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Genetic variability, correlation and path coefficient among bulb yield and yield traits in Ethiopian garlic germplasm

Kassahun Tsega, Akhilesh Tiwari* and Kebede Woldetsadik
Department of Plant Sciences, College of Agriculture
Haramaya University, Haramaya, Ethiopia

ABSTRACT

Variability and correlation among bulb yield and yield related traits of twenty five local garlic accessions was studied at Chilga, North Gondar Zone, Ethiopia during 2005 and 2006. Highly significant differences (P<0.01) among accessions were recorded for yield and its contributing characters, whereas harvest index showed significant (P<0.05) variation. Moreover, very little difference was found in between genotypic and phenotypic coefficient of variation indicating the variability among accessions were mainly characterized by their genetic constitution, whereas the environmental influence was very low. Comparatively high heritability coupled with high expected genetic advance as percent of mean was recorded for bulb dry weight, dry weight above ground, yield per plant, biological yield per plant, plant height, leaf length, weight of clove and cloves per bulb. Bulb yield per plant showed positive and significant phenotypic correlation with all characters except harvest index and days to maturity. Genotypic correlations were higher in magnitude than that of phenotypic correlations for the majority of the characters studied. Path coefficient analysis revealed that all characters except leaf length, dry weight above ground and bulb dry weight exerted positive direct effect on bulb yield per plant at phenotypic level. The low residual value indicated that the characters used were enough to explain their contribution and effects on bulb yield per plant in garlic towards yield.

Key words: *Allium,* garlic, variability, correlation, path coefficient analysis.

INTRODUCTION

Garlic (*Allium sativum* L., 2n = 16) belongs to the family Alliaceae and is the second most widely used *Allium* next to onion (Rubatzky and Yamaguchi, 7). It originated on the northwestern side of the Tien-Shan mountains of Kirgizia in the arid and semi-arid areas of Central Asia (Etoh and Simon, 9) and has a wide area of adaptation and cultivation throughout the world. In Ethiopia, garlic was cultivated on 6,042 ha land and 79,421 tonnes of yield was recorded during 2001-02. Out of the total production, 64% was used for household consumption and 22% was used for the market (CACC, 6). In this country, garlic is one of the most vital vegetable crops used as ingredients of local *stew wot*. It is produced by small and commercial growers for both local use and export. Keeping in view selection for yield and yield related traits require an integral approach, since the nature of yield contributing characters is highly variable and significantly modified by external factors. The effectiveness of selection depends on the amount of variability present in the genetic material for yield and yield related characters. Hence, the estimation of variability is of prime importance. The knowledge regarding the association and path coefficient between yield and its component characters are therefore of paramount importance in determining the real component characters that could be used as selection parameters for effective improvement. Figliuolo *et al. (*11), Shri Dhar (18), Naruka and Dhaka (16) in their work on garlic, found tremendous variability, association and direct and indirect effect among bulb yield and yield traits. However, information is lacking regarding these parameters among the different accessions existing in Ethiopia, especially yield and its related traits. Therefore, in the present study an attempt has been made to exploit the rich garlic germplasm and establish relationship between pairs of characters and relative contribution of yield components to the yield.

MATERIALS AND METHODS

The study was conducted in the northern part of Ethiopia, North Gondar Zone, Chilga *woreda* (District), located about 60 km west of *Gondar* town during 2005 and 2006. The research site has an altitude of 1,980 m above sea level, receives mean annual rainfall of 800 mm and has maximum and minimum mean temperatures of 25 and 12°C, respectively (CWARDO, 7). The soil type is sandy loam with 2.45% organic matter and pH of 6.01. Twenty-five local garlic accessions were used for the study. The accessions represent the national collections from different regions

*Corresponding author's present address: College of Agriculture, JNKVV, Ganj Basoda 464 221, Distt. Vidisha (M.P.); E-mail: tiwariethiopia@gmail.com

of the country, maintained at Debre Zeit Agricultural Research Centre, Ethiopia. The investigation was carried out in randomized block design (RBD) with three replications. Cloves were planted at a spacing of 30 cm and 10 cm between rows and plants, respectively. Land preparation, planting and other management practices were applied as per the recommendations of Getachew and Asfaw (12).

Fifteen economical characters were recorded on ten randomly taken plants from each plot. The plant height (PH) was measured in centimetre from the ground level to the top of the mature leaf. The total number of healthy leaves taken at physiological maturity was counted as number of leaves per plant (NLPP). The diameter of the longest leaf measured by vernier calliper at maturity was expressed as leaf diameter (LD) however, average length of the longest leaf expressed as leaf length (LL). Neck girth (NG) was calculated as average thickness measured at the neck point of the mature bulb. The diameter at the two poles measured as bulb polar diameter (BPD). However, the average size measured at the widest point in the middle portion of the bulb was recorded as bulb perimeter (BP). The total number of cloves per bulb (CB) counted after harvest and weight of clove was measured as weight of clove (WC) in gram. The average weight of mature bulb expressed in grams was recorded as yield per plant (YPP) however total yield (total biomass) at the time of maturity expressed as biological yield per plant (BYPP). Further, the ratio of total bulb yield per plant to the biological yield expressed in percentage recorded as harvest index per plant (HI). The average weight of the mature bulb in grams after oven dried at 80°C till the constant moisture level was measured as bulb dry weight (BDW) Similarly total dry weight of above ground biomass of physiologically mature plant was recorded as dry weight above ground (DWAG). Days to maturity (DTM) was measured as actual number of days from planting to a day at which more than 90% of the plants attained physiological maturity.

The collected data were subjected to analysis of variance using the linear model equation

$y_{ij} = \mu + T_i + \beta_j \cdot \varepsilon_{ij}$, where, μ = the overall mean, T_i = the effect of the i[th] treatment, β_j = the effect of the j[th] block, and ε_{ij} = the random effect associated with the experimental unit assigned to the i[th] treatment and occurring in the j[th] plot to determine the differences existing among the 25 garlic accessions. The variance was analyzed using the standard procedure applicable to randomized block design (RBD) as suggested by Gomez and Gomez (13) using MSTATC (15) statistical software. The variability present in the population was estimated on simple measures, namely range, mean, standard error, phenotypic and genotypic variance, coefficient of variations, heritability and genetic advance as suggested by Burton and De Vane (5), and Allard (2). Correlation and path analysis was calculated method suggested by Miller *et al.* (4), and Dewey and Lu (8).

RESULTS AND DISCUSSION

Analysis of variance (ANOVA) for all the characters is presented in Table 1. The mean squares due to accessions were found to be highly significant (P<0.01) for all the traits studied except harvest index which was significant at P<0.05, indicating the existence of sufficient genetic variability among the accessions. Figliuolo *et al.* (11) also reported highly significant difference with respect to plant height, leaf length, number of leaves per pant, neck girth, number of cloves per bulb, bulb polar diameter, bulb perimeter and weight of cloves.

The results of the present investigation on the estimates of different variability parameters for the characters studied are presented in Table 2. All characters presented wide range of variation across the accessions such as plant height (35.20 cm in G-42-1/94 to 53.33 cm in G-493), number of leaves per plant (3.4 for G-75/94 to 5.85 for G-15-2/94), leaf dia. (0.53 cm in G-22-2/94 to 1.13 cm in G-45/95), leaf length (19.50 cm for G-22/94 to 31.86 cm for G-52-2/94), neck girth (2.65 cm in G-22-2/94 to 3.78 cm in W-014), bulb perimeter (9.5 cm in G-05/94 to 14.02 cm in G-114-1/94), bulb polar diameter (4.16 cm for G-05/94 to 5.40 cm for G-114-1/94), number of cloves per bulb (5.00 in G-22-2/94 to 13.79 G-208-1/90). Weight of cloves, yield per plant and biological yield per plant showed a wide range of variability being the minimum for G-05/94 and maximum for W-014. Days to maturity recorded variation between 123.33 days (early) in G-36-1/94 and 157.66 days (late) in G-493. The mean performance for different characters of garlic genotypes at Chilga, North Gondar is given in Table 3. The range and the mean suggested the existence of sufficient variability among the tested accessions for majority of characters which showed that there is considerable potential in improvement of Ethiopian local garlic.

Phenotypic coefficients of variation (PCV) were higher than genotypic coefficients of variation (GCV) for all characters tested. A very narrow difference between PCV and GCV was observed in characters like days to maturity, cloves per bulb, bulb dry weight and plant height, which indicated less influence of the environmental factors in determining such traits. The

range for PCV was 7.16% for bulb polar diameter to 44.7% for bulb dry weight, whereas GCV ranged from 4.81% for harvest index to 44.57% for bulb dry weight. High PCV and GCV were observed in characters like dry weight above ground, yield per plant, biological yield per plant and weight of cloves. These variations in characters may attribute to the geographical origin of these accessions and it offers relatively wide scope for selection among these characters. Moderate PCV and GCV values were recorded for number of leaves per plant, bulb perimeter, plant height, cloves per bulb, leaf length and leaf diameter. These traits having considerable genetic variability, offer good opportunity for crop improvement through selection. Bulb polar diameter, days to maturity, neck girth and harvest index showed lower PCV and GCV values indicating limited scope for improvement of these traits through selection. This study was in conformity with that of Shri Dhar (18) in garlic, Abayneh (1) in onion and Fasika (10) in shallot. Broad sense heritability (h^2) for all characters exhibited high value of heritability except harvest index. It ranged from 42.7% for harvest index to 99.7% for biological yield per plant. Moreover, high expected genetic advance as percent of mean was observed for bulb dry weight, dry weight above ground, yield per plant, biological yield per plant, weight of clove and cloves per bulb. Hence, selection for such characters is likely to be effective, as high heritability values were associated with high genetic advance. In agreement with the present findings, Shri Dhar (2002) also reported high heritability and genetic advance for various characters.

Estimates of phenotypic and genotypic correlation coefficients between each pair of the studied characters are presented in Table 4. Genotypic correlation coefficients were found to be higher in magnitude than that of phenotypic correlation coefficients, which clearly indicated the presence of inherent association among various characters. Bulb yield per plant showed positive and significant phenotypic and genotypic associations with plant height, number of leaves per plant, leaf diameter, leaf length, neck girth, bulb polar diameter, bulb perimeter, cloves per bulb, weight of cloves, biological yield per plant, dry weight above ground, and bulb dry weight. Thus, it indicated that improvement of these characters could improve the physiological capacity of the crop to mobilize and translocate photosynthates to the organs of economic value, which in turn might have increased the bulb yield as observed in the study. In harmony with this study, Badshah and Umar (3), Naruka and Dhaka (16), and Baghalian *et al.* (4) observed the same result in garlic.

Table 1. Mean square of 15 quantitative characters of 25 Ethiopian garlic accessions.

Code	Source of variation			
	Replication	Accession	Error	CV(%)
PH (cm)	2.577	83.085**	1.848	3.2
NLPP	0.064	1.215**	0.132	7.6
LD (cm)	0.007	0.043**	0.003	6.5
LL (cm)	0.557	29.243**	0.355	2.5
NG (cm)	0.013	0.202**	0.011	3.1
BPD (cm)	0.016	0.304**	0.026	3.3
BP (cm)	0.061	4.337**	0.084	2.5
CB	0.103	13.049**	0.054	2.3
WC (g)	0.001	0.795**	0.003	3.0
YPP (g)	0.065	119.354**	0.200	2.2
BYPP (g)	0.386	183.540**	0.160	1.6
HI (%)	24.901	61.008*	18.802	5.5
DWAG (g)	0.004	0.999**	0.004	4.4
BDW (g)	0.004	19.493**	0.037	3.4
DTM (days)	0.413	336.167**	0.413	0.5

PH = plant height, NLPP = number of leaves per plant, LD = leaf diameter, LL = leaf length, NG = neck girth, BPD = bulb polar diameter, BP = bulb perimeter, CB = number of cloves per bulb, WC = weight of clove, YPP = yield per plant, BYPP = biological yield per plant, HI = harvest index per plant, DWAG = dry weight above ground, BDW = bulb dry weight, DTM = days to maturity. CV = coefficient of variation.

**,* = Significant at 1 and 5% levels of probability, respectively.

Table 2. Phenotypic (PCV) and genotypic (GCV) coefficients of variation, phenotypic ($\sigma^2 p$) and genotypic ($\sigma^2 g$) variances, heritability (h^2), genetic advance (GA) and genetic advance as percent of mean for 15 characters of 25 garlic accessions at Chilga.

Character	Range	Mean ± SE	$\sigma^2 p$	$\sigma^2 g$	PCV (%)	GCV (%)	$h^2(\%)$	GA	GA (%)
PH (cm)	35.20 - 53.33	43.06 ± 1.11	28.927	27.079	12.49	12.08	93.6	10.3	24.0
NLPP	3.40 - 5.85	4.76 ± 0.29	0.493	0.361	14.74	12.61	73.2	1.0	22.0
LD (cm)	0.53 -1.13	0.90 ± 0.04	0.016	0.013	14.27	12.72	81.2	0.2	23.3
LL(cm)	19.50 - 31.86	24.01 ± 0.48	9.984	9.629	13.16	12.92	96.4	6.2	26.1
NG (cm)	2.65 - 3.78	3.32 ± 0.08	0.074	0.063	8.20	7.59	85.1	0.4	14.1
BPD (cm)	4.16 - 5.40	4.80 ± 0.13	0.118	0.092	7.16	6.34	77.9	0.5	11.4
BP (cm)	9.50 - 14.02	11.75 ± 0.23	1.501	1.417	10.43	10.13	94.4	2.3	20.2
CB	5.00 - 13.79	10.23 ± 0.18	4.385	4.331	20.46	20.34	98.7	4.2	41.5
WC (g)	0.758 - 2.728	1.913 ± 0.04	0.267	0.264	27.02	26.86	98.8	1.0	54.8
YPP (g)	6.51- 29.44	19.99 ± 0.38	39.918	39.718	32.36	32.27	99.4	12.9	64.6
BYPP (g)	8.05 - 37.19	25.37 ± 0.32	61.286	61.126	31.29	31.25	99.7	16.0	63.3
HI (%)	72.22 - 88.50	78.56 ± 3.55	32.870	14.068	7.33	4.81	42.7	5.0	6.4
DWAG (g)	0.40 - 2.83	1.48 ± 0.05	0.335	0.331	39.12	38.88	98.8	1.1	79.0
BDW (g)	1.56 - 10.72	5.71 ± 0.15	6.522	6.485	44.70	44.57	99.4	5.2	91.4
DTM (days)	123.33 - 157.66	138.06 ± 0.52	112.331	111.918	7.68	7.66	99.6	21.7	15.7

PH = plant height, NLPP = number of leaves per plant, LD = leaf diameter, LL = leaf length, NG = neck girth, BPD = bulb polar diameter, BP = bulb perimeter, CB = number of cloves per bulb, WC = weight of clove, YPP = yield per plant, BYPP = biological yield per plant, HI = harvest index per plant, DWAG = dry weight above ground, BDW = bulb dry weight, DTM = days to maturity.

Table 3. Mean performance for different characters of ethiopian garlic genotypes at Chilga, North Gondar.

Genotype	PH (cm)	NLPP	LD (cm)	LL (cm)	NG (cm)	BPD (cm)	BP (cm)	CB	WC (g)	YPP (g)	BYPP (g)	HI (%)	DWA (g)	BDW (g)	DTM (days)
G-05/94	35.21	3.80	0.84	20.03	3.04	4.16	9.50	8.12	0.758	6.51	8.05	80.86	0.40	2.01	149.33
G-20/95	40.93	4.06	0.96	21.33	3.43	4.69	11.83	11.03	1.796	20.33	28.15	72.22	1.25	6.09	127.33
G-48-1/94	42.14	4.90	1.01	28.26	3.44	4.96	12.16	11.21	1.676	19.83	27.41	72.33	2.18	6.93	142.66
G-22-2/94	38.22	3.56	0.86	22.62	3.20	4.73	10.27	7.83	1.021	8.57	10.97	78.10	0.66	1.97	136.00
G-66-1/94	45.71	5.06	0.93	26.76	3.71	5.00	13.00	10.63	2.629	28.81	36.11	79.80	2.16	10.72	129.33
G-52-2/94	51.17	5.13	1.03	31.86	3.68	5.33	12.71	8.50	2.503	21.55	29.59	72.83	2.83	5.26	145.33
G-170-2/94	40.91	4.43	0.98	22.83	3.46	4.54	10.80	8.06	2.332	17.96	22.78	79.99	1.12	4.44	134.00
G-24-1/94	39.54	5.10	0.90	22.75	3.51	4.83	11.47	10.47	2.332	24.29	31.40	78.01	1.15	6.29	131.33
G-107-1/94	41.38	4.66	0.85	24.44	3.49	4.67	10.81	7.38	2.030	15.38	19.04	80.77	1.13	4.92	157.66
G-42-1/94	35.20	4.03	0.79	20.05	3.19	4.81	10.91	9.83	1.951	19.77	26.77	73.89	1.81	7.16	137.33
G-20-2/94	38.53	4.93	0.86	20.65	3.18	4.53	10.96	11.03	1.801	20.60	26.82	76.81	1.62	3.07	129.00
G-75-2/94	42.33	3.40	0.79	23.66	2.93	4.21	11.05	11.51	0.991	11.83	14.84	79.71	1.25	3.66	155.33
G-36-1/94	48.02	4.66	0.86	24.33	3.28	4.93	11.51	11.20	1.712	19.66	24.74	79.51	1.97	7.07	123.33
G-165-2/94	52.70	4.70	0.93	23.70	3.59	4.46	11.62	9.00	2.550	23.25	26.55	87.57	0.91	6.86	125.66
G-45/95	45.22	4.96	1.13	27.33	3.43	5.03	13.05	10.30	2.320	24.07	32.33	74.47	2.06	7.94	151.66
G-42-2/94	35.83	4.46	0.94	20.15	3.45	4.55	10.66	9.80	2.142	21.43	26.88	79.70	1.60	6.01	138.33
G-114-1/94	45.01	5.60	0.98	24.03	3.50	5.40	14.02	10.33	2.151	23.52	27.55	85.37	1.42	7.85	126.00
G-15-2/94	42.64	5.83	0.91	22.99	3.23	4.60	12.18	12.21	1.875	23.21	26.45	88.50	0.96	6.26	126.00
G-94-1/94	48.22	5.60	0.97	26.27	3.26	5.18	13.03	13.77	1.815	25.21	30.44	72.83	1.56	1.56	142.00
W-014	47.39	5.56	1.08	27.53	3.78	5.06	13.14	11.30	2.728	29.44	37.19	80.72	2.29	9.27	133.66
G-39-1/94	38.11	5.43	0.86	21.33	2.98	4.50	10.50	8.66	1.541	13.74	18.91	72.65	1.80	2.47	147.00
G-22-2/94	37.51	4.96	0.53	19.50	2.65	5.05	9.85	5.00	1.432	7.50	9.74	77.00	0.58	1.87	136.66
G-94-2/94	45.18	4.43	0.74	26.61	3.33	5.11	12.92	13.33	1.865	23.21	29.26	79.68	1.34	9.52	141.33
G-493	53.33	4.96	0.99	23.72	3.23	5.01	12.94	11.55	2.321	28.61	34.74	82.36	1.44	7.15	157.66
G-208-1/90	46.16	4.83	0.87	27.54	3.21	4.87	12.87	13.79	1.546	21.66	27.62	78.42	1.54	6.48	133.66
Mean	43.06	4.76	0.90	24.01	3.32	4.80	11.75	10.23	1.913	19.99	25.37	78.56	1.48	5.71	138.06
LSD 5 %	2.97	0.79	0.12	1.30	0.22	0.35	0.63	0.50	0.12	0.97	0.87	9.46	0.13	0.42	1.40
Max.	53.33	5.83	1.13	31.86	3.78	5.40	14.02	13.79	2.728	29.44	37.19	88.50	2.83	10.72	157.66
Min.	35.20	3.40	0.53	19.50	2.65	4.16	9.50	5.00	0.758	6.51	8.05	72.22	0.40	1.56	123.33

PH = plant height, NLPP = number of leaves per plant, LD = leaf diameter, LL = leaf length, NG = neck girth, BPD = bulb polar diameter, BP = bulb perimeter, CB = number of cloves per bulb, WC = weight of clove, YPP = yield per plant, BYPP = biological yield per plant, HI = harvest index per plant, DWAG = dry weight above ground, BDW = bulb dry weight, DTM = days to maturity.

Table 4. Correlation coefficients at genotypic (above diagonal) and phenotypic (below diagonal) levels of various characters of garlic accessions at Chilga, North Gondar during 2005 and 2006.

Character	PH (cm)	NLPP	LD (cm)	LL (cm)	NG (cm)	BPD (cm)	BP (cm)	CB	WC (g)	YPP (g)	BYPP (g)	HI (%)	DWAG (g)	BDW (g)	DTM (g)
PH		0.421*	0.482*	0.718*	0.476*	0.516*	0.750*	0.407*	0.536*	0.631*	0.582*	0.291	0.399*	0.440*	-0.168
NLPP	0.355		0.385*	0.366*	0.327*	0.594*	0.605*	0.244	0.581*	0.623*	0.581*	0.210	0.407*	0.251	-0.162
LD	0.416*	0.273		0.565*	0.788*	0.259*	0.607*	0.331*	0.587*	0.650*	0.675*	-0.039	0.565*	0.397*	0.070
LL	0.668**	0.313	0.477*		0.588*	0.625*	0.738*	0.396*	0.412*	0.506*	0.536*	0.130	0.674*	0.452*	0.254
NG	0.426*	0.238	0.652**	0.543**		0.399*	0.584*	0.205	0.816*	0.728*	0.736*	0.194	0.533*	0.678*	-0.037
BPD	0.443*	0.472*	0.214	0.539**	0.284		0.771*	0.219	0.493*	0.535*	0.561*	-0.251	0.539*	0.439*	-0.127
BP	0.692**	0.490*	0.530**	0.699**	0.533**	0.642**		0.667*	0.582*	0.831*	0.815*	0.138	0.558*	0.681*	-0140
CB	0.396	0.202	0.291	0.382	0.186	0.190	0.648**		0.107	0.621*	0.608*	0.025	0.322	0.410*	-0.164
WC	0.507**	0.499*	0.526**	0.408*	0.753**	0.432*	0.559**	0.100		0.827*	0.822*	0.228	0.526*	0.664*	-0.168
YPP	0.613**	0.535**	0.588**	0.492*	0.679**	0.481*	0.804**	0.617**	0.820*		0.984*	0.196	0.579*	0.749*	-0.234
BYPP	0.562**	0.497*	0.602**	0.526**	0.682**	0.499*	0.791**	0.605**	0.815**	0.981**		0.022	0.671*	0.752*	-0.194
HI	0.222	0.053	-0.001	-0.127	0.106	-0.107	0.086	0.033	0.132	0.154	0.003		-0.496*	0.325	-0.336
DWAG	0.385	0.343	0.508**	0.657**	0.491*	0.470*	0.543**	0.320	0.521**	0.576**	0.668**	-0.328		0.485	0.171
BDW	0.424*	0.223	0.355	0.444*	0.632**	0.395	0.659**	0.412*	0.659**	0.748**	0.750**	0.228	0.482*		-0.184
DTM	-0.164	-0.130	0.064	0.248	-0.035	-0.119	-0.135	-0.164	-0.166	-0.233	-0.193	-0.233	0.172	-0.183	

**,* = Significant at 1 and 5% levels, respectively.

PH = plant height, NLPP = number of leaves per plant, LD = leaf diameter, LL = leaf length, NG = neck girth, BPD = bulb polar diameter, BP = bulb perimeter, CB = number of cloves per bulb, WC = weight of clove, YPP = yield per plant, BYPP = biological yield per plant, HI = harvest index per plant, DWAG = dry weight above ground, BDW = bulb dry weight, DTM = days to maturity.

Table 5. Phenotypic direct effect (bold face) and indirect effect of various characters on bulb yield per plant of garlic accessions evaluated at Chilga, North Gondar during 2005 and 2006.

Character	r_p	PH (cm)	NLPP	LD (cm)	LL (cm)	NG (cm)	BPD (cm)	BP (cm)	CB	WC (g)	BYPP (g)	HI (%)	DWAG (g)	BDW (g)	DTM (days)
PH	0.355	0.073	0.020	0.002	-0.064	0.021	0.014	0.007	0.059	0.071	0.43	0.020	-0.016	-0.002	-0.005
NLPP	0.416	0.026	0.055	0.001	-0.030	0.012	0.015	0.005	0.030	0.070	0.366	0.005	-0.014	-0.001	-0.004
LD	0.668	0.030	0.015	0.005	-0.045	0.032	0.007	0.005	0.043	0.073	0.443	0.000	-0.021	-0.001	0.002
LL	0.426	0.049	0.017	0.002	-0.095	0.026	0.017	0.007	0.057	0.057	0.387	-0.011	-0.027	-0.002	0.008
NG	0.443	0.031	0.013	0.003	-0.052	0.048	0.009	0.005	0.028	0.105	0.502	0.010	-0.020	-0.002	-0.001
BPD	0.692	0.032	0.026	0.001	-0.051	0.014	0.031	0.007	0.028	0.060	0.367	-0.010	-0.019	-0.001	-0.004
BP	0.396	0.050	0.027	0.003	-0.067	0.026	0.020	0.010	0.096	0.078	0.582	0.008	-0.022	-0.002	-0.004
CB	0.507	0.029	0.011	0.001	-0.036	0.009	0.006	0.007	0.148	0.014	0.445	0.003	-0.013	-0.001	-0.005
WC	0.613	0.037	0.028	0.003	-0.039	0.036	0.013	0.006	0.015	0.139	0.600	0.012	-0.021	-0.002	-0.005
BYPP	0.562	0.041	0.028	0.003	-0.050	0.033	0.015	0.008	0.090	0.114	0.736	0.000	-0.027	-0.003	-0.006
HI	0.222	0.016	0.003	0.000	0.012	0.005	-0.003	0.001	0.005	0.018	0.002	0.090	0.013	-0.001	-0.008
DWAG	0.385	0.028	0.019	0.002	-0.062	0.024	0.015	0.006	0.047	0.073	0.491	-0.029	-0.041	-0.002	0.006
BDW	0.424	0.031	0.012	0.002	-0.042	0.031	0.012	0.007	0.061	0.092	0.552	0.020	-0.020	-0.004	-0.006
DTM	-0.164	-0.012	-0.007	0.000	-0.024	-0.002	-0.004	-0.001	-0.024	-0.023	-0.142	-0.021	-0.007	0.001	0.033

r_p= phenotypic correlation coefficient.

Residual effect = 0.0064.

PH = plant height, NLPP = number of leaves per plant, LD = leaf diameter, LL = leaf length, NG = neck girth, BPD = bulb polar diameter, BP = bulb perimeter, CB = number of cloves per bulb, WC = weight of clove, YPP = yield per plant, BYPP = biological yield per plant, HI = harvest index per plant, DWAG = dry weight above ground, BDW = bulb dry weight, DTM = days to maturity.

Table 6. Genotypic direct effect (bold face) and indirect effect of various characters on bulb yield per plant of garlic accessions evaluated at Chilga, North Gondar during 2005-2006.

Character	r_g	PH (cm)	NLPP	LD (cm)	LL (cm)	NG (cm)	BPD (cm)	BP (cm)	CB	WC (g)	BYPP (g)	HI (%)	DWAG (g)	BDW (g)	DTM (days)
PH	0.421	**0.027**	0.090	0.022	-0.197	0.087	0.057	-0.172	0.130	0.061	0.265	-0.018	-0.039	0.087	-0.016
NLPP	0.385	0.115	**0.213**	0.018	-0.100	0.059	0.066	-0.138	0.078	0.067	0.264	-0.013	-0.040	0.050	-0.015
LD	0.565	0.132	0.082	**0.046**	-0.155	0.143	0.029	-0.139	0.106	0.067	0.307	0.002	-0.056	0.079	0.007
LL	0.588	0.197	0.078	0.026	**-0.275**	0.107	0.070	-0.169	0.127	0.047	0.244	0.008	-0.066	0.090	0.024
NG	0.399	0.130	0.070	0.036	-0.162	**0.182**	0.044	-0.134	0.066	0.094	0.335	-0.012	-0.052	0.134	-0.003
BPD	0.771	0.141	0.126	0.012	-0.172	0.073	**0.111**	-0.170	0.070	0.057	0.255	0.016	-0.053	0.087	-0.012
BP	0.667	0.205	0.129	0.028	-0.203	0.106	0.086	**-0.229**	0.213	0.067	0.370	-0.009	-0.055	0.135	-0.013
CB	0.107	0.111	0.052	0.015	-0.109	0.037	0.024	-0.153	**0.320**	0.012	0.277	-0.001	-0.032	0.082	-0.015
WC	0.827	0.147	0.124	0.027	-0.113	0.148	0.055	-0.133	0.034	**0.115**	0.374	-0.004	-0.052	0.132	-0.016
BYPP	0.984	0.159	0.124	0.031	-0.147	0.134	0.062	-0.186	0.195	0.094	**0.455**	-0.001	-0.066	0.149	-0.018
HI	0.022	0.080	0.045	-0.002	0.036	0.035	-0.028	-0.032	0.007	0.026	0.010	**-0.063**	0.049	0.064	-0.031
DWAG	-0.496	0.109	0.087	0.026	-0.185	0.097	0.060	-0.128	0.103	0.060	0.305	0.031	**-0.098**	0.096	0.016
BDW	0.485	0.121	0.053	0.018	-0.124	0.123	0.049	-0.156	0.133	0.076	0.342	-0.020	-0.048	**0.198**	-0.017
DTM	-0.184	-0.046	-0.034	0.003	-0.070	-0.007	-0.014	0.032	-0.052	-0.019	-0.088	0.020	-0.017	-0.036	**0.094**

r_g = genotypic correlation coefficient.

Residual effect = 0.0037.

PH = plant height, NLPP = number of leaves per plant, LD = leaf diameter, LL = leaf length, NG = neck girth, BPD = bulb polar diameter, BP = bulb perimeter, CB = number of cloves per bulb, WC = weight of clove, YPP = yield per plant, BYPP = biological yield per plant, HI = harvest index per plant, DWAG = dry weight above ground, BDW = bulb dry weight, DTM = days to maturity.

Correlations among yield and yield components and other quantitative traits help in understanding the interdependence of the traits**.** Biological yield per plant showed positive and significant phenotypic and genotypic correlation with plant height, number of leaves per plant, leaf diameter, leaf length, neck girth, bulb polar diameter, bulb perimeter, cloves per bulb, weight of clove, bulb dry weight and dry weight above ground (Table 4). This suggested that increment in biomass production was a result of increase in bulb perimeter, leaf diameter, number of leaves per plant, which led to relatively giant plant morphology. Plant height showed a positive and significant genotypic relationship with number of leaves per plant, leaf diameter and leaf length that obviously led to increment in photosynthetic area and might have partly contributed to increment in yield of bulb per plant. Number of leaves per plant and leaf diameter indicated positive phenotypic and genotypic correlation with biological yield per plant, weight of clove, bulb polar diameter and bulb perimeter along with leaf diameter, leaf length, neck girth, cloves per bulb, dry weight above ground and bulb dry weight, it seems reasonable to conclude that leaves numbers and diameter contributed for bulb yield per plant. Neck girth and bulb perimeter positively correlated with all the characters except days to maturity. Bulb polar diameter also positively associated with all characters except harvest index and days to maturity at phenotypic and genotypic levels. These three characters were correlated to each other which could be the factor for improvement of bulb yield. However, in the present study number of cloves per bulb hardly correlated with bulb weight. Weight of clove was positively and significantly correlated with all characters except cloves per bulb, days to maturity and harvest index at both genotypic and phenotypic level.

Dry weight above ground was positively and significantly correlated with number of leaves per plant, clove number per bulb, plant height, leaf diameter, leaf length, neck girth, bulb polar diameter, bulb perimeter, weight of clove, biological yield per plant and bulb dry weight at genotypic level, thus implied the above ground biomass exerted a critical influence on dry matter production and resulted in high bulb yield. Harvest index showed positive correlation except leaf diameter, bulb polar diameter, dry weight above ground and days to maturity at both phenotypic and genotypic level. Days to maturity was positively correlated only with leaf diameter, leaf length and dry weight above ground at phenotypic and genotypic level. However, bulb dry weight was positively correlated to all characters except days to maturity at both phenotypic and genotypic level. In harmony with this study, Figliuolo *et al*. (11) and Shri Dhar (18) reported similar results. The positive and significant association of pairs of characters at phenotypic level and positive and high correlation at genotypic level justified the possibility of correlated responses to select and it follows that, with the increase in one character, there is a possibility of increment in the other. The negative correlations prohibit the simultaneous improvement of those traits.

Correlations in phenotypic and genotypic terms were analyzed further by path coefficient analysis technique, which involved partitioning of the correlation coefficient in to direct and indirect effects *via* alternative characters or pathways. The estimates of direct and indirect effects are presented in Tables 5 & 6. At phenotypic and genotypic level Biological yield per plant and cloves per bulb contributed their major effect as direct effects along with accompanying traits *viz*., number of leaves per plant, bulb dry weight, neck girth, weight of clove, bulb polar diameter, days to maturity, leaf diameter and plant height. These characters could be considered as major components of selection in a breeding program for obtaining higher bulb yield and those characters significantly correlated with each other. Negative direct effect at phenotypic level was recorded for bulbs dry weight (-0.004), dry weight above ground (-0.041) and leaf length (-0.095). However, these traits were positively and significantly correlated with bulb yield per plant and its negative direct effect on bulb yield per plant was counterbalanced by its positive indirect effects via other traits. Similarly, leaf length, bulb perimeter, harvest index and dry weight above ground showed negative direct effect at genotypic level, but this effect was compensated by positive indirect effects resulted into positive correlation with bulb yield per plant.

In addition to direct effect on bulb yield per plant, these various traits individually exhibited positive indirect effects through other traits except few which showed negative indirect effect. The positive indirect effects nullified the negative indirect effects on bulb yield per plant and instigated positive correlation at both phenotypic and genotypic level. The economic yield is derived from the large part of the biological yield partitioned to the sink part. By improving biological yield per plant and harvest index there would be a possibility to improve bulb yield per plant. Biological yield can be increased by increasing the photosynthetic efficiency of the plant by improving light interception and reducing respiration. Besides plant height and number of leaves per plant positive direct effect on bulb yield per plant, its favourable indirect effect was *via* biological yield per plant, leaf diameter, neck girth, bulb polar diameter, cloves per bulb and weight of clove. Negative indirect effect of these on bulb yield per plant was through leaf length, dry weight above ground, bulb dry weight and days to maturity. These

results confirmed previous findings of Singh (19) in garlic and Abayneh (1) in onion.

Neck girth and bulb perimeter favorably and indirectly affected bulb yield per plant through various traits. Indirect negative effect on bulb yield per plant was via leaf length, harvest index, dry weight above ground, bulb dry weight and days to maturity. In spite of its negative correlation with bulb yield per plant, days to maturity exerted positive direct effect. Furthermore, the indirect favourable effect of days to maturity on bulb yield per plant was through bulb dry weight at phenotypic level. The negative correlation of days to maturity with bulb yield per plant was mainly due to the sum total of its unfavourable indirect effect. The direct effect of days to maturity was counterbalanced by its negative indirect effects and results in negative correlation. Despite the positive and significant correlation with bulb yield per plant**,** cloves per bulb and weight of clove exerted positive direct effect on bulb yield per plant at genotypic level. Negative indirect effect on bulb yield per plant by theses characters were counterbalanced by the favourable indirect effect via plant height, number of leaves per plant, leaf diameter, neck girth, bulb polar diameter, biological yield per plant and bulb dry weight. Neck girth, bulb polar diameter and bulb dry weight displayed unfavourable indirect effect on bulb yield per plant at genotypic level through leaf length, bulb perimeter, dry weight above ground, and days to maturity. This unfavourable indirect effect was counterbalanced by the favourable indirect effect of these characters on bulb yield per plant via biological yield per plant, plant height, weight of clove, number of leaves per plant, cloves per bulb and leaf diameter. This study was in agreement with the works of Singh (19) in garlic, Abayneh (1) in onion and Fasika (10) in shallot. The low residual value at phenotypic level 0.0064 and genotypic level 0.0037 indicated that the traits studied were enough to contribute to bulb yield per plant in garlic.

The present study on local accessions demonstrated the existence of high genetic variability for different yield traits in Ethiopian garlic. The high heritability associated with high genetic advance as per cent of mean was observed in bulb dry weight, dry weight above ground, yield per plant, biological yield per plant, weight of clove and cloves per bulb indicating the scope for improving these traits through selection. due consideration has to be given for characters like biological yield per plant, cloves per bulb, weight of clove, plant height, number of leaves per plant, neck girth, harvest index, bulb polar diameter, bulb perimeter and leaf diameter while selecting garlic genotypes since these characters were positively correlated with bulb yield per plant and exerted positive direct effect on bulb yield per plant. However, further confirmation is needed across the locations with more cultivars including exotic accessions.

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