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COMBINE EFFECT OF GENOTYPES AND ENVIRONMENTAL FACTORS ON THE YIELD AND YIELD ATTRIBUTES OF STEM AMARANTH (*Amaranthus tricolor* L.)

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ABSTRACT

A research experiment was conducted at Genetics Farm, Department of Biotechnology and Genetic Engineering, Jahangirnagar University, Savar, Dhaka during the period from October of 2017 to May of 2018 to show the combine effect of genotypes and environmental factors on yield and yield attributes of stem amaranth. The experiment was laid out in the Randomized Complete Block Design with three replications. Three different successive sowing dates *viz.* November 05, 2017; 15 January, 2018 and 25 March, 2018 were used as three separate environment factors and 20 amaranth genotypes collected from Bangladesh Agricultural Research Institute (BARI) were used as experimental materials. Among the twenty genotypes, G-18 was produced the highest plant height (non-significant S^2d_i value-10.53), higher number of seed per plant (significant S^2d_i value-11773806.62**) and yield (161.480) whereas G-09 was showed the worst performances. But G-01 and G-03 were produced the thickest stem diameter (non-significant S^2d_i value-1.63) and earliest first flowering (non-significant S^2d_i value -8.71), respectively. On the other hand, in case of environments, sowing dates-II (15 January, 2018) & III (25 March, 2018) was considered as good environment for the production of plants with higher plant height, individual stem diameter and yield, whereas sowing date-I (05 November, 2017) was better for the production of plants with early first flowering and having more number of seed per plant. Based on stable responses considering, G-18 genotype and sowing date-II & III were the best in respect of yield of stem amaranth, and also it could be selected for effective use in breeding program.

Key words: *Amaranthus*, genotyope, environment, interaction, yield attributes

Introduction

The stem amaranth is a cross pollinated vegetable having chromosome number 2n=32 or 34 (Muthukrishnan and Irulappan, 1986). It is an erect, annual and fibrous shrub. Stem amaranth leaves are rich and inexpensive source of dietary fibre, protein, vitamins and a wide range of minerals (Shukla *et al*., 2006). The last year of stem amaranth production of Bangladesh is 25485 acres with production of 67358 tons having yield of 4.5 t ha^{-1} only (BBS, 2012), which is very low. The yield of stem amaranth is become low day by day because of the use of low yielding varieties and inefficient method of culture and environmental factors. Though it is a very common crop in Bangladesh during summer season, 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 the prime importance to the breeder. Varietal adaptability to environmental fluctuations is important for the stabilization of crop production both over regions and years. Genotype and environmental adaptability is the ability of a genotype to exhibit relatively stable performance in different environments. It is important to understand how the proportion of genetic component and genetic advance are affected by environments (Hamdi *et al*., 1991). 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. Combine interaction of genotypes and environment 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, the present 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

Research experiment was conducted at the Field Laboratory of Department of Biotechnology and Genetic Engineering of Jahangirnagar University, Savar, Dhaka during October of 2017 to May of 2018. 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. Three different successive sowing dates *viz.* November 05, 2017, 15 January, 2018 and 25 March, 2018 were used as three separate environment factors and 20 amaranth genotypes collected from Bangladesh Agricultural Research Institute (BARI) were used as experimental materials. The experiment was conducted in Randomized Complete Block Design (RCBD) with three replications. The unit plot size was 1mx1m. Land was prepared well with six ploughs. 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), individual stem diameter (mm), days to first flowering, no. of seed per plant and yield (Kg ha^{-1}) at three environments.

Data analysis: 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 the interaction of genotype andenvironment. The individual genotypic response i.e. regression coefficient (b_i) was tested by t- test using the standard error of the corresponding b_i value against the hypothesis. The individual deviations from linear regression tested by F-test using pooled error.

Results and Discussion

Results of combined analysis of variance of six characters *viz.* plant height (cm), individual stem diameter (mm), days to first flowering, no. of seed per plant and yield (Kg ha^{-1}) of twenty genotypes at three environments are presented in Table 1. Highly significant mean sum of squares due to environments (linear) indicated the difference between the environments.

Table 1. Combined analysis of variance including the partitioning of the G×E Interaction of five (05) characters of the Amaranth under three sowing dates

Source of variation	df	Mean Sum of Squares				
		Plant Height (cm)	Stem Diameter (mm)	Days to First Flowering	No. of Seed Plant^{-1}	Yield (Kg ha^{-1})
Genotypes (G)	19	1756.23**	47.303**	316.071**	75798600**	675249000**
Environment (E)	2	4495.10**	442507000**	714.606**	5071980**	442507000**
Interaction G×E	38	148.58**	15.165**	37.71**	3665040**	168027000**
AMMI component-1	20	53.72	5.619	12.153	59286800	59286800
AMMI Component-2	18	41.67	4.428	13.032	52367000	52367000
G×E (Linear)	19	47.85	5.899	13.032	52367000	52367000
Pool deviation	19	49.68	4.211	12.478	50556400	50556400
Pooled Error	118	2.186	0.306	0.336	394368	330909

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

The value of phenotypic indices (P_i), regression coefficient (b_i) and deviation from regression (S^2d_i) for plant height, individual stem diameter, days to first flowering, number of seed per plant and yield are presented in Tables 2-6. In case of plant height, the positive and negative environmental index (Ij) reflects the good or favorable and poor or unfavorable environments for this character, respectively. The environmental and genotypic mean ranged from 61.19 to 88.63 and 34.72 (G-09) to 93.97 (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_i) of one genotype namely G-20 was significantly different from unity which indicated high responsiveness of these genotypes across the environments. Among the twenty genotypes, G-18 and G-9 could be considered as tallest and the shortest stable genotype, respectively due to P_i value (18.58 & -40.60, respectively), positive non-significant b_i value (0.661 & 0.66, respectively) which tends to 1 and non-significant S^2d_i value (10.53 & 2.24, 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. The sowing date- I was poor and sowing dates II & III was considered as good environment for production of plants with higher plant height. These genotypes had positive index and non-significant b_i value and non-significant S^2d_i value which was desirable for this trait. Similar kind of result was found by Varalakshmi *et al*. (2011) in amaranth.

Table 2. Stability analysis for plant height (cm) of 20 genotypes of amaranth in three sowing dates

Genotypes (variety)	Environments				Phenotypic Index (P_i)	(b_i)	S^2d_i
	SD-I	SD-II	SD-III	Overall Mean			
G-01 (BD-10205)	50.24	60.78	88.7	66.57	-9.12	1.362	79.35**
G-02 (BD-7393)	60.54	76.05	107.2	81.26	5.70	1.665	775.56**
G-03 (BD-10207)	81.38	86.61	99.3	89.09	13.71	0.626	15.57*
G-04 (BD-10203)	64.74	81.21	89.3	78.41	2.80	0.919	4.95
G-05 (BD-7402)	73.59	77.71	95.93	82.41	6.93	0.726	47.42**
G-06 (BD-7404)	61.38	78.21	91.77	77.12	1.70	1.099	0.131
G-07 (BD-7412)	75.92	82.48	97.1	85.16	9.65	0.762	17.53*
G-08 (BD-10192)	42.78	80.08	73.63	65.49	-10.26	1.226	256.64**
G-09 (BD-10191)	24.36	36.95	42.87	34.72	-40.60	0.668	2.24
G-10 (BD-9941)	36.52	66.78	64.17	55.82	-19.68	1.048	139.13**
G-11 (BARI data -1)	51.29	73.61	82.77	69.22	-6.70	1.148	12.72
G-12 (BARI data-2)	45.96	68.81	76.5	63.75	-11.85	1.158	19.22*
G-13 (BD-7777)	45.63	77.48	73.27	65.46	-10.23	1.074	169.03**
G-14 (BD-7392)	64.32	74.38	89.3	76.02	0.45	0.904	10.49
G-15 (BD-7365)	76.23	79.51	97.43	84.39	8.89	0.757	51.92**
G-16 (BD-10220)	88.36	86.21	95.17	89.91	14.54	0.222	23.18*
G-17 (BD-7387)	71.01	81.38	96.43	82.94	7.48	0.917	10.66
G-18 (BD-10221)	85.36	92.25	104.3	93.97	18.58	0.661	10.53
G-19 (BD-10223)	60.39	88.75	106.3	85.14	9.70	1.673	3.83
G-20 (BD-10218)	63.85	84.88	101.3	83.34	7.66	1.383*	0.01
Mean	61.19	76.706	88.63	75.51			
En. Index (I_j)	-13.40	1.10	13.20				
LSD (0.05)				3.09			

SD=Sowing date

At individual stem diameter, among the twenty genotypes, G-01 and G-09 could be considered as the thickest and the narrowest stem diameter producing stable genotype due to P_i value (3.91 & -3.99, respectively), positive non-significant b_i value (2.72 & 0.802, respectively) and non-significant S^2d_i value (1.63 & 0.19, respectively). Considering the P_i, b_i and S^2d_i, 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. The sowing date-I was poor and sowing dates-II & III was considered as good environment for production of plants with higher individual stem diameter. This genotype showed positive index and non-significant b_i value and non-significant S^2d_i value which were desirable for this trait. Bhargava *et al*. (2008) found similar kind of result considering the individual stem diameter characeter in *Chenopodium*. Based on days to first flowering, G-03 and G-09 could be considered as the earliest and the highest days to first flowering stable genotype, respectively due to P_i value (-10.37 & 12.19, respectively), positive non-significant b_i value (1.377 & 1.34, respectively) and non-significant S^2d_i value (8.71 & 1.06, respectively). Considering the P_i, b_i and S^2d_i, 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. The sowing date- II & III was poor and sowing dates-I was considered as good environment for production of early maturing plants. These genotypes showed negative index and non-significant b_i value and non-significant S^2d_i 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.

Table 3. Stability analysis for individual stem diameter (mm) of 20 genotypes of amaranth in three sowing dates

Genotypes	Environments				Phenotypic Index (P_i)	(b_i)	S^2d_i
	SD-I	SD-II	SD-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			

SD= Sowing date

In case of no. of seed per plant, G-07 could be considered as the highest seed producing unstable genotype whereas G-05 was the lowest seed producing stable genotype due to P_i value (5862.11 & -4176.2, respectively), b_i value (0.045 & -1.436, respectively) and S^2d_i value (11773806.62** & 260802.7, respectively) within twenty genotypes. On the basis of P_i, b_i and S^2d_i, it was observed 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, which were desirable for this trait. The sowing date- II was poor and sowing dates-I & III was considered as good environment for production of plants with higher number of seed per plant. Yarnia, (2010) showed similar kind result in amaranth considering the number of seed per plant character. Finally, at yield, G-01 and G-09 could be considered as the highest and lowest yield producing stable genotype, respectively due to P_i value (24287.34 & -14424.89, respectively), negative non-significant b_i value (-2.287 & -0.965, respectively) and non-significant S^2d_i value (7821.539 & 688.8164, respectively) from twenty genotypes. From the result of P_i, b_i and S^2d_i, it was found 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. The sowing date- I was poor and sowing dates- II & III was considered as good environment for production of plants with higher yield. Those were desirable for this trait. Varalakshmi *et al*. (2011) and Dhanapal, (2009) found similar kind of results in studying the yield character of amaranth.

Table 4. Stability analysis for Days to First Flowering of 20 genotypes of amaranth in three sowing dates

Genotypes	Environments				Phenotypic Index (P_i)	(b_i)	S^2d_i
	SD-I	SD-II	SD-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	1.37	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			

SD=Sowing date

In case of 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 b_i 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 more the IPCA scores approximate to zero, the more stable or adaptation of a genotype in overall environments. From result, 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.

Table 5. Stability analysis for No. of Seed per plant of 20 genotypes of amaranth in three sowing dates

Genotypes	Environments				Phenotypic Index (P_i)	(b_i)	S^2di
	SD-I	SD-II	SD- 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	11350	10250	10930	10841.78	2079.78	1.791	70509.02
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	13880	14570	15410	14624.11	5862.11	0.045	11773806.62**
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			

Table 6. Stability analysis for Yield (Kg ha^{-1}) of 20 genotypes of amaranth in three sowing dates

Genotypes	Environments				Phenotypic Index (P_i)	(b_i)	S^2d_i
	SD-I	SD-II	SD-III	Overall Mean			
G-01	62400	53550	49620	55190	24190.21	-2.282	7819.533
G-02	36110	31220	41220	36183.33	5333.43	0.225	16962.809**
G-03	21420	22500	28750	24223.33	-6642.40	0.708	6437.572
G-04	27370	52350	36680	38800	7931.76	3.740	50931.475**
G-05	14430	37580	20200	24070	-6731.27	3.212	66030.010**
G-06	29810	32160	28300	30090	-812.71	0.056	5292.240*
G-07	22720	35490	35098	31102.67	122.78	2.560*	20.0903
G-08	23640	25790	36580	28670	-2200.10	1.350	22830.434**
G-09	20030	13540	16760	16776.67	-14420.52	-0.960	687.812
G-10	20850	24820	21140	22270	-8930.24	0.609	4440.365*
G-11	21660	27840	24860	24786.67	-9030.36	0.900	2995.086
G-12	20010	28080	38440	28843.33	-2052	2.590	22962.623**
G-13	31320	23002	41530	31950.67	1100.40	-0.161	65755.535**
G-14	14390	24852	44700	27980.67	-3275.32	3.882	98453.845**
G-15	26280	30652	19270	25400.67	-5800.50	-0.340	29448.238**
G-16	20070	35793	29830	28564.33	-2914.16	2.722	5334.592*
G-17	37580	25600	25180	29453.33	-1770.18	-2.801*	510.7578
G-18	33030	44800	43200	40343.33	9100.10	2.141	161.460
G-19	35720	32100	26640	31486.67	250.15	-1.502	7955.282*
G-20	32020	50680	51230	44643.33	13411.25	3.772	858.109
Mean	27543	32619.95	32961.4	31041.45			
En. Index (I_j)	-3120	1710	1320				
LSD (0.05)				852.56			

SD=Sowing dates

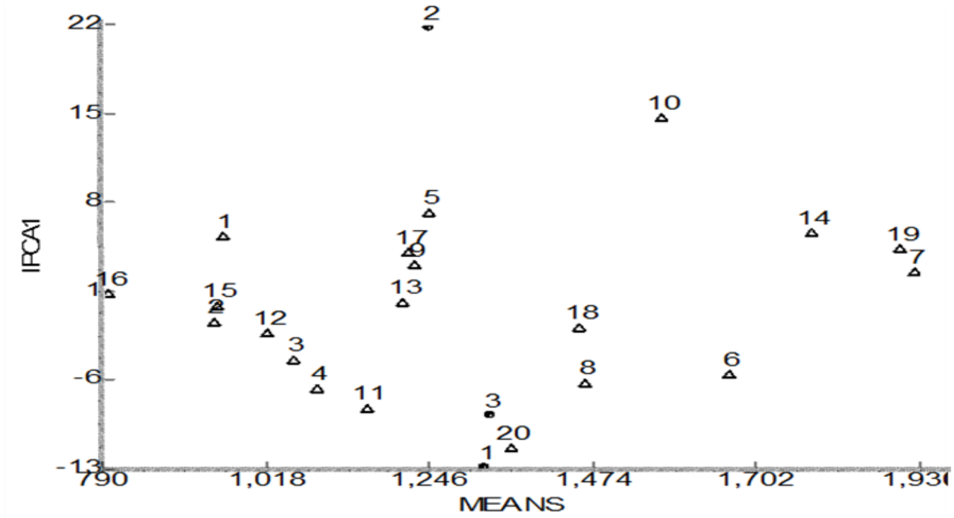

Fig. 1 Biplotof first AMMI interaction (IPCA-1) score (Y-axis) plotted against mean yield (X-axis) for twenty amaranth genotypes

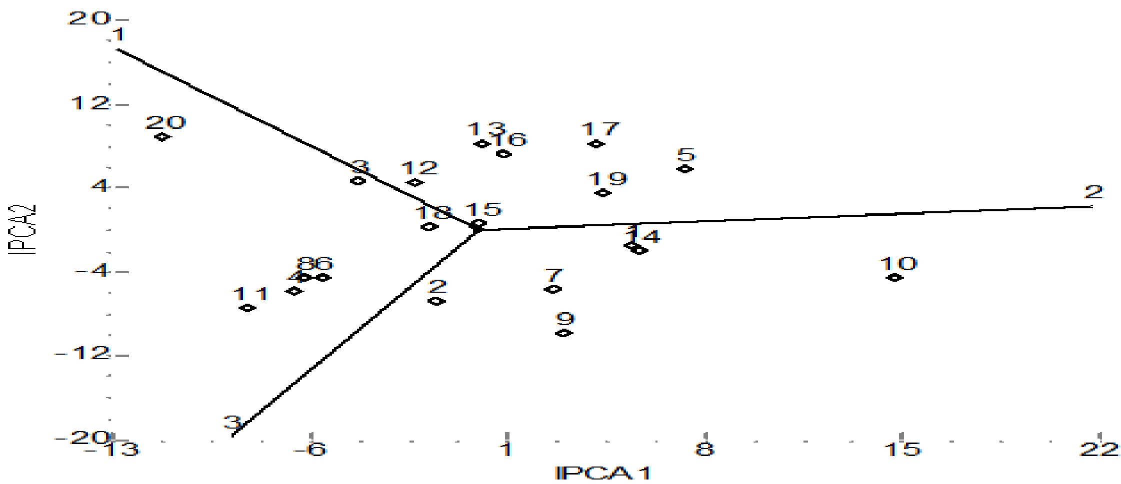

Fig. 2 Biplot of the first AMMI interaction (IPCA-2) score (Y-axis) plotted against AMMI interaction (IPCA-1) score (X-axis) for twenty amaranth genotypes.

Conclusion

From the above results it can be concluded that, significant combine effect of genotypes and environment factors were observed for all the characters. Among the twenty genotypes, G-18 was produced the highest plant height, higher number of seed per plant and yield. On the other hand, in case of environmental factors, sowing dates-II (15 January, 2018) & III (25 March, 2018) was considered as good environment for the production of plants with higher plant height, individual stem diameter and yield. Based on stable responses considering, G-18 genotype and sowing date-II & III were the best in respect of yield of stem amaranth, and also it could be selected for effective use in breeding program.

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