USING OF MULTIVARIATE ANALYSIS FOR EVALUATING WHEAT GRAIN YIELD AND ITS COMPONENTS UNDER WATER STRESS CONDITIONS

M. A. Abd El-Shafi & S. A. El-Hassia,*
Agronomy Department, Faculty of Agriculture, Cairo University, Egypt
Mathematic Department, Faculty of Science, Amer El-Mohtar University, Lybia

ABSTRACT

Twenty bread wheat genotypes differed in yield performance were grown at Kafr El-Hamam (El-Sharkea Governorate) during two seasons (2005/2006 and 2006/2007) under water stress conditions. Five statistical procedures (simple correlation, multiple linear regression, stepwise regression, factor analysis and principal components analysis) were used to study the relationship between wheat grain yield and its components under water stress conditions. The simple correlation coefficients revealed that the highest positive correlations to grain yield were no. of spikes/m^2, no. of grains/spike, biological yield t/ ha and harvest index.

Stepwise multiple regression analysis showed that 92.90% of the total variation in grain yield could be explained by the variation in harvest index, biological yield and grains weight/spike. The linear regression equation was (Y) = -2.201 + 0.092 X_9 + 0.300 X_8 -0.160 X_6, where Y, X_9 , X_8 and X_6 represent, grain yield t/ ha, harvest index, biological yield and grains weight/spike, respectively. Factor analysis indicated that four factors could explain approximately 76.5% of the total variation, which were 33.90% for grains weight/spike, 1000-grains weight and biological yield (factor 1), 18.50% for plant height and harvest index (factor 2), 14.60% for no. of grains/spike (factor 3) and 9.50% for no. of spikes/ m^2. The principal components analysis had grouped the estimated wheat variables into four main components, which accounted 77.00% from the total variation of grain yield. However, harvest index, biological yield, no. of spikes/m^2, grains weight/spike, no. of grains/spike and 1000-grains weight were the most important variables greatly affected grain yield. It could be concluded that the multiple statistical procedures which used in this study showed that the grains weight/spike, harvest index and biological yield were the most important yield variables to be considered under water stress conditions.

Key words: Water stress; Wheat; Simple correlation; Multiple linear regression**,** Stepwise regression; Factor analysis; Principal components analysis.

INTRODUCTION

Developing high yielding wheat cultivars under drought conditions in arid and semi-arid regions is an important objective of breeding programs. Grain yield of wheat is the integration of many variables that affect plant growth throughout the growing period. Great efforts have been made to develop proper models that can predict wheat grain yield and distinguish the ideal crop (ideotype). The knowledge of genetic association between grain yield and its components under water deficit conditions would improve the efficiency of breeding programs by identifying appropriate indices for selecting wheat varieties **(Evans and Fischer, 1999).** Simulating performance of wheat under soil moisture deficit presents special challenges for wheat modelers, because of wide variations in grain yield under normal and water stress conditions **(Gupta *et al*., 2001).**

Kumbhar *et al*. (1983) and Leilah and Khateeb (2005) illustrated that production efficiency of tillers and grains weight on wheat plants positively contributed to yield. Their studies have reflected the importance of both variables, particularly, grains weight/spike on breeding programs. Weight of grains/spike was reported by many researchers as the most closely variable related to grain yield per unit area and was often used in selecting high yielding wheat lines **(Kumbhar *et al*., 1983). However, Leilah and Khateeb (2005)** reported that 1000-grain weight exerted as the main yield component accounting 20% of variation in wheat grain yield. However, **Moghaddam *et al*. (1998)** showed that a negative correlation between plant height and grain yield was obtained due to the lower number of grains/spike.

Nasr and Geweifel (1991), Dawlat (1992) and Leilah and Al-Khateeb (2005) reported that stepwise multiple regression was more efficient than the full model regression. It is used to determine the best predictive equation for yield.

Factor analysis is a multivariate analysis method which aims to explain the correlation between a large set of variables in terms of a small number of underlying independent factors. It is assumed that each of the variables measured depends upon the underlying factors but is also subject to random errors. **Walton (1972)** proposed factor analysis as a new technique to identify growth and plant characters related to yield in spring wheat. **Moghaddam *et al*., (1998); Mohamed, (1999)** used factor analysis in wheat.

The principal components analysis is a multivariate statistical technique for exploration and simplifying complex data sets. The ability of this procedure to transform a number of possibly correlated variables into a smaller number of variables called principal components has been demonstrated by **Everitt and Dunn (1992)**. Each principal component is a linear combination of the original variables, and so it is often possible to ascribe the meaning to what the components represent.

Attempts to create an ideal model for wheat plants under arid and semi-arid drought conditions have rarely been made. This study was conducted as a practical trial to clarify the relationship between wheat grain yield and its components under water stress conditions. To achieve this goal five statistical procedures (simple correlation, multiple linear regression, stepwise multiple linear regression, factor analysis and principal components analysis) were used.

MATERIALS AND METHODS

The present study was performed at Kafr El-Hamam (El-Sharkea Governorate) during 2005/2006 and 2006/2007 seasons. Twenty wheat genotypes were chosen on the basis of the presence of wide range of genetic behavior of yield and yield components. The genetic materials employed for this study were obtained from Plant Genetic Resources Research Department (Bahteem Gene Bank), FCRI, ARC-Egypt. The twenty genotypes were planted in a randomized complete blocks design with four replications and grown under restricted irrigated conditions. Plots received water only at planting and tillering. In both seasons, sowing was done in the third week of November. Plots consisted of four rows (3 m long and 20 cm apart).

Ten plants were randomly chosen from each plot to measure the plant height, no. grains/spike and grains weight/spike. The grain yield was measured by harvesting of the center two rows of each plot at crop maturity.

Normality was checked out for each trait by the Wilk Shapiro test **(Neter *et al.*, 1996)**. The data were analyzed according to the randomized complete blocks design over years. A combined analysis of variance was conducted for the two seasons according to **Gomez and Gomez (1984)**. Homogeneity test of variances was performed according to procedures reported by **Gomez and Gomez (1984).** Thus, if the two trait error variances are homogeneous, the hypothesis cannot be rejected, the combined analysis of variance was computed. The combined data of yield and yield components over both seasons were used for the following statistical procedures. In order to determine the relationships between examined traits and grain yield, correlation coefficients were calculated with the MSTAT-C software package **(Freed *et al.*, 1989)**. Modeling was performed according to the multiple linear (full model) and stepwise multiple linear regression method, backward variable selections were applied using Open Stat version 1.9, a computer program, as suggested by **William (2007),** Statgraphics Plus for windows **(Manugistics, 1998) and SPSS computer software (1999)**.

The following analyses were performed:

1. Simple correlation: A matrix of simple correlation coefficients between grain yield and its components were computed according to **Steel *et al.* (1997)**.
2. Regression models: To describe the grain yield of wheat (y), multiple linear regression was fitted using different variables. The general regression model applied was: $Y=a+b_1X_1+b_2X_2+b_3X_3+\ldots\ldots+b_nX_n$.
   Where x_i is the input variable used for each particular model, *bi* is the coefficient to be determined, and n is the number of input variables used after the stepwise procedure.
3. The stepwise multiple linear regression as applied by **Draper and Smith (1966)**, was used to compute a sequence of multiple regression equations in a stepwise manner. At each step, one variable was added to the regression equations, it was the one that caused the maximum reduction in the residual sum of squares. Equivalently, it was the variable that had the highest partial correlation with the dependent variable adjusted for the variables already added. Similarly, it was the variable which if added, had the highest *F* value in the regression analysis of variance. Moreover, variables were forced into the regression equation and automatically removed when the values were below.
4. The factor analysis method was discussed by **Cattell (1965)**. The method consists of the reduction of a large number of correlated variables to a much smaller number of clusters of variables called factors. After the loading of the first factor were found, they were taken into account when the second factor was calculated. The process was repeated on the residual matrix to find further factors. When the contribution of a factor to the total percentage of the trace was less than 10%, the process stopped. After extraction, the matrix of factor loadings was submitted to a varimax orthogonal rotation, as applied by **Abd El-Mohsen (2008)**. The effect of rotation is to accentuate the larger loadings in each factor and to suppress the minor loading coefficient and in this way to improve the opportunity of achieving a meaningful biological interpretation of each factor. Thus, factor analysis indicates both groupings

and contribution percentage to total variation in the dependence structure. The factor loadings of the rotated matrix, the percentage variability explained by each factor and the communalities for each variable were determined, to know the way in which yield components were related to each other.

5. Principal components analysis: It is a mathematical procedure used to classify a large number of variables (items) into major components and their total variation. The first principal component accounted for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible **(Everitt and Dunn, 1992)**.

RESULTS AND DISCUSSION

Simple correlation analysis

Table (1) shows the minimum and maximum values, mean and standard deviation for all estimated variables of wheat. The results revealed that there was a wide variability in each trait tested.

Table (1): Statistics (minimum and maximum values, mean and standard deviation (SD) of the measured traits.

Traits	Statistic				
	Average	**Mini.**	**Maxi.**	**S.D.**	**C.V.%**
Heading date (days)	88.57	78.90	99.00	5.55	6.27
Maturity date (days)	133.01	121.50	143.00	7.17	5.39
Plant height (cm)	88.75	60.80	135.00	21.30	24.00
No. of Spikes/m^2	416.87	320.00	580.00	48.96	11.74
No. of grains/spike	36.96	30.20	47.20	3.54	9.58
Grains weight/spike (g)	2.69	2.00	3.90	0.46	17.10
1000-grains weight (g)	47.25	38.36	60.68	4.76	10.07
Biological yield (t/ ha)	11.47	7.4	16.8	1.83	15.95
Harvest index %	37.57	26.47	39.25	8.21	21.85
Grain yield (t/ ha)	4.22	2.67	5.87	0.59	13.98

Simple correlation coefficients among trait pairs are presented in Table (2). Results revealed that no. of spikes/m^2, no. of grains/ spike, biological yield t/ha and harvest index had significant positive correlation with grain yield t/ ha. On the contrary, heading date, maturity date and plant height had a significant negative correlation with grain yield. These results are in harmony with those obtained by **Moghaddam *et al*. (1998),** who showed a negative correlation between plant height and grain yield. They attributed that to the lower number of grains/spike with the tallest wheat plants. However, **Kumbhar *et al*. (1983) and Mohamed (1999)** reported that grains weight/spike, biological yield and no of spikes/m^2 were closely related to grain yield/m^2. The differential relations of yield components to grain yield may be attributed to environmental effects on plant growth **(Asseng *et al*., 2002)**.

Table (2): A matrix of simple correlation coefficients (*r*) for the measured ten traits of wheat

Traits	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	Y
X_1	1.00									
X_2	0.92**	1.00								
X_3	0.84**	0.89**	1.00							
X_4	0.57**	0.65**	0.64**	1.00						
X_5	0.72**	0.72**	0.62**	0.46*	1.00					
X_6	-0.01	-0.10	-0.08	-0.07	-0.06	1.00				
X_7	0.59**	0.51*	0.57**	0.46*	0.61**	0.08	1.00			
X_8	0.45**	0.44**	0.49**	0.47*	0.48*	-0.01	0.46*	1.00		
X_9	-0.50*	-0.50*	-0.53*	-0.44*	-0.45*	0.12	-0.44*	-0.06**	1.00	
Y	-0.46 *	-0.45 **	-0.44 **	0.50*	0.52*	0.14	0.07	0.58**	0.53*	1.00

***, ** Significant at 0.05 and 0.01 probability levels, respectively.**

X_1 = Heading date, X_2 = Maturity date, X_3 = Plant height, X_4 = No. of Spikes/m^2, X_5 = No. of grains/spike, X_6 = Grains weight/spike, X_7 = 1000-grains weight, X_8 = Biological yield, X_9 = Harvest index, Y= Grain yield.

Multiple linear regression analysis

Data presented in Table (3) show regression coefficients and the probability of the estimated variables in predicting wheat grain yield. The obtained results showed that the prediction equation for grain yield is formulated using the wheat plant variables as follows: $Y = -10.34 - 0.033 X_1 + 0.069 X_2 + 0.001 X_3 + 0.002 X_4 - 0.002 X_5 - 0.225 X_6 + 0.020 X_7 + 0.291 X_8 + 0.957 X_9$. The formula explains 96.30% of the total variation within the grain yield components, while the remaining 3.7% may be due to residual effects. Meanwhile, the adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independed traits, is 92.90%. The *t*-test showed that grains weight/spike, harvest index and biological yield have contributed significantly towards grain yield, while the other six traits did not. The overall results reflect the importance of the mentioned three traits for wheat selection in wheat breeding programs. These findings are in accordance with the results obtained by **Kumbhar *et al*. (1983)**. Furthermore, **Asseng *et al*. (2002)** reported that increased grains weight had improved potential yield of wheat under certain environmental conditions limited by water supply.

Table (3): The regression coefficient ($b_{y.x}$), standard error (SE), calculated *T*- value and its probability in predicting wheat grain yield by the multiple linear regression analysis.

Parameter	b	SE	*T*	*P*-Value
Constant	-10.340	4.511	-2.290	0.045
Heading date (X_1)	-0.033	0.020	-1.690	0.121
Maturity date (X_2)	0.069	0.035	1.970	0.078
Plant height (X_3)	0.001	0.005	0.200	0.846
No. of Spikes/m^2 (X_4)	0.002	0.001	1.590	0.143
No. of grains/spike (X_5)	-0.002	0.015	-0.130	0.898
Grains weight/spike (X_6)	-0.225	0.102	-2.290	0.045
1000-grains weight (X_7)	0.020	0.107	1.840	0.095
Biological yield (X_8)	0.291	0.041	7.060	0.000
Harvest index % (X_9)	0.957	0.008	11.760	0.000

R^2=96.30%, adj R^2=92.90%.

Stepwise multiple linear regression analysis

The results in Table (4) show that the stepwise method of linear regression indicated that the three traits, (grains weight/spike, harvest index and biological yield) had significant effect on grain yield (t/ ha).

Stepwise regression, shows the results of fitting a linear regression model to describe the relationship between grain yield and 9 independent traits. According to this analysis the predication equation runs as follows:

(Y) = -2.201 + 0.092 X_9 + 0.300 X_8 -0.160 X_6, where Y, X_9 , X_8 and X_6 represent, grain yield, harvest index, biological yield and grains weight/spike, respectively.

This model is apparently sufficient to cover most of the variation in yield in that the R^2 = 92.90% indicates that the model as fitted explains 92.90% of the variability in grain yield. The adjusted R^2, which is more suitable for comparing models with different numbers of independent variables, was 91.57%.

In determining whether the model can be simplified, it was noticed that the highest *P*-value on the independent variables is 0.03, belonging to grains weight/spike. Since the *P*-value is less than 0.05, that term is statistically significant at the 95% confidence level. Consequently, there was no need to remove any traits from the model. The obtained results are in agreement with results illustrated by **Mohamed (1999)** who found that spike weight and straw yield were associated significantly with wheat grain yield.

Table (4):The regression coefficient ($b_{y.x}$), *T*-value and its probability in predicting wheat grain yield by the multiple linear regression analysis

Model	*b*	*T* Statistic	*P*-Value
1. (Constant)	0.998	--------	--------
Harvest index (x_9)	0.086	4.72	0.000
2.(Constant)	-2.466	--------	--------
Harvest index (x_9)	0.092	11.48	0.000
Biological yield (x_8)	0.281	8.70	0.000
3.(Constant)	-2.201	--------	--------
Harvest index (x_9)	0.092	11.94	0.000
Biological yield (x_8)	0.30	9.10	0.000
Grains weight/spike (x_6)	-0.16	-2.10	0.037

Dependent traits: grain yield (y), y = -2.201 + 0.092 X_9 + 0.300 X_8 -0.160 X_6
R^2= 92.90%, R^2 (adjusted for d. f.) = 91.57%

Factor analysis

Data presented in Table (5) show that four main factors (groups) were accounted for 76.5% of the total variability in the dependent structure. The first factor (group) included no of grains weight/spike, 1000-grains weight and biological yield which accounted 33.90% of the total variability in the dependent structure. The sign of the loading indicates the direction of the relationship between the factor and the traits. The second factor included plant height and harvest index which accounted 18.50% of the total variability in the dependent structure. Again these traits had positive loadings. The third factor included no. of grains/spike which accounted 14.60% of the total variability in the dependence structure. The Fourth factor included no. of spikes/ m^2 which accounted 9.50% of the total variability in the dependence structure.

Table (5): Principal factor matrix after varimax rotation for 9 traits of 20 wheat genotypes.

Traits	Factors				Communality
	Factor 1	Factor 2	Factor 3	Factor 4	
Heading date (X_1)	-0.840	-0.150	0.120	0.100	0.750
Maturity date (X_2)	-0.670	0.370	0.150	0.190	0.650
Plant height (X_3)	0.320	0.670	-0.450	0.270	0.820
No. of Spikes/m^2 (X_4)	0.440	0.040	0.240	0.810	0.900
No. of grains/spike (X_5)	-0.650	0.190	0.510	-0.004	0.710
Grains weight spike (X_6)	0.540	-0.250	0.380	-0.002	0.410
1000-grains weight (X_7)	0.560	-0.570	0.120	-0.170	0.680
Biological yield t/ ha (X_8)	0.570	-0.650	-0.220	-0.230	0.850
Harvest index % (X_9)	-0.440	0.620	-0.560	-0.800	0.900
Variance	3.390	1.850	1.460	0.950	7.640
Variance %	33.90	18.50	14.60	9.50	76.50

Numbers in bold are those with factor loadings greater than 0.50.

Principal component analysis

Data presented in Table (6) demonstrate that an increase in the number of components was associated with a decrease in eigenvalues. This trend reached its maximum at four factors. Accordingly, it is reasonable to assume that the principal components analysis had grouped the estimated wheat variables into four main components which all together accounted for 77.00% of the total variation of grain yield. Results showed that PC1 correlated moderately well with no of grains/spike, 1000-grains weight and biological yield. Meanwhile, the PC2 correlated moderately with plant height. The third component (PC3) contained grains weight/spike. The fourth component (PC4) contained no of spikes/m^2. Results in Table (6) showed that PC1 accounted 34.00% of the variation in grain yield; PC2 52.00%, PC3 67.00% and PC4 77.00. Therefore, harvest index, biological yield, number of spikes/m^2, grains weight/spike, no. of grains/spike and 1000-grains weight have shown to be the important variables greatly affected grain yield. The factor loadings refer to the coefficients in each principle component or the correlation between the component and the variables. Similar results were reported by **Yin *et al*. (2002)** who stated that the grain yield was divided into three components, namely number of spikes/m^2, no. of grains/spike, and 1000-grains weight. However **Leilah and Khateeb (2005)** reported that the results of principal component analysis indicated that harvest index, biological yield, number of spikes/m^2, weight of grains/spike and 1000-grains weight have shown to be the important variables greatly affected grain yield.

Conclusions

The statistical procedures which have been used in this study showed that the grains weight/spike, harvest index and biological yield were the most important yield variables to be considered under water stress conditions. Thus, high yield of wheat plants under water stress conditions in El-Sharkea governorate (Egypt) can possibly be obtained by selecting breeding materials with high values grains weight/spike, biological yield and harvest index.

Table (6): Eigenvalue of the correlation matrix for the estimated variables of wheat using the principal component procedure.

Traits	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Heading date (X_1)	-0.460	-0.110	0.097	0.100	0.020	0.210	-0.550	-0.630	-0.050	0.130
Maturity date (X_2)	-0.370	0.270	0.130	0.200	0.290	0.560	0.340	0.180	-0.440	-0.120
Plant height (X_3)	0.170	-0.490	-0.370	0.270	0.044	0.210	0.520	-0.440	0.080	-0.010
No. of Spikes/m^2 (X_4)	0.240	0.030	0.200	0.830	0.140	0.260	0.140	-0.320	-0.080	-0.080
No. of grains/spike (X_5)	0.350	0.140	0.420	-0.004	-0.440	0.060	0.400	-0.080	0.570	0.004
Grains weight spike (X_6)	0.250	-0.190	0.310	-0.002	0.700	-0.510	0.210	-0.060	0.100	0.080
1000-grains weight (X_7)	0.310	-0.420	0.100	-0.170	-0.450	-0.330	0.160	0.040	-0.590	-0.113
Biological yield t/ ha (X_8)	0.310	-0.480	-0.180	-0.230	0.310	0.260	-0.200	0.400	0.340	-0.430
Harvest index % (X_9)	0.240	0.460	-0.460	-0.085	0.200	-0.320	0.090	-0.290	0.020	-0.570
Eigenvalue	3.390	1.850	1.460	0.950	0.840	0.640	0.330	0.310	0.220	0.020
Proportion	0.340	0.190	0.150	0.095	0.080	0.060	0.030	0.030	0.020	0.002
Cumulative (%)	34.00	52.00	67.00	77.00	85.00	91.00	95.00	98.00	99.00	100

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إستخدام التحليل متعدد المتغييرات لتقييم محصول القمح ومكوناته تحت ظروف الاجهاد المائى

محمد عبد المعبود عبد الشافى - سالم على الحاسيه*
قسم المحاصيل – كلية الزراعة – جامعة القاهرة - جمهورية مصر العربية
*** قسم الرياضيات - كلية العلوم - جامعة عمر المختار- ليبيا**

أجريت تجربة تحت ظروف الاجهاد المائى لتقييم ٢٠ من التراكيب الوراثية من القمح بمنطقة كفر الحمام (محافظة الشرقية) خلال موسمى ٢٠٠٥/٢٠٠٦ و ٢٠٠٦/٢٠٠٧. استخدمت خمس من الطرق الاحصائية تضم الارتباط البسيط، تحليل الانحدار المتعدد، تحليل الانحدار المتعدد المرحلى، تحليل العامل، تحليل المكونات الأساسية لدراسة العلاقة بين محصول الحبوب ومكوناته تحت ظروف الاجهاد المائى. أظهر معامل الارتباط البسيط وجود ارتباط معنوى موجب قوى بين صفة محصول الحبوب وصفات عدد السنابل/ م٢ ووزن حبوب السنبلة والمحصول البيولوجى ودليل الحصاد. بينما اظهر تحليل الانحدار المتعدد المرحلى ان ٩٢.٩٠ من التباين الكلى لمحصول الحبوب يمكن تفسيرها عن طريق التباين الراجع لصفات دليل الحصاد والمحصول البيولوجى ووزن حبوب السنبلة. حيث كانت معادلة الانحدار الخطى كالتالى:

$(Y) = -2.201 + 0.092\ X_9 + 0.300\ X_8 - 0.160\ X_6$ حيث Y , X_9, X_8 و X_6 تمثل محصول الحبوب، دليل الحصاد، المحصول البيولوجى، وزن حبوب السنبلة على التوالى. في حين اظهر تحليل العامل ان ٧٦.٥% من التباين الكلى يمكن ارجاعه الى تأثير اربع عوامل. العامل الاول يشمل على ٣٣.٩٠ من التباين الكلى ويضم صفات عدد حبوب السنبلة، وزن الـ ١٠٠٠ حبة والمحصول البيولوجى. بينما العامل الثانى احتوى على ١٨.٥٠% من التباين الكلى وضم صفات طول النبات ودليل الحصاد هي الاكثر فاعلية على محصول الحبوب. اما العامل الرابع فشمل على ٩.٥٠% من التباين الكلى وضم صفة عدد السنابل/ م^{٢}. من ناحية اخرى اظهر تحليل المكونات الاساسية تقسيم الصفات الى اربع مجموعات اشتملت على ٧٧.٠٠% من التباين الكلى وأظهرت أن صفات دليل الحصاد، المحصول البيولوجى، عدد السنابل/ م^{٢}، وزن حبوب السنبلة، عدد الحبوب فى السنبلة، ووزن الـ ١٠٠٠ حبة هى اكثر الصفات ارتباطا بمحصول الحبوب. يمكن تلخيص النتائج السابقة ان الطرق الاحصائية المستخدمة فى هذه الدراسة اشارت الى الارتباط الوثيق تحت ظروف الاجهاد المائى بين محصول الحبوب و وزن حبوب السنبلة و دليل الحصاد والمحصول البيولوجى.