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Genotype x environment interactions and stability analysis in elite lines of garlic (*Allium sativum* L.)

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Abstract

Thirty five elite lines and three released varieties of garlic (*Allium sativum*) were evaluated for their stability, with respect to yield and its contributing traits, for three years at Rajgurunagar (Maharashtra) during *rabi* season. Analysis of variance for stability of different characters indicated that mean differences for varieties and environments (years) were significant for all the characters except for number of leaves, indicating that the performance with respect to number of leaves in different years was not stable. Genotype 50 gave stable performance for higher plant height, clove weight, total yield and marketable yield, while genotypes 74 and 163 gave better yield under adverse situations. Genotype 117 had stability for dwarf plant height, less number of leaves and more equatorial diameter. Genotype 58 had stability in desired direction for less number of leaves and lesser neck thickness. Genotype 52 showed stability for higher plant height, greater neck thickness and average number of cloves with less number of leaves. Variety G-41 was stable for marketable yield only. In genotypes 52, 58, 117, 163, 200, 229 and variety G-41, the yield was more in favourable environmental conditions.

Key words: *Allium sativum*, garlic, genotype x environment interaction, stability analysis.

Introduction

Studies on performance of various genotypes of crop plants in different agro-climatic conditions provide information on genotype x environment (G x E) interactions but does not give information on stability of individual entries. In order to identify a stable genotype, stability analysis is of paramount importance and has been widely dealt in various field crops. However, little information is available on this aspect in garlic (*Allium sativum* L.). Hence, the present investigation was carried out on 35 elite lines along with 3 released varieties of garlic to identify a suitable and stable genotype for higher yield and other desirable traits.

Materials and methods

Thirty-five elite lines of garlic were evaluated along with three checks namely, G-41, GG-2 and GG-3 for three years. The crop was planted in a plot size of 3 m x 2 m in a randomized block design in the first fortnight of October for three years during 2000-01 to 2002-03 at National Research Centre for Onion and Garlic, Rajgurunagar (Maharashtra) representing VII Agricultural Zone. The crop was spaced at 15 cm x 10 cm with a fertilizer dose of 100:50:50 kg NPK ha^{-1}. A basal dose of NPK @ 50:50:50 kg ha^{-1} was applied at the time of planting whereas the remaining dose of N was applied in two split doses at an interval of 30 days after planting. Plant protection measures were followed uniformly in all the genotypes against thrips and diseases. Observations on plant height, number of leaves, polar and equatorial diameter of bulb, neck thickness, number of cloves, weight of 5 bulbs and weight of 50 cloves were recorded from 10 representative samples in each treatment. Total yield and marketable yield were calculated on the basis of plot yield. Vegetative growth characters were recorded at 100-110 days after planting and bulb characters were recorded after 10-15 days field curing of bulbs. Data were analysed on the basis of mean performance over the years as per the model suggested by Eberhart & Russell (1966) for different characters.

Results and discussion

Analysis of variance (pooled for three years) for stability of different characters indicated that the mean differences for varieties and environments (years) were significant for all the characters except for number of leaves (Table 1). These results are in conformity with the findings of Singh *et al.* (2000). Similarly, the effect of G x E was also significant for all the traits except plant height, clearly indicating that the genotypes interacted with the environment. Hence, stability analysis was further carried out.

The mean sum of squares due to G x E (linear) was significant for average weight of five bulbs and marketable yield showing that there were large differences among environments for these traits. Similar results were also reported by Kumar *et al.* (1994). Varietal differences for regression over environmental mean were further revealed from the highly significant mean squares due to environment (linear) for all the characters except polar diameter. Magnitude of variance due to environment (linear) for all the characters

Table 1. Analysis of variance for growth and bulb traits in elite lines of garlic

Source of variation	df	Test against MSS (F Test)	Plant height (cm)	No. of leaves	Polar diameter (cm)	Equatorial diameter (cm)	Neck thickness (cm)	Average no. of cloves	Average wt. of 5 bulbs (g)	Average wt. of 50 cloves (g)	Total yield ($t\ ha^{-1}$)	Marketable yield ($t\ ha^{-1}$)
G	37	G x E^{+}, PD^{*}	$6.953^{++,*}$	0.192	$0.096^{++,**}$	0.083+	$0.015^{+,**}$	$33.704^{++,**}$	$517.119^{++,**}$	$168.724^{++,**}$	$19.822^{++,**}$	$18.119^{++,**}$
E	2	G x E	351.917**	86.095**	0.011	1.921**	2.764**	214.002**	704.657*	683.911**	157.020**	130.899**
G x E	74	PE	3.118	0.125**	0.027**	0.047**	0.009**	10.593**	174.797**	41.725**	2.957**	2.853**
E + (G X E)	76	PD	12.297**	2.387**	0.026	0.096*	0.082**	15.945	188.740*	58.625	7.011**	6.222**
E (Linear)	1	PD	703.835**	172.192**	0.023	3.841**	5.529**	428.003**	1409.314**	1367.822**	314.041**	261.799**
G x E (Linear)	37	PD	2.605	0.084	0.015	0.034	0.011	9.163	283.098*	42.777	4.070**	3.421
Pooled deviation	38	PE	3.535	0.161**	0.037**	0.057**	0.007**	11.706**	113.430**	39.604**	1.794**	2.225**
Pooled error	228		2.604	1.668	0.011	0.092	0.003	5.46	48.630	20.047	0.909	0.982

*, +=Significant at 5% level; **, ++=Significant at 1% level
G=Genotype; E=Environment

over G x E (linear) were high which might be the reason for higher adaptation in relation to yield and other characters which is in accordance with the observations of Mohanty & Prusti (2001) in onion. Significant mean squares due to E + (G x E) interactions for the plant height, number of leaves, equatorial diameter, neck thickness, weight of five bulbs, total and marketable yield also indicated that the varieties interacted considerably with existing environmental conditions for these characters. The genotypes differed significantly with respect to stability for all the characters under study except for plant height, which is indicated by the significant pooled deviation indicating the presence of divergent genetic response of the genotypes to different environments (Jatasra & Paroda 1979). The pooled deviation was non significant only for plant height, indicating the absence of non-linear interactions for this character.

Stability analysis and genotype performance studies were done also for various characters (Tables 2 & 3). Three parameters namely, mean performance (X) and stability parameters i.e., b_i and S^2d_i were considered for determining the performance of various characters over environment. Grouping of genotypes on the basis of mean performance and stability parameters was also performed (Table 4). Dwarf plant height was stable in the genotypes 49, 51, 55, 63, 66, 92, 96 and 117, whereas taller plant height was stable in the genotypes 44, 50, 52, 200 and 201. The genotypes 38, 88, 217 and 219 were unstable. More number of leaves was stable in the genotypes 49, 55, 63, 72, 75, 100, 163 and 200 whereas, the genotypes 37, 38, 44, 52, 58, 61, 66, 73, 88, 92, 96, 98, 117, 225, 257 and varieties GG-2 and GG-3 exhibited stable performance for less number of leaves. Similar results were also reported by Singh *et al.* (2000) for variety G-41 which had more number of leaves under poor environment. None of the genotypes showed stable performance for higher polar diameter over population mean. The genotypes 221 and 229 had more polar diameter under favourable environment, while the genotypes 55, 61, 72 and 163 showed higher polar diameter under poor environment. Thirteen genotypes including the varieties G-41 and GG-3 were unstable for polar diameter. Two genotypes namely, 72 and 117 gave stable performance for equatorial diameter whereas the genotypes 75, 183, 200, 221, 229 and variety G-41 indicated their stability to favourable environmental conditions. Lower mean value, bi value close to one and non significant S^2di, indicative of stability for neck thickness, were found in the genotypes 55, 58, 61, 66, 100 and 217. Lower neck thickness gives more storability potential as reported by Singh *et al.* (2000). But Selvaraj *et al.* (1997) reported that neck diameter was directly and positively correlated with yield. Genotypes with higher neck thickness namely 37, 49, 52, 74, 117, 163 and G-41 were found to be stable. After considering the neck thickness with marketable yield it was found that genotype 117 had medium neck thickness and genotype 58 had thin neck and were stable for respective environments with little higher marketable yield than the population mean over environments.

Number of cloves and weight of 50 cloves were negatively correlated with each other as reported by Korla & Rastogi (1979). The genotypes 55, 66, 200 and 257 had stable and less number of cloves than the population mean over environment and stability in nine genotypes was found to be unpredictable. With reference to weight of five bulbs, none of the genotypes showed stable performance for higher bulb weight. The genotypes 52, 72, 74, 100, 117, 163, 200, 219, 229 and variety G-41 performed well under the favourable environment and the genotypes 37, 63 and 201 under the poor environment. Eight genotypes and the varieties GG-2 and GG-3 had unstable performance which was also reported by Singh *et al.* (2000) in GG-2. The genotypes 50 and 183 were found to be stable for more clove weight but it showed unstability for number of cloves. These findings are in conformity with the observations made by Singh *et al.* (2000) in garlic. The genotypes 61, 200, 219, 221, 225 and variety GG-3 had higher

Table 2. Genotypic performance and stability parameters of some promising lines of garlic

Genotype	Plant height (cm)			No. of leaves			Polar diameter (cm)			Equatorial diameter (cm)			Neck thickness (cm)		
	Mean	S^2d_i	b_i	Mean	S^2d_i	b_i	Mean	S^2d_i	b_i	Mean	S^2d_i	b_i	Mean	S^2d_i	b_i
44	52.65	-0.365	0.899	8.74	-0.002	1.075	2.46	-0.006	3.537	3.11	0.093**	0.650	0.58	0.006	1.231
49	51.57	-2.081	1.068	8.91	-0.064	1.097	2.63	0.070**	14.537	3.21	0.094**	1.817	0.70	-0.001	0.981
50	54.46	-0.617	1.043	8.98	0.034	0.847	2.63	0.015	-0.049	2.97	-0.008	0.200	0.53	0.000	0.629
51	52.02	-1.781	1.076	8.48	0.435*	0.998	2.57	-0.012	7.695*	2.98	-0.015	1.407	0.65	-0.004	0.849
52	52.40	0.883	0.957	8.81	-0.077	1.081	2.63	-0.010	-2.512	3.24	-0.014	.6.5	0.69	-0.004	1.038
55	51.96	1.198	1.058	9.11	-0.062	1.026	2.72	-0.007	-2.907	3.07	-0.016	0.549*	0.61	0.005	1.134
58	53.04	-1.591	1.362	8.76	-0.070	1.043	2.58	-0.010	-6.883	3.12	-0.006	0.050	0.59	-0.001	0.954
61	54.23	-2.579	0.417	8.78	0.066	0.969	2.67	-0.005	-0.025	3.10	0.052*	1.100	0.62	0.001	1.006
63	51.98	-1.657	1.084	9.03	-0.043	0.966	2.61	0.053*	-3.636	3.43	-0.006	0.637	0.67	0.005	0.515
66	50.42	-2.531	0.871	8.65	0.069	1.032	2.54	-0.006	-3.345	2.97	-0.011	0.865	0.57	0.002	0.932
72	52.16	-1.030	0.829	8.99	-0.077	0.972	2.81	-0.011	-3.563*	3.24	-0.015	1.062	0.69	-0.004	1.268*
75	51.12	-1.391	1.163	8.97	-0.074	1.103	2.51	0.001	7.921	3.10	0.040	1.405	0.61	0.033**	1.383
92	49.97	4.074	0.974	8.64	-0.055	1.122	2.44	0.025	4.963	2.71	0.058*	1.043	0.55	-0.003	0.715
96	51.26	-0.343	0.898	8.81	0.038	0.882	2.59	0.002	-5.326	3.82	0.032	0.175	0.66	0.013*	1.254
100	49.03	-1.726	2.067	9.13	-0.077	1.041	2.58	-0.011	-1.832	3.16	0.060*	0.800	0.61	-0.002	1.019
117	51.44	-1.550	0.914	8.83	-0.064	1.057	2.65	0.000	0.160	3.27	0.033	1.082	0.68	-0.002	1.116
163	53.50	-1.760	1.340	9.07	-0.055	0.919	2.79	0.006	-2.270	3.09	-0.016	0.042*	0.67	-0.003	1.347
183	53.82	2.321	1.321	9.50	-0.066	1.270	3.02	0.035*	9.684	3.50	0.042	1.419	0.83	-0.004	1.460*
200	54.50	-2.098	0.970	9.16	-0.021	0.890	2.91	0.115**	7.994	3.34	0.000	1.738	0.69	0.009	1.303
217	51.23	8.269*	1.178	8.97	0.579**	1.223	2.58	0.000	3.687	3.10	0.061*	1.067	0.56	0.005	0.942
221	53.89	-0.613	0.580	9.16	0.144	1.177	3.04	-0.011	10.013	3.31	0.041	1.806	0.67	0.020*	1.328
229	53.77	0.834	0.561	9.48	0.639**	1.153	2.92	0.021	3.131	3.22	-0.004	1.470	0.68	0.003	0.808
G-41	54.52	-0.791	0.652	9.04	0.172	0.716	2.91	0.042	-0.893	3.24	-0.004	1.281	0.71	0.005	0.925
GG-2	52.31	0.638	0.270	8.80	-0.035	0.904	2.41	-0.009*	1.235	2.78	0.189**	0.580	0.50	0.008	0.632
GG-3	50.64	2.142	1.364	8.56	-0.070	0.882	2.38	0.108**	-1.450	3.06	0.035	0.280	0.53	0.000	0.629
Pop. mean	52.20			8.91			2.66			3.13			0.63		
SE±m	1.33			0.28			0.14			0.17			0.06		

* Significant at 5% level; ** Significant at 1% level

Table 3. Genotypic performance and stability parameters of some promising lines of garlic

Genotype	Average no. of cloves			Average wt. of 5 bulbs (g)			Average weight of 50 cloves (g)			Total yield (t ha^{-1})			Marketable yield (t ha^{-1})		
	Mean	S^2d_i	b_i	Mean	S^2d_i	b_i	Mean	S^2d_i	b_i	Mean	S^2d_i	b_i	Mean	S^2d_i	b_i
50	16.67	23.649*	1.712	65.56	336.528**	-0.337	40.28	25.060	1.037	12.35	1.414	0.836	11.24	1.723	0.871
52	26.99	-5.308	1.087	85.28	-46.529	1.484	33.89	7.766	2.128	13.65	-0.821	1.368	12.49	-0.282	1.511
55	22.31	-5.099	1.039	65.83	183.592*	-3.472	27.06	-19.913	0.749	10.40	0.097	0.528	8.84	-0.805	0.646
58	25.11	-4.620	2.365	73.06	89.987	1.841	32.22	-8.171	-0.174	11.95	0.417	1.329	10.98	-0.979	1.444
63	28.54	26.012*	0.619	79.17	-46.182	0.849	31.94	-19.804	0.790	13.27	-0.844	1.363	12.31	-0.879	1.455
66	18.44	0.009	1.146	65.56	-44.276	1.132	35.83	-18.168	1.465	8.42	-8.205	0.794	7.28	-0.392	0.703
72	28.29	33.955**	1.175	89.72	68.961	3.608	29.44	-5.889	-0.073	13.03	4.743*	1.202	11.88	4.537*	0.863
74	21.22	12.815	1.074	105.00	-30.529	2.992	45.83	-2.242	0.562	13.59	-0.763	-0.209	12.64	1.208	-0.068
100	25.41	-4.108	-0.340	82.50	-3.069	3.910	38.06	294.079**	-0.079	8.78	-0.597	1.569	7.50	0.310	1.236
117	27.68	5.416	1.692	79.17	-43.348	2.004	30.83	-16.953	1.191	11.29	1.881	1.187	10.25	0.636	1.238
163	24.23	7.966	0.703	84.44	-48.407	2.910	40.00	-10.253	-0.274	12.21	-0.917	1.470	10.60	-0.806	0.761
183	23.64	44.318**	2.209	102.50	577.490**	4.223	48.33	-18.533	0.876	16.29	0.958	1.828	15.46	-0.909	1.830
200	20.96	-5.051	1.135	100.56	38.970	2.495	49.72	-20.035	1.867	15.66	-0.270	1.338	14.96	-0.536	1.587
201	21.33	-2.955	0.594	87.22	-44.157	-5.290	44.72	125.435**	0.608	14.38	0.212	1.550	13.10	-0.707	1.574
219	22.73	-4.754	0.560	89.44	-17.175	3.015	38.33	2.499	1.506	12.91	16.462**	2.689	12.14	3.774*	2.984
221	20.39	-0.681	0.248	103.61	290.916**	0.608	49.44	-20.041	2.556	15.31	4.914*	2.053	13.99	0.926	2.129
229	21.42	-5.417	0.218	93.06	-1.506	1.577	44.72	-9.119	0.415	14.52	0.487	1.810	13.68	-0.433	1.882
257	22.34	-5.470	0.905	61.67	77.973	1.558	33.89	-17.542	-0.502	11.79	3.336*	0.695	10.07	2.098	0.566
G-41	21.62	-2.280	0.764	95.56	-45.400	4.701	46.94	-19.449	-0.388	15.03	-0.537	1.262	14.36	0.934	1.008
GG-2	18.29	-4.916	-0.506	62.78	-48.000	-2.321	38.61	166.121**	0.016	7.30	0.324	0.000	5.93	-0.305	0.027
GG-3	20.64	-4.319	2.041	65.28	24.108	-2.189	37.50	24.580	2.315	7.37	-0.952	0.321	5.93	-0.890	0.223
Pop. mean	23.18			77.71			36.98			11.37			10.20		
SE±m	2.42			7.53			4.45			1.05			0.95		

* Significant at 5% level; ** Significant at 1% level

Table 4. Grouping of best three lines of garlic on the basis of mean, regression coefficient (b_i), deviation from regression (S^2d_i) of yield and yield attributing traits

Character	>Mean, $b_i>1$, S^2d_i (NS)	>Mean, $b_i=1$, S^2d_i (NS)	>Mean, $b_i<1$, S^2d_i (NS)	<Mean, $b_i>1$, S^2d_i (NS)	<Mean, $b_i=1$, S^2d_i (NS)	<Mean, $b_i<1$, S^2d_i (NS)	< or > Mean, b_i < = >, S^2d_i (S)
Plant height	58, 163, 183	50, 200, 201	37, 61, 221	73, 257, 263	66, 92, 96	53, 72	38, 88, 217, 219
No. of leaves	183, 221	55, 100, 200	50, 74, G-41		92, 257, GG-3	53, 201	51, 174, 217, 219, 229, 263
Polar diameter	221, 229		55, 72, 163	44, 92, GG-2	53	88, 98, 257	37, 38, 49, 63, 74, 174, 183, 200, 201, 219, 263, G-41, GG-3
Equatorial diameter	183, 200, 221	72, 117	52, 63	51, 98, 225	66	37, 50, 257	44, 49, 61, 73, 74, 88, 92, 100, 174, 201, 217, 219, 263, GG-2
Neck thickness	183, 200, 263	49, 74, G-41	63, 174, 229	44, 73, 98	58, 66, 217	50, GG-2, GG-3	53, 75, 96, 221
No. of cloves	58, 96, 117	52, 217, 225	49, 53, 100	38, 74, GG-3	55, 66, 200	61, 201, GG-2	37, 50, 63, 72, 88, 98, 174, 183, 263
Wt. of 5 bulbs	74, 200, G-41		37, 63, 201	73, 92, 257	66	75, GG-2, GG-3	49, 50, 55, 88, 96, 183, 221, 263
Wt. of 50 cloves	61, 200, 221	50, 183	74, 229, G-41	44, 75, 117	51, 53, 217	55, 73, 88	37, 38, 100, 174, 201, GG-2
Total yield	183, 200, G-41	50	74	73, 88, 100	38, 49, 98	51, GG-2, GG-3	44, 72, 96, 217, 219, 221, 257, 263
Marketable yield	183, 200, 221	50, G-41	74, 163	49, 73, 100	38, 53, 98	51, GG-2, GG-3	44, 72, 88, 96, 217, 219, 263

NS=Non-significant; S=Significant

clove weight in favourable environmental conditions whereas the genotypes 74, 163, 229, 263 and variety G-41 gave higher clove weight under adverse environmental situations.

The genotype 50 exhibited stable performance over the environments with higher total and marketable yield, whereas G-41 showed stability to marketable yield only. The genotypes 52, 58, 63, 183, 200, 201 and 229 gave better performance in favourable environment for both total and marketable yield, whereas the genotypes 117 and 221 were found to be better for marketable yield and genotype 163 and variety G-41 for total yield in favourable conditions only. Genotype 74 performed better in poor environment for both total and marketable yield and genotype 163 for marketable yield only.

In conclusion, genotype 50 gave stable performance for higher plant height, clove weight, total yield and marketable yield whereas, G-41 was stable for marketable yield and higher neck thickness but had more equatorial diameter, weight of five bulbs and total yield in favourable environmental conditions. Genotype 117 had stability for three characters namely, dwarf plant height, less number of leaves and more equatorial diameter while more number of cloves, weight of bulb and marketable yield were more in favourable environment. Genotype 58 had stability for lesser number of leaves, less neck thickness along with total yield and higher marketable yield in favourable environmental conditions. Genotype 52 showed stability for higher plant height, higher neck thickness and more number of cloves with less number of leaves. Weight of bulb, total and marketable yield were also more in favourable environment while more equatorial diameter was revealed under poor environment. Genotype 200 showed stability for less number of cloves, higher plant height and more number of leaves but equatorial diameter, weight of bulb, weight of cloves, total yield and marketable yield were more in favourable environmental conditions. Genotype 163 had stable performance for more number of leaves and higher neck thickness but weight of bulb and total yield were more in favourable situations, whereas polar diameter, weight of cloves and marketable yield showed higher values under unfavourable situations. Genotype 229 had more polar diameter, equatorial diameter, weight of 5 bulb, total yield and marketable yield in suitable environmental conditions, whereas number of cloves were less with more weight of cloves in unfavourable environmental situations. Genotype 74 gave higher total yield, marketable yield, more clove weight in poor environment and had less number of cloves, more bulb weight in favourable environment with stable performance for higher neck thickness. Hence, genotype 50 can be directly used for maximizing garlic production under short day conditions after undergoing large-scale multilocation trials. Whereas, emphasis on genotypes 52, 58, 74, 163, 117, 163, 200, 229 may be given to develop high yielding varieties. Because of the asexual nature of garlic, normal sexual hybridization programme cannot be initiated for its improvement. Therefore, exploitation of these genotypes, through conventional breeding namely, clonal selection or non conventional techniques namely, development of mutants or somaclonal variants may be considered for development of high yielding and stable garlic varieties ideal for short day Indian conditions.

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