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GENETIC VARIABILITY AND CHARACTER ASSOCIATION FOR BULB YIELD AND YIELD RELATED TRAITS IN GARLIC IN ETHIOPIA

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ABSTRACT

Garlic (*Allium sativum*) has for centuries been valued by humans for food, culinary and medicinal purposes world over. The objective of this study was to investigate genetic variability among garlic accessions for yield, yield related and phenology traits in Ethiopia. A field study was conducted at the DebreZeit Agricultural Research Center during 2012, using 49 garlic accessions from the highlands of North Shewa, East and West Arsi, Arsi, Bale and Sidama zones, which are among the major garlic producing areas in Ethiopia. The experiment was arranged in a 7x7 simple Lattice design, with two replications. Accession were highly significant (P < 0.01) for days to maturity, leaf number per plant, neck diameter, yield per plant, biological yield per plant, dry weight above ground, bulb dry weight, dry weight underground, clove number per bulb, and clove weight per bulb. Heritability estimates ranged from 82.48% for clove number, to 6.46% harvest index. High heritability, combined with high genetic advance (as per cent of mean) observed for mean clove number, yield per plant, biological yield per plant and clove weight per plant showed that these characters were controlled by additive gene effects. Thus phenotypic selection for these characters would likely be effective in variety selection and development. Bulb yield per plant had positive and highly significant genotypic and phenotypic correlations, with all characters, except plant height and harvest index. Path analysis at phenotypic level revealed that biological yield and bulb dry weight contributed major positive direct effects to bulb yield per plant. These traits showed positive and highly significant genotypic correlations with bulb yield except harvest index

Key Words: *Allium sativum*, genetic variability, heritability

RÉSUMÉ

L'ail (*Allium sativum*) est apprécié depuis des siècles par les humains à des fins alimentaires, culinaires et médicinales dans le monde entier. L'objectif de cette étude était d'étudier la variabilité génétique entre les accessions d'ail pour le rendement et le rendement liés traits phénologiques en Éthiopie. Une étude de terrain a été menée au centre de recherche agricole DebreZeit en 2012, en utilisant 49 accessions d'ail des zones montagneuses du Nord de Shewa, de l'Est et de l'Ouest d'Arsi, Arsi, Bale et Sidama, qui sont parmi les principales zones de production d'ail en Éthiopie. L'expérience a été organisée dans une conception de treillis simple 7x7, avec deux réplications. L'accession était très significative (P <0,01) pour les jours jusqu'à la maturité, le nombre de feuilles par plante, le diamètre du col, le rendement par plante, le rendement biologique par plante, le poids sec au-dessus du sol, le poids sec du bulbe, le poids sec sous terre, le nombre de clou de girofle par bulbe, et le poids de clou de girofle par bulbe. Les estimations d'héritabilité variaient de 82,48% pour le nombre de clous de girofle à 6,46% d'indice de récolte. Une héritabilité élevée, combinée à une avancée génétique élevée (en pourcentage de la moyenne) observée pour le nombre moyen de clous de girofle, le rendement par plante, le rendement biologique par plante et le poids de clou de girofle par plante ont montré que ces caractères étaient contrôlés par des effets génétiques additifs. Ainsi, la sélection phénotypique pour ces caractères serait probablement efficace dans la sélection et le développement des variétés. Le rendement en bulbes par plante avait des corrélations génotypiques et phénotypiques positives et très significatives, avec tous les caractères, à l'exception de la hauteur de la plante et de l'indice de récolte. L'analyse des chemins au niveau phénotypique a révélé que le rendement biologique et le poids sec du bulbe contribuaient à des effets directs positifs majeurs sur le rendement en bulbe par plante. Ces caractères ont montré des corrélations génotypiques positives et très significatives avec le rendement des bulbes, à l'exception de l'indice de récolte

Mots Clés: *Allium sativum*, variabilité génétique, héritabilité

INTRODUCTION

Garlic *(Allium sativum* L. *var. ascalonicum* Baker, 2n = 16) is a widely cultivated in Ethiopia and preferred by most Ethiopians for its strong pungent culinary value (Getahun *et al*., 2002; Sendek *et al*., 2008). Garlic and its close relatives, onion *(Allium cepa* L.), leek *(A. porrum)* and chives *(A. schoenoprasum)* are common vegetable crops throughout the world, which have been cultivated since 3000 B.C. According to Novak *et al.* (1980) and Brewster (1994), there are more than 500 species within the genus, originated in central Asia.

Ethiopia has been undertaking research on garlic since mid-1980s with the main objectives of collecting, characterising and evaluating accessions from major growing regions of the country; even though not exhaustively from all highland areas. As a result, three garlic varieties were obtained and released for being better yielders than the unimproved cultivars.

The objective of this study was to assess the extent of genetic variability for bulb yield and yield related traits of garlic and estimate heritability in broad sense and expected genetic advance due to selection in garlic in the Ethiopian highlands.

MATERIALS AND METHODS

Experimental site. This study was conducted at Debre Zeit, in Ethiopia, located at 8°7°N and 39°E, at an altitude of 1990 metres above sea level. The annual rainfall at the site reaches 866 m, with the long rainy season extending from June to September, and accounting for 84% of the precipitation. The mean annual maximum and minimum temperature ranges are 26 and 14 °C, respectively (Lemma and Derresa, 2009). The site soil was a Vertisol (Getahun *et al*., 2008).

Experimental materials. A total of 49 garlic accessions collected earlier (2011) from north Shewa, east and west Arsi, Arsi, Baleand Sidama zones of Ethiopia, and maintained at Debre Zeit Agricultural Research Centre, were used for this study (Table 1).

Experimental layout and management. Treatments included the 49 accessions laid out in a 7x7 simple lattice design, with two replications. Healthy and normal cloves of each

TABLE 1. Garlic accessions used in the study conducted at DebreZeit Agricultural Research Centre in Ethiopia

Number	Accession	Village	Zone	Number	Accession	Village	Zone
1	G-1/2003	Ababora	North Shewa	26	G-29/2003	Sagure	Arsi
2	G-2/2003	LemlemShenkora	North Shewa	27	G-30/2003	Sagure	Arsi
3	G-3/2003	Rarat	North Shewa	28	G-31/2003	Sagure	Arsi
4	G-5/2003	RaratMinjar	North Shewa	29	G-32/2003	HululeHarcosa	Arsi
5	G-6/2003	AramutiZemeskel	North Shewa	30	G-34/2003	HululeHarcosa	Arsi
6	G-7/2003	Welde-Giorgis	North Shewa	31	G-37/2003	MeraroLimu	Arsi
7	G-8/2003	TinishuAdibatu	North Shewa	32	G-38/2003	Inkolo-Bilawun	Arsi
8	G-9/2003	Tekuarigor	North Shewa	33	G-39/2003	Tifu	Arsi
9	G-11/2003	AkalatTekuari	North Shewa	34	G-41/2003	Aletawendo	Sidama
10	G-13/2003	RabutiTosign	North Shewa	35	G-50/2003	Aletawendo	Sidama
11	G-14/2003	RabutiTosign	North Shewa	36	G-52/2003	MinjarMinjar	North Shewa
12	G-15/2003	RabutiTosign	North Shewa	37	G-53/2003	Shashamane	West Arsi
13	G-16/2003	Welde-Giorgis	North Shewa	38	G-58/2003	Bale	Bale
14	G-17/2003	Akalat	North Shewa	39	G-59/2003	Bale	Bale
15	G-18/2003	Aramuti	North Shewa	40	G-60/2003	Minjar	North Shewa
16	G-19/2003	AramutiDachew	North Shewa	41	G-61/2003	Asela	Arsi
17	G-20/2003	Kuture	North Shewa	42	G-62/2003	Shashamane	West Arsi
18	G-21/2003	Chiracabosa	North Shewa	43	G-65/2003	Shunewachu	Arsi
19	G-22/2003	Raratbero	North Shewa	44	G-67/2003	Chefa	Arsi
20	G-23/2003	Shenkora	North Shewa	45	G-68/2003	Debash	Arsi
21	G-24/2003	Shenkora	North Shewa	46	G-69/2003	Burkite	Arsi
22	G-25/2003	Chiracha	North Shewa	47	G-74/2003	AdareGolba	Arsi
23	G-26/2003	Chiracha	North Shewa	48	G-76/2003	Didibe	Arsi
24	G-27/2003	Chiracha	North Shewa	49	G-78/2003	Negelle	Arsi
25	G-28/2003	Asela	Arsi				

accession were selected and planted on prepared plots of 2 m by 2.4 m. Each plot consisted of four rows, with 20 plants per row, and a total of 80 plants per plot. Plants pacing was 30 cm and 10 cm. Alleys of 1.5 cm each were left between plots. The middle two rows were used for data collection. Field agronomic practices used were as recommended for the crop (Getachew *et al*., 2009).

Data collection and analysis. Data collection included determination of days to seedling emergence and to maturity, plant height, leaf length and width, number of leaves per plant, neck diameter, bulb yield per plant, biological yield per plant, above and underground dry weight, bulb dry weight, clove number per bulb, clove weight per bulb and harvest index (%). These were recorded from eight randomly sampled plants in the two central rows of each plot, using the description of International Plant Genetic Resources Institute (IPGRI and GR, 2001).

The data collected were subjected to analysis of variance (ANOVA) for simple lattice design, using Proc Lattice and proc GLM procedures of SAS version 9.2 (Der and Everitt, 2008). Differences between significant treatment means were compared using least significant difference (LSD) at 1 and 5% probability levels. Correlation coefficients were analysed to estimate the nature and degree of association of component characters with yield to identify characters that played decisive roles in influencing yield.

Estimation of genetic parameters. The phenotypic and genotypic variance components, and coefficients of phenotypic and genotypic coefficients of variation were calculated by the methods suggested by Burton and others (Burton and Devane, 1953), illustrated below:

Genotypic variance (σ^{2g}) $= \frac{Msg - Mse}{r}$ ………………….........……… Equation 1

Phenotypic variance (σ^2p) $=\sigma^2$g+ σ^2e …….........................……………. Equation 2

Environmental variance (σ^2e) = Mean Square …..........................…………. Equation 3

Where:

MSg is Mean square due to genotype, MSe is Environmental variance, and r is the number of replication.

Phenotypic coefficient of variation (PCV)

$$PCV = \sqrt{\frac{\sigma^2 p}{X}} \times 100$$

………………………………….. Equation 4

Genotypic coefficient of variation (GCV)

$$GCV = \sqrt{\frac{\sigma^2 g}{X}} \times 100$$

………………………………….. Equation 5

Heritability in broad sense for all characters was computed using the formula given by Falconer (Falconer and Mackay, 1996) as:

$$H = \frac{\sigma^2 g}{\sigma^2 P} \times 100$$ ……………… Equation 6

Where:

H is heritability in broad sense, σ^2g is genotypic variance; σ^2p is phenotypic variance

Genetic advance under selection (GA). Expected genetic advances for each character at 5% selection intensity was computed by the formula described by Johnson *et al.* (1955).

Genetic Advances (GA) = k.σp.H ……… .... Equation 7

Where:

k is constant (selection differential where k = 2.056 at 5% selection intensity),$\sigma p$is phenotypic standard deviation, H is Heritability in broad sense.

Genetic advances as percent of mean was calculated to compare the extent of predicted advances of different traits under selection, using the formula:

$GAM = \frac{GA}{\overline{X}} \times 100$ (Falconer and Mackay, 1996) .... Equation 8

Where:

GAM is genetic advances as percent of mean, GA is Genetic advances under selection$\overline{X}$ is Mean of population in which selection was employed.

RESULTS

There were highly significant (P< 0.01) effects of garlic accessions on traits including leaf length, leaf width and days to emergence (Table 2), suggesting the existence of sufficient genetic variability for use in garlic varietal improvement. However, there were no significant (P>0.05) effects for harvest index and plant height.

There were highly significant variations among accessions in skin colour, bulb diameter, weight of cloves, number of bulbils, bulbil weight, plant vigour, leaf diameter (leaf width) and leaf number in garlic genotypes.

Belowground dry weight and biological yield. Dry weight (DW) of underground parts and biological yield per plant exhibited a wide

TABLE 2. Analysis of variance for 15 traits of garlic the accessions grown at Debre Zeit research station in Ethiopia

Variables	MSR	MSB	MSG	MSE	CV%
Date to emergence	24.50**	1.69ns	2.73*	1.64	9.91
Days to maturity	9.81ns	11.75ns	99.55**	9.89	2.59
Plant height	17.49ns	17.65ns	13.05ns	8.13	5.58
Leaf length	7.55ns	10.38*	8.23*	4.29	5.64
Leaf width	0.02ns	0.01ns	0.012*	0.01	5.07
Leaf number per plant	4.29**	0.98ns	1.35**	0.55	6.08
Neck diameter	0.06ns	1.29ns	2.67**	0.61	9.64
Yield per plant	34.68ns	29.05ns	88.93**	23.43	15.42
Biological yield per plant	94.43ns	101.54ns	227.45**	64.29	18.80
Dry weight above ground	0.003ns	0.71ns	1.58**	0.51	25.12
Bulb dry weight	1.70ns	4.17ns	7.45**	2.53	16.04
Dry weight under ground	121.23ns	277.17ns	478.34**	162.66	16.09
Clove number per bulb	6.48ns	6.75ns	40.62**	4.46	14.56
Clove weight per Bulb	3.13ns	34.21ns	59.33**	15.26	15.52
Harvest Index (%)	50.86ns	194.87ns	110.54ns	101.76	13.43

*, ** significant at 0.05 and 0.01 probability level, respectively; ns = non-significant; MSR = Mean square of replication; MSB = Mean square of block; MSG = mean square of genotype; MSE = Mean square of error; Cv = Coefficient of variation

range of variation among the accessions (Table 2). The maximum and minimum DW of bulb and biological yield per plant were121.4 and 52.63 g, and 71.56 and 28 g, respectively. Higher heritability (h^2) was recorded for days to maturity (82.48%), average clove number (80.08%), yield per plant (58.96%), neck diameter (56.57%), and biological yield per plant (55.26%). Wider ranges were observed for yield per plant (16.16-48.91), biological yield per plant (28-71.57), average clove number (7.5-24.1), and dry weight underground (52.63-121.36).

Days to emergence and maturity. Significant variation in days to emergence and maturity were recorded among the accessions (Table 3). Generally, the accessions required 97 to 130 days from planting to maturity. The early maturing accession (97 days) was G-19/03 and the late maturing (122.5 -131 days) were G-28/03, G-30/03, G-31/03,G-32/03, G-33/03, G-37/03, G-59/03, G-69/03, G-74/03 and G-77/03.

Plant height and leaf length. A wide variation was observed in plant height and leaf length among the accessions (Table 3). Genotypes G-50/03 and G-7/2003 had the shortest plant height (43.65 cm), fewest number of leaves per plant with shortest leaf (32.3 cm) and the narrowest neck diameter (5.9 cm), respectively; but G-32/2003 had the widest neck diameter (11.05 cm and largest number of leaves per plant (14.85) and widest leaf (1.65 cm); whereas the narrowest (1.35 cm) leaf was observed in G-21/2003. A wide range of variation also occurred in biological yield among the accessions. The maximum biological yield recorded in accession G-32/03 (71.550 g) whereas G-50/03 had the lowest (28.0 g) with a mean of 42.65. Likewise, yield per plant and dry weight of the underground parts were extremely variable; the smallest was

TABLE 3. Statistics and genetic information for 15 traits of garlic accessions grown at Debre Zeit research station in Ethiopia

Variables	Min	Mean	Max	α^2g	α^2p	PCV%	GCV%	h²%	GA	GAM
DE	10.5	12.93	16	0.7	2.84	13.03	6.47	24.65	0.86	6.62
DM	107.5	121.07	131	50.34	61.03	6.45	5.86	82.48	13.27	10.96
PH (cm)	43.65	51.14	56.7	4.01	14.07	7.33	3.92	28.50	2.20	4.31
LL (cm)	32.3	36.7	40.9	1.79	6.99	7.20	3.64	25.61	1.39	3.80
LW (cm)	1.35	1.51	1.65	-0.003	0.01	6.62	0.00	21.90	0.05	2.99
LNPP	10.75	12.24	14.85	0.39	1.08	8.49	5.10	36.11	0.77	6.31
ND (cm)	5.9	8.13	11.05	0.99	1.75	16.27	12.23	56.57	1.54	18.96
YPP	16.16	31.38	48.91	35.26	59.80	24.54	18.92	58.96	9.35	29.80
BYPP	28	42.65	71.57	86.97	157.39	29.41	21.77	55.26	14.28	33.48
DWAG	1.48	2.85	5.4	0.49	1.15	37.54	24.56	42.61	0.94	32.95
BDW	6.6	9.91	15.15	2.29	5.36	23.36	15.24	42.72	2.04	20.56
DWUG	52.63	79.27	121.36	145.34	343.80	23.39	15.21	42.27	16.15	20.37
ACN	7.5	14.51	24.1	20.7	25.85	35.01	31.35	80.08	8.38	57.75
ACW	17.5	25.18	42.7	20.29	40.24	25.18	17.89	50.42	6.59	26.15
HI (%)	58.44	75.11	90.85	8.09	125.23	14.90	3.79	6.46	1.49	1.98

DE = Date to emergence, DM = Date to maturity, PH = Plant height, LL = Leaf Length, LW = Leaf Width, LNPP = leaf number per plant, ND = Neck Diameter, YPP = Yield per plant, BYPP = Biological yield per plant, DWAG = Dry weight above ground, BDW = Bulb dry weight, DWUG = Dry weight underground, ACN = Average clove number, ACW = Average Clove weight, HI = Harvest Index observed in G-15/03 (16.16 g) for yield per plant and largest in G-30/2003 (48.91 g); while the largest was observed in G- 32/03 (121.36 g) for dry weight underground and smallest was recorded for G-41/2003 (52.63 g). Similarly, for harvest index, average clove weight per plant, average cloves number and bulb dry weight per plant also exhibited wide variations.

The lowest harvest index (58.44%) was recorded in G-15/03; while the highest was observed in (90.85%) in G- 50/03. This indicates that G-50/03 was 32.41% more efficient than G-15/03 in converting photosynthates in economical product. G-29/03 had the smallest cloves (17.5 g), but G-32/03 had the biggest cloves (42.70 g) among the accessions. The average number of cloves was very low in G-18/03 (7.5 cloves); whereas G-34/03 yielded 24.1 cloves. The dry weight of bulbs per plant between the accession that yielded the smallest G-41/2003 (6.6 g), and the highest was G-32/2003 (15.15 g), more than double.

Estimation of genotypic and phenotypic variance. A large amount of variability was noticed with respect to all the characters under the study (Table 3). Among the traits, high genotypic coefficient of variation (31.35%) was recorded for average cloves number per plant; followed by dry weight above ground (24.56%), biological yield per plant (21.77%), yield per plant (18.92%), bulb dry weight per plant (15.24%), dry weight underground parts (15.21%) and average clove weight per plant (17.89%), neck diameter (12.23%) and days to emergence (6.47%), and days to maturity (5.86%).

The estimated genotypic coefficient of variation ranged from (31.35%) for average clove number to (0.00%) for leaf width per plant and phenotypic coefficient of variation also varied from (37.54%) for dry weight above ground to (6.45%) for days to maturity.

Estimation of heritability in broad sense. Moderate heritability was observed for bulb dry weight per plant (42.72%), dry weight above ground (42.61), dry weight underground (42.27%), leaf number per plant (36.11%), plant height (28.5%), leaf length per plant (25.61%), date to emergence (24.65%) and leaf width per plant (21.9%) but low heritability was recorded for harvest index (6.46%).

Estimation of expected genetic advance. High genetic advance was attained for dry weight underground (16.15), biological yield per plant (14.28), and days to maturation (13.27). Intermediate values were obtained for yield per plant (9.35), average clove number (8.38), average clove weight (6.59), days to emergence (6.62%), leaf number per plant (6.31%), and plant height (4.31%) . The lowest values were recorded for plant height, bulb dry weight, neck diameter, harvest index, leaf length per plant, dry weight above ground, date to emergence, leaf number per plant and leaf width per plant(Table 3).

Traits which had higher estimates of heritability and genetic advance from the other yield contributing traits were dry weight of underground parts, days to maturity, biological yield per plant and clove weight per plant, suggested as traits for indirect selection. Yield per plant and clove number per bulb are suggested for direct selection.

Path Coefficient Analysis. Path coefficient analysis appeared to provide a clue onto the contribution of various components of yield to overall bulb yields in the genotypic and phenotypic correlation (Table 4). It provided an effective way of finding out direct and indirect sources of correlation. Direct and indirect effects of these components were determined on bulb yield (Table 4).

Path analysis at phenotypic level revealed that biological yield (1.068) and bulb dry weight

TABLE 4. Estimationof direct (bold diagonal) and indirect effects (off diagonal) at phenotypic level of fifteen traits on bulb yield per plant in garlic genotype

Variable	PH	LLPP	LWPP	LNPP	NDPP	DE	DM	BYPP	DWAG	BDW	DWUG	CNPP	CWPP	HI
PH	**0.007**	0.227	0.062	0.042	0.077	-0.054	-0.101	0.033	0.008	0.035	0.036	-0.089	0.069	-0.018
LLPP	0.064	**0.079**	0.120	0.071	0.138	-0.069	-0.042	0.109	0.061	0.080	0.080	-0.014	0.132	-0.046
LWPP	0.017	0.034	**-0.049**	0.104	0.139	0.019	0.060	0.092	0.079	0.069	0.069	0.087	0.080	-0.002
LNPP	0.012	0.020	0.029	**-0.032**	0.188	0.054	0.153	0.138	0.106	0.123	0.123	0.151	0.159	-0.038
NDPP	0.022	0.039	0.039	0.053	**0.007**	0.066	0.209	0.236	0.213	0.169	0.1701	0.159	0.229	-0.094
DE	-0.015	-0.019	0.006	0.015	0.019	**-0.005**	0.097	0.057	0.052	0.076	0.075	0.112	0.071	0.013
DM	-0.029	-0.012	0.017	0.043	0.059	0.027	**0.074**	0.179	0.190	0.144	0.144	0.222	0.165	-0.056
BYPP	0.009	0.031	0.026	0.039	0.067	0.016	0.051	**1.068**	0.222	0.202	0.202	0.164	0.242	-0.170
DWAG	0.002	0.017	0.023	0.029	0.060	0.015	0.054	0.063	**0.087**	0.133	0.133	0.151	0.168	-0.075
BDW	0.009	0.023	0.0197	0.035	0.048	0.021	0.041	0.057	0.038	**0.913**	0.327	0.151	0.249	-0.043
DWUG	0.01	0.023	0.0198	0.035	0.048	0.021	0.041	0.057	0.038	0.092	**-0.916**	0.150	0.249	-0.044
CNPP	-0.025	-0.004	0.025	0.043	0.045	0.032	0.063	0.046	0.043	0.043	0.042	**0.018**	0.159	-0.030
CWPP	0.019	0.037	0.023	0.045	0.065	0.020	0.047	0.068	0.048	0.070	0.070	0.045	**-0.027**	-0.084
HI	-0.005	-0.013	-0.001	-0.011	-0.026	0.004	-0.016	-0.048	-0.021	-0.012	-0.013	-0.009	-0.024	**0.581**

PH = Plant height, LL = Leaf Length, LW = Leaf width, LNPP = leaf number per plant, ND = Neck Diameter, DE = Date to emergence, DM = Date to maturity, YPP = Yield per plant, BYPP = Biological yield per plant, DWAG = Dry weight above ground, BDW = Bulb dry weight, DWUG = Dry weight underground, CNPP = clove number, CWPP = Clove weight, HI = Harvest Index

(0.913) contributed major positive direct effects to bulb yield per plant. These traits showed positive and highly significant genotypic correlations with bulb yield, except harvest index. The other characters that exerted direct positive effects included harvest index; followed by dry weight above ground per plant, leaf length, days to maturity, average clove number, plant height, and neck diameter. As a result, these characters could be considered as major components for selection in a breeding programme for higher bulb yield. Earlier studies also indicated positive direct effects of plant height, number of splitted bulbs per plant and bulb diameter on bulb yield; suggesting that direct selection for bulb yield through these traits would be effective (Haydar *et al*., 2007).

Singh (1981) reported a positive direct effect of harvest index and plant height on bulb yield of garlic and negative direct effects were shown on bulb yield by dry weight underground, leaf width, leaf number, average clove weight, and days to emergence. These negative direct effects were counter balanced by the positive indirect influences through plant height, leaf length, neck diameter, days to maturity, biological yield per plant, dry weight above ground, bulb dry weight, bulb dry weight underground, average clove number and bulb diameter. These traits, except plant height, had positive and highly significant phenotypic correlations with bulb yield (Table 4).

Plant height revealed a direct positive effect on bulb yield, but it had a non-significant correlation with bulb yield. Leaf length exhibited a positive direct effect on bulb yield and affected indirectly negatively *via* days to maturity, days to emergence, average clove number and harvest index.

Direct and indirect effects. Biological yield had maximum positive direct effect on bulb yield per plant followed by bulb dry weight, harvest index, days to maturity, leaf length, and dry weight above ground, plant height and average clove number (Table 4). Biological yield showed favorable indirect effect on bulb yield through bulb diameter, dry weight above ground, bulb dry weight, average clove number, and average clove weight**.**

The positive indirect effects nullify the negative indirect effects on bulb yield per plant *via* plant height, leaf length, neck diameter, days to emergence and days to maturity (Table 4). Besides its positive and highly significant correlation with bulb yield, bulb dry weight showed direct positive effect on bulb yield per plant. Positive indirect effect on bulb yield per plant exerted by bulb dry weight was through dry weight underground, average clove number and average clove weight per bulb; whereas the negative indirect effect of bulb dry weight on bulb yield was exerted via plant height, leaf length, leaf width, leaf number, neck diameter, days to emergence, days to maturity, and dry weight above and ground parts.

Days to maturity had positive and highly significant correlation with bulb yield per plant (Table 4); besides it exerted maximum positive direct effect on bulb yield per plant. Its negative indirect effect on bulb yield per plant was through leaf width per plant, leaf number per plant, neck diameter, and harvest index. Its positive indirect effect exerted on bulb yield per plant was *via* plant height, leaf length, bulb diameter, dry weight above ground, bulb dry weight, dry weight underground, average clove number and average clove weight per plant.

The negative indirect effect of this trait exerted to bulb yield was *via* leaf width, leaf number, and neck diameter, biological yield per plant, bulb dry weight, and dry weight above ground, dry weight underground and average clove weight (Table 5). Although, dry weight of above ground parts positively and highly significant correlates with bulb yield per plant, it had minimum positive direct effect on bulb yield per plant (Table 5). Positive indirect effects of this trait affected bulb yield per plant *via* plant height, bulb dry weight, dry weight underground parts, average clove number and average clove weight. The indirect negative

TABLE 5. Estimation of direct (bold diagonal) and indirect effects (off diagonal) at genotypic level of fourteen traits on bulb yield per plant in garlic genotype

Variable	PH	LLPP	LWPP	LNPP	NDPP	DG	DM	BYPP	DWAG	BDW	DWUG	CNPP	CWPP	HI
PH	**0.006**	0.210	0.079	0.017	0.069	-0.114	-0.257	0.046	-0.079	0.029	0.031	-0.263	0.116	0.016
LLPP	-0.01	**0.086**	0.148	0.106	0.141	-0.048	-0.048	0.134	0.033	0.112	0.113	-0.029	0.165	-0.101
LWPP	-0.002	-0.003	**-0.017**	0.143	0.198	0.028	0.114	0.126	0.129	0.103	0.103	0.113	0.117	-0.009
LNPP	-0.0002	-0.002	-0.003	**-0.03**	0.2383	0.033	0.2198	0.213	0.167	0.171	0.171	0.196	0.204	-0.088
NDPP	-0.001	-0.003	-0.004	-0.005	**-0.087**	0.089	0.275	0.297	0.268	0.237	0.238	0.202	0.286	-0.146
DG	0.003	0.001	-0.001	-0.001	-0.002	**-0.0008**	0.133	0.109	0.082	0.137	0.136	0.177	0.117	-0.019
DM	0.0033	0.001	-0.003	-0.005	-0.006	-0.003	**0.152**	0.237	0.254	0.189	0.190	0.271	0.214	-0.108
BYPP	-0.0004	-0.003	-0.003	-0.005	-0.006	-0.002	-0.005	**1.137**	0.302	0.266	0.267	0.215	0.322	-0.182
DWAG	0.0009	-0.0007	-0.003	-0.004	-0.006	-0.002	-0.005	-0.007	**0.018**	0.199	0.200	0.216	0.231	-0.161
BDW	-0.0003	-0.002	-0.002	-0.004	-0.005	-0.003	-0.004	-0.006	-0.004	**0.934**	0.369	0.185	0.314	-0.068
DWUG	-0.0003	-0.002	-0.002	-0.004	-0.005	-0.003	-0.004	-0.006	-0.004	-0.008	**-0.902**	0.184	0.315	-0.070
CNPP	0.003	0.0006	-0.002	-0.004	-0.004	-0.004	-0.006	-0.005	-0.005	-0.004	-0.004	**0.004**	0.181	-0.057
CWPP	-0.001	-0.004	-0.003	-0.004	-0.006	-0.003	-0.005	-0.007	-0.005	-0.007	-0.007	-0.004	**-0.057**	-0.142
HI	0.0001	0.002	0.0002	0.002	0.003	0.0004	0.002	0.004	0.004	0.002	0.002	0.001	0.003	**0.4401**

TABLE 6. Estimation of correlation coefficients at phenotypic (above diagonal) and genotypic (below diagonal) levels of 15 traits in garlic

Traits	PH	LLPP	LWPP	LNPP	NDPP	DG	DM	YPP	BYPP	DWAG	BDW	DWUG	CNPP	CWPP	HI
PH	**1.00**	0.69**	0.19	0.127	0.24*	-0.17	-0.31**	0.09	0.10	0.03	0.11	0.11	-0.27**	0.21	-0.06
LLLP	0.73**	**1.00**	0.37**	0.22*	0.42**	-0.2*	-0.13	0.33**	0.33**	0.19	0.25*	0.25*	-0.04	0.40**	-0.14
LWPP	0.22	0.40**	**1.00**	0.32**	0.42**	0.06	0.18	0.29**	0.28**	0.24*	0.21*	0.21*	0.27**	0.25*	-0.01
LNPP	0.03	0.29*	0.39**	**1.00**	0.57**	0.17	0.47**	0.39**	0.42**	0.32**	0.37**	0.38**	0.46**	0.49**	-0.12
NDPP	0.09	0.38**	0.54**	0.65**	**1.00**	0.20*	0.64**	0.68**	0.72**	0.65**	0.52**	0.52**	0.49**	0.69**	-0.29**
DG	-0.36**	0.13	0.07	0.09	0.24	**1.00**	0.29**	0.20*	0.17	0.16	0.23*	0.23*	0.34**	0.22*	0.04
DM	-0.41**	-0.13	0.31*	0.59**	o.75**	0.36**	**1.00**	0.55**	0.55**	0.58**	0.44**	0.44**	0.68**	0.50**	0.17
YPP	-0.01	0.29*	0.37**	0.54**	0.73**	0.32*	0.62**	**1.00**	0.84**	0.69**	0.62**	0.61**	0.53**	0.69**	-0.01
BYPP	0.05	0.36**	0.34*	0.58**	0.81**	0.29*	0.64**	0.92**	**1.00**	0.68**	0.62**	0.62**	0.50**	0.74**	-0.52**
DWAG	-0.12	0.09	0.35**	0.45**	0.73**	0.22	0.69**	0.74**	0.82**	**1.00**	0.41**	0.41**	0.46**	0.51**	-0.23*
BDW	0.04	0.30*	0.28*	0.46**	0.64**	0.37**	0.51**	0.74**	0.72**	0.54**	**1.00**	0.99**	0.46**	0.76**	-0.13
DWUG	0.04	0.31*	0.28*	0.46**	0.65**	0.37**	0.52**	0.74**	0.73**	0.54**	0.99**	**1.00**	0.46**	0.76**	-0.13
CNPP	-0.43**	-0.08	0.31*	0.53**	0.55**	0.48**	0.74**	0.61**	0.58**	0.59**	0.50**	0.50**	**1.00**	0.49**	-0.09
CWPP	0.14	0.45**	0.32*	0.55**	0.78**	0.32*	0.58**	0.81**	0.87**	0.63**	0.85**	0.85**	0.49**	**1.00**	-0.26*
HI	-0.12	-0.29*	-0.02	-0.24	0.4**	-0.05	-0.29*	-0.13	-0.49**	-0.44**	-0.18	-0.19	-0.15	-0.39**	**1.00**

DM = Date to maturity, YPP = Yield per plant, BYPP = Biological yield per plant, DWAG = Dry weight above ground, BDW = Bulb dry weight, DWUG = Dry weight underground, ACN = Average clove number, ACW = Average Clove weight, HI = Harvest Index.3

effect of this trait on bulb yield per plant was exerted through leaf length per plant, leaf width per plant, leaf number per plant, neck diameter, days to germination, days to maturity, biological yield per plant, bulb diameter and harvest index.

The unfavourable indirect effect of average clove number on bulb yield was through the rest of the traits was sufficient to be able to nullify the favourable indirect effects which resulted in the association to be positive (rg = 0.61). At genotypic level, negative direct effects on bulb yield per plant was exerted on bulb yield by leaf width, leaf number, days to emergence, dry weight underground and average clove weight. However, bulb yield per plant was positively and highly significantly correlated with bulb yield per plant, with most traits except with plant height and harvest index.

Average clove weight exerted negative direct effects, though it had positively and highly significant correlation with bulb yield (Table 5). Clove weight exerted positive indirect effects on bulb yield through all the traits considered. The negative indirect effect was also exerted on bulb yield per plant by all characters.

Days to emergency exerted a minimum negative direct effect on bulb yield per plant (Table 5). Positive indirect effects of days to maturity were exerted on bulb yield through leaf width, leaf number, neck diameter, days to emergence and harvest index. However, days to maturity were positively and significant correlated with bulb yield per plant. The negative indirect effect on bulb yield exerted *via* this trait were through bulb yield components. Leaf number per plant exerted negative direct effect on bulb yield per plant. It exerted negative indirect effect *via* plant height, leaf length and harvest index and positive indirect effect *via* the rest of the traits which ultimately led to the total highly significant positive correlation between leaf number and bulb yield per plant (Table 6).

High phenotypic coefficient of variation was recorded for dry weight above ground, clove number per plant, biological yield per plant, yield per plant, average clove weight, bulb dry weight and dry weight underground. Similarly, low phenotypic coefficient of variation recorded for days to maturity and leaf length. The estimated range recorded was (6.45%) for days to maturity to (37.54%) for dry weight above ground.

Dry weight above ground showed positive and highly significant genotypic correlation with leaf width, neck diameter per plant, date to maturation, yield per plant, biological yield per plant, bulb dry weight, dry weight underground, average clove number, average clove weight, and showed negative and highly significant with harvest index.

DISCUSSION

The results from analysis of variance components showed highly significant differences ($P < 0.01$) among genotypes for leaf length, leaf number, neck diameter, date to maturation, yield per plant, biological yield per plant, dry weight above ground, bulb dry weight, dry weight underground, average clove number, and average clove weight. These results are in line with the findings of Dhotre (2008) in that plant height, number of leaves per plant, and bulb weight varied significantly among onion accessions. Similarly, Stavìlíková (2008) also reported that leaf width ranged from 1.5 to 2 cm, shaft length from 18 to 27 cm and shaft diameter from 0.8 cm to 1 cm in garlic genotypes. Abdlkader-Helmy *et al.* (2011) and Jenderek and Zewdie (2005) also reported significant variations within accessions for bulb and clove weight, number of cloves per bulb, flower stack height, number of cloves per bulb, plant height and days to maturity were significant as reported. The results of the present study are in agreement with Stavìlíková (2008), Volk and Stern (2009), and Jenderek and Zewdie (2005) that reported significant variations among the sexually derived families for bulb and clove weight, number of cloves per bulb, bulb shape, flower stalk, height, number of leaves per plant, and days to maturity within and among families of garlic The result is in agreement with Kassahun (2006) who found out that plant height has a direct positive effect on bulb yield in garlic, but contradict with the early report on onion that plant height revealed a direct negative effect on the bulb yield (Dhotre, 2008). Singh (1981) also reported a positive direct effect of harvest index and plant height on bulb yield of garlic and negative direct effects were shown on bulb yield by dry weight underground, leaf width, leaf number, average clove weight, and days to emergence. Dry weight underground and average clove weight showed negative direct effect on bulb yield and influenced it indirectly and positively through all the traits except harvest index which affected the bulb yield indirectly and negatively. Similar result reported by (Dhotre, 2008) in onion. This showed the positive indirect and negative indirect effects were exerted equally on bulb yield via average clove weight.

Genotypic coefficient of variation also recorded high for average clove number and dry weight above ground but low for leaf length. The range estimated for genotypic correlation was (0.00) for leaf length to (31.35) for clove number per plant. High phenotypic and genotypic variance was recorded for dry weight underground, biological yield per plant and harvest index. Low phenotypic variance was recorded for leaf width, leaf number and neck diameter.

Low genotypic variance recorded for leaf width, leaf number and neck diameter. Genetic advance that could be expected from selecting the top 5% of the genotypes as a percent of mean varied from (57.75%) for average clove number to (1.98%) for harvest index. This shows that by selecting the top 5% of the studied genotypes using characters could result in advance of 1.98% to 57.75% over the population mean.

Thus the present study suggested that selection based on the most heritable traits such as clove number per plant, yield per plant, biological yield per plant and clove weight per plant would be effective for the development of garlic through breeding. Similar results were reported by Sumathi and Muralidharan (2011). The findings of the present study are in agreement with that of Haydar *et al.*, (2007) who reported high broad sense heritability estimates with high genetic gain for bulb yield per hectare and number of green leaves per plant in onion.

Path coefficient analysis of genotypes revealed that biological yield per plant and bulb dry weight contributes the maximum positive direct effect on bulb yield per plant.

Estimation of genotypic and phenotypic correlation coefficients between each pair of the studied characters is presented in Table 6. Bulb yield per plant had positive and highly significant correlations with leaf width per plant, leaf number per plant, neck diameter per plant, days to maturity, biological yield per plant, dry weight above ground, bulb dry weight per plant, dry weight, underground of biomass, average clove number per plant, and average clove weight per plant. These results are in agreement with Mahanthesh *et al.* (2007) and Hosamani *et al*. (2010) reported that bulb yield had positive and significant correlation with number of leaves per plant, neck thickness, number of rings per bulb, ring thickness, weight of bulb and volume of bulb the in onion.

As a result, these characters could be considered as major components for selection in a breeding programme for higher bulb yield. Earlier studies also indicated positive direct effects of plant height, number of splitted bulbs per plant and bulb diameter on bulb yield; suggesting that direct selection for bulb yield through these traits would be effective (Haydar *et al*., 2007).

The correlation between yield per plant and these traits suggested that improvement of these traits could improve the physiological capacity of the crop to mobilise and translocate photosynthate to the organs of economic value (the bulb), which in turn might have increased the bulb yield as observed in the study. The findings of Haydar *et al*. (2007) and Degewine *et al*. (2011) agree with the result of the present study. In line with this study Hosamani *et al.* (2010) reported that number of leaves per plant showed negative direct effect on bulb yield in onion

Higher positive relationship between harvest index and economic yield suggested that in accessions which produced higher yield, was relatively more in favour of yield which indicates that harvest index might serve as indices for identifying genotypes with higher yield. Thus, it can be inferred from this study that varieties having the potential of high production are of no use if they do not have the potential of converting large portion of biological yield into economic (bulb) yield. Therefore, it is of vital importance to give due attention to harvest index while selecting varieties for commercial cultivation as improving harvest index can substantially increase garlic yield. Biological yield per plant showed positive and highly significant phenotypic correlation with all characters except with days to emergence and plant height. In line with this study Marey *et al.* (2012) reported that plant height had highly significant positive correlation with number of leaves/plant, days to maturity, total yield, and highly significant negative correlation with bulb ratio in onion. As well it showed highly and positively significant correlation at phenotypic level with all traits except with harvest index. In harmony with this study Marey *et al*. (2012) reported that number of leaves/plant had highly significant positive correlations with each of plant fresh weight and total yield in onion.

Plant height, neck diameter, harvest index, leaf length, days to germination, leaf number per plant, dry weight above ground, leaf width per plant had low genetic advance and thus improvement through selection for these traits is not possible which might be due to non-additive gene action. This is in agreement with the finding of (Singh *et al*., 2011).

In line with the present study Marey *et al.* (2012) reported that plant dry weight showed a significant positive correlation with each of marketable yield/fed., and number of complete rings/bulb.

CONCLUSION

In this study, the characters with significant and positive correlations with bulb yield and positive direct effect will be considered for selection and variety development efforts. From the present study, it is recommended that traits such as biological yield per plant and bulb dry weight that showed positive direct effect on bulb yield per plant at genotypic level could be good selection criteria to improve bulb yield in garlic through breeding/selection as showed sufficient genetic variability.

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