0.07
Mean	24.23	24.38	22.98	23.86			
En. Index (I_j)	0.37	0.52	-0.88				
LSD(0.05)				1.78			

Plants with lengthier leaf and negative represented the undesirability of production of plants with lengthier leaf among the genotypes.

The season III possess the negative environmental index (Ij) while season I and season II possess the positive environmental index (Ij). Thus the season III was poor and the season I & season II was considered as good environment for the production of plants with higher leaf length. (Plate4. Length of leaves of some amaranth genotypes used in the research)

The regression coefficient (bi) values of these genotypes ranged from -0.619 to 4.186. These differences in bi values indicated that all the genotypes respond differently to different environments. The regression coefficient (bi) of one genotype namely G-12 was significantly different from unity which indicated high responsiveness of these genotypes across the environments. Five genotypes namely G-02, G-06, G-07, G-09, and G-19 possess low value of bi around 1. These genotypes are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of leaf length character.

Among the genotypes G-12, G-14, G-17 and G-20 possess negative bi value so these may be grown only in poor environment.

The S^2di value of G-01, G-03, G-04, G-08, G-09, G-10, G-11, G-12, and G-20 tends to near zero. So, these genotypes could be called as stable genotypes. Deviation from regression (S^2di) of the genotypes G-02, G-07, G-14, G-17 and G-19 was significantly different from zero. So, linear prediction of these five genotypes was not possible. These genotypes are unstable for leaf length character.

Among the twenty genotypes, G-02 could be considered as the lengthiest leaf producer genotype and this genotype was unstable. This was unstable due to highest positive Pi value (1.76), positive non significant bi value (0.801) but significant value of S^2di (16.09**).

Plate 4. Legth of leaves of some amaranth genotypes used in the research.

Among the twenty genotypes G-09 could be considered as the shortest leaf producer genotype and this was stable. This was due to highest negative Pi value (-1.98), positive non significant bi value (1.003) and non significant S^2di value (0.09).

Considering the Pi, bi and S^2di, it was evident that all the genotypes showed different response to adaptability under differential conditions and the genotype G-06 was the genotype with higher leaf length and stable across all environmental conditions. This genotype showed positive index and non significant bi value and non significant S^2di value which was desirable for this trait. Hiroyoshi *et al.* (2002) found similar kind of result

4.2.4. Leaf Breadth (cm)

The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for leaf breadth are presented in Table 6.

The environmental mean and genotypic mean ranged from 8.685 to 10.31 and 8.3 (G-15) to 10.33 (G-01), respectively. Thirteen genotypes namely G-01, G-04, G-05, G-06, G-07, G-08, G-09, G-10, G-12, G-13, G-14, G19, and G-20 showed positive phenotypic index while the other genotypes had negative phenotypic index. Positive phenotypic index represented the desirability of production of plants with higher leaf breadth and negative represented the undesirability of production of plants with higher leaf breadth among the genotypes.

The season III possess the negative environmental index (Ij) while season I and season II possess the positive environmental index (Ij). Thus the season III was poor and the season I & season II was considered as good environment for the production of plants with higher leaf breadth.

The regression coefficient (bi) values of these genotypes ranged from -0.214 to 2.003. These differences in bi values indicated that all the genotypes respond

Table 06. Stability analysis for Leaf Breadth (cm) of 20 genotypes of amaranth in three seasons

Genotypes	Environments				Phenotypic Index (P_i)	(b_i)	S^2di
	Season I	Season II	Season III	Overall Mean			
G-01	10.830	10.900	9.267	10.330	0.801	0.999	0.38
G-02	8.233	9.100	8.633	8.656	-0.873	-0.214	0.32
G-03	8.633	9.767	8.233	8.878	-0.651	0.307	1.14**
G-04	8.767	11.030	9.133	9.644	0.115	-0.127	2.94**
G-05	11.670	9.900	9.133	10.230	0.701	1.527	0.28
G-06	10.770	9.700	9.267	9.911	0.382	0.903	0.11
G-07	10.700	10.100	8.400	9.733	0.204	1.434	0.12
G-08	10.870	10.070	8.367	9.767	0.238	1.551	0.06
G-09	10.570	10.170	8.500	9.744	0.215	1.295	0.18
G-10	10.600	9.833	9.233	9.889	0.360	0.833	0.02
G-11	10.900	8.267	8.600	9.256	-0.273	1.338	1.73**
G-12	10.370	8.900	9.500	9.589	0.060	0.482	0.78*
G-13	11	9.467	8.567	9.678	0.149	1.475	0.14
G-14	11.470	9	8.133	9.533	0.004	2.003	0.65
G-15	9.700	7.833	7.367	8.300	-1.229	1.395	0.46
G-16	10.270	9.267	8	9.178	-0.351	1.394*	0.00
G-17	10.070	8.600	9.267	9.311	-0.218	0.440	0.82*
G-18	9.133	9.967	9.100	9.400	-0.129	0.060	0.48
G-19	11.400	10.130	8.333	9.956	0.427	1.889*	0.01
G-20	10.300	9.833	8.667	9.600	0.071	1.016	0.04
Mean	10.31	9.592	8.685	9.529			
En. Index (I_j)	0.781	0.063	-0.844				
LSD(0.05)				0.47			

differently to different environments. The regression coefficient (bi) of two genotypes namely G-16 and G-19 was significantly different from unity which indicated high responsiveness of these genotypes across the environments. Four genotypes namely G-01, G-06, G-10 and G-20 possess low value of bi around 1. These genotypes are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of leaf breadth character.

Among the genotypes G-02 and G-04 possess negative bi value so these may be grown only in poor environment.

The S^2di value of G-06, G-07, G-08, G-09, G-10, G-13, G-16, G-19 and G-20 tends to near zero. So, these genotypes could be called as stable genotypes. Deviation from regression (S^2di) of the genotypes G-03, G-04, G-11, G-12 and G-17 was significantly different from zero. So, linear prediction of these five genotypes was not possible. These genotypes are unstable for leaf breadth character.

Among the twenty genotypes, G-01 could be considered as the lengthiest leaf breadth producer genotype and this genotype was stable. This was due to highest positive Pi value (0.801), positive non significant bi value (0.999) and non significant S^2di value (0.38).

Among the twenty genotypes G-15 could be considered as the shortest leaf breadth producer genotype and this genotype was stable. This was due to highest negative Pi value (-1.229) positive non significant bi value (1.395) and non significant S^2di value (0.46).

Considering the Pi, bi and S^2di, it was evident that all the genotypes showed different response to adaptability under differential conditions and the genotype G-01, G-06 and G-10 were the genotype with lengthier leaf breadth and stable across all environmental conditions. These genotypes showed positive index and non significant bi value and non significant S^2di value which was desirable for this trait. Hiroyoshi *et al.* (2002) found similar kind of result in citrus.

4.2.5. Individual Stem Diameter (mm)

The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for individual stem diameter are presented in Table 7.

The environmental mean and genotypic mean ranged from 16.75 to 18.58 and 13.7 (G-09) to 21.6 (G-01), respectively. Eleven genotypes namely G-01, G-04, G-07, G-08, G-12, G-13, G-14, G-17, G-18, G-19 and G-20 showed positive phenotypic index while the other genotypes had negative phenotypic index. Positive phenotypic index represented the desirability of production of plants with higher individual stem diameter and negative represented the undesirability of production of plants with higher individual stem diameter among the genotypes.

The season I possess the negative environmental index (Ij) while season II and season III possess the positive environmental index (Ij). Thus the season I was poor and the season II & season III was considered as good environment for the production of plants with higher individual stem diameter.

The regression coefficient (bi) values of these genotypes ranged from -1.546 to 4.009. These differences in bi values indicated that all the genotypes respond differently to different environments. The regression coefficient (bi) of any genotype was not significantly different from unity which indicated there is no high responsiveness of any genotype across the environments for the character under studied. Four genotypes namely G-02, G-09, G-10 and G-11 possess low value of bi around 1. These genotypes are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of individual stem diameter character.

Among the genotypes G-05, G-06, G-07, G-12, G-14 and G-15 possess negative bi value so these may be grown only in poor environment.

The S^2di value of G-06, G-07, G-08, G-09, G-10, G-13, and G-17 tends to near zero. So, these genotypes could be called as stable genotypes. Deviation from

Table 07. Stability analysis for Individual Stem Diameter (mm) of 20 genotypes of amaranth in three seasons

Genotypes	**Environments**				**Phenotypic Index (P_i)**	**(b_i)**	**S^2di**
	Season I	**Season II**	**Season III**	**Overall Mean**			
G-01	19.53	24.56	20.7	21.6	3.91	2.702	1.63
G-02	13.85	14.78	18.6	15.74	-1.95	0.641	11.96**
G-03	13.73	16.98	17.13	15.95	-1.74	1.829	1.78
G-04	17.33	24.64	19.01	20.33	2.64	3.925	3.51*
G-05	19.25	18.12	14.48	17.28	-0.41	-0.753	11.47**
G-06	17.66	15.11	15.92	16.23	-1.46	-1.405	0.08
G-07	19.24	17.04	17.32	17.87	0.18	-1.227	0.34
G-08	18.45	18.69	18.83	18.65	0.96	0.139	0.04
G-09	13.11	14.61	13.40	13.70	-3.99	0.802	0.19
G-10	14.02	15.21	15.23	14.82	-2.87	0.669	0.21
G-11	13.46	14.97	16.36	14.93	-2.76	0.891	2.87*
G-12	21.14	18.26	22.03	20.48	2.79	-1.499	4.01*
G-13	18.19	24.09	21.10	21.13	3.44	3.219	0.06
G-14	19.49	16.48	20.95	18.97	1.28	-1.546	6.37**
G-15	16.70	16.05	12.66	15.14	-2.55	-0.474	9.04**
G-16	12.54	18.67	17.15	16.12	-1.57	3.397	1.08
G-17	17.93	19.25	19.56	18.91	1.22	0.754	0.56
G-18	16.13	22.05	20.51	19.56	1.87	3.273	0.89
G-19	19.44	20.97	14.52	18.31	0.62	0.653	22.03**
G-20	13.82	21.04	19.44	18.10	0.41	4.009	1.90
Mean	16.75	18.58	17.74	17.69			
En. Index (I_j)	-0.94	0.89	0.05				
LSD(0.05)				0.86			

regression (S^2di) of the genotypes G-02, G-04, G-05, G-11, G-12, G-14, G-15 and G-19 was significantly different from zero. So, linear prediction of these eight genotypes was not possible. These genotypes are unstable for individual stem diameter character.

Among the twenty genotypes, G-01 could be considered as the thickest stem diameter producing genotype and this genotype was stable. This was due to highest positive Pi value (3.91), positive non significant bi value (2.72) and non significant S^2di value (1.63).

Among the twenty genotypes G-09 could be considered as the least individual stem diameter producing genotype and this genotype was stable. This was due to highest negative Pi value (-3.99), positive non significant bi value (0.802) and non significant S^2di value (0.19).

Considering the Pi, bi and S^2di, it was evident that all the genotypes showed different response to adaptability under differential conditions and the genotype G-17 was the genotype with higher individual stem diameter and stable across all environmental conditions. This genotype showed positive index and non-significant bi value and non significant S^2di value which was desirable for this trait. Bhargava *et al.* (2008) found similar kind of result considering the individual stem diameter characeter in *Chenopodium*.

4.2.6. Individual Leaf Weight (gm)

The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for individual leaf weight are presented in Table 8.

The environmental mean and genotypic mean ranged from 38.7 to 51.38 and 33.11 (G-15) to 81.51 (G-01), respectively. Nine genotypes namely G-01, G-04, G-06, G-07, G-08, G-09, G-11, G-18 and G-20 showed positive phenotypic index while the other genotypes had negative phenotypic index. Positive phenotypic index represented the desirability of production of plants with

Table 08. Stability analysis for Individual Leaf Weight (gm) of 20 genotypes of amaranth in three seasons

Genotypes	**Environments**				**Phenotypic Index (P_i)**	**(b_i)**	**S^2di**
	Season I	**Season II**	**Season III**	**Overall Mean**			
G-01	106.90	82.77	54.87	81.51	35.94	-3.995	46.08**
G-02	35.08	39.51	45.08	39.89	-5.68	0.765	2.17
G-03	26.30	40.35	41.16	35.94	-9.63	1.234	14.76*
G-04	35.53	68.03	49.62	51.06	5.49	1.417	366.56**
G-05	19.72	63.26	51.77	44.92	-0.65	2.831	360.60**
G-06	58.52	45.74	55.5	53.25	7.68	-0.378	77.50**
G-07	34.70	53.43	57.64	48.59	3.02	1.865	12.60
G-08	48.92	36.49	53.52	46.31	0.74	0.166	153.07**
G-09	52.96	37.28	52.34	47.53	1.96	-0.246	152.78**
G-10	25.22	47.21	45.46	39.3	-6.27	1.717	56.95**
G-11	33.47	49.23	54.83	45.84	0.27	1.716	3.78
G-12	30.7	39.15	45.15	38.34	-7.23	1.132	0.22
G-13	50.45	33.94	51.72	45.37	-0.20	-0.123	195.63**
G-14	21.87	38.38	57.56	39.27	-6.30	2.740	22.03*
G-15	31.83	32.02	35.47	33.11	-12.46	0.260	2.84
G-16	20.75	50.48	54	41.74	-3.83	2.738	52.22**
G-17	36.71	36.99	50.93	41.54	-4.03	1.011	48.34**
G-18	34.34	54.68	64.63	51.22	5.65	2.407	1.28
G-19	37.66	42.10	41.84	40.53	-5.04	0.353	2.18
G-20	32.45	41.59	64.55	46.20	0.63	2.390	78.08**
Mean	38.7	46.63	51.38	45.57			
En. Index (I_j)	-6.87	1.06	5.81				
LSD (0.05)				2.07			

higher individual leaf weight and negative represented the undesirability of production of plants with higher individual leaf weight among the genotypes.

The season I possess the negative environmental index (Ij) while season II and season III possess the positive environmental index (Ij). Thus the season I was poor and the season II & season III was considered as good environment for the production of plants with higher individual leaf weight.

The regression coefficient (bi) values of these genotypes ranged from -3.995 to 2.831. These differences in bi values indicated that all the genotypes respond differently to different environments. The regression coefficient (bi) of any genotype was not significantly different from unity which indicated there is no high responsiveness of any genotype across the environments for the character under studied. Five genotypes namely G-02, G-03, G-04, G-12 and G-17 possess low value of bi around 1. These genotypes are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of individual leaf weight character.

Among the genotypes G-01, G-06, G-09, and G-13 possess negative bi value so these may be grown only in poor environment.

Among these genotypes G-01 could be considered as the higher individual leaf weight producing and stable genotype under poor environment. This was due to the higher positive Pi value, negative bi value and non significant S^2di value from zero.

The S^2di value of G-02, G-11, G-12, G-15, G-18, and G-19 tends to near zero. So, these genotypes could be called as stable genotypes. Deviation from regression (S^2di) of the genotypes G-01, G-03, G-04, G-05, G-06, G-08, G-09, G-10, G-13, G-14, G-16, G-17 and G-20 was significantly different from zero. So, linear prediction of these thirteen genotypes was not possible. These genotypes are unstable for individual leaf weight character.

Among the twenty genotypes, G-01 could be considered as the highest individual leaf weight producing genotype and this genotype was unstable. This was due to highest positive Pi value (35.94), negative non significant bi value (-3.995) but significant S^2di value (46.08**).

Among the twenty genotypes G-15 could be considered as the least individual leaf weight producing genotype and this genotype was stable. This was due to highest negative Pi value (-12.46), positive non significant bi value (0.26) and non significant S^2di value (2.84).

Considering the Pi, bi and S^2di, it was evident that all the genotypes showed different response to adaptability under differential conditions and the genotypes G-07 and G-11 were the genotypes with higher individual leaf weight and stable across all environmental conditions. These genotypes showed positive index and non significant bi value and non significant S^2di value which were desirable for this trait. Shudhir *et al.* (2003) found similar kind of result considering the individual leaf weight character.

4.2.7. Individual Stem Weight (gm)

The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for individual stem weight are presented in Table 9.

The environmental mean and genotypic mean ranged from 103 to 120.1 and 38.31 (G-09) to 197.93 (G-01), respectively. Seven genotypes namely G-01, G-02, G-04, G-13, G-18, G-19 and G-20 showed positive phenotypic index while the other genotypes had negative phenotypic index. Thus positive phenotypic index represented the desirability of production of plants with higher individual stem weight and negative represented the undesirability of production of plants with higher individual stem weight among the genotypes.

The season I possess the negative environmental index (Ij) while season II and season III possess the positive environmental index (Ij). Thus the season I was

Table 09. Stability analysis for Individual Stem Weight (gm) of 20 genotypes of amaranth in three seasons

Genotypes	Environments				Phenotypic Index (P_i)	(b_i)	S^2di
	Season I	Season II	Season III	Overall Mean			
G-01	206.90	193.60	193.30	197.93	85.53	-0.836	15.13
G-02	148.70	121.80	161	143.84	31.44	-1.221	582.68**
G-03	85.56	76.83	104.80	89.07	-23.33	-0.211	403.80**
G-04	108.50	196.70	133.70	146.30	33.9	4.783	700.81**
G-05	57.51	135.10	49.59	80.74	-31.66	3.844	2252.73**
G-06	94.76	119.60	85.58	99.99	-12.41	1.152	421.94**
G-07	83.74	125.80	117.20	108.92	-3.48	2.540	21.14
G-08	74.21	92.98	130.20	99.14	-13.26	1.629	1228.52**
G-09	46.59	36.83	31.52	38.31	-74.09	0.677	48.09
G-10	79.41	80.72	59.10	73.08	-39.32	0.179	289.16**
G-11	81.46	93.17	72.01	82.21	-30.19	0.480	190.04**
G-12	75.08	107	147.20	109.74	-2.66	2.489	1679.80**
G-13	111.20	86.58	158.10	118.63	6.23	0.684	2570.04**
G-14	53.86	85.98	171	103.61	-8.79	3.044	5936.54**
G-15	104.90	124.70	61.41	97	-15.40	0.480	2061.71**
G-16	79.75	128.30	96.66	101.57	-10.83	2.669	147.18
G-17	154.80	91.69	73.74	106.75	-5.65	4.182	1003.73**
G-18	134.20	168.90	152.60	151.91	39.51	1.982	12.98
G-19	146.80	121	92.38	120.04	7.64	1.967	900.72**
G-20	132.50	213.80	194	180.10	67.70	4.866	39.85
Mean	103	120.1	114.3	112.4			
En. Index (I_j)	-9.4	7.7	1.9				
LSD(0.05)				3.95			

poor and the season II & season III was considered as good environment for the production of plants with higher individual stem weight.

The regression coefficient (bi) values of these genotypes ranged from -4.182 to 4.866. These differences in bi values indicated that all the genotypes respond differently to different environments. The regression coefficient (bi) of any genotype was not significantly different from unity which indicated there is no high responsiveness of any genotype across the environments for the character under studied. Five genotypes namely G-06, G-08, G-11, G-15 and G-18 possess low value of bi around 1. These genotypes are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of individual stem weight character.

Among the genotypes G-01, G-02, G-03, G-09, G-10, G-13, G-17 and G-19 possess negative bi value so these may be grown only in poor environment.

The S^2di value of G-01, G-03, G-09, G-10, G-11, G-16, G-17, G-18, and G-20 tends to near zero. So, these genotypes could be called as stable genotypes. Deviation from regression (S^2di) of the genotypes G-02, G-03, G-04, G-05, G-06, G-08, G-10, G-11, G-12, G-13, G-14, G-15, G-17 and G-19 was significantly different from zero. So, linear prediction of these fourteen genotypes was not possible. These genotypes are unstable for individual stem weight character.

Among the twenty genotypes, G-01 could be considered as the highest individual stem weight producing genotype and this genotype was stable only in poor environment. This was due to highest positive Pi value (85.53), negative non significant bi value (-0.836) and non significant S^2di value (15.13).

Among the twenty genotypes G-09 could be considered as the least individual stem weight producing genotype and this genotype was stable only in poor environment. This was due to highest negative Pi value (-74.09), negative non significant bi value (-0.677) and non significant S^2di value (48.09).

Considering the Pi, bi and S^2di, it was evident that all the genotypes showed different response to adaptability under differential conditions and the genotype G-18 was the genotype with higher individual stem weight and stable across all environmental conditions. This genotype showed positive index and non significant bi value and non significant S^2di value which was desirable for this trait. Ejieji *et al.* (2010) found similar kind of result in grain amaranth considering this character.

4.2.8. Marketable Stem Weight (gm)

The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for marketable stem weight are presented in Table 10.

The environmental mean and genotypic mean ranged from 142.4 to 166.8 and 85.93 (G-09) to 279.49 (G-01), respectively. Eight genotypes namely G-01, G-02, G-04, G-07, G-13, G-18, G-19 and G-20 showed positive phenotypic index while the other genotypes had negative phenotypic index. Positive phenotypic index represented the desirability of production of plants with higher marketable stem weight and negative represented the undesirability of production of plants with higher marketable stem weight among the genotypes.

The season I possess the negative environmental index (Ij) while season II and season III possess the positive environmental index (Ij). Thus the season I was poor and the season II & season III was considered as good environment for the production of plants with higher marketable stem weight.

The regression coefficient (bi) values of these genotypes ranged from -2.81 to 3.892. These differences in bi values indicated that all the genotypes respond differently to different environments. The regression coefficient (bi) of two genotypes namely G-07 and G-17 were significantly different from unity which indicated high responsiveness of these genotypes across the environments. Three genotypes namely G-03, G-10 and G-11 possess low value of bi around 1. These genotypes are less responsive to the environmental changes and these

Table 10. Stability analysis for Marketable Stem Weight (gm) of 20 genotypes of amaranth in three seasons

Genotypes	**Environments**				**Phenotypic Index (P_i)**	**(b_i)**	**S^2di**
	Season I	**Season II**	**Season III**	**Overall Mean**			
G-01	316.50	273.80	248.2	279.49	121.49	-2.29	451.59
G-02	186.50	161.60	206.2	184.76	26.76	0.23	979.55**
G-03	112.60	118	143.8	124.81	-33.19	0.711	371.8
G-04	142.40	267.30	183.6	197.72	39.72	3.747	2940.79**
G-05	77.67	194.40	101.1	124.40	-33.6	3.221	3812.53**
G-06	154.10	166.30	141.5	153.98	-4.02	0.059	305.73
G-07	118.60	181.90	175.5	158.70	0.70	2.569*	1.16
G-08	123.70	134.40	183	147.04	-10.96	1.361	1318.27**
G-09	100.70	73.18	83.94	85.93	-72.07	-0.967	39.77
G-10	104.70	129.60	105.8	113.38	-44.62	0.613	256.43
G-11	114.30	144.70	124.4	127.80	-30.20	0.912	173.10
G-12	105	145.90	192.3	147.73	-10.27	2.599	1325.96**
G-13	162.60	120.50	207.7	163.60	5.60	-0.164	3796.74**
G-14	76.45	124.80	223.6	141.61	-16.39	3.892	5684.46**
G-15	136.90	153.90	96.38	129.04	-28.96	-0.348	1700.36**
G-16	101.80	179.30	149.3	143.46	-14.54	2.729	308.06*
G-17	193.40	128.20	125.9	149.17	-8.83	-2.81*	29.49
G-18	170.80	224.50	216.1	203.81	45.81	2.124	9.38
G-19	184.10	160.60	133.2	159.31	1.31	-1.508	459.37*
G-20	165.60	253.50	256.2	225.12	67.12	3.783	49.66
Mean	142.4	166.8	164.9	158			
En. Index (I_j)	-15.6	8.8	6.9				
LSD(0.05)				4.34			

are more adaptive than other genotypes in respect of marketable stem weight character.

Among the genotypes G-01, G-09, G-13, G-15, G-17 and G-19 possess negative bi value so these may be grown only in poor environment.

The S^2di value of G-07, G-09, G-17, G-18 and G-20 tends to near zero. So, these genotypes could be called as stable genotypes. Deviation from regression (S^2di) of the genotypes G-02, G-04, G-05, G-08, G-12, G-13, G-14, G-15, G-16, and G-19 was significantly different from zero. So, linear prediction of these ten genotypes was not possible. These genotypes are unstable for marketable stem weight character.

Among the twenty genotypes, G-01 could be considered as the highest marketable stem weight producing genotype and this genotype was stable only in poor environment. This was due to highest positive Pi value (121.49), negative non significant bi value (2.29) and non significant S^2di value (451.59).

Among the twenty genotypes G-09 could be considered as the least marketable stem weight producing genotype and this genotype was stable only in poor environment. This was due to highest negative Pi value (-72.07), negative non significant bi value (-0.967) and non significant S^2di value (39.77).

Considering the Pi, bi and S^2di, it was evident that all the genotypes showed different response to adaptability under differential conditions and the genotypes G-18 was the genotype with higher marketable stem weight and stable across all environmental conditions. That genotype showed positive index and non significant bi value and non significant S^2di value which was desirable for this trait. Varalakshmi *et al.* (2011) found the similar kind of result in amaranth.

4.2.9. Days to First Flowering

The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for days to first flowering are presented in Table 11.

The environmental index (Ij) directly reflected the favorable and unfavorable environments in terms of positive and negative Ij, respectively. However for this trait, negative environmental index (Ij) is the favorable environment for genotypes with fewer days to first flowering i.e. early maturing genotypes.

The environmental mean and genotypic mean ranged from 39 to 45.88 and 32.22 (G-03) to 54.78 (G-09), respectively. Seven genotypes namely G-02, G-03, G-05, G-15, G-16, G-19 and G-20 showed negative phenotypic index while the other genotypes had positive phenotypic index. Negative phenotypic index represented the desirability of production of early maturing plants and positive represented the undesirability of production of early maturing plants among the genotypes.

The season II and season III possess the positive environmental index (Ij) while season I possesses the negative environmental index (Ij). Thus the season II & season III was poor and the season I was good environment for the production of early maturing plants.

The regression coefficient (bi) values of these genotypes ranged from -0.44 to 2.365. These differences in bi values indicated that all the genotypes respond differently to different environments. The regression coefficient (bi) of one genotype namely G-13 was significantly different from unity which indicated high responsiveness of these genotypes across the environments. Seven genotypes namely G-02, G-03, G-09, G-10, G-16, G-17 and G-19 possess low value of bi around 1. These genotypes are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of days to first flowering character.

Table 11. Stability analysis for Days to First Flowering of 20 genotypes of amaranth in three seasons

Genotypes	**Environments**				**Phenotypic Index (P_i)**	**(b_i)**	**S^2di**
	Season I	**Season II**	**Season III**	**Overall Mean**			
G-01	47.67	53.33	44	48.33	5.74	0.738	31.23**
G-02	35.67	42	41.33	39.67	-2.92	0.946	2.91
G-03	25.67	34.67	36.33	32.22	-10.37	1.377	8.71
G-04	48.67	50.33	45	48	5.41	0.185	14.07**
G-05	27.67	43.67	40	37.11	-5.48	2.365	7.25
G-06	41.67	55	43.33	46.67	4.08	1.865	22.73**
G-07	38	52	42	44	1.41	1.986	10.08**
G-08	45	46.33	45.33	45.56	2.97	0.189	0.12
G-09	50.33	59.67	54.33	54.78	12.19	1.34	1.06
G-10	46	56.33	48	50.11	7.52	1.454	9.72
G-11	38.33	42	49	43.11	0.52	0.639	49.02**
G-12	38	49	46	44.33	1.74	1.62	2.13
G-13	45	42	43	43.33	0.74	-0.44*	0.06
G-14	38.33	44	46	42.78	0.19	0.878	13.25**
G-15	37.33	36	38	37.11	-5.48	-0.176	1.33
G-16	28.33	33.67	37.67	33.22	-9.37	0.853	6.52
G-17	39	46.33	45	43.44	0.85	1.088	2.30
G-18	44	48	41	44.33	1.74	0.516	18.32**
G-19	38.33	45	39.67	41.00	-1.59	0.939	3.91
G-20	27	38.33	32.67	32.67	-9.92	1.637	0.35
Mean	39	45.88	42.88	42.59			
En. Index(I_j)	-3.59	3.29	0.29				
LSD (0.05)				1.10			

In this case, if the bi value is negative, the genotype may be grown only in favorable environment with early maturing character.

Among the genotypes G-13 and G-15 possess negative bi value so these may be grown only in favorable environment for early flowering character. Among these genotypes G-15 could be considered as early flower producer and stable genotype under favorable environment. This was due to the higher negative Pi value (-5.48), negative non significant bi value (-0.178) and non significant S^2di value (1.33).

The S^2di value of G-02, G-03, G-08, G-13, G-15, G-17 and G-20 tends to near zero. So, these genotypes could be called as stable genotypes. Deviation from regression (S^2di) of the genotypes G-01, G-04, G-06, G-07, G-11, G-14, and G-18 was significantly different from zero. So, linear prediction of these seven genotypes was not possible and these genotypes are unstable for days to first flowering character.

Among the twenty genotypes, G-03 could be considered as the earliest first flowering genotype and this genotype was stable. This was due to highest negative Pi value (-10.37), positive non significant bi value (1.377) and non significant S^2di value (8.71).

Among the twenty genotypes G-09 could be considered as the highest days to first flowering producing genotype and this genotype was stable. This was due to highest positive Pi value (12.19), positive non significant bi value (1.34) and non significant S^2di value (1.06).

Considering the Pi, bi and S^2di, it was evident that all the genotypes showed different response to adaptability under differential conditions and the genotypes G-03 and G-16 were the genotype with lesser days to first flowering character and stable across all environmental conditions. These genotypes showed negative index and non significant bi value and non significant S^2di value which were desirable for this trait. Varalakshmi *et al.* (2011) found the similar kind of result considering days to first flowering in grain amaranth.

4.2.10. No. of Seed per Plant

The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for number of seed per plant are presented in Table 12.

The environmental mean and genotypic mean ranged from 8426 to 8941 and 4585.78 (G-05) to 14624.11 (G-07), respectively. Seven genotypes namely G-07, G-08, G-10, G-14, G-17, G-18 and G-19 showed positive phenotypic index while the other genotypes had negative phenotypic index. Positive phenotypic index represented the desirability of production of plants with higher number of seed per plant and negative represented the undesirability of production of plants with higher number of seed per plant among the genotypes.

The season II possess the negative environmental index (Ij) while season I and season III possess the positive environmental index (Ij). Thus the season II was poor and the season I & season III was considered good environment for the production of plants with higher number of seed per plant.

The regression coefficient (bi) values of these genotypes ranged from -5.529 to 5.794. These differences in bi values indicated that all the genotypes respond differently to different environments. The regression coefficient (bi) of any genotype was not significantly different from unity which indicated there is no high responsiveness of any genotype across the environments for the character under studied.

Three genotypes namely G-12, G-13 and G-18 possess low value of bi around 1. These genotypes are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of number of seed per individual plant character.

Among the genotypes G-01, G-05, G-09, G-10, G-14, G-16, G-17 and G-19 possess negative bi value so these may be grown only in poor environment.

Table 12. Stability analysis for No. of Seed per plant of 20 genotypes of amaranth in three seasons

Genotypes	**Environments**				**Phenotypic Index (P_i)**	**(b_i)**	**S^2di**
	Season I	**Season II**	**Season III**	**Overall Mean**			
G-01	4980	5616	5524	5373.33	-3388.70	-0.76	138728.30
G-02	7144	6669	8932	7581.56	-1180.40	2.597	1709791.12*
G-03	6292	4753	5327	5457	-3305	2.161	419993.75
G-04	6000	4851	7178	6009.67	-2752.30	3.370	788000.81
G-05	4681	5084	3992	4585.78	-4176.20	-1.436	260802.70
G-06	8569	7660	9351	8526.89	-235.11	2.526	353233.06
G-07	13880	14570	15410	14624.11	5862.11	0.045	11773806.62**
G-08	14640	12390	15910	14312.11	5550.11	5.648	991686.06
G-09	6889	8151	9124	8054.56	-707.44	-0.439	2479134.50*
G-10	9322	12690	10580	10863.33	2101.33	-5.529	636509.88
G-11	6816	5395	8274	6828.44	-1933.6	4.167	1206549.25
G-12	7146	5814	5904	6287.89	-2474.1	1.493	730769.50
G-13	9449	7640	7425	8171.33	-590.67	1.719	1972227*
G-14	11920	12820	12400	12378.89	3616.89	-1.348	103795.08
G-15	8855	7789	8551	8398.22	-363.78	1.835	34619.11
G-16	7547	6669	5627	6614.44	-2147.6	-0.034	1848786*
G-17	11260	11330	8348	10309.89	1547.89	-2.829	4423319**
G-18	11350	10250	10930	10841.78	2079.78	1.791	70509.02
G-19	11320	11540	10960	11273.44	2511.44	-0.773	70499.74
G-20	10770	6844	8609	8741.33	-20.67	5.794	2063190.75*
Mean	8941	8426	8918	8762			
En. Index (I_j)	179	-336	156				
LSD(0.05)				897.75			

The S^2di value of G-15, G-18 and G-19 tends to near zero. So, these genotypes could be called as stable genotypes. Deviation from regression (S^2di) of the genotypes G-02, G-07, G-09, G-13, G-16, G-17 and G-20 was significantly different from zero. So, linear prediction of these seven genotypes was not possible. These genotypes are unstable for number of seed per plant character.

Among the twenty genotypes, G-07 could be considered as the highest number of seed per plant producing genotype and this genotype was unstable. This was due to highest positive Pi value (5862.11), positive non significant bi value (0.045) and significant S^2di value (11773806.62**).

Among the twenty genotypes G-05 could be considered as the least number of seed per plant producing genotype and this genotype is stable only in poor environment. This was due to highest negative Pi value (-4176.2), negative non significant bi value (-1.436) and non significant S^2di value (260802.7).

Considering the Pi, bi and S^2di, it was evident that all the genotypes showed different response to adaptability under differential conditions and the genotypes G-18 was the genotype with higher number of seed per plant and stable across all environmental conditions. This genotype showed positive index and non significant bi value and non significant S^2di value which were desirable for this trait. Yarnia *et al.* (2010) showed similar kind result in amaranth considering the number of seed per plant character.

4.2.11. Yield (Kg/ha)

The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for yield are presented in Table 13.

The environmental mean and genotypic mean ranged from 28480 to 33360 and 17185.11 (G-09) to 55897.34 (G-01), respectively. Eight genotypes namely G-01, G-02, G-04, G-07, G-13, G-18, G-19 and G-20 showed positive phenotypic index while the other genotypes had negative phenotypic index. Positive phenotypic index represented the desirability of production of plants with

Table 13. Stability analysis for Yield (Kg/ha) of 20 genotypes of amaranth in three seasons

Genotypes	Environments				Phenotypic Index (P_i)	(b_i)	S^2di
	Season I	Season II	Season III	Overall Mean			
G-01	63300	54750	49640	55897.34	24287.34	-2.287	7821.539
G-02	37310	32320	41230	36952.22	5342.22	0.230	16965.810**
G-03	22520	23600	28770	24961.55	-6648.45	0.710	6439.576
G-04	28470	53450	36710	39544.89	7934.89	3.742	50934.480**
G-05	15530	38880	20220	24877.33	-6732.67	3.216	66033.020**
G-06	30810	33260	28310	30795.33	-814.67	0.059	5295.244*
G-07	23720	36390	35100	31736.89	126.89	2.566*	20.0912
G-08	24740	26890	36600	29408.67	-2201.33	1.359	22832.440**
G-09	20130	14640	16790	17185.11	-14424.89	-0.965	688.816
G-10	20950	25920	21160	22675.11	-8934.89	0.612	4441.368*
G-11	22860	28940	24880	22559.55	-9050.45	0.910	2998.092
G-12	21010	29180	38450	29546	-2064	2.595	22965.630**
G-13	32520	24100	41550	32720.44	1110.44	-0.164	65759.540**
G-14	15290	24960	44720	28323.55	-3286.45	3.887	98454.850**
G-15	27380	30770	19280	25808.45	-5801.55	-0.348	29450.240**
G-16	20370	35850	29850	28691.78	-2918.22	2.726	5335.599*
G-17	38680	25630	25190	29834.67	-1775.33	-2.809*	510.7668
G-18	34030	44900	43220	40719.11	9109.11	2.149	162.461
G-19	36820	32110	26650	31862.22	252.22	-1.506	7956.288*
G-20	33120	501710	51240	45023.33	13413.33	3.778	860.111
Mean	28480	33360	32980	31610			
En. Index (I_j)	-3130	1750	1370				
LSD(0.05)				882.67			

higher yield and negative represented the undesirability of production of plants with higher yield among the genotypes.

The season I possess the negative environmental index (Ij) while season II and season III possess the positive environmental index (Ij). Thus the season I was poor and the season II & season III was considered as good environment for the production of plants with higher yield.

The regression coefficient (bi) values of these genotypes ranged from -2.809 to 3.887. These differences in bi values indicated that all the genotypes respond differently to different environments. The regression coefficient (bi) of two genotypes namely G-07 and G-17 were significantly different from unity which indicated high responsiveness of these genotypes across the environments. Three genotypes namely G-03, G-10 and G-11 possess low value of bi around 1. These genotypes are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of yield character.

Among the genotypes G-01, G-09, G-13, G-15, G-17 and G-19 possess negative bi value so these may be grown only in poor environment. Among these genotypes G-01 could be considered as the higher yielder and stable genotype under poor environment. This was due to the higher positive Pi value, negative insignificant bi value and non significant S^2di value from zero.

The S^2di value of G-01, G-03, G-06, G-09, G-10, G-11, G-18 and G-20 tends to closer to zero. So, these genotypes could be called as stable genotypes. Deviation from regression (S^2di) of the genotypes G-02, G-04, G-05, G-06, G-10, G-08, G-12, G-13, G-14, G-15, G-16, and G-19 was significantly different from zero. So, linear prediction of these twelve genotypes was not possible. These genotypes are unstable for yield character.

Among the twenty genotypes, G-01 could be considered as the highest yield producing genotype and this genotype was stable only in poor environment. This was due to highest positive Pi value (24287.34), negative non significant bi value (-2.287) and non significant S^2di value (7821.539).

Among the twenty genotypes G-09 could be considered as the least yield producing genotype and this genotype was stable only in poor environment. This was due to highest negative Pi value (-14424.89), negative non significant bi value (-0.965) and non significant S^2di value (688.8164).

Considering the Pi, bi and S^2di, it was evident that all the genotypes showed different response to adaptability under differential conditions and the genotypes G-18 was the genotype with higher yield and stable across all environmental conditions. This genotype showed positive index and non significant bi and non significant S^2di value which were desirable for this trait. Varalakshmi *et al.* (2011) and Dhanapal *et al.* (2009) found similar kind of results in studying the yield character of amaranth.

4.3 The AMMI model 2-biplot

The AMMI biplot provide a visual expression of the relationship between the first interaction principle component axis (AMMI component 1) and mean of genotypes and environment (Fig.1) with the bi plot up to 100% of the treatment sum of squares. The first interaction principle component axis (AMMI component 1) was highly significant and explained the interaction pattern better than other interaction axis.

In Fig. 1 the IPCA scores for both the genotypes and the environments were plotted against the mean yield for the genotypes and the environments, respectively. By plotting both the genotypes and the environments on the same graph, the association between the genotypes and the environments can be seen clearly.

The IPCA scores of a genotype in the AMMI analysis were an indication of the stability or adaptation over environments. The greater the IPCA scores, negative or positive (as it is a relative value), the more specific adaptation of a genotype to certain environments. The more the IPCA scores approximate to zero, the more stable or adaptation of a genotype in over all environments.

Considering only the IPCA 1 scores G-04, G-05, G-09, G-10, G-11, G-17, G-19 and G-20 were more unstable genotypes and also adapted to the high yielding environments (Fig. 1). The most stable genotypes just considering the IPCA 1 scores were G-03, G-08, G-12, G-14, G-15, and G-18.

Since IPCA 2 scores also play a significant role in explaining the GEI, and the IPCA 1 scores were plotted against the IPCA 2 scores to further explore adaptation (Fig. 2).

According to the Fig. 2, G-20 & G-10 were outlier (unstable) followed by G-11, G-05, G-17, G-19, G-09, and G-04. The genotypes G-15, G-18, G-12, G-13, and G-14 showed to be more stable when plotted the IPCA 1 and IPCA 2 scores.

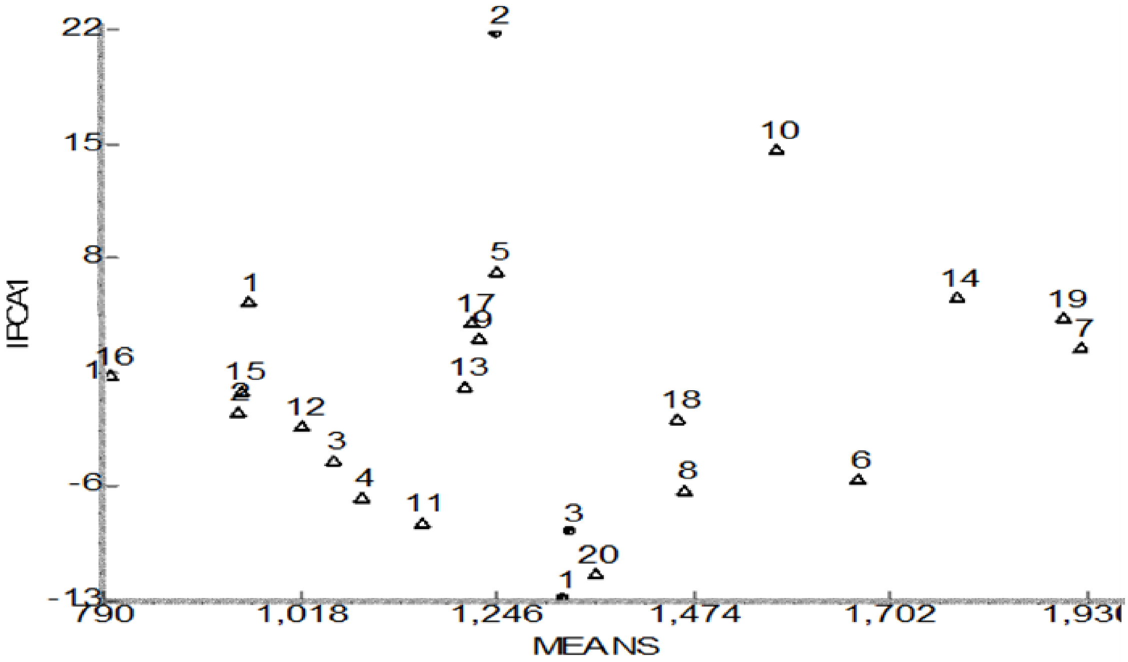

Fig.1. **Biplot of first AMMI interaction (IPCA 1) score (Y-axis) plotted against mean yield (X-axis) for twenty amaranth genotypes.**

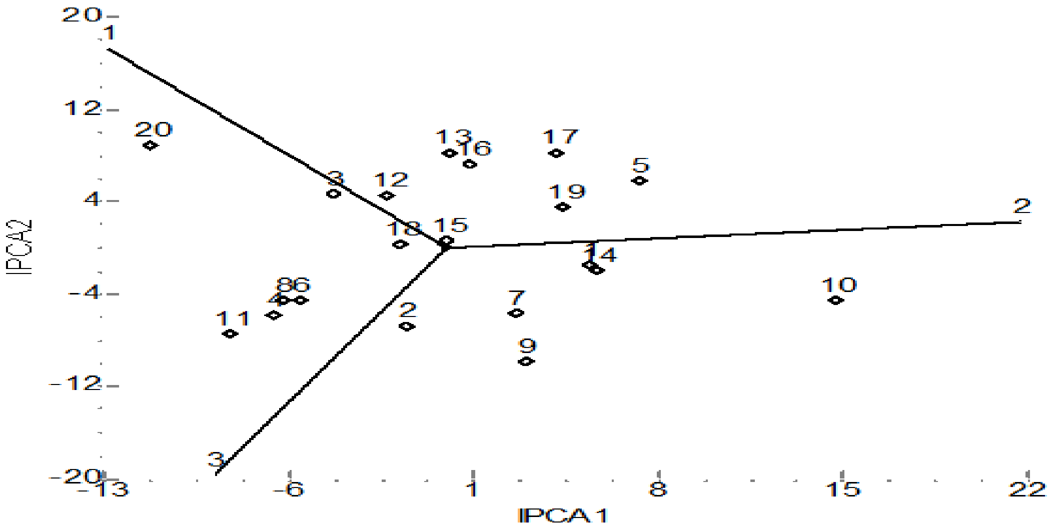

Fig.2. **Biplot of the first AMMI interaction (IPCA 2) score (Y-axis) plotted against AMMI interaction (IPCA 1) score (X-axis) for twenty amaranth genotypes**.

Chapter 5

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

The present experiment was undertaken to study the genotype-environment interaction in 20 amaranth genotypes and to identify the stable genotypes which could be grown over different environments. Three growing seasons were considered as three different environments and the experiment was conducted at Sher-e-Bangla Agricultural University campus. Randomized Complete Block Design with three replications was followed in the experiment. Eleven plant characters were studied.

Out of twenty genotypes, thirteen genotypes namely G-02, G-03, G-04, G-05, G-06, G-07, G-14, G-15, G-16, G-17, G-18, G-19 and G-20 were found desirable for higher plant height based on positive phenotypic index. Ten genotypes namely G-03, G-04, G-05, G-06, G-09, G-07, G-14, G-15, G-17 and G-18 were less responsive to the environmental changes and these are more adaptive than other genotypes in respect of plant height character.

The season I was poor and the season II & season II was considered as good environment for the production of plants with higher plant height.

Among the twenty genotypes, nine genotypes namely G-02, G-05, G-06, G-09, G-10, G-11, G-13, G-15 and G-20 were found desirable for higher number of leaves based on positive phenotypic index. Four genotypes namely G-01, G-07, G-13, and G-18 are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of number of leaves character. The genotypes G-02, G-09, G-10, G-15 and G-20 could be considered as the more leaf producer and stable genotypes under poor environment.

The season I was poor and the season II & season II was considered as good environment for the production of plants with more number of leaves.

Twelve genotypes namely G-01, G-02, G-04, G-05, G-06, G-07, G-08, G-13, G-14, G-16, G18 and G-19 were found desirable for higher leaf length based on the positive phenotypic index. Five genotypes namely G-02, G-06, G-07, G-09, and G-19 are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of leaf length character. The genotypes G-12, G-14, G-17 and G-20 may be grown only in poor environment.

The season III was poor and the season I & season II was considered as good environment for the production of plants with higher leaf length. .

Among the twenty genotypes, thirteen genotypes namely G-01, G-04, G-05, G-06, G-07, G-08, G-09, G-10, G-12, G-13, G-14, G19, and G-20 were found desirable for higher leaf breadth based on positive phenotypic index. Four genotypes namely G-01, G-06, G-10 and G-20 are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of leaf breadth character. The genotypes G-02 and G-04 may be grown only in poor environment. Among these genotypes G-04 could be considered as the lengthier leaf breadth producer and stable genotypes under poor environment.

The season III was poor and the season I & season II was considered as good environment for the production of plants with higher leaf breadth.

Eleven genotypes namely G-01, G-04, G-07, G-08, G-12, G-13, G-14, G-17, G-18, G-19 and G-20 were found desirable for higher individual stem diameter based on positive phenotypic index. Four genotypes namely G-02, G-09, G-10 and G-11 are less responsive to the environmental changes and these are more adaptive. The genotypes G-05, G-06, G-07, G-12, G-14 and G-15 may be grown only in poor environment. Among these genotypes G-14 could be considered as the higher individual stem diameter producer and stable genotypes under poor environment.

The season I was poor and the season II & season III was considered as good environment for the production of plants with higher individual stem diameter.

In case of individual leaf weight character, nine genotypes namely G-01, G-04, G-06, G-07, G-08, G-09, G-11, G-13 and G-20 were found desirable for higher individual leaf weight based on positive phenotypic index. Five genotypes namely G-02, G-03, G-04, G-12 and G-17 are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of individual leaf weight character. The genotypes G-01, G-06, G-09, and G-13 may be grown only in poor environment Among these genotypes G-09 could be considered as the higher individual leaf weight producing and stable genotype under poor environment.

The season I was poor and the season II & season III was considered as good environment for the production of plants with higher individual leaf weight.

Out of twenty genotypes, seven genotypes namely G-01, G-02, G-04, G-13, G-18, G-19 and G-20 were found desirable for higher individual stem weight based on positive phenotypic index. Five genotypes namely G-06, G-08, G-11, G-15 and G-18 are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of individual stem weight character. The genotypes G-01, G-02, G-03, G-09, G-10, G-13, G-17 and G-19 may be grown only in poor environment. Among these genotypes G-01 could be considered as the higher individual stem weight producing and stable genotype under poor environment.

The season I was poor and the season II & season III was considered as good environment for the production of plants with higher individual stem weight.

Among the twenty genotypes, eight genotypes namely G-01, G-02, G-04, G-07, G-13, G-18, G-19 and G-20 were found desirable for higher marketable stem weight based on positive phenotypic index. Three genotypes namely G-03, G-10 and G-11 are more adaptive than other genotypes in respect of marketable stem weight character. The genotypes G-01, G-09, G-13, G-15, G-

17 and G-19 may be grown only in poor environment. Among these genotypes G-01 could be considered as the higher marketable stem weight producing and stable genotype under poor environment.

The season I was poor and the season II & season III was considered as good environment for the production of plants with higher marketable stem weight.

In case of days to first flowering character, seven genotypes namely G-02, G-03, G-05, G-15, G-16, G-19 and G-20 were found desirable for earlier days to first flowering plant based on negative phenotypic index. Seven genotypes namely G-02, G-03, G-09, G-10, G-16, G-17 and G-19 are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of days to first flowering character. The genotypes G-13 and G-15 may be grown only in favorable for early flowering character.

The season II & season III was poor and the season I was considered as good environment for the production of early maturing plants.

Among twenty genotypes, seven genotypes namely G-07, G-08, G-10, G-14, G-17, G-18 and G-19 were found desirable for higher number of seed per plant based on positive phenotypic index. Three genotypes namely G-12, G-13 and G-18 are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of number of seed per plant character. The genotypes G-01, G-05, G-09, G-10, G-14, G-16, G-17 and G-19 may be grown only in poor environment. Among these genotypes G-18 could be considered as the number of seed per plant producing and stable genotype under poor environment.

The season II was poor and the season I & season III was considered as good environment for the production of plants with higher number of seed per individual plant.

Out of twenty genotypes, eight genotypes namely G-01, G-02, G-04, G-07, G-13, G-18, G-19 and G-20 were found desirable for higher yield based on positive phenotypic index. Three genotypes namely G-03, G-10 and G-11 possess low value of bi around 1. These genotypes are less responsive to the environmental changes and these are more adaptive than other genotypes in respect of yield character. The genotypes G-01, G-09, G-13, G-15, G-17 and G-19 possess negative bi value so these may be grown only in poor environment. Among these genotypes G-01 could be considered as the higher yielder and stable genotype under poor environment.

The season I was poor and the season II & season III was considered as good environment for the production of plants with higher yield.

Considering the IPCA 1 scores G-04, G-05, G-09, G-10, G-11, G-17, G-19 and G-20 were more unstable genotypes and also adapted to the high yield or more adapted environments. The most stable genotypes were G-03, G-08, G-12, G-14, G-15 and G-18. According to the IPCA 2 scores G-20, G-10, G-11, G-05, G-17, G-19, G-09, and G-04 were unstable but to a lesser extent. The genotypes G-15, G-18, G-12, G-13, and G-14 showed to be more stability in a range of environments.

Based on the results on the research, the following conclusions may be drawn

Significant genotype-environment interactions were observed for all the characters. The genotypes G-08 and G-18 showed the positive phenotypic index (Pi), non significant regression coefficient (bi) and deviation from regression (S^2di) for yield making the genotypes more stable over wide range of environments (November - May).

The genotype G-01 for yield character showed higher positive phenotypic index (Pi), negative non significant regression coefficient (bi) and non significant deviation from regression (S^2di) value indicating the suitability of the genotype under unfavorable environment. The genotype G-20 for yield character showed higher positive phenotypic index, higher positive regression coefficient (bi) and non significant deviation from regression (S^2di) value indicating the suitability of the genotype under favorable environment.

The genotypes G-07 and G-11 for individual leaf weight and the genotype G-18 for individual stem weight showed higher positive phenotypic index (Pi), positive non significant regression coefficient (bi) and non significant deviation from regression (S^2di) value indicating the suitability of the genotypes across all environmental conditions.

The genotypes G-03 and G-16 for days to first flowering character showed higher negative phenotypic index (Pi), positive non significant regression coefficient (bi) and non significant deviation from regression (S^2di) value indicating the suitability of the genotypes as early days to first flowering plants.

According to IPCA 1 scores, the genotypes G-04, G-05, G-09, G-10, G-11, G-17, G-19 and G-20 were more unstable and also adapted to favorable environments. The most stable genotypes were G-03, G-08, G-12, G-14, G-15 and G-18.

According to the IPCA -2, G-20, G-10, G-11, G-05, G-17, G-19, G-09, and G-04 were unstable. The genotypes G-15, G-18, G-12, G-13, and G-14 showed to be more stable in a range of environments.

Based on the results on the research, further recommendation may be drawn for future effective breeding program.

Plant height, individual leaf weight, individual stem weight, marketable stem weight, individual stem diameter and number of leaves per plant could be selected as yield contributing characters in stem amaranth.

Based on stable responses considering the higher yield character G-08 and G-18, for higher individual leaf weight G-07 and G-11, for higher individual stem weight G-18, for lesser dry weight of stem G-14 and G-18 and for early days to first flowering G-03 and G-16 genotypes could be selected for effective use in breeding program.

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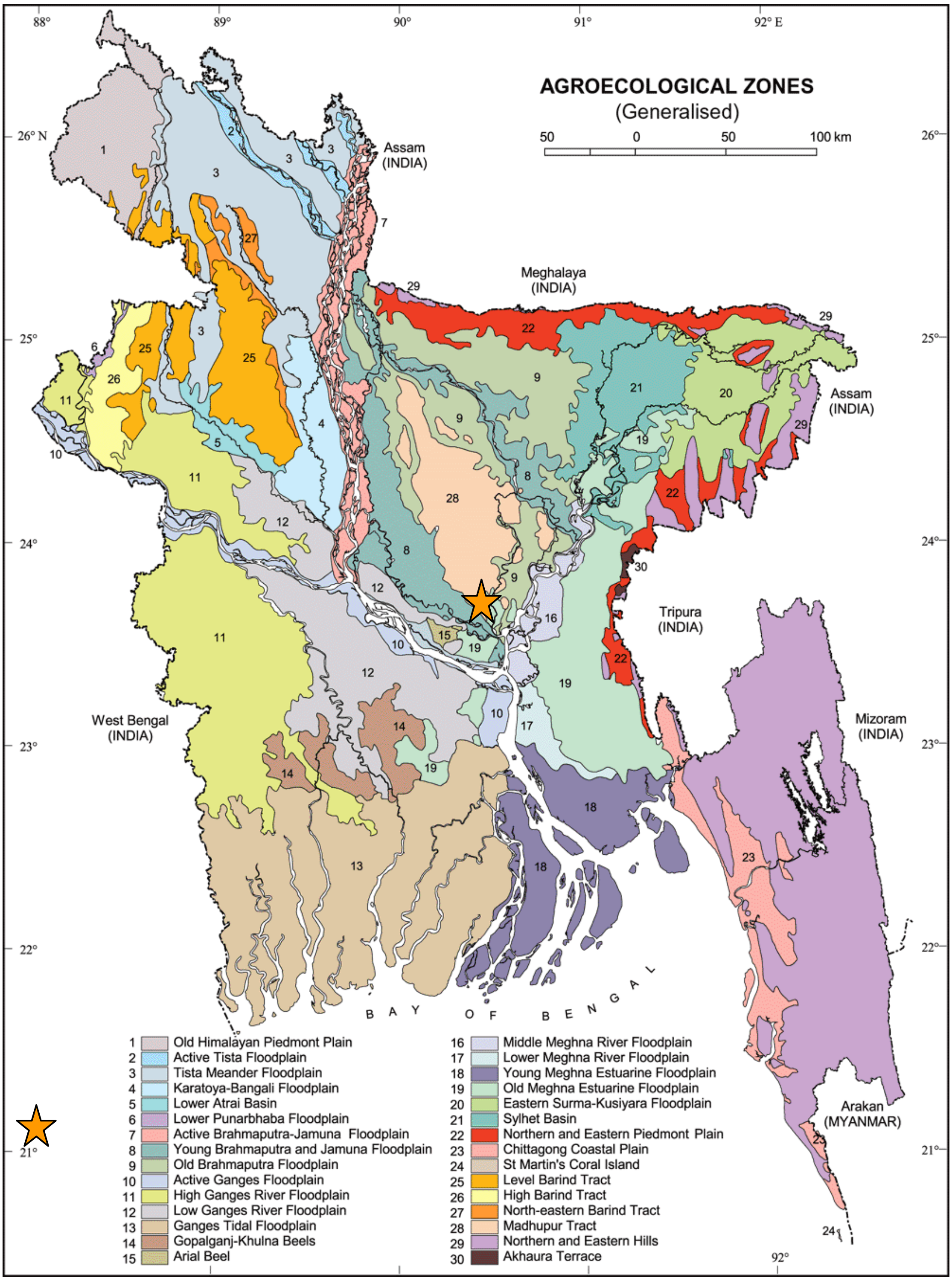
Appendices

APPENDICES

Appendix I. Map showing the experimental site under study



Appendix II. Monthly records of air temperature, relative humidity, rainfall and sunshine hours during the period from October 2013 to May 2014

Month	**Year**	**Monthly average air temperature (^oC)**			**Average relative humidity (%)**	**Total rainfall (mm)**	**Total sunshine (hours)**
		Maximum	**Minimum**	**Mean**			
October	2013	29.36	18.54	23.95	74.80	Trace	218.50
November	2013	28.52	16.30	22.41	68.92	Trace	216.50
December	2013	27.19	14.91	21.05	70.05	Trace	212.50
January	2014	25.23	18.20	21.80	74.90	4.0	195.00
February	2014	31.35	19.40	25.33	68.78	3.0	225.50
March	2014	32.22	21.25	26.73	72.92	4.0	235.50
April	2014	33.34	22.50	27.00	74.32	7.00	246.39
May	2014	34.23	23.12	27.74	74.63	9.00	247.32

Source: Bangladesh Meteorological Department (Climate division), Agargaon Dhaka-1212

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Appendix III: Physical and chemical characteristics of initial soil (0-15 cm depth)

A. Physical composition of the soil

Soil separates	%	Methods employed
Sand	36.90	Hydrometer method (Day,1915)
Silt	26.40	Do
Clay	36.66	Do
Texture class	Clay loam	Do

B. Chemical composition of the soil

Sl. No.	Soil characteristics	Analytical data	Methods employed
1	Organic carbon (%)	0.82	Walkley and Black, 1947
2	Total N (kg/ha)	1790.00	Bremner and Mulvaney, 1965
3	Total S (ppm)	225.00	Bardsley and Lanester, 1965
4	Total P (ppm)	840.00	Olsen and Sommers, 1982
5	Available N (kg/ha)	54.00	Bremner, 1965
6	Available P (kg/ha)	69.00	Olsen and Dean, 1965
7	Exchangeable K (kg/ha)	89.50	Pratt, 1965
8	Available S (ppm)	16.00	Hunter, 1984
9	pH (1 : 2.5 soil to water)	5.55	Jackson, 1958
10	CEC	11.23	Chapman, 1965