GENOTYPE X ENVIRONMENT INTERACTION EFFECTS ON 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, individual leaf weight (gm), individual stem weight (gm), marketable stem weight (gm), yield (Kg/ha) at three environments. G-18 was the tallest with non significant S²di value (10.5) and G-9 was the shortest (2.22). G-20 produced most number of leaves with non significant S²di value (2.59) and G-01 was the least (11.56**). G-01 was the highest individual leaf weight with significant S²di value (46.08**) and G-15 was the least (2.84). G-01 was the highest individual stem weight with non significant S²di value (15.13) and G-09 was the least (48.09). G-01 produced highest marketable stem weight with non significant S²di value (451.59) and G-09 was the least (39.77). G-01 was the highest yield producing with non significant S²di 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 genotypes could be selected for effective use in breeding program.

Keywords: *Amaranthus*, environment, genotype, interaction, field performances

INTRODUCTION

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. (Haider *et al.*, 1991).

The amaranth is a cross pollinated vegetable crop. It has chromosome number 2n=32 or 34; under the genus *Amaranthus*. *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). 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). 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).

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 (Brammer, 1971).

The development of new cultivars involves breeding of cultivars with desired characteristics such as high economic yield, tolerance or resistance to biotic and abiotic 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 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 to identify the environmentally stable genotypes of amaranth for the breeding, to assess the heritability of yield contributing characters of different amaranth genotypes and to select the most promising genotypes for future breeding program.

MATERIALS AND METHODS
The experiment was conducted at the Research Farm of the Sher-e-Bangla Agricultural University in three successive sowing dates: 05.11.2013, 15.01.2014 and 25.03.2014, respectively. Three different sowing dates were used as three separate environment and 20 amaranth genotypes collected from Bangladesh Agricultural Research Institute (BARI) were used as experimental materials. The details of these genotypes are given in Table 1. The location of the experimental site was situated at 23°74’ N latitude and 90°35’ E longitudes with an elevation of 8.6 meter from the sea level. The pH was 5.47 to 5.63 and organic carbon content is 0.82%. The experiment was conducted in Randomized Complete Block Design (RCBD) with three replications. The unit plot size was 1m x 1m. Land was prepared accordingly. After land preparation, the seeds were sown in line. All intercultural operations were done as and when necessary. Five plants were selected randomly from each plot for recording data at the marketable stage of the
The harvested plants were measured either by manually or by using many
devices to get data. Data were recorded on plant height (cm), no. of leaves per plant,
individual leaf weight (gm), individual stem weight (gm), marketable stem weight (gm),
yield (Kg/ha) at three environments.

During data analysis, different sowing dates are considered as separate environment.
Data were subjected to analyze by the statistical approaches provided by Eberhart and
Russell (1966) and Panwar et al. (1995) for the estimation of genotype ^ environment
interaction. 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.

Table 1. List of 20 amaranth genotypes used in the research work

| Sl. No. | Variety Name  | Source            |
|---------|---------------|-------------------|
| G1      | BD-10205      | BARI, Gazipur     |
| G2      | BD-10203      | BARI, Gazipur     |
| G3      | BD-10205      | BARI, Gazipur     |
| G4      | BD-7393       | BARI, Gazipur     |
| G5      | BD-10207      | BARI, Gazipur     |
| G6      | BD-7402       | BARI, Gazipur     |
| G7      | BD-7404       | BARI, Gazipur     |
| G8      | BD-7412       | BARI, Gazipur     |
| G9      | BD-10192      | BARI, Gazipur     |
| G10     | BD-10191      | BARI, Gazipur     |
| G11     | BD-9941       | BARI, Gazipur     |
| G12     | BARI data-1   | BARI, Gazipur     |
| G13     | BARI data-2   | 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     |

RESULTS AND DISCUSSION

Combined analysis of variance

Results of combined analysis of variance of six characters viz. plant height (cm), no. of leaves per plant, individual leaf weight (gm), individual stem weight (gm), marketable stem weight (gm), 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.

Plant height (cm)
The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression ($S^2$) 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 regression coefficient \( b \) of one genotype namely G-20 was significantly different from unity which indicated high responsiveness of these genotypes across the environments.

Table 2. Combined analysis of variance including the partitioning of the G x E Interaction of 6 characters of the Amaranth under three seasons

| Source of variation | df | Mean sum of squares |
|---------------------|----|---------------------|
|                     |    | Plant Height (cm)   | No. of Leaves per Plant | Individual Leaf Weight (gm) | Individual Stem Wt. (gm) | Marketable Stem Wt. (gm) | Yield (Kg/ha) |
| Genotypes (G)       | 19 | 1759.69**          | 314.58**               | 897.789**                   | 12315.11**               | 16890.3**               | 675249003**   |
| Environment (E)     | 2  | 4498.38**          | 11032.7**              | 4498.38**                   | 11032.7**                | 13904.09                | 52567000      |
| Interaction G X E   | 38 | 151.43**           | 311.625**              | 432.881**                   | 2841.70**                | 4198.85**               | 168027000**   |
| AMMI Comp 1         | 20 | 56.88              | 160.106                | 199.628                     | 1062.69                  | 1481.14                 | 59268600      |
| AMMI Comp 2         | 18 | 43.36              | 41.396                 | 82.81                       | 818.949                  | 1309.04                 | 52567000      |
| G x E (Linear)      | 19 | 49                 | 167.405                | 201.763                     | 818.949                  | 1309.04                 | 52567000      |
| Pool deviation      | 118| 2.218              | 1.655                  | 2.198                       | 5.522                    | 8.178                   | 330909        |

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

Table 3. Stability analysis for plant height (cm) of 20 genotypes of amaranth in three seasons

| Genotypes | Environments | Season I | Season II | Season III | Overall Mean | Phenotypic Index \((P_i)\) | \((b_i)\) | \(S'^{di}\) |
|-----------|--------------|----------|-----------|-------------|--------------|---------------------------|--------|---------|
| 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    | 86.63     | 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      |              | 47.87    | 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       | 77.39        |                           |        |         |
| En. Index |              | -14.39   | 1.14      | 13.25       |              |                           |        |         |
| LSD (0.05)|              | 3.08     |           |             |              |                           |        |         |
non significant bi value and non significant $S^2_{di}$ value which was desirable for this trait. Similar kind of result was found by Varalakshmi et al. (2011) and Yarnia, (2010) in amaranth.

No. of leaves per Plant
The value of phenotypic indices ($P_i$), regression coefficient ($b_i$) and deviation from regression ($S^2_{di}$) 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.

Table 4. Stability analysis for number of leaves per plant of 20 genotypes of amaranth in three seasons

| Genotype | Environments | Phenotypic Index ($P_i$) | ($b_i$) | $S^2_{di}$ |
|----------|--------------|--------------------------|---------|------------|
| G-01     | 25           | 32                       | 28      | 28.33      |
| G-02     | 44           | 47.33                    | 32.67   | 41.33      |
| G-03     | 15           | 45.67                    | 40.67   | 34.11      |
| G-04     | 23.33        | 36                       | 46      | 35.11      |
| G-05     | 45           | 46.67                    | 46      | 45.89      |
| G-06     | 50.33        | 36                       | 61.67   | 49.33      |
| G-07     | 28           | 28.33                    | 39      | 31.78      |
| G-08     | 25.67        | 41                       | 39.67   | 35.44      |
| G-09     | 67           | 42.33                    | 20      | 43.11      |
| G-10     | 51.67        | 32.67                    | 34      | 39.44      |
| G-11     | 31.67        | 43                       | 41      | 38.56      |
| G-12     | 26           | 35                       | 40      | 34.67      |
| G-13     | 36           | 45                       | 42      | 41         |
| G-14     | 24           | 30.33                    | 41      | 31.78      |
| G-15     | 53.33        | 39.33                    | 40      | 44.22      |
| G-16     | 24           | 47                       | 45      | 38.67      |
| G-17     | 26           | 44                       | 44      | 38         |
| G-18     | 27.67        | 33.33                    | 36      | 32.33      |
| G-19     | 30.67        | 39                       | 39.33   | 36.33      |
| G-20     | 62.67        | 44                       | 43      | 49.89      |

Mean 36.35 39.80 40.45 36.87
En. Index ($l_j$) -0.52 2.93 3.58
LSD(0.05) 2.15

G-20 could be considered as the most number of leaves producing, stable genotype whereas G-01 is the least leaves producing genotype which is unstable under poor environment. Considering the $P_i$, $b_i$ and $S^2_{di}$, 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 $S^2_{di}$ 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.

Individual Leaf Weight (gm)
The value of phenotypic indices ($P_i$), regression coefficient ($b_i$) and deviation from regression ($S^2_{di}$) for individual leaf weight are presented in Table 8.
Table 5. Stability analysis for individual leaf weight (gm) of 20 genotypes of amaranth in three seasons

| Genotypes | Season I | Season II | Season III | Overall Mean | Phenotypic Index (Pi) | (b) | S^2 di |
|-----------|---------|----------|-----------|-------------|----------------------|-----|-------|
| 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      | 34.72   | 57.64    | 48.59     | 51.06       | 7.68                 | -0.378  | 77.50**|
| G-06      | 48.92   | 36.49    | 53.52     | 46.31       | -3.995               | 1.234   | 14.76* |
| G-07      | 32.45   | 41.59    | 64.55     | 51.22       | -74.09               | 2.070   | 78.08**|

Among the twenty genotypes, G-01 and G-15 could be considered as the highest and the lowest individual leaf weight producing unstable and stable genotype, respectively due to Pi value (35.94 & -12.46, respectively), bi value (-3.995 & 0.26, respectively) and S^2 di value (46.08** & 2.84, respectively). Considering the Pi, bi and S^2 di, 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^2 di value which were desirable for this trait. Shudhir et al. (2003) found similar kind of result considering the individual leaf weight character.

Individual Stem Weight (gm)
The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2 di) for individual stem weight are presented in Table 6.

Among the twenty genotypes, G-01 and G-09 could be considered as the highest and the lowest individual stem weight producing stable genotype due to Pi value (85.53 & -74.09, respectively), negative non significant bi value (-0.836 & -0.677, respectively) and non significant S^2 di value (15.13 & 48.09, respectively). Considering the Pi, bi and S^2 di, 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^2 di value which was desirable for this trait. Ejieji and Adeniran, (2010) found similar kind of result in grain amaranth considering this character.
Table 6. Stability analysis for individual stem weight (gm) of 20 genotypes of amaranth in three seasons

| Genotypes | Season I  | Season II | Season III | Overall Mean | Phenotypic Index (P_i) | (b_i) | S’di |
|------------|-----------|-----------|------------|--------------|-----------------------|-------|------|
| G-01       | 206.90    | 193.60    | 193.30     | 197.93       | 85.53                 | -8.36 | 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       | 33.90                 | 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       103.5          -9.4 | 1.9 | 3.95

Table 7. Stability analysis for Marketable Stem Weight (gm) of 20 genotypes of amaranth in three seasons

| Genotypes | Season I  | Season II | Season III | Overall Mean | Phenotypic Index (P_i) | (b_i) | S’di |
|------------|-----------|-----------|------------|--------------|-----------------------|-------|------|
| 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                  | -0.16 | 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 |

Marketable Stem Weight (gm)

The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S’di) for marketable stem weight are presented in Table 7. G-01 and G-09 could be considered as the highest and the lowest marketable stem weight producing stable genotype, respectively due to Pi value (121.49 & -72.07, respectively), bi value
Considering the Pi, bi and S²di, 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 S²di value which were desirable for this trait. Varalakshmi et al. (2011) found the similar kind of result in amaranth.

Yield (Kg/ha)
The value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S²di) for yield are presented in Table 8.

Table 08. Stability analysis for Yield (Kg/ha) of 20 genotypes of amaranth in three seasons

| Genotypes | Environments | Phenotypic Index (Pi) | (bi) | S²di |
|-----------|--------------|-----------------------|------|------|
|            | Season I     | Season II             | Season III | Overall Mean |           |         |
| G-01      | 63300        | 54750                 | 49640 | 55897.34       | 24287.34 | -2.287  |
| G-02      | 37310        | 32240                 | 41230 | 36952.22       | 5342.22  | 0.230   |
| G-03      | 22520        | 23600                 | 28770 | 24961.55       | -6648.45 | 0.710   |
| G-04      | 28470        | 53450                 | 36710 | 39544.89       | 7934.89  | 3.742   |
| G-05      | 15530        | 38880                 | 20220 | 24877.33       | -6732.67 | 3.216   |
| G-06      | 30810        | 33260                 | 28310 | 30795.33       | -814.67  | 0.059   |
| G-07      | 23720        | 36390                 | 35100 | 31736.89       | 126.89   | 2.566*  |
| G-08      | 24740        | 26890                 | 36600 | 29048.67       | -2201.33 | 1.359   |
| G-09      | 20130        | 14640                 | 16790 | 17185.11       | -14424.89| -0.965  |
| G-10      | 20950        | 25920                 | 21160 | 22675.11       | -8934.89 | 0.612   |
| G-11      | 22860        | 28940                 | 24880 | 22559.55       | -9050.45 | 0.910   |
| G-12      | 21010        | 29180                 | 38450 | 29546          | -2064    | 2.595   |
| G-13      | 32520        | 24100                 | 41550 | 32720.44       | 1110.44  | -0.164  |
| G-14      | 15290        | 24960                 | 44720 | 28323.55       | -3286.45 | 3.887   |
| G-15      | 27380        | 30770                 | 19280 | 25808.45       | -5801.55 | -0.348  |
| G-16      | 20370        | 35850                 | 29850 | 28691.78       | -2918.22 | 2.726   |
| G-17      | 38680        | 25630                 | 25190 | 29834.67       | -1775.33 | -2.809* |
| G-18      | 34030        | 44900                 | 43220 | 40719.11       | 9109.11  | 2.149   |
| G-19      | 36820        | 32110                 | 26650 | 31862.22       | 252.22   | -1.506  |
| G-20      | 33120        | 501710                | 51240 | 45023.33       | 13413.33 | 3.778   |

Mean 28480 33360 32980 31610
En. Index (I) LSD(0.05) -3130 1750 1370 882.67

Among the twenty genotypes, G-01 and G-09 could be considered as the highest and lowest yield producing stable genotype, respectively due to Pi value (24287.34 & -14424.89, respectively), negative non significant bi value (-2.287 & -0.965, respectively) and non significant S²di value (7821.539 & 688.8164, respectively). Considering the Pi,
bi and $S^2_{di}$, 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 $S^2_{di}$ value which were desirable for this trait. Varalakshmi *et al.* (2011) and Dhanapal (2009) found similar results for yield characters of amaranth.

**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.

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

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.

**CONCLUSION**

From the above results it can be concluded that, significant genotype-environment interactions were observed for all the characters. The season I was poor and the season II & III was considered as good environment for the production of plants with higher plant height, more number of leaves, leaf weight, stem weight, marketable stem weight and finally higher yield.

**REFERENCES**

Anonymous. 2012. Yearbook of Agricultural Statistics of Bangladesh, Bangladesh Bureau of Statistics, Ministry of Planning, Govt. of People’s Republic of Bangladesh, Dhaka, Bangladesh. 143 p.

Baker, R. J. 1988. Tests for crossover genotype x environment interactions. Canadian Journal of Plant Science. 68: 405–410.

Brammer, H. 1971. Soil Resources Soil Survey Project, Bangladesh. AGL: SF/Pac. 6. Technical Report 3. 8p.

Dhanapal, B. 2009. Optimization of sowing window on growth and yield of grain amaranth, Mysore J. Agri. Sci. 43(3): 444-448.

Ejieji, C. J. and K. A. Adeniran. 2010. Effects of water and fertilizer stress on the yield, fresh and dry matter production of grain Amaranth (*Amaranthus cruentus*), Australian Journal of Agricultural Engineering. 1(1): 18-24.

Grubben, G.J. 1997. Tropical vegetables and their genetic resources, Ed. H., 123-124 pp.

Haider, J., T. Maruomoto and A.K. Azad. 1991. Estimation of microbial biomass, carbon and nitrogen in Bangladesh soils. Science of Plant Nutrient. 37(4): 591-599.

Oke, O. L. 1980. Amaranth in Nigeria. In “Proceedings of the Second Amaranth Conference.” Rodule Press Emmaus. PA, 22 p.

Palada, M.C. and L.C. Chang. 2008. AVDRC International Cooperators, Agron. J. 100: 344-351.

Shukla, S., Bhargava, A. Chatterjee, Srivastava and S.P. Singh. 2006. Genotypic variability in vegetable amaranth (*Amaranthus tricolor* L.) for foliage yield and
its contributing traits over successive cuttings and years. Euphytica. 151 (1):103-110.
Sudhir, S., S.P. Shukla and Singh. 2003. Stability of foliage yield in vegetable amaranth (Amaranthus tricolor L.). Indian J. Genet. Plant Breed. 63(4): 357-358.
Tomkins, J. P. and E. R. Shipe. 1997. Environmental adaptation of long-juvenile soybean cultivars and elite strains. Agron. J. 89(2):257-262.
Varalakshmi, B., Reddy and V.V. Pratap. 2011. Genotype x environment interactions for some quantitative characters in grain amaranth (Amaranthus hypochondriacus L.) Indian Institute of Horticultural Research, 560-589 pp.
Voltas, J., E. Eeuwijk, and J. Igatua. 2002. Genotype by environment interaction and adaptation in barley breeding: basic concepts and methods of analysis. Crop Sci. 205-241 pp.
Yarnia. 2010. Sowing dates and density evaluation of amaranth (cv. Koniz) as a new crop, Advances-in-Environmental-Biology Ma'an, Jordan: American Eurasian Net. Sci. In. 4(1): 41-46.