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Morphological variability and character association in diverse collection of garlic germplasm

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Analysis of variance (mean square) revealed the existence of highly significant variation for all the traits except leaf width (4th leaf) indicating greater variability in the germplasm. High estimates of heritability were obtained for pseudostem diameter, days to maturity, polar diameter of bulb, equatorial diameter of bulb, average weight of 10 cloves and plant height. Average weight of 10 cloves, number of cloves per bulb, bulb yield per hectare, equatorial diameter of bulb and plant height exhibited higher value of genetic advance as percentage of mean. High heritability coupled with high genetic advance as percentage of mean was observed for equatorial diameter of bulb, average weight of 10 cloves and plant height at 60 days after planting (DAP) suggesting that they can be improved through direct selection. Path coefficient analysis revealed that highest consideration for varietal improvement should be given to plant height, polar diameter of bulb, average weight of 10 cloves, number of cloves per bulb and pseudostem diameter and these traits are also positively and significantly correlated with bulb yield per plant in garlic.

Key words: Garlic germplasm, traits, analysis of variance.

INTRODUCTION

Garlic (*Allium sativum* L.), is one of the most important remunerative bulbous spice and medicinal crop grown commercially. It is the second most widely used spice after onion. Garlic is grown globally, but China is the largest producer of garlic accounting for 75% of world output. Crop improvement is based on available genetic variability and extent to which the desirable characters are heritable. Hence, studies on genetic variability with the help of suitable genetic parameters become indispensable for an effective breeding progamme. Yield is very complex entity influenced by several yield components sensitive to the environmental fluctuations. Thus, the selection based on yield components will have better chance of success. It is therefore, necessary to know the types and nature of yield components and their inter relationship. The correlation coefficient analysis and path coefficient analysis provide information on their relative importance of various contributing characters. Measurement of existing variability in plant population has been the basic requirement of plant breeding. Heritability and genetic advance have been proved useful in predicting the gain through selection. Keeping this in view, the present investigation was carried out for to determine the following objectives:

1. Estimates of genetic parameters of variation for

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Table 1. Mean performance of different characters in fifty six lines of garlic.

S/N	Lines	Plant height (cm)	No. of leaves per plant	Leaf length (4th leaf)	Leaf width (4th leaf)	Pseudostem length (cm)	Pseudostem diameter (mm)	Polar diameter bulb (mm)	Equatorial diameter bulb (mm)	No. of cloves/ bulb	Av. wt. of 10 cloves (g)	Days to maturity	Bulb yield per
1	JAS-1	55.58	7.46	44.50	1.61	8.75	12.06	30.24	26.88	23.40	7.90	140.00	115.54
2	JAS-2	61.75	7.50	44.50	1.35	10.24	10.00	34.21	29.10	19.80	10.80	144.66	147.54
3	JAS-3	45.66	6.58	32.83	1.55	6.69	7.05	23.99	20.43	17.60	3.13	155.00	45.99
4	JAS-4	51.66	6.91	39.25	1.59	8.98	9.88	27.10	25.38	25.03	9.30	150.00	98.56
5	JAS-5	65.16	7.50	44.41	1.55	11.27	10.03	30.28	27.30	19.20	9.26	150.00	118.54
6	JAS-6	64.41	6.83	48.08	1.94	13.05	13.67	31.55	26.02	26.40	6.70	159.66	96.78
7	JAS-7	59.16	7.41	42.25	1.58	11.49	9.72	26.56	27.98	22.40	6.40	140.33	83.24
8	Local (c)-1	66.33	7.66	48.58	1.81	11.16	11.26	31.37	29.14	24.40	10.30	155.00	131.42
9	JAS-8	48.83	7.41	39.58	1.85	7.16	9.36	31.25	25.55	18.60	10.90	145.00	107.22
10	JAS-9	63.08	7.50	43.08	1.40	13.05	14.05	30.53	26.20	16.60	12.50	155.00	124.75
11	JAS-10	62.83	7.00	43.58	1.68	12.94	11.93	28.81	28.51	23.40	9.20	140.33	134.30
12	JAS-11	63.08	7.16	44.25	1.68	9.97	10.97	36.49	38.89	25.40	9.60	150.33	140.30
13	JAS-13	65.08	7.00	46.08	1.73	11.05	13.24	40.57	40.87	26.60	11.46	145.00	172.27
14	JAS-14	71.91	7.75	47.91	1.57	9.30	11.32	38.65	36.41	24.40	11.90	154.66	131.19
15	JAS-15	72.75	8.58	48.50	1.63	12.16	12.23	40.36	40.71	25.40	10.70	145.00	167.60
16	JAS-16	69.25	7.75	46.00	1.60	11.44	8.61	41.47	40.85	25.80	11.00	145.00	165.38
17	JAS-51	68.33	7.83	47.00	1.48	11.10	10.45	37.81	36.93	23.80	10.40	149.66	136.97
18	JAS-17	62.83	7.58	47.00	1.61	12.27	12.06	42.25	39.14	17.20	7.43	165.00	122.09
19	JAS-18	55.08	7.75	39.91	1.87	8.62	11.69	36.19	33.57	31.80	7.40	141.33	88.78
20	JAS-19	65.98	8.83	47.16	1.64	11.43	11.35	38.63	41.82	25.70	13.30	146.00	166.05
21	JAS-21	58.75	7.41	41.66	1.29	9.59	10.47	38.03	38.19	31.46	9.30	151.00	143.41
22	JAS-22	53.61	7.25	43.33	1.55	10.86	9.98	37.11	33.96	22.40	9.20	147.00	99.90
23	JAS-23	72.75	8.08	50.83	1.77	10.26	10.84	40.36	39.64	24.73	13.50	142.00	171.49
24	JAS-24	54.08	7.33	39.00	1.64	10.16	9.27	36.16	33.58	20.20	8.40	141.00	79.91
25	JAS-52	46.75	7.08	34.91	1.52	7.99	9.83	29.32	28.15	19.40	5.50	146.66	57.27
26	JAS-25	68.75	8.25	47.00	1.36	13.66	17.58	33.69	28.65	20.20	4.80	150.66	56.16
27	JAS-26	72.25	8.16	50.00	1.48	11.66	9.39	39.57	40.06	29.00	11.90	156.00	162.50
28	JAS-27	73.25	8.83	51.33	1.49	10.05	11.34	43.61	43.37	45.60	19.63	156.66	191.80
29	JAS-28	69.16	8.41	49.08	1.46	11.66	9.98	38.91	39.82	31.40	11.60	160.00	156.05
30	JAS-29	66.00	7.66	46.33	1.51	10.95	8.94	39.14	38.71	29.60	12.20	157.33	155.39
31	JAS-30	71.16	8.00	50.50	1.52	9.72	11.01	38.42	38.88	29.58	11.06	157.00	170.93
32	JAS-31	60.16	7.25	44.66	1.52	11.27	12.96	38.76	40.89	29.40	11.06	151.66	160.05
33	JAS-32	53.00	7.08	37.50	1.34	8.71	8.44	28.78	27.70	20.00	7.80	140.33	81.02

Table 1. Contd.

34	JAS-33	58.58	6.91	44.00	1.55	8.83	9.84	41.11	36.61	21.60	4.80	165.33	106.11
35	JAS-34	69.25	7.58	46.91	1.46	10.33	10.28	38.74	38.52	29.60	11.50	150.66	159.17
36	JAS-35	62.33	8.58	45.00	1.41	10.88	10.99	42.58	40.81	26.60	14.50	152.00	171.60
37	JAS-36	73.08	8.08	49.50	1.47	10.51	11.49	39.24	38.48	27.20	9.00	151.00	146.51
38	JAS-37	62.50	7.33	46.75	1.82	11.08	13.22	42.93	40.79	34.80	8.20	156.66	178.26
39	JAS-38	53.91	8.41	39.66	1.92	7.66	9.51	39.92	40.03	17.53	14.40	143.00	133.19
40	JAS-39	66.12	8.50	50.41	1.52	10.88	9.81	41.71	37.94	19.80	9.63	144.00	145.96
41	JAS-41	59.58	7.41	42.41	1.49	10.66	10.73	37.15	39.64	19.00	9.20	144.33	134.75
42	JAS-42	65.66	7.66	45.16	1.27	11.27	9.75	35.06	34.12	25.40	9.60	151.66	106.77
43	JAS-43	64.50	7.75	45.50	1.71	10.75	12.30	40.36	40.06	29.60	8.56	147.00	138.30
44	JAS-44	64.08	7.83	45.75	1.84	9.55	10.97	40.77	38.38	25.40	10.20	152.33	145.63
45	JAS-45	48.96	7.25	34.66	1.57	9.34	8.83	35.30	33.91	34.20	6.20	135.00	89.01
46	JAS-46	51.16	7.58	35.25	1.62	9.38	9.54	30.99	29.49	25.13	4.80	135.00	77.25
47	JAS-47	62.83	8.82	44.08	1.78	8.83	11.48	40.22	37.57	27.20	8.00	135.33	123.75
48	JAS-40	66.41	7.58	46.08	1.33	11.11	10.82	40.97	40.83	25.80	12.00	140.33	160.60
49	Local (c)-2	70.75	8.33	48.75	1.74	10.22	10.65	39.79	35.59	22.40	12.00	156.00	143.63
50	JAS-48	69.91	8.33	47.75	1.42	10.66	11.09	40.28	40.48	19.60	10.90	141.00	165.60
51	JAS-49	67.58	8.08	44.75	1.61	10.83	9.73	40.87	39.82	24.46	11.36	146.66	160.50
52	JAS-50	58.75	8.58	42.16	1.80	9.83	10.06	40.39	38.67	20.60	11.13	153.33	131.64
53	JAS-12	64.83	8.00	42.75	1.79	8.92	12.36	37.20	38.42	23.00	10.03	141.66	126.53
54	JAS-20	63.75	8.41	46.66	1.45	10.61	10.32	40.15	34.87	33.60	10.26	153.00	148.29
55	JAS-53	71.00	8.25	49.58	1.59	11.77	9.06	40.27	37.47	25.00	11.50	145.33	170.27
56	JAS-54	53.41	7.91	35.75	1.80	8.32	9.64	40.43	41.32	21.00	11.40	146.00	122.32
	SEm±	2.51	0.23	1.52	6.92	0.48	1.07	0.96	1.16	0.046	0.52	0.84	12.21
	CD at 5%	7.04	0.65	4.27	NS	1.35	3.00	2.69	3.27	1.31	1.45	2.38	34.23

different characters in garlic.

2. Genotypic and phenotypic correlation coefficient for yield and its contributing characters in garlic.

MATERIALS AND METHODS

The experiment was conducted at Vegetable Research Farm, Department of Horticulture, Maharajpur, JNKVV, Jabalpur (M.P.), India during the rabi season of 2009-2010 and 2010-2011. The experiment was laid out in Randomized Complete Block Design with three replications and each replication consisted of fifty six genotypes. All the genotypes were randomized separately in each replication. Observations were recorded on 10 randomly selected plants from each plot on vegetative traits viz., plant height (cm), number of leaves per plant, leaf length (cm), leaf width (cm) and pseudostem diameter (mm) at 85 to 90 days after sowing and observations for yield parameters viz., polar diameter of bulb (mm), equatorial diameter of bulb (mm), number of cloves per bulb, average weight of 10 clove (g), bulb yield per hectare (q) and number of days to maturity were recorded after harvest (Table 1).

RESULTS AND DISCUSSION

Analysis of variance

The mean squares due to lines were highly significant for all the characters except leaf width (4^{th} leaf) indicating the presence of genetic variability in the materials. The maximum range of

Table 2. Estimates of genetic parameters of variation different characters in garlic.

S/N	Characters	Mean	Range		Variance			Coefficient of variation		Heritability (%)	Genetic advance	G.A. ad % of mean
			Min.	Max.	Pheno.	Geno.	Env.	Pheno.	Geno.			
3	Plant height (cm) at 90 DAS	62.63	45.66	73.25	66.28	47.32	18.96	12.99	10.98	71.39	11.97	19.11
6	No. of leaves at 90 DAS	7.75	6.58	8.83	0.42	0.25	0.16	8.39	6.55	60.92	0.81	10.53
7	Leaf length (cm) 4th leaf	44.46	32.83	51.33	24.54	17.55	6.98	11.14	9.42	71.53	7.30	16.41
8	Pseudostem length (cm)	10.37	6.69	13.66	2.61	1.90	0.70	15.57	13.30	73.05	2.43	23.43
9	Pseudostem diameter (mm)	10.77	7.05	17.58	5.06	1.62	3.43	20.87	11.81	32.07	1.48	13.78
10	Polar diameter of bulb(mm)	36.90	23.99	43.61	24.83	22.06	2.77	13.50	12.72	88.83	9.12	24.71
11	Equatorial diameter (mm)	35.48	20.43	43.37	34.63	30.54	4.09	16.58	15.57	88.18	10.69	30.12
12	No. of cloves/bulb	24.90	16.60	45.60	28.83	28.20	0.66	21.57	21.32	97.71	10.81	43.43
13	Average wt. of 10 cloves (g)	9.72	3.13	19.63	6.57	5.76	0.81	26.36	24.67	87.64	4.63	47.59
14	Bulb yield/plant (g)	19.72	6.90	28.80	33.96	22.45	11.51	29.55	24.02	66.10	7.93	40.23
15	Bulb yield/plot (kg)	7.89	2.76	11.51	5.24	3.61	1.63	28.99	24.06	68.90	3.25	41.15
16	Bulb yield/ha (q)	131.61	45.99	191.80	1463.92	1016.30	447.62	29.07	24.22	69.42	54.71	41.57
17	Days to maturity	148.58	135.0	165.33	52.16	50.00	2.16	4.86	4.75	95.85	14.26	9.59

variability was observed for bulb yield per hectare and plant height at 90 DAP (Tables 2, 3 and 4).

Genetic variability

Significant differences were recorded among the lines with regard to the plant height. The maximum plant height was recorded in JAS-27 (73.25 cm) and the minimum (45.60 cm) was observed in JAS-3. The variability for plant height was also observed by Nurzynska-Wierdak (1997), Kohli and Prabal (2000), Jogdande et al. (2004) and Sengupta et al. (2007).

The investigation on number of leaves per plant indicated that all the lines differed significantly. The highest 8.83 leaves/plant was exhibited in line JAS-27, while it was the lowest, 6.58 leaves/plant in JAS-7. These findings are in agreement with the works of Nurzynska-Wierdak (1997), Jogdande et al. (2004) and Sengupta et al. (2007).

Significant differences were recorded among the lines with regards to the leaf length (4th leaf). The maximum leaf length (51.33 cm) was observed in line local check-1. However, the lowest leaf length was noted in JAS-3. These findings are in agreement with Kohli and Prabal (2000) and Sengupta et al. (2007).

The lines did not show any significant impact on the leaf width (4th leaf). The highest leaf width was found in JAS-6 and narrow in JAS-42. The results were in close proximation of results of Kohli and Prabal (2000) and Sengupta et al. (2007).

Pseudostem diameter was found to be minimum in JAS-3 and it was exhibited maximum in line JAS-25. The findings of Jogdande et al. (2004) are similar to that of the present findings.

Significant differences were observed between the lines with regards to the polar diameter of bulb. The maximum polar diameter of bulb was recorded in JAS-27, and the minimum in JAS-3. The findings were quite similar as reported by Pandey et al. (1996), Kohli and Prabal (2000), Sood et al. (2000) and Sengupta et al. (2007).

The investigation on equatorial diameter of bulb indicated that all the lines have shown significant variation. The line JAS-27 was recorded in maximum equatorial diameter of bulb while the minimum equatorial diameter of bulb was found in line JAS-3. These findings of Lommerink (1989), Pandey et al. (1996, Sood et al. (2000), Jogdande et al. (2004) and Sengupta et al. (2007) are in close harmony with the result of the present investigation.

Significant variations were recorded among the lines with regard to the number of cloves per bulb. The maximum number of cloves per bulb was recorded in JAS-27 and minimum was in JAS-9. Similar, results have been reported by Heredia et al. (1991), Perez and Lopez (2002), Pandey et al. (1996), Kohli and Prabal (2000), Shri (2002-2003), Jogdande et al. (2004) and Anonymous (2006-

Table 3. Genotypic and phenotypic correlation coefficient for yield and its contributing characters in garlic.

Parameter		Number of leaves/ plant at 90 DAP	Leaf length(cm) (4th leaf)	Leaf width (cm) (4th leaf)	Pseudo-stem length (cm)	Psedo-stem diameter (mm)	Polar diameter (mm)	Equatorial diameter (mm)	Number of cloves/ bulb	Average weight of 10 cloves (g)	Days to maturity	Bulb yield/ plant (g)
Plant height 90 DAP (cm)	G	0.537	0.969	0.582	0.685	0.420	0.589	0.573	0.312	0.546	0.316	0.817
	P	0.442**	0.829**	-0.023	0.514**	0.270*	0.433**	0.456**	0.256*	0.406**	0.248	0.564**
Number of leaves/plant	G		0.434	0.522	0.070	-0.120	0.619	0.570	0.117	0.570	-0.034	0.547
	P		0.438**	-0.094	0.062	0.044	0.448**	0.420**	0.091	0.410**	-0.022	0.378**
Leaf length (cm) 4th leaf	G			0.603	0.664	0.427	0.552	0.473	0.292	0.512	0.432	0.796
	P			0.002	0.513**	0.323*	0.424**	0.392**	0.250	0.371**	0.357**	0.570**
Leaf width (cm) (4th leaf)	G				0.525	0.374	-0.380	0.538	0.705	0.767	0.518	0.617
	P				0.081	-0.019	-0.003	-0.037	-0.037	-0.016	-0.033	0.007
Pseudostem length (cm)	G					0.426	0.172	0.170	0.098	0.195	0.242	0.336
	P					0.201	0.131	0.127	0.081	0.146	0.214	0.271*
Psedostem diameter (mm)	G						0.188	0.215	0.220	0.221	0.258	0.465
	P						0.106	0.110	0.136	0.124	0.160	0.197
Polar diameter (mm)	G							0.944	0.352	0.497	0.219	0.810
	P							0.867**	0.325*	0.452**	0.209	0.607**
Equatorial diameter (mm)	G								0.430	0.566	0.096	0.851
	P								0.395**	0.492**	0.099	0.665**
Number of cloves/bulb	G									0.064	0.141	0.483
	P									0.052	0.136	0.382**
Average weight of 10 cloves (g)	G										0.049	0.826
	P										0.044	0.621**
Days to maturity	G											0.219
	P											0.185

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

2007b). The maximum average weight of 10 cloves was recorded in JAS-27, while the minimum average weight of 10 cloves was exhibited in JAS-3. These findings are quite similar to those of Lammerink (1989), Nurzynska Wierdak (1997), Kohli and Prabal (2000), Jogdande et al. (2004) and Anonymous (2006-07b). Line JAS-33 was found late in maturity (165.33 days). The lines JAS-45

Table 4. Genotypic and phenotypic path coefficient showing direct and indirect effects of bulb yield and its contributing characters

Characters		Plant height 90 DAT (cm)	Number of leaves/ plant	Leaf length (cm) (4th leaf)	Leaf width (cm) (4th leaf)	Pseudo -stem length (cm)	Psedo-stem diameter (mm)	Polar diameter (mm)	Equatorial diameter (mm)	Number of cloves/ bulb	Average weight of 10 cloves (g)	Days to maturity	Corr. coeff. value of bulb yield/ Plant (g)
Plant height 90 DAT (cm)	G	1.133	0.609	1.098	0.460	0.776	0.476	0.667	0.650	0.354	0.619	0.359	0.817
	P	0.021	0.009	0.017	-0.0005	0.010	0.005	0.009	0.009	0.005	0.008	0.005	0.564**
Number of leaves/plant	G	-0.227	-0.424	-0.184	-1.069	-0.029	0.050	-0.262	-0.242	-0.049	-0.242	0.014	0.547
	P	-0.018	-0.042	-0.018	0.003	-0.002	-0.001	-0.018	-0.017	-0.003	-0.017	0.001	0.378**
Leaf length (cm) 4th leaf	G	-0.606	-0.271	-0.625	-1.003	-0.416	-0.267	-0.345	-0.296	-0.183	-0.320	-0.270	0.796
	P	0.206	0.109	0.249	0.0007	0.127	0.080	0.105	0.097	0.063	0.092	0.089	0.570**
Leaf width (cm) (4th leaf)	G	0.013	0.005	0.003	0.002	0.001	0.004	-0.0008	0.001	0.003	0.001	0.001	0.617
	P	-0.0006	-0.002	0.0001	0.026	0.002	-0.0005	-0.0001	-0.001	-0.001	-0.0004	-0.0009	0.007
Pseudostem length (cm)	G	-0.149	-0.015	-0.145	-0.114	-0.218	-0.093	-0.037	-0.037	-0.021	-0.042	-0.053	0.336
	P	0.010	0.001	0.010	0.001	0.020	0.004	0.002	0.002	0.001	0.003	0.004	0.271*
Psedostem diameter (mm)	G	0.026	-0.007	0.026	0.146	0.026	0.061	0.011	0.013	0.013	0.013	0.016	0.465
	P	0.0007	0.0001	0.0009	-0.0001	0.0006	0.002	0.0003	0.0003	0.0004	0.0003	0.0004	0.197
Polar diameter (mm)	G	0.585	0.616	0.549	-0.378	0.171	0.187	0.994	0.939	0.350	0.494	0.021	0.810
	P	0.003	0.003	0.003	0.00001	0.001	0.0009	0.008	0.0075	0.002	0.003	0.001	0.607**
Equatorial diameter (mm)	G	-0.380	-0.378	-0.313	-0.356	-0.112	-0.142	-0.626	-0.662	-0.285	-0.375	-0.063	0.851
	P	0.145	0.134	0.125	-0.012	0.040	0.035	0.277	0.319	0.126	0.157	0.031	0.665**
Number of cloves/bulb	G	0.084	0.031	0.078	0.458	0.026	0.059	0.094	0.115	0.268	0.017	0.038	0.483
	P	0.043	0.015	0.041	-0.006	0.013	0.022	0.054	0.066	0.167	0.008	0.022	0.382**
Average weight of 10 cloves (g)	G	0.363	0.379	0.340	0.510	0.130	0.147	0.330	0.376	0.043	0.664	0.032	0.826
	P	0.148	0.149	0.135	-0.0058	0.053	0.045	0.164	0.179	0.019	0.364	0.016	0.621**
Days to maturity	G	-0.230	0.002	-0.031	-0.038	-0.017	-0.019	-0.016	-0.007	-0.010	-0.003	-0.073	0.219
	P	0.003	-0.0003	0.004	-0.0004	0.002	0.002	0.002	0.001	0.001	0.0006	0.013	0.185

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

and JAS-46 were recorded as early maturing (135 days). Similar results have been reported by Sharma et al. (1998), Sood et al. (2000), Shridhar (2002) and Jogdande et al. (2004). The higher bulb yield per hectare was obtained in line JAS-27 and JAS-37, while the lowest bulb yield was found in JAS-3. Higher bulb yield may be attributed to cumulative effects of number of leaves per plant, polar and equatorial diameter of bulb, number of

cloves per bulb and average weight of cloves. Variation in yield amongst the lines was also reported by Pandey et al. (1996), Nurzynska Wierdak (1997), Singh et al. (2002), Shrivastava et al. (2004), Raghuwanshi et al. (2004), and Anonymous (2006-2007b).

Coefficient of variation

In the present investigation phenotypic coefficient of variation was observed to be higher than the corresponding genotypic coefficient of variation for all the characters studied. However the differences were narrow which implied their relative resistance to environmental variation. It also described that genetic factors were predominantly responsible for expression of these attributes and selection could be made effectively on the basis of phenotypic performance. The findings of Narayan and Khan (2002), Shri (2002) and Singh and Chand (2004) are similar to that of the present findings.

High estimate of phenotypic coefficient of variation was observed for bulb yield per hectare and average weight of ten cloves. The findings of Korla et al. (1981) for weight of 20 cloves; Mehta and Patel (1985) for clove weight and bulb yield per plant; Frasca et al. (1997) for bulb weight; Narayan and Khan (2002) for bulb yield per plot and bulb weight; Shri (2002) for bulb yield and weight of 50 clove; Agrawal and Tiwari (2004) for clove weight and bulb yield; Singh and Chand (2004) for average clove weight, bulb weight and bulb yield per hectare, and Haydar et al. (2007) for bulb yield are in good consistent with the findings of the present study.

Heritability and genetic advance

High heritability coupled with high genetic advance for characters like equatorial diameter of bulb, average weight of ten cloves and plant height at 60 DAP and high values of heritability supplemented with moderate genetic advance as percentage of mean were manifested by pseudostem diameter and polar diameter of bulb suggested the preponderance of additive gene actions. It also indicated higher response for selection of high yielding line as these characters are governed by additive gene action. These results are in conformity to those reported by Singh (1981), Mehta and Patel (1685) for clove weight; Kohli and Prabal (2000) for bulb diameter, Shri (2002) for clove weight and plant height; Singh and Chand (2004) for average clove weight.

Association analysis

Correlation coefficient

Correlation coefficient was estimated between yield and its attributes at genotypic and phenotypic levels to know the inter-relationship among the characters. It provides information about the nature, extent and direction of selection pressure to be applied for practical consideration. In general, genotypic one because of masking effect of genotypes for the expression of characters. Similar results have been reported by Shri (2002) and Agrawal and Tiwari (2009).

Correlation between yield and its components

In the present findings significant positive correlation of bulb yield per hectare was observed with plant height at 90 DAP, number of leaves per plant at 90 DAP, leaf length (4^{th} leaf); pseudostem length, pseudostem diameter, polar diameter of bulb, equatorial diameter of bulb, number of cloves per bulb, average weight of 10 cloves and days to maturity. These findings corroborated with the earlier findings of Kalloo et al. (1982) for plant height, bulb weight, bulb diameter, clove weight; Lokhande and Pawar (1988) for plant height, bulb weight and number of cloves per bulb; Sharma et al. (1998) for bulb weight, bulb diameter and plant height; Thakur et al. (1997) for plant height, leaves per plant; Burba et al. (1997) for clove weight, diameter of bulb and growth period; Sharma et al. (1998) plant height, leaves per plant, neck girth, length and bulb diameter, cloves per bulb; Kohli and Prabal (2000) for bulb diameter for number of equatorial diameter of bulb; Wani (2004) for number of leaves and number of cloves per bulb; Shrivastava et al. (2004a) for plant height, leaves per plant, stem diameter and bulb diameter, Singh et al. (2004) for equatorial bulb diameter, number of cloves per plant, average clove weight and days to maturity; Haydar et al. (2007) for bulb length and bulb diameter for plant height, number of leaves per plant equatorial bulb diameter and polar bulb diameter, and Agrawal and Tiwari (2009) for clove weight, bulb diameter and neck diameter.

Correlation between yield contributing characters themselves

Plant height showed significant positive correlation with yield attributing all the characters except leaf width (4^{th} leaf) viz., leaf length, pseudostem length, equatorial diameter of bulb, number of leaves per plant at 90 DAP, polar diameter of bulb, average weight of 10 cloves, pseudostem diameter, number of cloves per bulb and days to maturity.

Number of leaves per plant had positive and highly significant correlation with polar diameter of bulb, leaf length, equatorial diameter of bulb and average weight of 10 cloves. Leaf length (4^{th} leaf) was found to be positively and significantly correlated with pseudostem length, polar diameter of bulb, equatorial diameter of bulb, average weight of 10 cloves, days to maturity, pseudostem diameter and number of cloves per bulb. Significantly and positive correlation of pesudostem length was observed

with day to maturity and pseudostem diameter. Pseudostem diameter was observed to have a significant and positive association with days to maturity. Polar diameter of bulb showed positive and significant association with equatorial diameter of bulb, average weight of 10 cloves, number of cloves per bulb and days to maturity. Equatorial diameter of bulb expressed a significant and positive association with average weight of 10 cloves and number of cloves per bulb. These results are in close harmony with the findings of Kohli and Mahajan (1993) for number of cloves per bulb; Shri (2002) for days to maturity and number of cloves; Shrivastava et al. (2004a) for leaves per plant, stem diameter and bulb diameter Shrivastava et al. (2004b) for leaves biomass; Haydar et al. (2007) for bulb diameter Meena et al. (2007) for number of leaves per plant equatorial bulb diameter and polar bulb diameter; Agrawal and Tiwari (2009) for bulb weight, clove weight, bulb diameter, clove length, leaf area index and neck diameter.

Path coefficient analysis

Correlation coefficients are the indication of simple association between variables. In a biological system, however the relationship may exist in a very complex form. It is therefore, essential to study the relationship among variable in a comprehensive way. Path coefficient analysis is a powerful tool, which enable partitioning of the given relationship in its further components. In other words, it takes into account not only the relationship of component characters with the dependent characters, but simultaneously takes care of its relationship with other components also. Thus, it helps in understanding the causal system in a better way because it enables portioning the total correlations coefficient in to direct and indirect effects of various characters.

In the present investigation path coefficient analysis was carried out for characters understudy using genotypic and phenotypic correlation coefficient and taking bulb yield per plant as dependable variable, in order to see the causal factor and so as to identify the components which are responsible for producing bulb yield per plant.

Positive direct effect

Path coefficient analysis of the different characters revealed that plant height at 90 DAP had highest positive direct effect on bulb yield hectare followed by polar diameter of bulb, average weight of 10 cloves, number of cloves per bulb and pseudostem diameter. The results are in propinquity with Rahman and Das (1985) for bulb diameter, plant height and bulb length, Singh (1981) for bulb diameter; Singh et al. (2004) for average clove weight; Shrivastava et al. (2004a) clove weight, clove per bulb, and stem diameter. The characters plant height, polar diameter, average weight of 10 cloves, number of cloves per bulb and pseudostem diameter had correlation coefficient value at par with their direct effect on bulb yield per hectare.

Negative direct effect

However, the highest negative direct effect was observed in equatorial diameter of bulb, leaf length, number of leaves per plant and pseudostem length on bulb yield per plant. The findings of Shrivastava et al. (2004a) for bulb diameter and leaves per plant are in close harmony to the present findings. These characters exhibited the significant correlation with bulb yield per hectare. The role of these traits in the contribution towards bulb yield cannot be ignored.

Positive indirect effect

The positive indirect effect on bulb yield per plant was recorded for plant height at 90 DAP via leaf length (4^{th} leaf), pseudostem length, polar diameter of bulb, equatorial diameter of bulb, average weight of 10 cloves and number of leaves per plant. The indirect effects for number of leaves per plant at 90 DAP via pseudostem diameter and days to maturity were found to be positive and lower magnitude. Leaf width showed the positive indirect effects for all the traits except the polar diameter and value of all the indirect effects was exhibited in low magnitudes. The positive indirect effects were recorded for pseudostem diameter via leaf width followed by plant height at 90 DAP, leaf length and pseudostem length. The indirect effects of polar diameter of bulb via equatorial diameter, number of leaves at 90 DAP, plant height at 90 DAP, leaf length average weight of 10 cloves and number of cloves per bulb were observed to be positive. The positive indirect effects on bulb yield per hectare were observed for number of cloves per bulb via leaf width, equatorial diameter of bulb and polar diameter of bulb. Average weight of 10 cloves exhibited positive indirect effect via leaf width, number of leaves per plant, equatorial diameter of bulb, plant height, leaf length and polar diameter of bulb. The indirect effect of other character via number of leaves per plant was found to be positive. The findings Shrivastava et al. (2004a) for clove weight, followed by cloves per bulb and stem diameter on bulb weight are in close harmony to the present findings. This indicated that the indirect effect was the cause of correlation and the indirect causal factors are to be considered simultaneously for selection.

Negative indirect effects

Higher magnitude of negative indirect effects were observed for leaf length via leaf width, plant height, pseudostem length, polar diameter of bulb and average weight of 10 cloves. The indirect effects of pseudostem

length via plant height at 90 DAP, leaf length, leaf width and pseudostem diameter were found to be negative. Equatorial diameter of bulb was recorded the negative indirect effect via polar diameter of bulb, plant height, number of leaves per plant, average weight of 10 cloves and leaf width. Similarly, days to maturity possessed the highest negative indirect effect via leaf width, leaf length, plant height, pseudostem diameter and pseudostem length. The findings of Rahman and Das (1985) for leaves per plant are in close harmony to the present findings.

An overall observation of path coefficient analysis of bulb yield with its components viz., plant height, polar diameter of bulb, average weight of 10 cloves, number of cloves per bulb, pseudostem diameter, equatorial diameter of bulb and leaf length played an important role in determining the bulb yield per hectare.

Conclusions

Analysis of variance (mean square) revealed that highly significant variation for all the traits except leaf width (4^{th} leaf) indicating greater variability in the existing material. High estimates of heritability were obtained for pseudostem diameter, days to maturity, polar diameter of bulb, equatorial diameter of bulb, average weight of 10 cloves and plant height. Average weight of 10 cloves, number of cloves per bulb, bulb yield per hectare, equatorial diameter of bulb and plant height exhibited higher value of genetic advance as percentage of mean. High heritability coupled with high genetic advance as percentage of mean was observed for equatorial diameter of bulb, average weight of 10 cloves and plant height at 60 DAP suggested that they can be improved through direct selection.

Path coefficient analysis revealed that highest consideration for their relative importance of various yield contributing characters should be given to plant height, polar diameter of bulb, average weight of 10 cloves, number of cloves per bulb and pseudostem diameter and these traits are also positively and significantly correlated with bulb yield per hectare in garlic.

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