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Stability analysis in red amaranths (*Amaranthus tricolor* L.)

Bhagwat Saran Asati and Nitin Kumar Rastogi

Bhagwat Saran Asati
College of Agriculture and Research Station, Chhuikhadan, Rajnandgaon, Chhattisgarh, India

Nitin Kumar Rastogi
College of Agriculture and Research Station, Chhuikhadan, Rajnandgaon, Chhattisgarh, India

Corresponding Author:
Bhagwat Saran Asati
College of Agriculture and Research Station, Chhuikhadan, Rajnandgaon, Chhattisgarh, India

Abstract
Stability analysis in red amaranths (*Amaranthus tricolor* L.) on twenty genotypes evaluated in four environment years 2017-18, 2018-19, 2019-20 and 2020-21 at Pt KLS College of Horticulture and Research Station, Rajnandgaon, Chhattisgarh. Analysis of variance indicated significant variation between genotypes for all traits except the studied plant height, leaf width and petiole length. The pooled analysis of variance indicated significant variation among the environments for all the characters studied revealed that the environments were random and different and they exercised influence on the expression of characters. Analysis of variance revealed that both linear and non-linear components of genotypes environment interaction (GEI) was found to be non-significant for all characters. This indicated that the genotypes performed uniformly in different environments means genotypes having almost similar values in four environments. When the genotypes were grouped according to Eberhart and Russell stability model, it was concluded that genotypes namely, Amar-09, Amar-03, Amar-07, Amar-15 Amar-12, Amar-21, Amar-23 (Pusa Lal Chaulai), Amar-20, Amar-08, Amar-17, Amar-11 were most stable and well adopted to all four environment conditions for the all study characters.

Keywords: G x E interaction, stability, amaranths

Introduction
Amaranths (*Amaranthus tricolor* L.) is a unique leafy vegetable that is grown in a wide range of agro-climates and various cropping systems, which is originated from Southeast Asia or in India (Rai and Yadav, 2005) [12]. It is popularly known as "Chaulai" and is described as a “Poor Man's Vegetable”. Red amaranths is a rich source of nutrients it serves as an alternative source of nutrition for rural people in India especially in Chhattisgarh. In spite of the excellent nutritional qualities of amaranths, not much work has been done on its genetic improvement to increase its foliage yield potential. Genotype x environment interaction (GEI) has been defined as failure of genotypes to achieve the same relative performance in different environments (Becker and Leon, 1988) [3]. The effects of genotypes and environments on genotype environment interactions are non-additive which indicates that differences in yield among genotypes will depend on the environment (Yue *et al.*, 1997) [18]. Therefore, selection methodologies based on mean yield of genotypes in a given environment are less efficient (Hopkins *et al.*, 1995) [8]. Knowledge of GEI and yield stability is important for breeding new cultivars with improved adaptation to the environmental constraints prevailing in the target environment. According to the dynamic concept of stability, a stable genotype is the one which has no departure from this expected response to environments (Becker and Leon, 1988) [3]. It is important to identifying the stable genotypes under different growing season which have great significant to the plant breeders for improvement of this crop. In a view of the above circumstance, a study was undertaken to identifying the environmental stable genotype of amaranths for the breeding and to selecting the most promising genotype for future breeding programme.

Materials and Methods
The plant material for the present investigations includes 20 genotypes of *A. tricolor* (Table 1) collected from different eco-geographical region of India. The experiment was conducted during 4 environments (years 2017-18, 2018-19, 2019-20 and 2020-21) in *Rabi* season at Pt. KLS College of Horticulture and Research Station, Rajnandgaon (C.G) to evaluate genotype x environment interaction and stability in the material, in a randomized block design with three replications. The seed are sowing in direct field at the distance 15 cm for row to row and 5 centimeter for plant-plant was maintained and the plot size was 1 m^2.

Recommended cultural packages of practice were adopted for well crop growth. Five random plants were selected from each plot to record observations on various characters. The Eberhart and Russell (1966) [4] model of stability was used to analyze genotypes for different stability parameters.

Table 1: Source of material (*Amaranthus tricolor* L.)

S. No.	Genotypes	Place of collection	S. No.	Genotypes	Place of collection
1.	Amar-1	Baloda Bazar	11.	Amar-11	Rajnandgaon
2.	Amar-2	Rajnandgaon	12.	Amar-12	Kanker
3.	Amar-3	Delhi	13.	Amar-13	Rajnandgaon
4.	Amar-4	Raipur	14.	Amar-14	Bacheli
5.	Amar-5	Raigarh	15.	Amar-15	Janjgir
6.	Amar-6	Bemetara	16.	Amar-16	Kawardha
7.	Amar-7	Bangalore	17.	Amar-17	Raipur
8.	Amar-8	Raipur	18.	Amar-18	Berla
9.	Amar-9	Bilaspur	19.	Amar-19	Bilaspur
10.	Amar-10	Mungeli	20.	Pusa Lal Chaulai	New Delhi (Check)

Results and Discussion

The analysis of variance as per the Eberhart and Russell (1966) [4] model showed significant differences between the 20 genotypes for most of the characters *viz*., number of leaves per plant, number of branches per plant, leaves length, plant fresh weight, dry plant weight, days of first harvest, foliage yield except plant height, leaves width, petiole length studied over four different environments, indicates sufficient amount of variability was present among the genotypes and environments for the studied characters (Table 2). Similar results were reported by Singh *et al.* (2018) [15], Kishore *et al* (2007) [9], and Haydar (2018) [7]. The variances due to environment were also found highly significant for all the studied characters, indicating that the presence of wide variation among environmental conditions used for the evaluation of the materials. The significant mean sum of square revealed that the environments were random and different and they exercised influence on the expression of characters. Galton (1988) [5], Anuja and Mohideen (2007) [2] and Varalakshmi and Devaraju (2010) [16] had observed similar results.

The genotype x environment interaction of 20 genotypes is presented in Table 2. Variances due to Genotypes × Environment (G×E) were found non-significant for all the traits enumerate the fact that variable environment did not play a significant role in creating variation among the genotypes. Both linear and non-linear component of environment was found to be non-significant for all characters. This indicated that the genotypes performed uniformly in different environments means genotypes having almost similar values in four environments. Present results are in agreement with those of earlier reports of Ahamad *et al.*, (2012) [1] and Hasan *et al.* (2013) [6]. Components analysis of the Environment + (Genotype × Environment) interaction was found to be highly significant for all the characters except for petiole length. Similar results were reported by Varalakshmi and Pratap Reddy (1994) [17].

Partitioning of this variation into linear and non-linear components indicated that mean sum squares due to environment (linear) were highly significant for all the characters tested against pooled deviation as well as pooled error, hence predicting that value for all the characters under study could be attributed to linear regression. Table 2 also showed that the mean square due to pooled deviation was found significant for all characters *viz.* plant height, number of leaves per plant, leaves length, leaves width, petiole length, dry plant weight, days of first harvest, except number of branches per plant, plant fresh weight, foliage yield, indicating greater role of non-predictable components in genotypes × environment interaction. Thus, both linear and non-linear components were useful for determining the stability in the current study.

Estimates of stability parameters *viz.* mean performance, regression coefficient (bi), deviation from regression (S^2di) for all the characters according to Eberhart and Russell model (1966) [4] is presented in Table 3. On the basis of stability parameters the genotypes showing high mean performance, regression coefficient was non-significant from unity (bi=1) and deviation from regression close to zero ($S^2di=0$), were considered as stable and well adopted to all environments, the genotypes sowing high average performance, regression coefficient was significant from unity (bi>1) and deviation is non-significant from zero ($S^2di=0$), were considered as stable and suitable for favourable conditions and the genotypes had high mean performance, regression coefficient was significant from unity (bi<1) and deviation is non-significant from zero ($S^2di=0$), these genotypes were found stable and specially adopted to unfavourable environments.

Table 4 shows that when the genotypes were grouped according to stability parameters, it was found that 11 genotypes are stable namely, Amar-09, Amar-03, Amar-07, Amar-15 Amar-12, Amar-21, Amar-23 (Pusa Lal Chaulai), Amar-20, Amar-08, Amar-17, Amar-11 for foliage yield in all environments. On other hand, genotypes Amar-6, 13, 17, 5, 1, 4, 10, 16 for foliage yield under high stability and low performance or poor environments were placed, for high stability and high performance or richer environments genotypes Amar-11, 8, 20, 19, 7, 9, 18, 12, 14, 15 were placed, for low stability and low performance or poorer environments genotype Amar-2 was a sole bearer, while for the last category low stability and high performance or richer environments genotype Amar-3 was placed (Table 5). In general, the stability for foliage yield was due to the stability of yield contributing traits i.e. plant fresh weight, number of leaves per plant and number of branches per plant. Hence, it would be advantageous to exploit these high yielding genotypes in practical plant breeding programme after critically evaluation over the environments of locations and years. The stability parameters measured in present study has also been reported by several workers i.e. Sharma *et al.* (2001) [13] in grain Amaranths and Pawar *et al.* (1996) [11] in buckwheat, Singh *et al.* (2015) [14] and Pan *et al.* (2007) [10] in vegetable soybean.

Table 2: Combined analysis of variance for stability in red amaranths under four different environments

Source of variation	DF	Mean Sum of Squares									
		Plant height (cm)	No of leaves per plant	No of branches per plant	Leaves length (cm)	Leaves width (cm)	Petiole length (cm)	Plant fresh weight (gm)	Dry plant weight (gm)	Days of first harvest	Foliage yield (kg per plot)
Replication	8	1.909 **	2.240 ***	0.029	0.057	0.005	0.061	0.250 ***	0.000	4.006	0.521 ***
Genotypes	19	1.148	0.294 *	0.291 ***	0.154 *	0.076	0.107	0.212 ***	0.006 ***	16.489 ***	0.214 ***
Environments	3	17.973 ***	26.042 ***	4.812 ***	7.015 ***	5.830 ***	1.002 ***	3.956 ***	0.065 ***	20.000 **	19.464 ***
Geno. X Env.	57	0.648	0.140	0.056	0.077	0.047	0.074	0.053	0.001	3.321	0.057
Env. + (Geno. X Env.)	60	1.514 **	1.435 ***	0.294 ***	0.424 ***	0.336 ***	0.120	0.249 ***	0.004 ***	4.155**	1.027 ***
Environments (Lin.)	1	53.919 ***	78.125 ***	14.437 ***	21.046 ***	17.490 ***	3.006 ***	11.868 ***	0.196 ***	60.000 ***	58.392 ***
Geno. X Env. (Lin.)	19	0.623	0.104	0.069	0.078	0.013	0.061	0.037	0.001	1.841	0.040
Pooled Deviation	40	0.628 ***	0.150 *	0.047	0.072 *	0.061 ***	0.077 ***	0.059	0.001 **	3.857 ***	0.062
Pooled Error	152	0.242	0.101	0.055	0.047	0.014	0.017	0.049	0.001	1.052	0.056
Total	79	1.426	1.160	0.293	0.359	0.274	0.117	0.240	0.005	7.121	0.832

*and **indicates significant at 5% and 1% against pooled deviation respectively

Table 3: Estimation of mean and stability parameters in red amaranths genotypes

Genotypes	Plant height			No of leaves per plant			No of branches per plant			Leaves length (cm)			Leaves width (cm)		
	Mean	bi	s²di	Mean	bi	s²di	Mean	bi	s²di	Mean	bi	s²di	Mean	bi	s²di
Amar-01	14.906	0.528	0.2174	6.342	0.942	-0.1194	2.492	0.786	-0.0053	3.731	0.674	-0.0254	3.618	0.729	0.0360 *
Amar-02	14.968	0.026	2.5791 ***	6.443	0.611	-0.0042	2.69	0.703	-0.0110	3.848	0.381	0.1124 *	3.536	0.819	0.1719 ***
Amar-03	16.659	1.648	0.3474	7.371	1.028	-0.1914	3.619	1.195	0.1117 *	4.396	0.751	0.0211	3.89	1.059	0.0366 *
Amar-04	15.756	1.441	0.5987	6.188	0.833	-0.0205	2.638	1.102	0.0392	4.003	1.036	-0.0434	3.718	0.998	0.0209
Amar-05	15.853	0.86	0.8592 *	6.814	1.02	-0.0347	2.786	1.115	-0.0471	3.987	1.007	-0.0457	3.657	0.934	0.0109
Amar-06	15.273	1.229	-0.2911	6.306	1.034	-0.0362	2.664	1.051	-0.0472	3.882	0.905	-0.0400	3.589	0.986	0.0403 *
Amar-07	16.526	0.477	0.2437	6.919	0.847	-0.1664	3.262	0.178*	-0.0320	4.436	1.126	0.0324	3.884	1.145	0.1135 ***
Amar-08	15.583	1.29	-0.1818	6.47	1.074	-0.1007	2.695	1.167	-0.0467	3.979	1.159	-0.0356	3.644	1.01	-0.0128
Amar-09	15.556	1.907*	-0.2953	6.471	1.368**	-0.2058	2.67	1.375	0.0067	3.954	1.194	0.1895 **	3.543	1.022	0.0144
Amar-10	15.123	1.172	0.5621	6.463	1.072	0.0158	2.683	1.247	-0.0160	3.873	0.969	-0.0319	3.573	0.967	-0.0068
Amar-11	15.768	0.684	-0.1455	6.727	1.055	-0.1435	2.758	0.967	-0.0510	4.018	0.972	-0.0470	3.618	1.039	0.0184
Amar-12	15.803	1.313	-0.2398	6.665	1.14	-0.1783	2.81	1.06	-0.0443	4.087	1.262	0.1948 **	3.808	1.242*	-0.0124
Amar-14	15.311	0.78	-0.2986	6.593	1.078	0.5257 *	2.669	0.898	-0.0051	3.937	0.779	-0.0384	3.548	0.871	0.0469 *
Amar-15	15.315	1.43	-0.2134	6.468	1.029	-0.1565	2.842	1.739	0.1202 *	4.023	1.023	0.1178 *	3.652	0.926	0.0159
Amar-17	15.268	0.274	0.4475	6.448	0.698	-0.1125	2.858	1.126	-0.0039	3.861	0.829	-0.0398	3.655	0.983	-0.0054
Amar-18	15.93	1.502	1.0972 *	6.595	1.038	-0.1155	2.747	0.816	0.0010	4.013	0.74	-0.0341	3.653	0.937	-0.0019
Amar-19	15.714	0.813	0.3946	6.409	1.129	0.1944	2.669	0.747	0.0224	3.827	1.231	0.0402	3.777	1.182	0.0303 *
Amar-20	16.676	0.756	-0.2113	6.856	0.936	-0.1911	3.178	0.972	-0.0531	4.2	1.124	-0.0062	3.967	1.14	0.2996 ***
Amar-21	16.369	0.882	-0.0001	6.88	1.086	-0.0474	3.15	0.895	-0.0444	4.173	1.156	-0.0045	3.906	1.031	0.1219 ***
Amar-23 (Pusa Lal Chaulai)	16.103	0.989	0.5844	6.721	0.984	-0.0728	2.984	0.86	-0.0195	4.374	1.682	0.1809 **	3.882	0.982	0.0227
Population Mean	15.723			6.607			2.843			4.03			3.706		

Table to be cont.……

Genotypes	Petiole length (cm)			Plant fresh weight (gm)			Dry plant weight (gm)			Days of first harvest			Foliage yield (kg per plot)		
	Mean	bi	s²di	Mean	bi	s²di	Mean	bi	s²di	Mean	bi	s²di	Mean	bi	s²di
Amar-01	2.964	0.43	0.0583 *	2.892	0.849	-0.0296	0.313	0.583	0.0012	31.667	1.333	-0.4222	4.001	0.85	-0.0271
Amar-02	2.996	0.033	0.1073 **	3.123	0.675	-0.0401	0.329	0.977	0.0112 ***	27.583	0.944	17.2815 ***	4.202	0.738	0.1083
Amar-03	3.423	0.996	0.0542 *	3.624	1.434	0.0052	0.465	1.006	0.0000	23.667	0.444	2.5037 *	4.802	1.179	0.1728 *
Amar-04	3.152	0.817	-0.0159	2.99	1.26	0.0263	0.327	0.813	0.0005	29.667	1.556	7.2815 **	4.158	0.957	-0.0261
Amar-05	3.151	0.677	0.0289	2.87	0.569	0.1570 *	0.346	1.322	-0.0003	28.917	0.056	4.6148 **	4.229	0.937	-0.0474
Amar-06	2.986	1.458	0.0781 **	2.828	0.965	-0.0560	0.334	0.791	-0.0007	31.5	1	-1.2000 **	4.082	0.883	-0.0757
Amar-07	3.287	0.912	-0.0113	3.324	0.616	-0.0422	0.41	1.001	-0.0007	26.417	0.167	0.9111	4.716	1.106	0.0845
Amar-08	2.833	1.689	0.1810 ***	2.891	1.083	-0.0300	0.325	0.973	0.0009	30.083	-0.056	1.2815	4.103	1.034	-0.0571
Amar-09	2.933	2.384	0.0706 *	2.811	1.095	-0.0170	0.324	0.862	0.0004	30.333	1.111	2.1704	4.165	1.211	-0.0568
Amar-10	2.848	2.223	0.0286	2.915	1.082	-0.0506	0.304	1.284	-0.0005	30.917	0.722	-0.9407	4.093	0.98	-0.0325
Amar-11	3.029	0.704	-0.0058	2.94	0.896	-0.0340	0.313	1.243	-0.0006	29.5	-0.111	0.7259	4.088	1	-0.0683
Amar-12	2.958	0.843	0.0930 **	3.087	1.384*	-0.0571	0.343	1.422	-0.0006	28.75	1.056	8.2815 ***	4.264	1.093	-0.0386
Amar-14	3.197	0.714	0.0328	3.004	0.727	-0.0481	0.326	0.563	-0.0003	30.583	1.611	2.1704	4.128	0.842	-0.0617
Amar-15	2.900	1.987	0.1028 **	2.873	0.822	0.3237 **	0.33	1.127	0.0006	29.333	0.222	2.9481 *	4.24	1.096	0.0184
Amar-17	2.931	0.464	0.0495 *	3.218	1.206	0.0298	0.343	1.356	-0.0002	30.167	1.667	0.1333	4.148	1.029	-0.0107
Amar-18	3.25	0.731	0.0202	2.873	0.842	-0.0552	0.339	0.489	0.0000	28.917	2.944	4.3926 *	4.263	0.944	-0.0101
Amar-19	3.096	0.902	-0.0170	2.926	0.992	-0.0355	0.342	1.299	-0.0002	30.25	1.611	1.2815	4.127	0.953	-0.0552
Amar-20	3.281	0.319*	-0.0173	3.412	1.27	0.0011	0.393	1.091	0.0014	26.25	0.722	-0.2741	4.651	1.036	-0.0260
Amar-21	3.051	0.623	0.3161 ***	3.308	1.04	-0.0581	0.383	1.006	0.0001	26.333	0.889	0.6148	4.593	1.072	-0.0677
Amar-23 (Pusa Lal Chaulai)	3.207	1.094	-0.0112	3.31	1.192	0.0098	0.368	0.792	0.0008	28.5	2.111	-0.6074	4.288	1.06	-0.0661
Population Mean	3.074			3.061			0.348			28.967			4.267		

and ** indicates significant at 5% and 1% deviation from unity.

Table 4: Stability status of red amaranths genotypes under four environment conditions based on stability parameters

Stability	Plant height	No of leaves per plant	No of branches per plant	Leaves length (cm)	Leaves width (cm)
Stable and well adopted to all environments (Greater mean, bi = >1 and S^2di = 0)	Amar-09	Amar-09	Amar-15	Amar-23 (Pusa Lal Chaulai)	Amar-12
	Amar-03	Amar-12	Amar-09	Amar-12	Amar-19
	Amar-18	Amar-19	Amar-10	Amar-19	Amar-07
	Amar-04	Amar-21	Amar-03	Amar-09	Amar-20
	Amar-15	Amar-14	Amar-08	Amar-08	Amar-03
	Amar-12	Amar-08	Amar-17	Amar-21	Amar-11
	Amar-08	Amar-10	Amar-05	Amar-07	Amar-21
	Amar-06	Amar-11	Amar-04	Amar-20	Amar-09
	Amar-10	Amar-18	Amar-12	Amar-04	Amar-08
		Amar-03	Amar-06	Amar-15	Amar-04
		Amar-06		Amar-05	
		Amar-15			

Stability	Petiole length (cm)	Plant fresh weight (gm)	Dry plant weight (gm)	Days of first harvest	Foliage yield (kg per plot)
Stable and Well adopted to all environments (Greater mean, bi = >1 and S^2di = 0)	Amar-09	Amar-03	Amar-12	Amar-18	Amar-09
	Amar-10	Amar-12	Amar-17	Amar-23 (Pusa Lal Chaulai)	Amar-03
	Amar-15	Amar-20	Amar-05	Amar-17	Amar-07
	Amar-08	Amar-04	Amar-19	Amar-14	Amar-15
	Amar-06	Amar-17	Amar-10	Amar-19	Amar-12
	Amar-23 (Pusa Lal Chaulai)	Amar-23 (Pusa Lal Chaulai)	Amar-11	Amar-04	Amar-21
	Amar-03	Amar-09	Amar-15	Amar-01	Amar-23 (Pusa Lal Chaulai)
		Amar-08	Amar-20	Amar-09	Amar-20
		Amar-10	Amar-03	Amar-12	Amar-08
		Amar-21		Amar-06	Amar-17
					AMAR-11

Table 5: Classification of red amaranths genotypes under environments and stability parameters

Characters	High stability and low performance environments	High stability and high-performance environments	Low stability and low performance environments	Low stability and high-performance environments
Foliage yield	Amar-6, 13, 17, 5, 1, 4, 10, 16	Amar-11, 8, 20, 19, 7, 9, 18, 12, 14, 15	Amar -2	Amar -3

Conclusion
The assessment of the level and patterns of genotypes environment interaction (GEI) and stability is an important component for crop improvement. Stable genotypes can be utilized for cultivation in adverse condition. At the four environmental locations, analysis of variance indicated significant variation between genotypes for all traits except the studied plant height, leaf width and petiole length. The pooled analysis of variance indicated significant variation among the environments for all the characters studied revealed that the environments were random and different and they exercised influence on the expression of characters. Environments (Linear) also showed highly significant differences for all the characters under study. It reveals that wide difference between environments. Analysis of variance revealed that both linear and non-linear components of genotypes environment interaction (GEI) was found to be non- significant for all characters. This indicated that the genotypes performed uniformly in different environments means genotypes having almost similar values in four environments. When the genotypes were grouped according to Eberhart and Russell stability model, it was concluded that genotypes namely, Amar-09, Amar-03, Amar-07, Amar-15 Amar-12, Amar-21, Amar-23 (Pusa Lal Chaulai), Amar-20, Amar-08, Amar-17, Amar-11 were most stable and well adopted to all four environment conditions for the all study characters.

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