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Multivariate Statistical Analysis of Bulb Yield and Morphological Characters in Garlic (*Allium sativum* L.)

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ABSTRACT

Fifteen garlic (*Allium sativum* L.) varieties introduced from Egypt, were evaluated for genetic variation of some morphological and physiological characters. This research has been conducted at Faculty of Agriculture's farm, *"Slok"* zone, Benghazi, Libya, using randomized complete block design with two replications. The investigated traits included leaf number, plant height, false stem length and weight, fifth leaf length, width and weight, leaf area, total dry weight, bulb diameter, bulb height, cloves/bulb and bulb yield. Analysis of variance showed that garlic genotypes were significantly different for all traits. Bulb yield was positively and significantly correlated with fifth leaf length and width, false stem weight, leaf area, total dry weight, bulb diameter and bulb height. The results of stepwise regression indicated that 87.1% of variation in yield is explained by bulb diameter, cloves/bulb and bulb height. Thus, high yield of garlic plants under semi arid environmental conditions in Libya can possibly be obtained by selecting breeding materials with these aforementioned three variables.

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INTRODUCTION

Garlic is diploid species in the subgenus *Allium* of the *Alliaceae* family, it belongs an apomixis type; therefore its reproduction is vegetative (Ipek *et al*., 2005). The garlic primary center of origin is Central Asia (Kazakhstan), and the secondary center is the Mediterranean and Caucasus zones (Etoh and Simon, 2002). Its value as a crop has been recognized from very ancient times; its presence was recorded in ancient Egypt, where it is estimated that has been cultivated for over 5000 years. During all this time the garlic has been used as food, condiment and medicine by many civilizations in Asia and the Mediterranean region (Ipek *et al*., 2005). Although of its infertility, a wide range of morphological and agronomic diversity have been observed in garlic such as color and size of the bulb, number and size of the cloves, plant height, flowering, days to harvesting, dormancy and adaptation to agro-climatic conditions, resistance to storage capacity (Figliuolo *et al*., 2001).

Garlic yield is the integration of many variables that affect plant growth during the growing period. The knowledge of genetic association between garlic yield and its components would improve the efficiency of breeding programs by identifying appropriate indices for selecting garlic varieties (Singh, *et al*., 2011). Dubey *et al*. (2010) and Barad *et al*. (2012) illustrated that production efficiency of number of cloves and bulb diameter on garlic plants positively improved yield. Their studies have reflected the importance of either variables, particularly, bulb weight, number of cloves and plant height on breeding programs. Bulb diameter was reported by many researchers as the most closely variable related to yield per unit area and was often used in selecting high yielding garlic strains (Rahman and Das, 1985; Kohli and Nutan, 1993; Singh and Singh, 1999).

Different statistical techniques have been used in modeling crops yield, including correlation, regression, path analysis, factor analysis, factor components and cluster analysis. Correlation coefficient is an important statistical procedure to evaluate breeding programs for high yield, as well as to examine direct and indirect contribution of the yield variables (Barad *et al*., 2012). Attempts to create an ideal model for garlic plants under semi-arid Libyan conditions have rarely been made. This study was conducted as a practical trial to clarify the relationship between garlic yield and its components under semi arid conditions. The aim was to provide theoretical foundations to guide garlic breeders who are researching the genetic correlation of the main agronomic characters and their influence in garlic plant productivity. To achieve this goal the relationship between yield and its components for garlic was studied using correlation and stepwise multiple regression procedures.

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MATERIAL AND METHODS

Plant material and experimental design:

The seed bulbs of fifteen garlic (*Allium sativum* L.) varieties were obtained from Egypt. The experiment was carried out at the farm of the Faculty of Agriculture, "*Slok*" zone, University of Benghazi, Libya. Before planting, the seed bulbs were vernalized in a cold chamber at 4°C and 80% humidity for 30 days. This treatment has been done to improve the growth and yield of garlic plants. Experiments were set up in a randomized complete block with two replications. Every genotype in 5 rows and 15cm intervals and 3 meter in width were planted in first week of November, 2012. Immediately, after planting the field was irrigated to soil moisture and all other standard agronomic practices were applied to the genotypes. Harvesting of the plant was done in the middle of March, 2013. The data were recorded on ten randomly selected plants of each entry from each replication for leaf number (X1), plant height (X2=cm), false stem length (X3=cm), fifth leaf length (X4=cm), fifth leaf width (X5=cm), fifth leaf weight (X6=g), false stem weight (X7=g), leaf area (X8=cm^2), total dry weight (X9=g), bulb diameter (X10=cm), bulb height (X11=cm), cloves/bulb (X12) and bulb yield (X13=Kg/ha).

Table 1: Name of garlic genotypes used in the experiment.

Number	Genotype	Number	Genotype	Number	Genotype
1	Japanese	6	Line 11	11	T2
2	Native	7	T4-9841	12	T1-98
3	T4-9842	8	T7 SE	13	T8
4	T4-98	9	T7 S	14	HOS
5	Spanish	10	TC-18	15	TC-20

Statistical analysis:

The results of the replicates were pooled and expressed as Mean, standard Error (SE), standard deviation (SD), minimum and maximum. A one-way analysis of variance (ANOVA) was used to analyze the genotypes at 5% level of significance. A matrix of simple correlation coefficients between all the traits were computed (Snedecor and Cochran, 1981).

The methods of variation inflation factor (VIF) and tolerance index (TOL) were employed. First, it is because the VIF relies on multiple correlations among regressors, rather than pairwise correlations. Second, both VIF and TOL indicate how each independent variable is explained by other regressors in terms of variance. The procedure of computing VIF and TOL is first to make each independent variable as the criterion variable regressing against all other explanatory variables. Then TOL and VIF are calculated as follows:

$$\mathbf{TOL = 1 - R^2}$$

Where, R^2 = Coefficient of multiple determination

TOL is simply the variance unexplained. A small TOL denotes high multi-collinearity. Hair *et al*. (1992) suggested a cut off for the TOL at 0.10.

$$\mathbf{VIF = 1 / (1 - R^2)}$$

VIF measures the inflation that occurs for each regression coefficient above the ideal situation (all variances are explained) of uncorrelated predictors (Myers, 1986). In contrast to TOL, a large VIF signifies high multicollinearity. If any VIF exceeded 10, the correspondent variable was deleted.

Multiple linear regression and partial coefficient of determination (R^2) was estimated for each variable (Snedecor and Cochran, 1981) in order to evaluate the relative contribution and to develop the prediction model for bulb yield according to the formula:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_p X_p + \varepsilon$$

Step-wise multiple linear regression using PROC REG in SAS program was employed for better understanding of relationships between bulb yield and shoot-related characters. This procedure first fits a simple linear regression for each of the shoot characters as independent variables (X_i) and bulb yield as dependent variable (Y). The X variable with F-value exceeding a predetermined significance level is the candidate for first addition. After entering the first variable, step-wise procedure fits all regression models with two X variables, where, the previous variable is one among the pair. The X variable with a significant partial F-value is the candidate for addition at the second stage. Next, the procedure examines whether any of the other X variables already in the model should be dropped, and so on until no further X variable can either be added or deleted. At this point the search terminates.

RESULTS AND DISCUSSION

Analysis of variance (Table 2) showed significant differences among the genotypes in all the traits. This illustrates the high potential of these genotypes to use them as the genetically source for breeding purposes.

Table 2: Results of analysis of variance for studied traits in garlic.

S.O.V	d.f	M.S												
		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
Rep.	1	0.13	67.50	24.30	76.80	0.02	0.10	443.90	418.13	24.084	0.32	0.01	26.75	737399.00
Genotype	14	16.63**	259.57**	57.19**	191.00**	2.54**	82.73**	5163.57**	149173.91**	212.925**	0.79**	1.57**	233.36**	7084834.79**
Error	14	0.34	11.57	8.23	22.08	0.06	0.82	204.35	1040.63	31.805	0.15	0.16	12.42	689610.00
C.V%		6.59	3.80	7.20	8.86	8.53	8.29	12.22	6.61	17.88	8.14	9.01	16.93	14.70

* and **: means that r is significant at 5%, 1% level of probability.
X1=leaf number, X2=plant height, X3=false stem length, X4=fifth leaf length, X5=fifth leaf width, X6=fifth leaf weight, X7=false stem weight, X8=leaf area, X9=total dry weight, X10=bulb diameter, X11=bulb height, X12=cloves/bulb and X13=bulb yield.

Results of Table 3 showed mean, standard error (SE), standard deviation (SD), minimum, maximum and range of traits of garlic genotypes, which demonstrated existence of high diversity among varieties studied for yield evaluation. That is in agreement to results of Dubey *et al*. (2012).

Table 3: Basis statistics, mean, standard error (SE), standard deviation (SD), minimum and maximum values for the estimated variables of garlic.

Variables	Mean	SE	SD	Minimum	Maximum	Range
Leaf number	8.93	0.52	2.86	6.00	19.00	13.00
Plant height	89.50	2.10	11.69	64.00	110.00	46.00
False stem length	39.83	1.03	5.69	30.00	53.00	37.00
Fifth leaf length	53.00	1.87	10.27	33.00	70.00	37.00
Fifth leaf width	3.06	0.20	1.12	1.50	6.70	5.20
Fifth leaf weight	10.97	1.15	6.35	3.90	27.60	23.70
False stem weight	116.89	9.32	51.05	21.40	250.00	228.60
Leaf area	487.93	49.17	269.31	116.00	1295.00	1179.00
Total dry weight	31.54	1.99	10.90	1.88	55.90	54.02
Bulb diameter	4.83	0.12	0.68	3.00	5.80	2.80
Bulb height	4.46	0.16	0.91	2.60	7.00	4.40
Cloves/bulb	20.81	1.99	10.93	9.00	49.00	40.00
Bulb yield	5648.10	354.89	1943.86	1447.20	8803.80	7356.60

Estimates of phenotypic correlation coefficients among the component traits of garlic are presented in Table 4. The correlation studies revealed that, bulb yield was positively and significantly correlated with fifth leaf length, fifth leaf width, false stem weight, leaf area, total dry weight, bulb diameter and bulb height indicating that selection based on these traits will help in increasing the yield (Table 4). Godhani and Singh (2000), Naruka and Dhaka (2004) and Dubey *et al*. (2010) have also reported similar significant positive correlation between bulb yield with bulb diameter, bulb size and total dry weight.

Bulb diameter was significantly and positively correlated with fifth leaf length and width, false stem weight, leaf area, total dry weight and bulb height. It is suggested that, if leaf area increased then bulb diameter will be increased. It may be concluded from the correlations that, the traits, fifth leaf length and width, false stem weight, leaf area, total dry weight, bulb diameter and bulb height are correlated to each other and helpful in increasing in the bulb yield as reported earlier by Dhar (2002) and Tsega *et al*. (2010).

Table 4: Simple correlation coefficients (r) for the estimated thirteen variables of garlic.

	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
X1	0.33	0.13	0.43*	0.24	0.03	0.34	0.30	0.36*	-0.06	0.01	-0.11	-0.07
X2	1	0.55**	0.80**	0.21	-0.03	0.47**	0.36*	0.60**	0.28	0.03	0.34	0.13
X3		1	0.18	-0.23	-0.55**	0.01	-0.18	0.22	-0.02	-0.10	0.55**	-0.20
X4			1	0.46*	0.26	0.68**	0.58**	0.69**	0.40*	0.24	0.02	0.39*
X5				1	0.67**	0.88**	0.91**	0.54**	0.46**	0.66**	-0.25	0.50**
X6					1	0.564**	0.66**	0.10	0.02	0.25	-0.23	0.14
X7						1	0.91**	0.80**	0.50**	0.63**	-0.11	0.53**
X8							1	0.58**	0.50**	0.63**	-0.16	0.54**
X9								1	0.48**	0.43*	-0.16	0.49**
X10									1	0.65**	0.10	0.89**
X11										1	-0.12	0.73**
X12											1	-0.14

* and **: means that r is significant at 5%, 1% level of probability.
X1=leaf number, X2=plant height, X3=false stem length, X4=fifth leaf length, X5=fifth leaf width, X6=fifth leaf weight, X7=false stem weight, X8=leaf area, X9=total dry weight, X10=bulb diameter, X11=bulb height, X12=cloves/bulb and X13=bulb yield.

To find a good method of relating shoot morphological traits with bulb yield, multiple regression approach was employed (Table 5). Multicollinearity test using variance inflation and tolerance factors are presented in the same table. The obtained results showed that the prediction equation for bulb yield is formulated using all garlic plant variables as follows:

$$Y = -3402.74 - 55.45X_1 - 27.43X_1 - 27.00X_3 + 36.30X_4 - 442.21X_5 - 3.32X_6 + 7.26X_7 + 0.20X_8 + 0.43X9 + 2091.97X10 + 451.99X11 - 26.58X12$$

The formula explains 89.73% of the total variation within the bulb yield-related traits, while the remaining 10.3% maybe due to residual effects. The *t*-test showed that bulb diameter (X10) has contributed significantly towards bulb yield, while the other eleven variables did not (Table 5). The overall results reflect the importance of the mentioned trait in garlic selection for breeding programs. But, large variation inflation was recorded for fifth leaf width (12.92), false stem weight (68.38), leaf area (20.11) and total dry weight (23.70). These variables were deleted to avoid the multicollinearity problem in multiple regression (Table 6).

Table 5: The regression coefficient (b), standard error (SE), T-value, probability, tolerance and variance inflation of the estimated variables in predicting garlic bulb weight by the multiple linear regression analysis.

Variables	d.f	Coefficient of regression (B)	SE	T	Prob>T	Tolerance	Variance inflation
Leaf number	1	-55.45	72.51	-0.76	0.45	0.52	1.88
Plant height	1	-27.43	39.36	-0.69	0.49	0.11	9.04
False stem length	1	-27.00	63.68	-0.42	0.67	0.17	5.76
Fifth leaf length	1	36.30	38.41	0.94	0.35	0.14	6.82
Fifth leaf width	1	-442.21	483.36	-0.91	0.37	0.07	12.92
Fifth leaf weight	1	-3.32	71.26	-0.04	0.96	0.11	8.97
False stem weight	1	7.26	24.47	0.29	0.77	0.01	68.38
Leaf area	1	0.20	2.51	0.08	0.93	0.04	20.11
Total dry weight	1	0.43	67.43	0.01	0.99	0.04	23.70
Bulb diameter	1	2091.97	484.30	4.31**	0.00	0.20	4.80
Bulb height	1	451.99	339.02	1.33	0.20	0.23	4.22
Cloves/bulb	1	-26.58	30.26	-0.87	0.39	0.20	4.79

* and **: means that r is significant at 5%, 1% level of probability. Y-intercept (a) = -3402.74, SE = 3880.57, R^2 = 0.8973, Root MSE = 813.58, Adj R^2 = 0.824.

When fifth leaf width, false stem weight, leaf area and total dry weight were totally omitted from the independent variables, bulb diameter (X10) was still found to be the most significant variable as it could explain about 79.3% of variability in bulb yield, followed by cloves/bulb (X12) (5.8%) and bulb height (X11) (3%) (Table 6 and Table 7).

Table 6: The regression coefficient (b), standard error (SE), T-value, probability, tolerance and variance inflation of the estimated variables in predicting garlic bulb weight by the multiple linear regression analysis after removing highly variance inflation variables.

Variables	d.f	Coefficient of regression (B)	SE	T	Prob>T	Tolerance	Variance inflation
Leaf number	1	-64.38	58.51	-1.10	0.28	0.70	1.41
Plant height	1	-30.02	31.38	-0.95	0.34	0.15	6.63
False stem length	1	-21.63	51.27	-0.42	0.67	0.23	4.30
Fifth leaf length	1	49.69	32.73	1.51	0.143	0.17	5.71
Fifth leaf weight	1	-17.93	35.55	-0.50	0.619	0.38	2.57
Bulb diameter	1	2038.38	366.89	5.55**	0.0001	0.31	3.18
Bulb height	1	410.50	252.62	1.62	0.119	0.36	2.70
Cloves/bulb	1	-23.60	17.65	-1.33	0.195	0.53	1.88

* and **: means that r is significant at 5%, 1% level of probability. Y-intercept (a) = -3865.67, SE = 2046.23, R^2 = 0.8900, Root MSE = 757.51, Adj R^2 = 0.848 .

Table 7 shows the data representing partial and cumulative R^2 as well as the probability for the accepted limiting three garlic variables in bulb yield prediction. These variables are bulb diameter (79.4%), cloves/bulb (5.8%) and bulb height (1.9%). According to the results, 87.1% of the total variation in bulb yield could be attributed to these aforementioned three variables. The other variables were not included in the analysis due to their low relative contributions. Regression coefficients for the accepted variables are shown in Table 8. The predicted equation for bulb yield (Y) formula was:

$$Y = -6235.78 + 2241.82X_{10} + 403.24X_{11} - 36.51X_{12}$$

Our findings are similar to the results illustrated by Godhani and Singh (2000); Naruka and Dhaka (2004) and Dubey *et al*. (2010) who found that bulb diameter and bulb height were associated significantly with garlic yield.

Table 7: Relative contribution (partial and model R^2) in predicting garlic bulb weight, F-value and probability by the stepwise procedure analysis.

Step	Variable entered	Partial R^2	Model R^2	F	Prob>F
1	Bulb diameter	0.794	0.793	108.165	0.0001
2	Cloves/bulb	0.058	0.852	10.851	0.0030
3	Bulb height	0.019	0.871	3.886	0.0500

Table 8: The regression coefficient (b), standard error (SE), T-value, probability, tolerance and variance inflation of the estimated variables in predicting garlic bulb weight by the multiple linear regression analysis.

Variables	d.f	Coefficient of regression (B)	SE	T	Prob>T
Bulb diameter	1	2241.82	273.28	8.20**	0.0001
Bulb height	1	403.24	204.55	1.97*	0.0594
Cloves/bulb	1	-36.51	12.99	-2.80**	0.0093

* and **: means that r is significant at 5%, 1% level of probability. Y-intercept (a) = -6235.78, SE = 990.68, R^2 = 0.8718, Root MSE = 735.06, Adj R^2 = 0.857.

Conclusion:

The multiple statistical procedures which have been used in this study showed that the bulb diameter, bulb height and cloves/bulb were the most important yield variables to be considered under the target environmental conditions. This was clear with all used statistical procedures. Thus, high yield of garlic plants under *Slok* environmental conditions in Libya can possibly be obtained by selecting breeding materials with these aforementioned three variables.

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