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HIGH YIELD AND STABILITY IMPROVED CULTIVAR OF GRAIN AMARANTH (*AMARANTHUS HYPOCHONDRIACUS* L.) IN PLAIN REGIONS OF INDIA

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ABSTRACT

The aim of the study was to select Grain amaranth (*Amaranthus hypochondriacus* L.) varieties with high grain yield and stable performance across different environments. The material for study consist of set of 13 release varieties of Grain amaranth subjected to multilocation seed yield trial for two years (2012-13) at five locations in randomization block design. The test of significance for genotype x environment (GE) interaction and eight non-parametric measures of stability analysis were used to identify genotypes with higher yield and stability in performance across five environments tested across the country. A new approach Combined Stability Index based on yield stability performance calculated on the ranking of the used stability major of all the genotypes, Durga ($CSI_{(i)}$=11) and BGA 2 ($CSI_{(i)}$=14) were identified most stable and high potential yield.

Based on low value of Combined Stability Index, Durga($CSI_{(i)}$=11) and BGA 2 ($CSI_{(i)}$=14) were identified most stable and high potential yield. The non-parametric measures were observed to be associated with high mean grain yield. The variety Durga in section I was the most favourable genotype due to high grain yield as well as high stability performance according to plotting diagram of all non-parametric measures with grain yield. Durga (G3), which had higher grain yield (13.65 q/ha) and high protein content (14.10%) with better stability across the environments was suitable for cultivation across India both in Hills and Plains.

Key words : Grain amaranth (*Amaranthus hypochondriacus* L.), Genotype x environment interaction, Non-parametric stability methods, Combined Stability Index.

Introduction

Grain amaranth, an edible pseudocereal is now a crop of interest because of its higher and quality protein and high micronutrients contents. Grain amaranth possess C_4 pathway, which confers physiological advantage of high rate of photosynthesis. This crop can be grown even in hospitable environments. The three principal species that are considered for grain production include: *Amaranth hypochondriacus*, *A. cruentus* and *A. caudatus*. In some of the Indian languages, it is known as *rajgira* ("king of seeds") in Gujarati, *ramdana* ("seed sent by god") in Bihar, Odisha and Uttar Pradesh, *Chuka* in Bengal, *Kalaghesa, chumera* and *ganhar* in central India and *Bathu* in HP etc. Amaranthus are widely distributed throughout the Old and New World. In Asia-Pacific regions covering India, China, Manchuria, Nepal, Bhutan, Afghanistan, Indonesia, Japan, Thailand and Israel, this crop is cultivated as minor crop. In India, grain amaranth is primarily cultivated in hill regions but of late in 1990s, its cultivation gained momentum in Central and Western

Plateau regions of India. However, it is estimated that the crop is grown in about 40-50 thousand ha in India. Grain amaranth cultivation in Gujarat has gained momentum as compared to other parts of the country. In Gujarat, there has been remarkable increase in the area, production and productivity of Rajgira during last 10 years. The area under this crop is increasing, particularly in Banaskantha and Kheda districts Fig. 1, where this crop replaces wheat and potato because of water scarcity. The cultivation area under this crop in Gujarat is about >12,000 ha (Rabi 2017-18). In Gujarat, Palanpur APMC market of Banaskantha district is one of the biggest markets for amaranths grain selling /purchasing, from where the grain is exported to other parts of the country. It is unlikely that the area under grain amaranth would increase significantly owing to its limited usage as a food crop.

Very less work has been taken up on genetic improvement of this crop so far in India. Globally, information on genetic improvement, adaptability and genotype environment interaction of Grain amaranth is restricted to few publications. Therefore, the present study was undertaken with objectives (i) to identify genotype that has high grain yield as well as most stable performance across different environment; (ii) to investigate the nature of relationship among non-parametric stability measures.

To increase and stabilize the production and productivity, identification of suitable varieties with high yielding potential are of the paramount importance through stability analysis helps in understanding the varietal adaptation under variable environments (Raiger *et al.*, 2011). Thus, the use of highly adaptable variety is important in stabilizing productivity over seasons and regions.

Materials and Methods

Plant materials : Secondary data on grain yield (q/ha) for this study was obtained from set of 13 varieties of grain amaranth experiments conducted over two seasons (Bhubaneswar, S.K. Nagar, Mandor, Rahuri, *Rabi* 2012-2013 and Bangalore, *Kharif* 2013) at five locations in plain regions of India. The names, source and codes and quality parameters of tested varieties are given in Tables 1 and 2 (Raiger *et al*., 2009; Raiger and Bhandari, 2012).

Experimental detail: Experiments were laid in randomized complete block design with three replications

Table 1 : Variety name and origin of 13 Grain amaranth varieties.

S. no.	Variety name	Pedigree	Released Year	Maturity (Days)	Area of Adoption
1	Annapurna	Selection from the population of NC 59937	1989	140-150	Indian Himalayan Region
2	BGA-2	Angul Local 2	2006	90-100	Karnataka, Orissa and Tamil Nadu
3	Durga	Selection from the population of NIC 22535	2006	120-125	Indian Himalayan Region
4	GA-1	Selection from local germplasm material	1991	110-115	Gujarat
5	GA-2	Rasana -2	2002	98-102	Gujarat
6	GA-3	Vasada-1-5	2008	95-100	Gujarat and Jharkhand
7	PRA-1	Selection from Ranichauri germplasm collection	1996	115-120	North-Western Himalayan
8	PRA-2	Selection from Sabli local (PRA-9101	2000	132	North-Western Himalayan region
9	PRA-3	PRA 8801 X Suvarna	2003	72-99	North-Western Himalayan
10	RMA-4	Selection from IC 35647	2009	122	Plain zone
11	RMA-7	Selection from RU 7-SPS 7	2011	126	Plain zone
12	Suvarna	Selection from R-104-1-1	1992	85 - 90	Peninsular Region
13	VL Chua-44	Pure line selection from IC 5564	2006	116	Uttarakhand hills

Source: Underutilized Crops: Varieties Released (1982-2012) in India (Raiger and Bhandari, 2012).

Table 2 : Quality parameter (%) of release varieties of grain amaranth.

Variety code	Varieties	Protein (%)	Lysine (%)	Oil (%)	Ca (mg/100 g)	Fe (mg/100 g)	Zn (mg/100 g)	K (mg/100g)
G1	Annapurana	15.90	5.80	8.70	321.00	11.60	6.20	568.00
G2	BGA-2	14.20	5.20	9.70	315.00	21.40	7.50	436.00
G3	Durga	14.10	5.20	10.50	317.00	10.80	6.80	566.00
G4	GA-1	15.90	5.50	11.80	264.25	5.90	2.70	418.00
G5	GA-2	14.10	5.70	8.70	327.00	15.90	7.20	428.00
G6	GA-3	13.70	5.60	-	-	-	-	-
G7	PRA-1	14.06	4.80	-	-	-	-	-
G8	PRA-2	15.00	5.80	9.10	308.00	11.10	5.80	574.00
G9	PRA-3	13.70	5.80	7.10	327.00	11.80	6.30	643.00
G10	RMA-4	13.60	5.80	-	-	-	-	-
G11	RMA-7	12.90	5.80	8.10	323.00	23.30	5.60	454.00
G12	Suvarna	16.80	5.60	10.30	327.00	30.10	7.20	412.00
G13	VL-44	11.80	-	6.30	308.00	10.40	5.20	-

at each location. The experimental plot consisted of 5.4m^{2}gross area and row to row and plant to plant distances was maintained at 45 cm and 15cm, respectively at all environments. Normal and uniform agronomical practices were followed. Grain yield was estimated on plot basis and converted into q/ha for each variety at each test location.

Statistical analysis : Combined analysis of variance (F Test) (Comstock and Moll, 1963) and eight non-parametric stability measures. Huehn (1979) and Nassar and Huehn (1987) proposed four non-parametric stability statistics ($Si^{(1)}$, $Si^{(2)}$, $Si^{(3)}$, $Si^{(6)}$) that combined mean yield and stability on yield rank of varieties in each environment. Non-parametric stability measures[($NP_i(1)$, $NP_i(2)$, $NP_i(3)$, $NP_i(4)$] (Thennarashu, 1995). Combined Stability Index ($CSI_{(i)}$) of ith variety is the sum of rank of mean yield of ith variety (RY_i), rank of mean rank of stability measures of ith variety and rank of standard deviation ($RSd_{(i)}$) of stability measures. All statistical analysis was done using MS-excel (2007), R, SPSS and SAS packages.

Results and Discussion

Test for significance of variety x environment interaction : In the present study, error mean squares of the four experiments were heteroscedasticity. This was confirmed by Bartlett's test, which showed a highly significant value for the Chi-square. Accordingly, the weighted analysis as explained by Cochran (1937), the computed ÷^{2} value with the significant point for test for GE interaction. Thus, the weighted analysis (χ^2, df 29=421.26**) showed the presence of GE interaction. As described earlier, not every interaction of this sort causes rank changes among the varieties (rank interaction), from the stand point of a breeder interaction might be tolerable so long as it does not affect rank orders. If the interaction is so large as to cause rank changes among varieties, then one can speak of rank interaction, which is also termed as qualitative or cross-over interaction and thus the true treatment differences vary not only in magnitude, but also in direction. In contrast, in quantitative or non-crossover interaction the treatment differences vary only in magnitude. Following the above-described concepts, the intensity of the interaction was assessed and conclusions were drawn on a strictly non-parametric approach.

Stability analysis : The non-parametric measures were based on the rank of the varieties across the locations. They showed equal weight for each location. The variety with less change in ranks are expected to be more stable for simultaneous selection of most suitable varieties (high yielding and stable), the calculated value of each non-parametric measures was plotted against mean grain yield performance separately (Table 3).

Each generated plot can be divided into four distinct sections *viz*.; section IV had low stability and low yield, section III low stability high grain yield and section II high stability and low grain yield and section I with high stability and high grain yield. The varieties in section I were most suitable (stable and high yielding). and were be selected. The varieties, RMA-4, Durga, GA-2, GA-3, and PRA-3had the lowest value and ranked 10th, 3rd, 1st, 4th and 12th for grain yield, respectively. For considering yield and stability measures, Durga, GA-2, GA-3 were the most stable high yielding varieties. The highest $Si^{(1)}$ for varieties Suvarna, RMA-7, PRA-1, VL-44, Annapurna, BGA-2, PRA-2, indicating to be highly unstable varieties. These varieties were released in

Table 3 : Mean grain yields and stability parameter for 13varieties of Grain amaranth tested in 5 environments.

Code	Accession No.	Mean (q/hq)	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	$NP_i(1)$	$NP_i(2)$	$NP_i(3)$	$NP_i(4)$
G1	Annapurana	7.61	4.20	10.80	5.40	1.20	3.40	0.34	0.40	0.56
G2	BGA-2	11.92	4.20	9.36	7.55	2.13	2.80	0.47	0.54	0.71
G3	Durga	13.65	1.80	1.84	2.56	1.78	1.40	0.35	0.45	0.61
G4	GA-1	14.10	4.00	8.56	10.19	3.14	3.00	0.75	0.90	1.14
G5	GA-2	14.19	2.40	3.84	5.33	2.67	3.20	1.60	1.09	1.50
G6	GA-3	13.04	3.60	6.64	7.22	2.52	2.40	0.60	0.62	0.87
G7	PRA-1	11.15	5.00	13.76	9.56	2.11	3.80	0.54	0.63	0.86
G8	PRA-2	8.43	4.20	11.44	6.09	1.45	4.20	0.38	0.51	0.68
G9	PRA-3	8.40	3.80	7.76	3.96	1.35	3.20	0.29	0.38	0.51
G10	RMA-4	9.18	0.60	0.24	0.13	0.25	1.60	0.16	0.23	0.31
G11	RMA-7	11.34	5.40	15.36	9.85	2.21	3.80	0.48	0.55	0.77
G12	Suvarna	11.04	5.60	16.16	11.22	2.33	2.80	0.35	0.50	0.69
G13	VL-44	9.76	4.40	10.24	6.74	1.79	3.40	0.49	0.54	0.74
	LSD (0.05)	3.24								

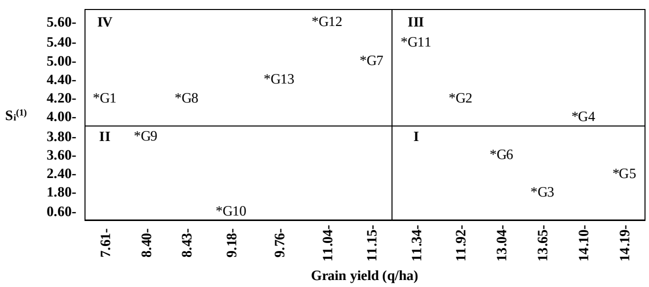

Fig. 1 : The plot $S_i^{(1)}$ against mean grain yield (q/ha) of grain amaranth varieties over environment.

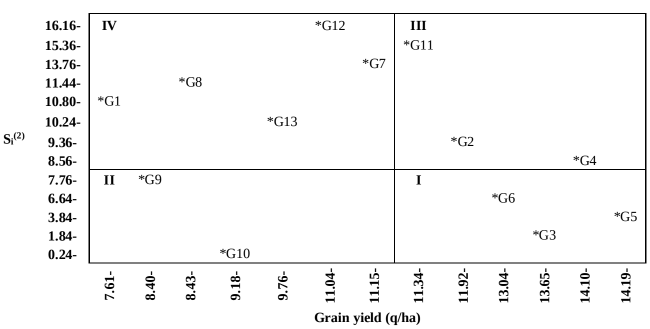

Fig. 2 : The plot $S_i^{(2)}$ against mean grain yield (q/ha) grain amaranth varieties over environment.

different years for hill areas except RMA-7 and BGA-2 which were not good performer in plain regions of India (Figs. 1 and 2).

The sections 1st revealed that varieties Durga, GA-3, GA-2 with high grain yield and small $Si^{(1)}$ values can be considered as a stable and well adopted to all environments. $Si^{(2)}$ estimates are simply the variance of the ranks for each variety across the locations. For the variance of the rank, $Si^{(2)}$ estimates show the relative stability. The varieties RMA-4, Durga, GA-2 were considered stable due to less value of $Si^{(2)}$, whereas RMA-4, Durga, GA-2 ranked 10th, 3rd and 1st for mean grain yield, respectively. Considering both the criteria of yield and stability parameter of $Si^{(2)}$, Durga & GA-2 were found as the most stable high yielding genotypes (in Section-I). Durga variety was recommended for hill areas of India, but performed well both in plain and hill regions. The varieties Suvarna, RMA-7, PRA-2 had a highest value of $Si^{(2)}$ which were considered unstable in plain regions.

The $Si^{(3)}$ and $Si^{(6)}$ non-parametric measures were calculated by using the ranks which were given to varieties on the basis of original mean data within the environment. The results of $Si^{(3)}$ and $Si^{(6)}$ showed that varieties RMA-4, Durga ranked1st and 2nd, respectively. They occupied 10th,3rd positions in mean grain yield as well. Based on these parameters, Durga is most suitable variety both for plain and hill regions.

The variety Durga was found to be stable and adopted to all environments both for hills and plains. The estimates of $Si^{(3)}$ and $Si^{(6)}$ revealed that the varieties Suvarna, GA-1 were found to be the most unstable varieties. The plot of $Si^{(3)}$ and $Si^{(6)}$, mean grain yield for Grain amaranth varieties over locations were portrayed and divided in to four sections. The variety Durga with high grain yield and small values of $Si^{(3)}$ and $Si^{(6)}$ can be considered as a stable variety and adopted well to all environments in plain regions. Section IV exhibits that the variety are low yielding and small values of $Si^{(3)}$ and $Si^{(6)}$ indicating resistance to environment fluctuations and therefore increasing specificity of adaptability to low yield in environments (Figs. 3 and 4).

Thennarasu's (1995) non-parametric stability

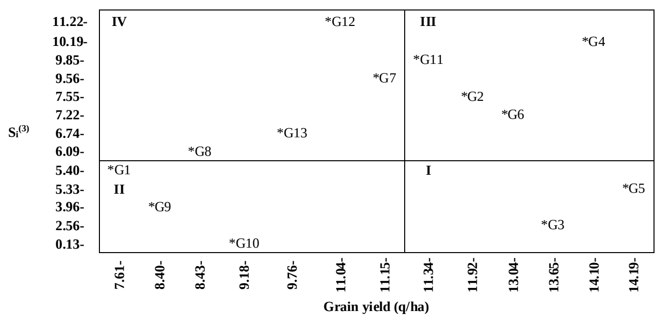

Fig. 3 : The plot $\mathbf{S_i^{(3)}}$ against mean grain yield (q/ha) of grain amaranth varieties over environment.

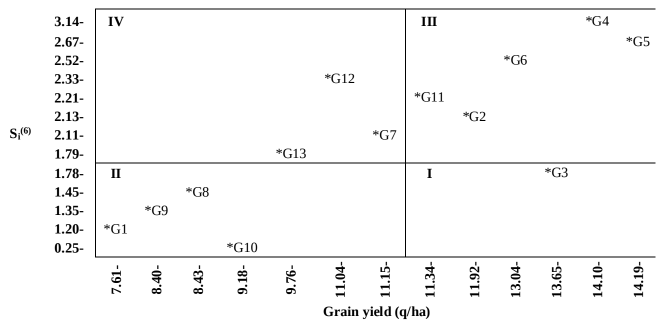

Fig. 4 : The plot $\mathbf{S_i^{(6)}}$ against mean grain yield (q/ha) of grain amaranth varieties over environment.

measures for grain yield of 13 varieties are presented in Figs. 5-8. The stability measures [$NP_i(1)$, $NP_i(2)$, $NP_i(3)$, $NP_i(4)$]. The varieties Durga, RMA-4, GA-3 & Suvarna with lower $NP_i(1)$ values were identified as stable in comparison to other varieties.

Fig. 2 revealed that the varieties RMA-4, PRA-3, Annapurna and Durga had the lowest $NP_i(2)$ values and thus were stable, while varieties GA-1, GA-2 had the highest values and were considered as unstable. The varieties RMA-4, PRA-3, Annapurna & Durga had the lowest value $NP_i(3)$, and therefore were the most stable varieties. However, the varieties GA-2, GA-1 with maximum values were identified as unstable varieties. ThevarietiesRMA-4, PRA-3, Annapurna & Durga had the lowest $NP_i(4)$ values and therefore were the most stable. The $NP_i(2)$, $NP_i(3)$ &$NP_i(4)$ measures gave same performance in selecting the varieties for stability but the negative response with yield (Raiger and Jajoriya, 2019). Thus, selection based on these stability parameters would be less useful when yield is the primary target of selection. On the basis of Thennarasu's (1995) non-parametric stability measures, Durga variety is most stable and high yielding whereas the GA1, and GA-2with highest value of $NP_i(4)$ were unstable varieties.

Combined Stability Index of variety : The genotypic selection index was calculated by ranking the mean grain yield of the varieties across the environments and standard deviation of the rank of eight stability

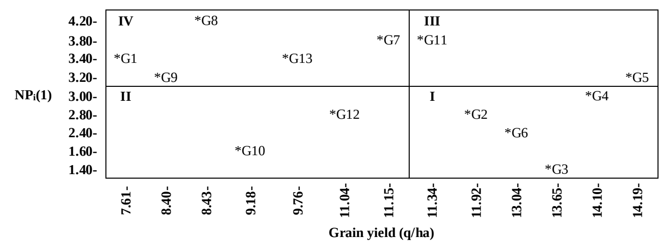

Fig. 5 : The plot $NP_i(1)$ against mean grain yield (q/ha) of grain amaranth varieties over environment.

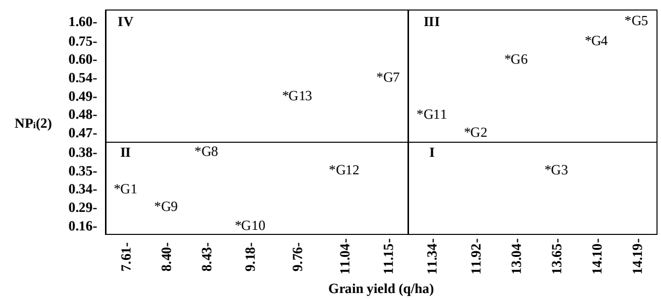

Fig. 6 : The plot $NP_i(2)$ against mean grain yield (q/ha) of grain amaranth varieties over environment.

measures (*Sdi*). The rank of standard deviations and eight stability measures were calculated. Combined Stability Index is measured in terms of sum of the rank yield mean rank and the rank of standard deviation of rank stability measure. Low values of this parameter are considered for selection of a stable variety and with high yield. The varieties Durga ($CSI_{(i)}$=11), BGA-2 ($CSI_{(i)}$=14) were identified as a most stable and with high potential yield varieties on the basis of Combined Stability Index. Table 4 showed ranking frequencies for eight stability measures

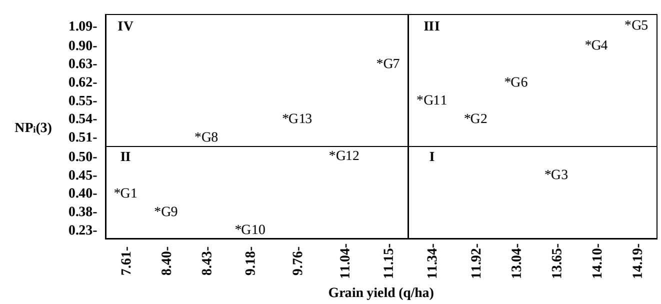

Fig. 7 : The plot $NP_i(3)$ against mean grain yield (q/ha) of grain amaranth varieties over environment.

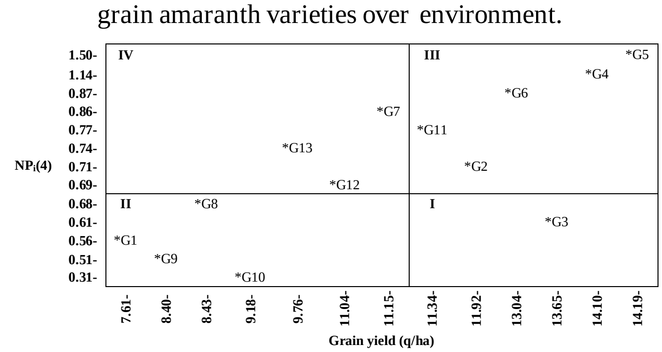

Fig. 8 : The plot $NP_i(4)$ against mean grain yield (q/ha) of grain amaranth varieties over environment.

Table 4 : Estimated combined Stability Index of Grain amaranth variety.

S. no.	Varieties	Rank of Yield and Stability Measures									$Mean(\overline{R})$	$Mean(\overline{R})$	$Sd^{(i)}$	Rank of $Sd^{(i)}$	$ISC^{(i)}$	Frequency
		Mean	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	$NP_i(1)$	$NP_i(2)$	$NP_i(3)$	$NP_i(4)$						
G1	Annapurana	13	7	9	5	2	9	3	3	3	6.00	**4**	3.74	10	27	8
G2	BGA-2	5	7	7	9	8	4	7	7	7	6.78	**5**	1.48	3	14	8
G3	Durga	3	2	2	2	5	1	4	4	4	3.00	**2**	1.32	2	11	8
G4	GA-1	2	6	6	12	13	6	12	12	12	9.00	**11**	4.00	12	20	**1**
G5	GA-2	1	3	3	4	12	7	13	13	13	7.67	**8**	5.07	13	20	4
G6	GA-3	4	4	4	8	11	3	11	10	11	7.33	**6**	3.54	9	19	4
G7	PRA-1	7	11	11	10	7	11	10	11	10	9.78	**13**	1.64	4	22	0
G8	PRA-2	11	7	10	6	4	13	6	6	5	7.56	**7**	3.05	7	23	1
G9	**PRA-3**	12	**5**	**5**	**3**	**3**	**7**	**2**	**2**	**2**	4.56	**3**	3.28	8	27	5
G10	**RMA-4**	10	**1**	**1**	**1**	**1**	**2**	**1**	**1**	**1**	2.11	**1**	2.98	6	24	8
G11	RMA-7	6	12	12	11	9	11	8	9	9	9.67	**12**	2.00	5	21	0
G12	Suvarna	8	13	13	13	10	4	4	5	6	8.44	**10**	3.91	11	26	2
G13	VL-44	9	10	8	7	6	9	9	8	8	8.22	**9**	1.20	1	19	0
Correlation with rank mean **grain** yield		1.00	0.21*	0.31*	-0.25*	-0.81**	0.37*	-0.72**	-0.72**	-0.75**						

* Significant at the 0.01 probability level** significant at the 0.05 probability level.

and mean yields. The varieties were divided in three layers (Top, Mid, Low) in each environment. The variety in the top four ranks from each environment were categorized as stable and more adaptive. The stable variety based on ranking frequency was Durga (8) and considered as the most suitable variety for plain regions where this variety was initially released for hill regions of India. Durga is most suitable variety for plain as well as hill areas. Durga variety is early maturing, high protein content, high yielding which can be recommended for cultivation across the India (Hills & Plains). The production and productivity of grain amaranth could be increased drastically in India.

Relationship between mean grain yield and stability measures

The relationship between statistical measure and mean grain yield was estimated for each variety and are presented in Table 4. The mean grain yield was significantly and positively rank correlated with $Si^{(1)}$,$Si^{(2)}$ and $NP_i(1)$ (Category I), applied non-parametric measures reported positive rank correlations between $S_1^{(1)}$ and $S_1^{(2)}$ in job's tear (*Coix lacryma-jobi* L.) non-significantly and negative correlated with $S_i^{(3)}$, $S_i^{(6)}$, (Category II) and significant negatively correlated with $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ (Category III). As the parameters under category I are most suitable to find out the best variety and therefore, either of these three parameters ($S_i^{(1)}$, $S_i^{(2)}$ and $NP_i^{(1)}$) can suitably be used to find out the best stable variety. Based on these parameters, the variety Durga was found to be the best suitable variety for plain regions of India.

Relationship between quality traits and stability measures

The stability measures ($S_i^{(1)}$, $S_i^{(2)}$ and $NP_i^{(1)}$) were positively co-related to mean seed yield. Quality traits (protein, oil content and minerals (Raiger *et al.*,2009) are given in Table

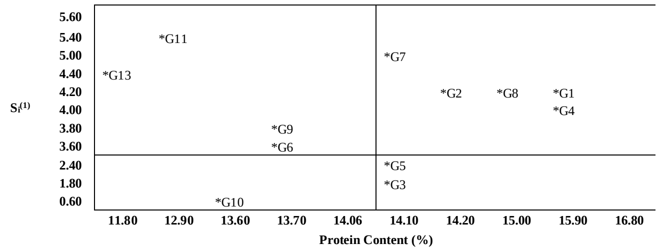

Fig. 9 : The plot Si$^{(1)}$ against mean Protien content (%).

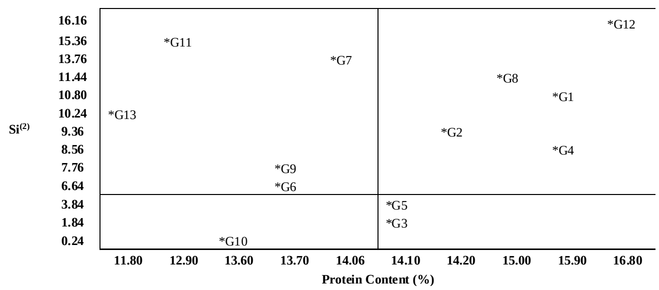

Fig. 10 : The plot Si$^{(2)}$ against mean Protien content (%).

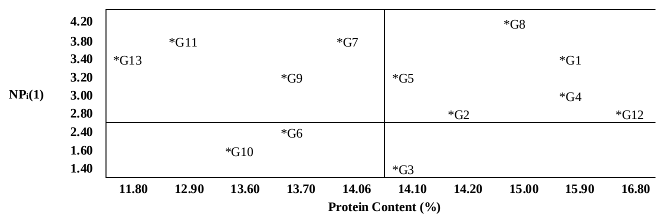

Fig. 11 : The plot NP$_i$(1) against mean Protien content (%).

No.8. The stability measures were plotted with quality parameters. The variety Durga appeared in section-I (Figs. 9-11). The protein was plotted against the stability measure and positively correlated with mean seed yield (Figs. 9, 10 and 11). The varieties were found distributed in different sections (Figs. 9, 10 and 11). The section-I included the variety Durga (G-3), which was considered to be the most stable and well adopted variety across environments with high protein content. Similar trend was observed for oil content, calcium and potassium contents in Durga whereas iron and zinc content were found high in unstable genotypes. The present investigation clearly revealed that quality parameter as well as stability measures will help in selecting a good variety by the farmers across environments.

Conclusion

The eight stability measures that were used in this study helped in identifying suitable varieties for seed yield, stability and both of them simultaneously. Selection of a variety for high yield and stability at a time was found to beautiful effect of the variety and environment interaction and selection of variety can be done in refined manner. GxE interaction were highly significant ($p<0.05$), suggesting different response of varieties to the test location/year. Based on low value of non-parametric measures and combined stability index, Durga was identified as most stable and well potential yielding variety across the environments in plain regions of the country.

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Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Authors' contribution

HL Raiger writing, editing nutritional traits and plant descriptors and discussion. NK Jajoriya data collection and table formation. All authors contributed to the article and approved the submitted version.

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