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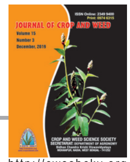

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Stability investigation for seed yield and component characteristics in grain amaranth [*Amaranthus hypochondriacus* L.] under different environments

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ABSTRACT

A study was done to evaluate the stability of twenty-five genotypes of grain amaranth for thirteen quantitative characteristics along with grain yield plant^{-1}(g). Genotype × environment relationships demonstrate significant differences in leaf area plant^{-1} (cm^2), number of branches plant^{-1}, stem diameter, grain yield plant^{-1} (g) and protein content (%) when examined against pooled error. The assessment of the environmental index (I_j) showed that E_1 (day of seeding: 11th November, 2019) was the most enthusiastic environment for the grain amaranth. Genotypes SKGPA-150, SKNA-401 and SKNA-808 expressed average stability for grain yield plant^{-1} (g) in addition to stem diameter (mm), leaf area plant^{-1} (cm^2) and protein content (%), whereas SKGPA-61 showed average stability for grain yield plant^{-1} (g) along with stem diameter (mm) and protein content (%). SKNA-903 showed stability for leaf area plant^{-1} (cm^2), protein content (%) and grain yield plant^{-1}(g). Whereas, BGA-7-1 revealed stability for stem diameter (mm) and leaf area plant^{-1} (cm^2) with grain yield plant^{-1} (g).

***Keywords*:** Environmental index, genotype × environment interaction, grain amaranth, stability

Grain amaranth, originating in America and Europe, has been grown for over 8000 years as a grain (Brien and Price, 1983). Thousands of hectares of this pseudo-cereal were grown by pre-Columbian civilizations. Grain amaranth is reported in India from the tropical plains to 3500 metres in the Himalayan region (Sauer, 1967). Amaranth is grown in Sikkim, Assam, Meghalaya, Maharashtra, Gujarat, Nagaland, Tripura, Jharkhand, Arunachal Pradesh, Chhattisgarh, Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Orissa, Karnataka and Tamil Nadu both in the hills and plains (Dua *et al*., 2009). Amaranth has a "C_4" photosynthetic pathway that makes it uniquely efficient at using sunlight and nutrients at high temperatures. Potential crops such as amaranth have newly earned globally awareness in this regard, as this crop contains an ample quantity of all the usual nutrients needed for standard human development.

It has been emphasised that the analysis of individual yield components will lead to simplification in genetic interpretation of yield stability and thus, it is important to breeders in predicting and evaluating environmental effects. It is predominant to identify the stable genotypes in various growing seasons and environments that have considerable significance to the plant breeders for advancement of this crop. Identification of these stable varieties provides benefits to farmers and researchers in the further development of the crop and in the research field. The selection of the best genotypes suited to the wide range of environments specifically suitable for each of the growing seasons will help to increase both the selection efficiency and the productivity of amaranth in that region (Admassu *et al.,* 2008).

MATERIALS AND METHODS

Stability investigation for seed yield and component characteristics in grain amaranth was conducted at the Center for Crop Improvement (24°19 N latitude; 27°19 E longitude and at an altitude of 154.52 metres exceeding sea level) in Sardarkrushinagar, Dantiwada Agricultural University, Sardarkrushinagar, Banaskantha, Gujarat. The experimental materials used for the analysis

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consisting twenty-five genotypes of grain amaranth (Table 1.). Materials obtained from the Center for Crop Improvement were set up in a randomized block design and replicated thrice in three different environments during the winter *rabi* season, sown on November 11th timely, November 21st late, and December 2nd very late, respectively in 2019–20. Data was recorded on five taken plants for days to 50 per cent flowering, days to maturity, plant height (cm), length of inflorescence (cm), girth of inflorescence (cm), stem diameter (mm), number of branches plant^{-1}, leaf area plant^{-1} (cm^2), grain yield plant^{-1} (g), harvest index (%), test weight (g 10 per ml), and protein content (%). According to Eberhart and Russell (1966) methodology, the linear and nonlinear elements of genotype (G) and environment (E) interaction were premeditated through stability parameters using R studio software.

RESULTS AND DISCUSSION

The pooled analysis of variance (ANOVA) (Table 2) revealed that presence of significant genetic variability for all the traits studied the genotypes, significant mean squares for genotypes × environment (G × E) interactions were observed, as well as linear effects of environments all had extremely significant differences noticed for all thirteen characters. Thus there existed substantial variation in the mean performance of all the genotypes over environments for most of the characters.

The mean square due to environment and environment (liner) was highly remarkable for all the attributes omitting harvest index. This revealed that the environment was distinctive to each and every one of them. When assessed against pooled error, the genotype × environment interaction revealed substantial changes in leaf area plant^{-1} (cm^2), stem diameter, number of branches plant^{-1}, grain yield plant^{-1} (g), and protein content, indicating a wide difference between environments and differential behavior of genotypes in different environments. Genotype × environment (liner) was observed to be significant for girth of inflorescence, leaf area plant^{-1} (cm^2), stem diameter, number of branches, grain yield plant^{-1} (g) and protein content (%) when examined in opposition with pooled deviation. Analysis of variance for morphological stability demonstrated that variation of genotype × environment (liner) is higher and much more important than the non-linear component for leaf area plant^{-1} (cm^2), number of branches plant^{-1}, stem diameter (mm), grain yield plant^{-1} (g), and protein content (%). This proved that a significant proportion of the relationship was linear in nature, and that leaf area plant^{-1} (cm^2), number of branches plant^{-1}, stem diameter (mm), grain yield plant^{-1} (g), and protein content (%) could be anticipated across environments. The pooled deviation has a high significance except for the number of branches plant^{-1} and the protein content (%).

The environmental index reveals the suitability of an environment at a specific location. The environmental index's negative and positive values indicate unfavourable and favourable conditions for each character, respectively (Reddy *et al*., 1992). Assessments of the environmental index (Ij) for various attributes (Table 3) proposed that E_1 was the most favourable environment, whereas E_3 was the most unfavourable environment for all characters, except days to 50 per cent flowering and days to maturity. The E_2 was favourable for days to 50 per cent flowering, length of inflorescence (cm), girth of inflorescence (cm), number

Table 1: List of grain amaranth genotypes selected for study

Sr. No.	Genotypes	Source	Sr. No.	Genotypes	Source
1.	SKGPA-61	Indigenous collection of germplasm of grain amaranth from Center for crop improvement S.D.A.U, S.K. NAGAR.	**14.**	BGA-7-1	Indigenous collection of germplasm of grain amaranth from Center for crop improvement S.D.A.U, S.K. NAGAR.
2.	SKGPA-74		**15.**	CGA-18-1	
3.	SKGPA-150		**16.**	CGA-18-2	
4.	SKNA-401		**17.**	GA-1	
5.	SKNA-808		**18.**	GA-2	
6.	SKNA-903		**19.**	GA-3	
7.	SKNA-1313		**20.**	SUVARNA	
8.	SKNA-1406		**21.**	ANNPURNA	
9.	SKNA-1407		**22.**	IC-469820	
10.	SKNA-1503		**23.**	IC-506575	
11.	SKNA-1508		**24.**	IC-436953	
12.	SKNA-1510		**25.**	IC-279511	
13.	SKNA-1701				

Table 2: Analysis of variance for morphological stability in grain amaranth for several attributes

Sources	d.f	DF	DM	PH	LI	GI	SD	NB	LA	BY	GY	HI	TW	PC
Genotype (G)	24	220.65**	302.49**	2293.55**	170.08**	17.94**	17.93**	12.74**	375058.12**	843.05**	55.88**	152.79*	0.71**	0.86**
Environment(E)	2	749.13**	3016.55**	3748.36**	352.27**	94.69**	114.13**	0.99**	1907372.53**	7689.20**	879.34**	140.45	24.63**	9.33**
G × E	48	5.28	36.41	85.71	40.35	5.59	1.37*	0.19**	60829.65**	155.42	18.58**	74.98	0.16	0.28**
Environment (linear)	1	1498.26**	6033.11**	7496.72**	704.54**	189.39**	228.26**	1.98**	3814745.06**	15378.40**	1758.69**	280.91	49.27**	18.66**
G × E (linear)	24	6.35	29.90	89.63	34.60	7.76*	2.07**	0.34**	107419.23**	192.94	31.72**	79.67	0.18	0.41**
Pooled deviation	25	4.04**	41.20**	78.51**	44.26**	3.28**	0.65**	0.04	13670.46**	113.18**	5.22**	67.48**	0.14**	0.14
Pooled error	144	1	1	9	3	1	0	0	2739	8	1	7	0	0

Note: *, ** Remarkable at 5% and 1 % level of probability, independently

D.F: Days to 50 per cent flowering, DM: Days to maturity, PH: Plant height (cm), LI: Length of inflorescence (cm), GI: Girth of inflorescence (cm), SD: Stem diameter (mm), NB: Number of branches plant^{-1}, LA: Leaf area plant^{-1} (cm^2), BY: Biological yield plant^{-1} (g), GY: Grain yield plant^{-1} (g), HI: Harvest index (%), TW: Test weight (g/10 ml) and PC: Protein content (%)

of branches plant^{-1}, days to maturity, harvest index (%), test weight (g/10 ml) and protein content (%).

A stable genotype, according to Eberhart and Russell model (1966), is one that shows (i) a mean square deviation from regression (s^2d_i) near to zero, (ii) a regression co-efficient ($b_i = 1$) equal to unity, and (iii) a high mean. Consequently, there are three types of linear remarks (b_i) *viz.,* $b_i < 1$, $b_i = 1$ and $b_i > 1$ have been factored and interpreted as $b_i = 1$, average stability and adaptable to a diverse environment; $b_i > 1$, below average stability, rising environmental responsiveness and well-adapted to favourable conditions; and $b_i < 1$, above average stability, higher tolerance towards changes in the environment; as an outcome, genotypes would be more adaptive to low-yielding environments (Shukla and Singh, 2003). The stability parameters, *viz.,* regression co-efficient ($b_i = 1$), mean performance, and a mean square deviation from regression (s^2d_i) of 25 genotypes for five characters, were generated to determine relative stability over a range of environments and are handed over in Table 4.

Significant deviations from regression (s^2d_i) demonstrated that they were unstable for stem diameter (mm) revealed in four genotypes. Fifteen genotypes manifested a higher mean worth than the general mean (10.52). Furthermore, six genotypes showed non-significant regression (b_i) and non-significant deviation from regression (s^2d_i), implying average stability across contexts. Significant unit regression ($b_i < 1$) and good for poor environmental conditions were observed in genotypes SKNA-401, SKNA-903, SKNA-1503, SKNA-1508, SKNA-1510, SKNA-1701, BGA-7-1, CGA-18-1, CGA-18-2, ANNPURNA, IC-469820, IC-506575, and IC-279511. The divergence from regression (s^2d_i) was considerable for three genotypes, revealing that they were unstable. Two genotypes, IC-506575 and IC-279511, reported a strong mean value than the general mean, as well as non-significant regression (b_i) and non-significant divergence from regression (s^2d_i), demonstrating average stability in diverse environments in number of branches plant^{-1}.

Seven genotypes had significant deviations from regression (s^2d_i), indicating that they were unstable. Fourteen genotypes indicated a higher mean worth than the average mean (731.73). Six genotypes revealed non-significant regression (b_i) and non-significant divergence from regression (s^2d_i), which indicated average stability across environments. Significant unit regression (bi < 1) was reported in the SKNA-903, SKNA-1503, SKNA-1701, BGA-7-1, CGA-18-1, SUVARNA, ANNPURNA, IC-469820, IC-506575, IC-436953, and IC-279511 genotypes, whereas non-significant s^2d_i were identified

Table 3: Assessments of the environmental index (Ij) for various attributes in diverse contexts are expressed as a variation from the overall mean

Sr. No.	Attributes	Environments		
		E_1	E_2	E_3
1	Days to 50 per cent flowering	-5.52	0.1	5.42
2	Days to maturity	-12.67	6.74	5.94
3	Plant height (cm)	14	-8.74	-5.24
4	Length of inflorescence (cm)	0.76	3.32	-4.07
5	Girth of inflorescence (cm)	1.85	0.16	-2.03
6	Stem diameter (mm)	2.31	-0.39	-1.91
7	Number of branches plant^{-1}	0.05	0.17	-0.22
8	Leaf area plant^{-1} (cm^2)	318.94	-158.62	-160.33
9	Biological yield plant^{-1} (g)	18.49	-2.07	-16.4
10	Grain yield plant^{-1} (g)	6.39	-1.07	-5.32
11	Harvest index (%)	2.28	0.17	-2.45
12	Test weight (g/10 ml)	1	0	-0.99
13	Protein content (%)	0.25	0.45	-0.69

in inadequate environments. Significant unit regression (b_i >1) was identified in genotype SKGPA-150, and non-significant s^2d_i was proposed for a better environment for leaf area plant^{-1} (cm^2). Eleven genotypes were revealed to be unstable because their divergence from regression (s^2d_i) was considerable. Fifteen genotypes exhibited higher mean worth than the overall mean (11.56). Elsewhere, six genotypes revealed non-significant regression (b_i) and divergence from regression (s^2d_i), implying average stability across environments. The genotypes SKNA-1313, SKNA-1406, SKNA-1407, SKNA-1503, SUVARNA, ANNPURNA showed significant unit regression (b_i < 1) and non-significant s^2d_i, whereas IC-506575 was good for unfavourable environments may thus be recommended as better yielding genotypes for rich environment in the present study for grain yield plant^{-1} (g). Similar findings were observed by Varalakshmi and Reddy (2002), Kishore *et al*. (2007), for analysis over environments in genetically diverse amaranth genotypes. CGA-18-1 was unstable because the divergence from regression (s^2d_i) was high. Twelve genotypes had higher mean worth than the overall mean (12.79). Ten genotypes exhibited non-significant regression (b_i) and non-significant deviation from regression (s^2d_i), indicating average stability throughout environments. The genotypes SKNA-150, SKNA-401, SKNA-808, SKNA-1510, SKNA-1701, GA-1, and GA-2 showed significant unit regression (b_i <1) and non-significant s^2d_i good for poor environment found for protein content (%).

Detailed analysis of stability parameters (Table 5) indicated that no one of the genotypes were stable for all of the characters. The situation was similar in terms of average performance and responsiveness. As a result, any generalization about genotype stability and responsiveness for all characteristics was impossible. According to the stability analysis, the five genotypes have average stability and wide adaptability for grain yield plant^{-1} (g). Significant pooled deviation for yield indicated that different genotypes fluctuated significantly from their respective linear path of response to environments (Sarkar, 2015). Other characteristics have average, above-average, or below-average stability. Genotypes SKGPA-150, SKNA-401 and SKNA-808 showed average stability for grain yield plant^{-1} (g) along with stem diameter (mm), leaf area plant^{-1} (cm^2), and protein content (%), whereas SKGPA-61 showed average stability for grain yield plant^{-1} (g) along with stem diameter (mm) and protein content (%). SKNA-903 showed stability for leaf area plant^{-1} (cm^2), protein content (%), and grain yield plant^{-1} (g), whereas BGA-7-1 showed stability for stem diameter (mm) and leaf area plant^{-1} (cm^2) along with grain yield plant^{-1} (g).

Based on the major yield and attributing traits, above study revealed that SKGPA-74, SKNA-1313, SKNA-1406, SKNA-1407, SKNA-1503, SUVARNA, ANNPURNA and IC-506575 could be identified as the most promising and show stability for grain yield plant^{-1} (g) in poor environmental conditions. These genotypes may be recommended for growing in the regions of northern India. They may also be further

Table 4: Stability indices of different genotypes for various components in grain amaranth

Sr. No.	Genotypes	Stem diameter (mm)			Leaf area plant^{-1} (cm^2)			Grain yield plant^{-1} (g)			Protein content (%)			No. of branches plant^{-1}		
		Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i
1	SKGPA-61	10.80	0.72**	-0.15	1422.00	2.69**	98114.27**	19.15	1.83	1.33	12.40	1.71**	0.015	1	-	-0.036
2	SKGPA-74	12.42	1.19	-0.01	834.22	1.41**	40388.70**	6.95	0.70**	-0.66	12.41	1.22**	-0.116	1	-	-0.036
3	SKGPA-150	10.77	0.89**	-0.15	710.33	1.41**	6735.18	13.41	1.23	-0.58	13.18	0.38*	-0.115	1	-	-0.036
4	SKNA-401	10.33	0.97**	-0.31	992.11	2.75	5865.20	15.04	1.33	1.50	13.07	0.86**	-0.08	1	-	-0.036
5	SKNA-808	13.81	1.32	0.02	1344.88	1.94	-637.87	11.74	1.18	-0.49	12.45	0.04	-0.126	1	-	-0.036
6	SKNA-903	11.23	0.44	0.26	504.16	0.17**	-2052.55	13.83	1.25	0.37	12.42	1.87**	0.078	1	-	-0.036
7	SKNA-1313	11.61	1.10	0.25	1060.22	1.66	-2231.50	9.95	0.85**	-0.35	12.34	2.70**	-0.097	1	-	-0.036
8	SKNA-1406	11.84	0.97*	1.54*	826.77	1.33	-237.40	9.58	0.40**	-0.84	13.25	0.72	0.307	1	-	-0.036
9	SKNA-1407	12.67	1.06	0.03	1116.00	1.04	43233.92**	12.32	0.90**	0.12	12.78	0.61	0.113	1	-	-0.036
10	SKNA-1503	10.12	0.73**	-0.32	736.44	0.38**	255.96	10.85	0.60**	-0.63	12.88	1.15	-0.068	1	-	-0.036
11	SKNA-1508	10.71	0.78**	-0.002	630.11	0.13	60744.08**	15.07	1.63**	4.00*	13.29	0.42	-0.059	1	-	-0.036
12	SKNA-1510	9.96	0.52**	0.018	807.88	1.14**	10461.63*	14.00	1.52**	11.02**	12.75	0.82**	-0.081	1	-	-0.036
13	SKNA-1701	13.32	0.97**	-0.33	893.27	0.67**	6651.62	19.10	2.25**	3.76*	12.58	0.17**	-0.141	1	-	-0.036
14	BGA-7-1	10.19	0.75**	0.064	644.33	0.49*	3509.12	13.74	1.52	0.06	13.61	0.24	0.066	1	-	-0.036
15	CGA-18-1	10.14	0.97**	-0.013	535.88	0.59**	-1797.04	16.69	1.58**	2.79*	12.57	0.80	0.536*	1	-	-0.036
16	CGA-18-2	10.63	0.79**	0.026	642.88	1.08**	9902.27*	11.97	1.59**	11.97**	12.55	1.53**	-0.089	1	-	-0.036
17	GA-1	11.79	2.00**	1.63*	766.66	0.61*	8186.46*	12.76	1.12**	7.73**	13.45	0.14	-0.131	1	-	-0.036
18	GA-2	13.17	1.71	0.93	1243.22	2.72	309.04	16.33	1.88**	7.14**	13.41	0.85**	-0.14	1	-	-0.036
19	GA-3	12.20	1.15	0.014	733.33	1.24	-2625.89	13.49	1.07**	6.60**	13.05	1.10	-0.073	1	-	-0.036
20	SUVARNA	13.64	2.46**	1.97**	818.88	0.10	2340.68	4.03	0.22*	-0.22	13.60	1.97	0.363	1	-	-0.036
21	ANNPURNA	5.85	0.66**	-0.32	221.33	0.55**	-2702.52	6.92	-0.09	0.40	12.91	0.59	0.037	5.91	5.82**	0.15*
22	IC-469820	5.95	0.25**	-0.33	235.88	0.045	-2532.24	6.43	-0.08	34.33**	12.97	0.73	-0.011	5.57	3.64**	0.10*
23	IC-506575	7.73	0.80**	0.42	164.77	0.17**	-2493.59	5.94	0.05	0.22	12.20	2.77**	-0.063	6.33	5.99	0.021
24	IC-436953	5.61	0.83	2.75**	181.00	0.29**	-2702.87	3.61	0.12	4.07*	11.20	0.29	0.157	5.43	4.06	0.68**
25	IC-279511	6.48	0.85**	-0.17	226.55	0.30**	-2621.03	8.96	0.26	15.85**	12.38	1.22**	-0.131	6.82	5.40	-0.001
	Mean	**10.52**			**731.73**			**11.56**			**12.79**			**2.00**		
	S.Em(±)	**0.68**			**142.40**			**2.49**			**0.31**			**0.26**		

Note: * and **: Remarkable at 5 and 1 per cent levels of significance, independently

When, $H_{0:}$ $b_i = 1$ and H_0: $S^2d_i = 0$, $H_{a:}$ $b_i \neq 1$ and $H_{a:}$ $S^2d_i \neq 0$

Table 5: Stable genotypes for grain yield plant^{-1} (g) along with stability for component characteristic

Genotypes	Mean	b_i	S^2d_i	Average stability for other characters
SKGPA-61	19.15	1.83	1.33	SD, PC
SKGPA-150	13.41	1.23	-0.58	SD, LA, PC
SKNA-401	15.04	1.33	1.50	SD, LA, PC
SKNA-808	11.74	1.18	-0.49	SD, LA, PC
SKNA-903	13.83	1.25	0.37	LA, PC
BGA-7-1	13.74	1.52	0.06	SD, LA

Where,
SD=Stem diameter (mm)
LA=Leaf area plant^{-1} (cm^2)
PC=Protein content (%)

utilized in breeding programmes for developing stable varieties.

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