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CHARACTER ASSOCIATION AND PATH ANALYSIS IN GARLIC (*ALLIUM SATIVUM* L.)

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ABSTRACT
An experiment was conducted using one hundred and thirty-one genotypes of garlic for identifying the characters which mainly contributed to the bulb weight per plant with correlation and path analysis using twelve morpho-agronomic characters. The character association analysis revealed the bulb weight per plant showed positive significant correlation with plant height (0.541, 0.508), leaf length (0.461, 0.419), pseudostem height (0.430, 0.417), pseudostem diameter (0.562, 0.509), polar diameter of bulb (0.733, 0.714), equatorial diameter of bulb (0.858, 0.827), number of cloves per bulb (0.322, 0.317), clove length (0.581, 0.545) and clove weight (0.713, 0.706) at both genotypic and phenotype levels, respectively. The maximum direct effect with significant positive correlation were showed by equatorial diameter of bulb (0.828), polar diameter of bulb (0.714), clove weight (0.706), length of clove (0.545) and pseudostem diameter (0.510). The characters like equatorial diameter of bulb, clove weight, number of cloves per bulb shows that they are the most important bulb weight determinants, because of their high direct and indirect effects *via* many other yield improving characters. The study indicated that these characters can be used as key traits for improving the bulb weight of garlic.

INTRODUCTION

Garlic [*Allium sativum* L.] (2n = 16) is the second most important bulb crop grown after onion. It is used as a spice flavoring agent and also in pharmaceutical preparations due to its high valued medicinal properties throughout the world. Garlic has higher nutritious value than other bulb crops and its dried products have good export value. Cloves are rich in energy (149 kcal), carbohydrates (33.06 g), protein (6.36 g), Vitamin B6 (1.2 mg), Vitamin C (31.2 mg), calcium (181 mg), phosphorus (153 mg) and potassium (401 mg) for every 100g of garlic (Anonymous, 2014a). It is grown in the world in over 12.25 lakh hectares with 242.55 lakh tons and productivity of 12.80 tons/hectare. In India, the area under garlic production is 2.3 lakh hectares with an annual production of 12.5 lakh tons and average productivity of 5.4 tons/ hectare (Anonymous, 2014b), which is quite low to meet rapid growing population mainly due to poor yielding potential of varieties and effect of pest and diseases. To meet up with the national requirement, export demands, selection of varieties with desired traits is needful for improvement of garlic germplasm.

Garlic is being exclusively vegetatively propagated by cloves and its scope of development over breeding methods is inadequate. However, recent studies revealed that garlic shows wide-ranging morphological and agronomical variations in plant height, days to flowering, number and size of the clove, days to harvesting, dormancy and adaption to agro-climate conditions (Lu *et al*., 2001, Singh *et al.,* 2013).

Improvement of bulb yield is a multifaceted quantitative character and it is prejudiced by a number of contributing traits, directly and indirectly. A study of correlation between quantitative characters (Agrawal and Tiwari, 2009; Dubey *et al*., 2010; Tsega *et al*., 2010; Singh *et al*., 2011; Bayad *et al*., 2012) provides an idea of association of characters between yield and its attributes at genotypic and phenotypic levels to know the inter-relationship among the characters. Path coefficient analysis is simply a standardized partial regression coefficient and as such, measures the direct influence of one variable upon another and permits the division of the correlation coefficient into components of direct and indirect effects (Dewey and Lu, 1959). Several path analysis studies have been conducted in garlic genotypes (Dubey *et al*., 2010; Singh *et al*., 2011; Lu *et al*., 2012; Bayad *et al*., 2012 and Panse *et al*., 2013). Hence, the association of bulb yield with the morpho-agronomic characters and the extent of the contribution of each character to bulb yield both, directly and indirectly, will be most effective for yield improvement. This can be found using the correlation and path analysis which are the two effective biometrical techniques extensively used. The present study was conducted to evaluate association among different components and there direct and indirect contribution to bulb yield in garlic for effective improvement of garlic germplasm.

MATERIALS AND METHODS

The present research was conducted at Horticultural Research

Centre, SVPUA&T, Meerut during *Rabi,* 2014. The details of all the one hundred and thirty-one genotypes included in the present study along with their sources are presented in table 1. The genotypes which were chosen for the present study were grown in a randomized block design with three replications. In each replication, cloves were sown in a plot size of 2.0m X 1.5m, in which row to row distance was 15 cm and plant to plant 10 cm. All the recommended techniques and plant protection measures were followed to ensure a healthy crop (DOGR, Rajgurunagar). Twelve morphological traits *viz*., plant height (cm), leaf length (cm), number of green leaves per pseudostem green, number of dry leaves per pseudostem, pseudostem height (cm), pseudostem diameter (cm), polar diameter of bulb (cm), equatorial diameter of bulb (cm), bulb weight per plant (g), number of cloves per bulb, length of the clove (cm) and clove weight (g) was measured by the method proposed by Singh *et al*. (2013) and recorded on five randomly selected plants in each replication per accession on plot basis. The data was statistically analyzed to estimate genotypic and phenotypic correlation coefficients (Johnson *et al*., 1995) and path analysis (Dewey and Lu, 1959 and Rai *et al*., 2014) using WINDOW STAT software (Saroj *et al*., 2013).

RESULTS AND DISCUSSION

Analysis of variance revealed that the difference among the genotypes was highly significant for all the characters studied (Table 2). In the present investigation, the genotypic correlation coefficients were higher than those of their corresponding phenotypic correlation coefficients in many cases, furthermore, genotypic correlation has been reported to be highly reliable and these results are in consistent with the reports of Dubey *et al*. (2010) and Tsega *et al*. (2010). The correlation studies revealed that bulb weight per plant was positively and significantly correlated with plant height, leaf length, pseudostem height, pseudostem diameter, the polar diameter of the bulb, equatorial diameter of the bulb, the number of cloves per bulb, the length of the clove and clove weight at the phenotypic level (Table 3), which implies that the improvement of the above listed characters will enhance the increase in bulb weight per plant. These findings were earlier reported by Sharma *et al*. (1998) for plant height, leaves per plant, neck girth, length and bulb diameter, cloves per bulb. Kohli and Prabal (2000) also observed bulb diameter for a number of equatorial diameter of the bulb. Meanwhile, Wani (2004) noted the number of leaves and number of cloves per bulb. Similarly, Shrivastava *et al*. (2004) reported the correlation between plant height, leaves per plant, stem diameter and bulb diameter with bulb weight per plant. Singh *et al*. (2004) as well, investigated equatorial bulb diameter, the number of cloves per plant, average clove weight and days to maturity in relation to bulb weight per plant. In addition, Haydar *et al*. (2007) and Bayad *et al*. (2012) noted bulb length and bulb diameter in relation to plant height, the number of leaves per plant equatorial bulb diameter and polar bulb diameter. Furthermore, Agrawal and Tiwari (2009) and Singh *et al*. (2011) studied clove weight, bulb diameter and neck diameter with bulb weight per plant.

The estimation of correlation coefficient analysis mostly showed the interrelationship of different characters but does not provide information on cause and effect. Meanwhile, path coefficient analysis would elucidate the direct and indirect relationship between traits, which will enhance breeders to select the most effective traits for identifying the key for selection. In this investigation, Path coefficient analysis was carried out for characters understudy using genotypic and phenotypic correlation coefficient and taking bulb weight per plant as a dependable variable, in order to see the causal factor and so as to identify the components which are

Table 1: List of garlic genotypes and their respective source of collection

Source	Number of Genotypes	Genotypes
Punjab Agriculture University,Ludhiana	37	AVTG-5, GRS-1330, W6-12840, PG-31, F-2013-10., BGSD-1228, BGSD-1217, F-2013-7, PG-24, AVTG-2, IETG-5, BGSD-1230, AL-50, BGSD-1219, IETG-9, BGSD-1225, F-2013-16, GRS-1337, INGD-216, F-2013-11, GRS-1345, F-2013-13, F-2013-12, GRS-1332, F-2013-18, W6-35698, PG-18, AVTG-4, F-II-SF, IETG-6, BG-117, F-2013-17, F-2013-4, PG-20, GRS-1338, BGSD-1232, F-2013-3
Jammu and Kashmir	2	K1 and K2
Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut.	51	F-4, KANT GOLA, F-5, PG-32, GODAVARI, CFG-3, BG-108, GG-1, G-50, F-2, CFG-2, PHULE BASANT, PG-35, CL LAMBA, SINGLE KALE, CFG-4, G-335, F-3, CHACHENA MOTA, AVT G-4, F-13, GG-4, BHIMA OMKAR, CGG-8, BHIMA PURPLE, DESI LASHUN, KADARI-4, CFG-6, CFG-5, CFG-7, CFG-1, F-6 SF, AVTG-1, G-282, PG-17, G-282, UP CHATTA, PG-24, CFG-8, PG-9, JAWA, ROHINI-2, CHEENIA, HARI RANI, INDIAN GARLIC, G-323, F-2 SF, F-1, SAKHA-44, F-3-1, GG-2.
Directorate of Onion anf Garlic, Pune	30	581, M-162, IC-372944, IC-370510, M-352, WG-34, 646, IC-374981, IC-372907, 606, 650, WG-418, IC-372930, 681, IC-175327, 486, WG-13, IC-372954, AC-200, RG-338, 604, WG-29, IC-87880, 599, IC-64363, 678, 652, IC-372905, RG-77, WG-48
Palampur, Himachal Pradesh	4	PALAMPUR SELECTION, GHC-1, CHAMLOA LOCAL, PUNNUR LOCAL
Telangana	7	TG-F1, TG-F2, TG-F3, TG-F4, TG-F5, TG-F6, TG-F7,

Table 2: Analysis of variance for 12 characters in garlic (*Allium sativum* L.)

Sources of variation	*d.f*	Mean Squares X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
Replication	2	57.85	543.85	39.67	0.3	7.03	0.1	1.98	2.14	136.94	157.02	2.54	0.39
Genotypes	130	338.24**	164.08**	7.33**	1.48**	89.76**	0.13**	1.391**	1.38**	247.76**	94.88**	0.83**	1.97**
Error	260	10.86	12.31	0.39	0.04	1	0	0	0.04	2.2	4.22	0.03	0

**Significant at 1% level. *d.f* = degree of freedom, X1 = Plant height (cm), X2 = Leaf length (cm), X3 = Number of green leaves per pseudostem, X4 = Number of dry leaves per pseudostem, X5 = Pseudostem height (cm), X6 = Psedustem diameter (cm), X7 = Polar diameter of bulb (cm), X8 = Equatorial diameter of bulb (cm), X9 = Bulb weight (g), X10 = Number of cloves per bulb, X11 = Length of clove (cm), X12 = Weight of clove (cm)

Table 3: Estimates of genotypic and phenotypic correlation co-efficient between different characters in garlic.

Trait	G/P	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	G	1	0.93	0.055	0.096	0.772	0.758	0.502	0.671	0.541	0.38	0.433	0.343
	P	1	0.782**	0.069	0.074	0.729**	0.642**	0.469**	0.617**	0.508**	0.340**	0.398**	0.324**
X_2	G	0.93	1	0.018	0.062	0.371	0.661	0.459	0.603	0.461	0.402	0.416	0.272
	P	0.782**	1	0.023	0.056	0.307**	0.599**	0.391**	0.510**	0.419**	0.369**	0.326**	0.251**
X_3	G	0.055	0.018	1	0.094	0.095	0.066	0.037	-0.01	0.042	0.013	0.041	0.003
	P	0.069	0.023	1	0.083	0.082	0.024	0.099*	0.056	0.073	0.055	0.08	0.023
X_4	G	0.096	0.062	0.094	1	0.095	0.071	0.123	0.085	0.088	-0.065	0.178	0.097
	P	0.074	0.056	0.083	1	0.083	0.071	0.109*	0.077	0.085	-0.048	0.166**	0.093
X_5	G	0.772	0.371	0.095	0.095	1	0.55	0.374	0.507	0.43	0.188	0.312	0.299
	P	0.729**	0.307**	0.082	0.083	1	0.489**	0.351**	0.475**	0.417**	0.172**	0.275**	0.290**
X_6	G	0.758	0.661	0.066	0.071	0.55	1	0.639	0.554	0.562	0.082	0.59	0.526
	P	0.642**	0.59**	0.024	0.071	0.489**	1	0.548**	0.470**	0.509**	0.079	0.488**	0.478**
X_7	G	0.502	0.459	0.037	0.123	0.374	0.639	1	0.728	0.733	0.209	0.675	0.68
	P	0.469**	0.391**	0.099**	0.109*	0.351**	0.548**	1	0.720**	0.714**	0.207**	0.630**	0.657**
X_8	G	0.671	0.603	-0.01	0.085	0.507	0.554	0.728	1	0.858	0.503	0.524	0.547
	P	0.617**	0.510**	0.056	0.077	0.475**	0.470**	0.720**	1	0.827**	0.471**	0.488**	0.529**
X_9	G	0.541	0.461	0.042	0.088	0.43	0.562	0.733	0.858	1	0.322	0.581	0.713
	P	0.508**	0.419**	0.073	0.085	0.417**	0.509**	0.714**	0.827**	1	0.317**	0.545**	0.706**
X_{10}	G	0.38	0.402	0.013	-0.065	0.188	0.082	0.209	0.503	0.322	1	0.061	-0.121
	P	0.340**	0.369**	0.055	-0.048	0.172**	0.079	0.207**	0.471**	0.317**	1	0.066	-0.0997*
X_{11}	G	0.433	0.416	0.041	0.178	0.312	0.59	0.675	0.524	0.581	0.061	1	0.65
	P	0.398**	0.326**	0.08	0.166**	0.275**	0.488**	0.630**	0.488**	0.545**	0.066	1	0.609**
X_{12}	G	0.343	0.272	0.003	0.097	0.299	0.526	0.68	0.547	0.713	-0.121	0.65	1
	P	0.324**	0.251**	0.023	0.093	0.290**	0.478**	0.657**	0.529**	0.706**	-0.100*	0.609**	1

*significant at 5% level; **significant at 1% level, G = Genotypic, P = Phenotypic, X1 = Plant height (cm), X2 = Leaf length (cm), X3 = Number of green leaves per pseudostem, X4 = Number of dry leaves per pseudostem, X5 = Pseudostem height (cm), X6 = Psedustem diameter (cm), X7 = Polar diameter of bulb (cm), X8 = Equatorial diameter of bulb (cm), X9 = Bulb weight (g), X10 = Number of cloves per bulb, X11 = Length of clove (cm), X12 = Weight of clove (cm)

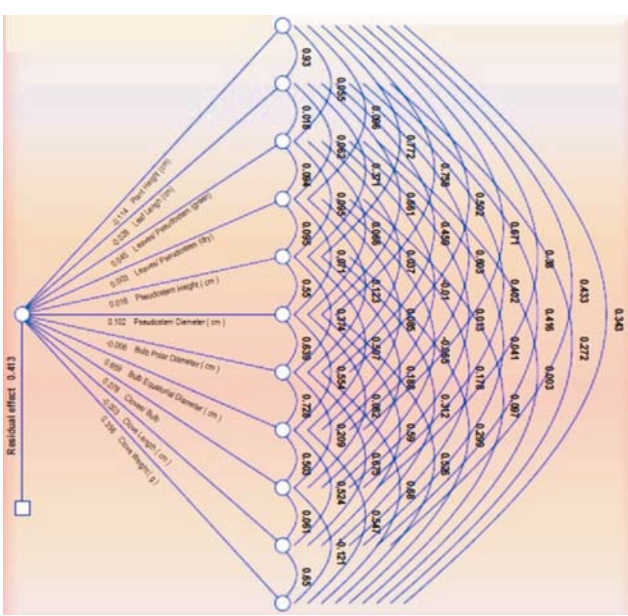

Figure 1: Genotypic path diagram showing cause- effect relationship for bulb weight plant^{-1} in garlic (*Allium sativum* L.).

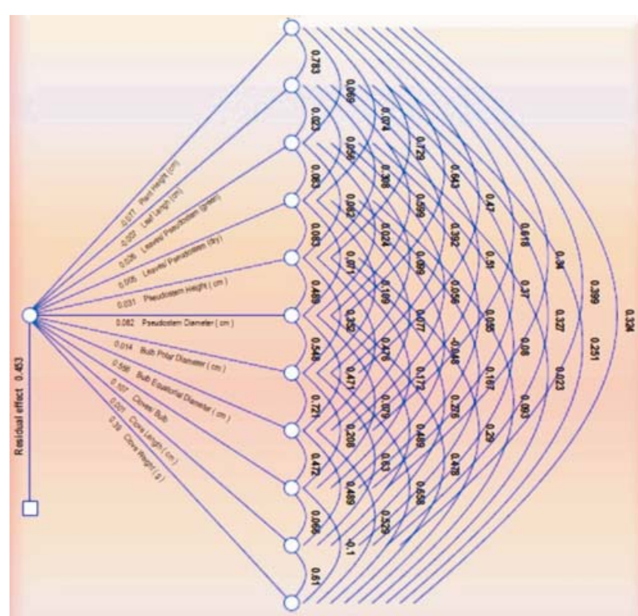

Figure 2: Phenotypic path diagram showing cause- effect relationship for bulb weight plant^{-1} in garlic (*Allium sativum* L.)

Table 4: Direct and indirect effect of different characters on bulb weight/plant at genotypic and phenotypic level

Trait	G/P	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	r
X_1	G	-0.114	-0.026	0.002	0	0.012	0.078	-0.003	0.442	0.03	-0.001	0.122	0.541
	P	-0.077	-0.006	0.002	0	0.023	0.053	0.007	0.343	0.036	0.001	0.126	0.508**
X_2	G	-0.106	-0.028	0.001	0	0.006	0.068	-0.003	0.397	0.031	-0.001	0.097	0.461
	P	-0.06	-0.007	0.001	0	0.01	0.049	0.005	0.284	0.04	0	0.098	0.419**
X_3	G	-0.006	-0.001	0.045	0	0.001	0.007	0	-0.007	0.001	0	0.001	0.042
	P	-0.005	0	0.026	0	0.003	0.002	0.001	0.031	0.006	0	0.009	0.073
X_4	G	-0.011	-0.002	0.004	0.003	0.001	0.007	-0.001	0.056	-0.005	-0.001	0.035	0.088
	P	-0.006	0	0.002	0.005	0.003	0.006	0.002	0.043	-0.005	0	0.036	0.085
X_5	G	-0.088	-0.011	0.004	0	0.016	0.056	-0.002	0.334	0.015	-0.001	0.106	0.43
	P	-0.056	-0.002	0.002	0	0.031	0.04	0.005	0.265	0.018	0	0.113	0.417**
X_6	G	-0.087	-0.019	0.003	0	0.009	0.102	-0.004	0.365	0.006	-0.002	0.188	0.562
	P	-0.05	-0.004	0.001	0	0.015	0.082	0.008	0.262	0.008	0.001	0.187	0.510**
X_7	G	-0.058	-0.013	0.002	0	0.006	0.065	-0.006	0.48	0.016	-0.002	0.242	0.733
	P	-0.036	-0.003	0.003	0.001	0.011	0.045	0.014	0.4	0.022	0.001	0.257	0.714**
X_8	G	-0.077	-0.017	0	0	0.008	0.057	-0.005	0.659	0.039	-0.002	0.195	0.858
	P	-0.048	-0.004	0.001	0	0.015	0.039	0.01	0.556	0.051	0.001	0.206	0.828**
X_9	G	-0.043	-0.011	0.001	0	0.003	0.008	-0.001	0.331	0.078	0	-0.043	0.322
	P	-0.026	-0.003	0.001	0	0.005	0.007	0.003	0.262	0.107	0	-0.039	0.318**
X_{10}	G	-0.05	-0.012	0.002	0.001	0.005	0.06	-0.004	0.346	0.005	-0.003	0.232	0.581
	P	-0.031	-0.002	0.002	0.001	0.009	0.04	0.009	0.272	0.007	0.001	0.238	0.545**
X_{11}	G	-0.039	-0.008	0	0	0.005	0.054	-0.004	0.36	-0.009	-0.002	0.356	0.713
	P	-0.025	-0.002	0.001	0	0.009	0.039	0.009	0.294	-0.011	0.001	0.39	0.706**

Residual effect = 0.4527 (P) & 0.4129 (G), G = Genotypic, P = Phenotypic, X1 = Plant height (cm), X2 = Leaf length (cm), X3 = Number of green leaves per pseudostem, X4 = Number of dry leaves per pseudostem, X5 = Pseudostem height (cm), X6 = Psedustem diameter (cm), X7 = Polar diameter of bulb (cm), X8 = Equatorial diameter of bulb (cm), X9 = Number of cloves per bulb, X10 = Length of clove (cm), X11 = Weight of clove (cm), r = correlation coefficient.

responsible for influencing bulb weight per plant.

Path analysis revealed that bulb weight per plant had significantly positive direct effect on plant height, leaf length, pseudostem height, pseudostem diameter, the polar diameter of the bulb, equatorial diameter of the bulb, the number of cloves per bulb, the length of clove and weight of clove (Table 4). Therefore, direct selection for these characters is likely to bring about an overall improvement in bulb weight per plant. The results were in propinquity with Rahman and Das (1985) for bulb diameter, plant height and bulb length, Singh *et al.* (1981) for average clove weight. Shrivastava *et al.* (2004) for clove weight, clove per bulb and stem diameter. Panse *et al.* (2013) for plant height, polar diameter, the average weight of 10 cloves and Dubey *et al.* (2010) and Ghodhani and Singh (2003) for bulb weight and equatorial bulb diameter. The characters like equatorial diameter of bulb, clove weight, number of cloves per bulb were the most important bulb weight determinants, because of their high direct effects and high indirect effects *via* many other yield improving characters. The high indirect effect also showed that most of the characters influenced the bulb weight through pseudostem height, pseudostem diameter and number of green and dry leaves per pseudostem. This suggests that emphasis must be given on such traits while exercising selection to improve the bulb weight in garlic.

The residual effect of 0.453 & 0.413 on bulb weight per plant at phenotypic and genotypic levels, respectively, was normal thereby suggested that some minor yield components are left out in the programme (Fig. 1 and Fig. 2). This is in agreement with Lenka and Mishra (1973) suggesting the need for further research to enhance breeding for yield and quality parameters.

In conclusion, the present study affirms that equatorial diameter of the bulb, clove weight, the number of cloves per bulb, pseudostem diameter, pseudostem height, had high significantly positive association, along with high positive direct effect on bulb weight per plant. These characters will be effective for improvement of bulb weight per plant through conventional breeding or use of novel molecular breeding.

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