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

M. N. N. Dewan, M. E. Haq, M. M. Hasan[1], M. S. Hossain and M. Z. Tareq[2*]

Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh; [1]Adaptive Research Division, BRRI, Gazipur 1706, Bangladesh
[2]Jute Agriculture Experimental Station, BJRI, Manikganj, Bangladesh
*Corresponding author's: zablulbarj@gmail.com

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 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-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 highest marketable stem weight with non significant S^2di value (451.59) and G-09 was the least (39.77). 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 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 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 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 **23^0 74'** N latitude and **90^0 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 plant. Then 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 approches 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-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

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^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 regression coefficient (bi) 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**	12315.1**	16890.3**	675249000**
Environment (E)	2	4498.38**	11032.7**	4498.38**	4498.38**	11032.7**	442507000**
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	59286800
AMMI Comp 2	18	43.36	41.396	82.81	818.949	1309.04	52367000
G x E (Linear)	19	49	167.405	201.763	818.949	1309.04	52367000
Pool deviation	19	51.95	40.3451	86.824	1079.3	1263.91	50556400
Pooled Error	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				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			

Among the twenty genotypes, G-18 and G-9 could be considered as tallest and the shortest stable genotype, respectively due to Pi value (18.55 & -40.59, respectively), positive non significant bi value (0.667 & 0.66, respectively) which tends to 1 and non significant S^2di value (10.5 & 2.22, respectively). 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, (2010) in amaranth.

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.

Table 4. Stability analysis for number 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-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 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.

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.

Table 5. 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			

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^2di value (46.08** & 2.84, respectively). 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.

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 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^2di value (15.13 & 48.09, respectively). 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 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	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			

Table 7. 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			

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 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

(2.29 & -0.967, respectively) and non significant S^2di value (451.59 & 39.77, respectively). 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 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 (S^2di) 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 (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			

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 S^2di value (7821.539 & 688.8164, respectively). 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 (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.

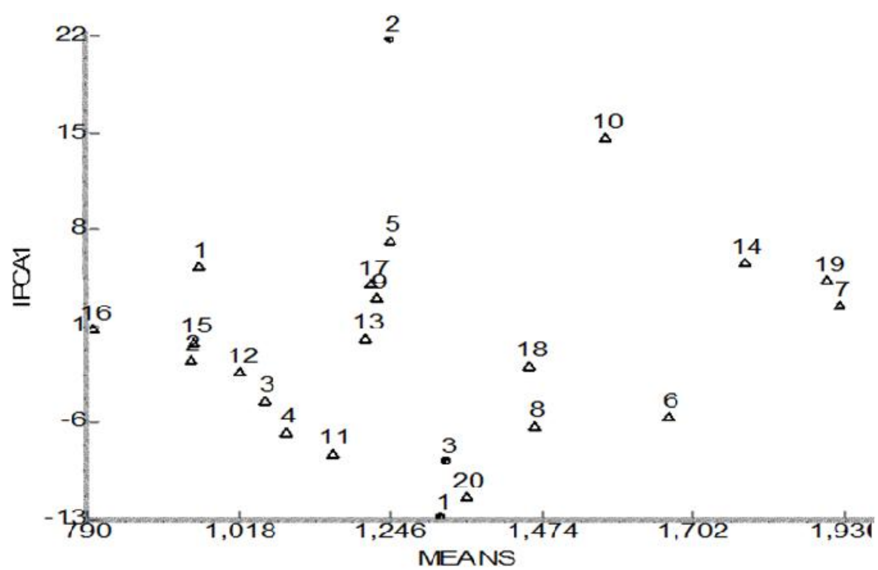

Fig.1. Biplot of first AMMI interaction (IPCA 1) score (Y-axis) plotted against mean yield (X-axis) for twenty amaranth genotypes.

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.

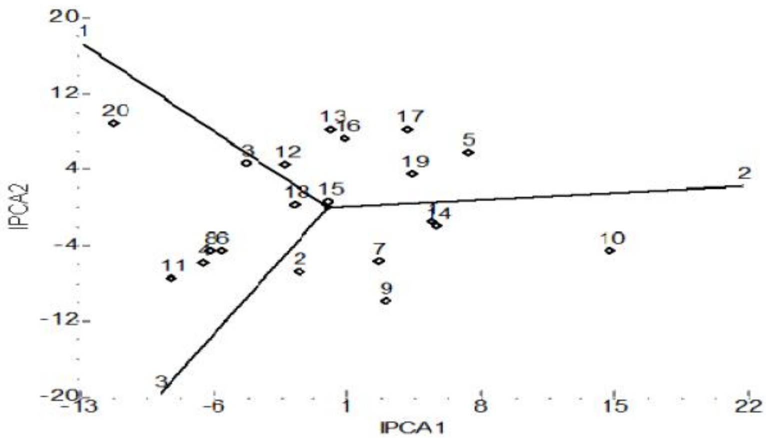

Fig.2. Biplot of the first AMMI interaction (IPCA 2) score (Y-axis) plotted against AMMI interaction (IPCA 1) score (X-axis) for twenty amaranth genotypes.

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.

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