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Regression and path analysis in Egyptian bread wheat

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A B S T R A C T

Two field experiments were conducted in 2010/2011 and 2011/2012 growing seasons at the experimental farm of the Faculty of Agriculture, Cairo University, Giza, Egypt. Twenty bread wheat Egyptian cultivars were evaluated in alpha lattice design with three replications for nine traits. The aims were to determine relationships between yield and its components and examine the efficiency of such components in building yield capacity by using four different statistical methods. Highly significant differences were detected among cultivars for all studied traits. Highly significant and positive correlation estimates were detected between grain yield plant^{-1} and each of number of number of tillers plant^{-1}, number of spikelet's spike^{-1}, number of grains spike^{-1}, 1000-grain weight and harvest index. On the other hand, days to 50% heading and plant height showed negative association with grain yield plant^{-1}. Based on simple regression analysis, linear regression of number of tillers plant^{-1}, spike length, number of spikelet's spike^{-1}, number of grains per spike, thousand grain yield and harvest index it leads to increase the grain yield plant^{-1} by 0.67, 0.52, 0.32, 0.30, 0.64 and 0.63 units, respectively. Path analysis showed that maximum positive direct effect on grain yield plant^{-1} was contributed mostly by number of tillers plant^{-1}, followed by number of grains spike^{-1}, harvest index and 1000-grain weight were the major contributors towards grain yield. Also, stepwise multiple linear regression analysis revealed that four traits included number of tillers plant^{-1}, number of grains spike^{-1}, harvest index and 1000-grain weight with R^2 = 97.29%, had justified the best prediction model. Results of stepwise regression and path analysis revealed that the two methods are equivalent in determine the dependence relationship between grain yield and yield component characters. Also, results in the study with respect to four statistical methods which have been used in this study showed that that the number of tillers plant^{-1}, harvest index, number of grains spike^{-1} and 1000-grain weight were the most important characteristics and they were highly effective on grain yield. These characters have to be ranked the first in any breeding program to improve wheat grain yield

Keywords: *Wheat, Grain yield, Statistical procedures, Simple correlation, Path analysis, Stepwise multiple linear regression analysis.*

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is one of the most important crops in Egypt and cultivated area is about 1.28 million hectares (3.049 million feddan). The local production is about 8 million tons however; it covers less than 53.3% of local consumption (FAO, 2012). An important objective of the Egyptian Government is consequently to reduce the dependence on imported wheat by enhancing average grain yield and production. Increasing wheat productivity is a national target in Egypt to fill the gap between wheat consumption and production.

The production of wheat can be increased either by increasing cultivation area or by increasing yield per unit area. Currently, it is nearly impossible to increase area under wheat crop due to competition with other crops and because of restricted irrigation water supply, etc. Therefore, the only alternative left is to increase it's per feddan (4200 m^2) yield by better crop management techniques and introducing high yielding varieties along with resistance against environmental stresses.

The main objective for a plant breeder is to evolve high yielding varieties. Grain yield is a complex trait and highly influenced by many genetic factors and environmental fluctuations. In plant breeding programme, direct selection for yield as such could be misleading. A successful selection depends upon the information on the genetic variability and association of morpho-agronomic traits with grain yield.

There are many factors, on which the yield of wheat crop depends, such as days to 50% heading, plant height, number of tillers per plant, number of spikletes per spike, number of grains per spike, spike length, 1000-grain weight and harvest index etc. It is desirable for plant breeder to know the extent of relationship between yield and its various components which will facilitate him in selecting plants of desirable characteristics. The needs of new cultivars having higher grain yield leads to the objective of wheat breeding programs to develop new cultivars having higher quality and greater yielding ability. The knowledge of relationship among various yield components has been successfully exploited towards wheat improvement.

There are various statistical techniques covering correlation, regression, path analysis to evaluate yield and yield components for breeding programs. Leilah and Al-Khateeb (2005) used seven statistical procedures to study the relationship between wheat grain yield and its components. Correlation analysis among yield and yield components is one of the prerequisite techniques to determine the influence of environment on productivity and yield potential. The information on the nature and magnitude of correlation coefficients help breeders to determine the selection criteria for simultaneous improvement of various characters along with yield. Determination of correlation coefficients between various wheat characters helps to obtain best combinations of attributes for obtaining higher return per unit area. Correlation studies along with path analysis provide a better understanding of the association of different characters with grain yield. Path coefficient analysis separates the direct effects from the indirect effects through other related characters by partitioning the correlation coefficient (Dixet & Dubey, 1984).

The statistical technique that is used to establish the existence of linear relationship between the dependent variable and the independent variables is the regression analysis. If there is a single independent or predicator variable is referred to as simple linear regression, while if it involved more than one independent or predictor variables we have the case of Multivariate regression or multiple regression analysis. Stepwise multiple linear regression aims to construct a regression equation that includes the variables accounting for the majority of the total yield variation. Mohamed, (2005) found that number of spikes m^{-2}, spike length and weight of 1000 grains were from the characters significantly contributed to the total variation of plant grain yield of wheat. Ashmawy, (2010) used stepwise regression analysis and reported that number of spikes m^{-2}, number of grains $spike^{-1}$ and weight of 1000 grains were the most important contributing characters in the total variability of grain yield. Soleymanfard, (2012) reported that 75% variation in grain yield was due to spikes m^{-2}, 1000 grain weight and plant height.

This study was undertaken in order to determine the dependence relationship between grain yield and yield component characters of twenty Egyptian cultivars of bread wheat by using certain statistical procedures under Middle Egypt region conditions. The aim of this study to help wheat breeders, how to determine the effect of yield components and what yield components could be efficiently used in breeding programs.

MATERIALS AND METHODS

Experimental site and plant materials

This investigation was carried out at the experimental farm of the Faculty of Agriculture, Cairo University, at Giza, Egypt, during the two wheat successive growing seasons, 2010/2011 and 2011/2012. The experimental material comprised of twenty breed wheat (*Triticum aestivum* L.), cultivars from the Agricultural Research Center (ARC), Giza, Egypt, namely, Sids 1, Sids 4, Sids 6, Sids 12, Sids 13, Gemmeiza 3, Gemmeiza 5, Gemmeiza 7, Gemmeiza 9, Gimmeiza 10, Marute, Sakha 8, Sakha 69, Sakha 93, Sakha 94, Giza 157, Giza 164, Giza 168, Misr 1 and Misr 2. These cultivars were used as treatments and evaluated in the study.

Layout and experimental design

The experiment was laid out according to an alpha lattice design with incomplete blocks with three replications, 20 cultivars, 4 blocks within a replicate and 5 plots per block in each replication. This arrangement of experimental units and blocks has been found to minimize variation within the block while maximizing variation among blocks. The randomization of 20 cultivars was done with Crop Stat v7.2.3 software (2007). The cultivars were planted in plots with six rows of 3.5 meter length and 20 cm apart and the distance between plants was 5 cm for each cultivar in each replication. The net experimental plot area was 4.2 m^2.

Cultural practices

Cultivars were sown at the seed rate of 60 kg/fed and sowing dates were 10^{th} and 17^{th} of November in the two successive seasons, respectively. The plants were subjected to recommended package of agronomic and plant protection practices to obtain a healthy crop. Calcium super phosphate (15.5% P_2O_5) was applied during soil preparation at the rate of 100 kg $feddan^{-1}$ P_2O_5. Five irrigations were added during growth by flooding system. Total nitrogen fertilization was applied at a rate of 100 kg feddan-

[1] N as Urea (46.5%) in two equal doses, before the first and second irrigations. All the recommended cultural practices were followed up to harvest.

Recording of observations

Data were recorded on days to 50% heading estimated on plot basis by visual observations. Observations were recorded on ten randomly selected plants from the two middle rows in each cultivar per replication for the following traits viz., days to 50% heading, plant height (cm), number of tillers plant^{-1}, spike length (cm), number of spikelets spike^{-1}, number of grains spike^{-1}, harvest index (%), 1000-grain weight (g) and grain yield plant^{-1} (g).

Statistical analysis and interpretation of data

1- Descriptive analysis

The row data was compiled by taking the means of all plants taken for each treatment and replication for different traits in both seasons. The pooled means of both seasons were subjected to further statistical and biometrical analysis. Simple statistical estimates, viz. average, range, standard error and coefficient of variation were analyzed according to Steel, (1997).

2-Analysis of variance

In the data analysis, normalizing the data distribution as one of the primary assumptions was carried out by using SPSS (2008). Therefore, the normality of the data was evaluated using the Kolmogrov-Smirnov method. Also, data were tested for violation of assumptions underlying the analysis of variance.

The data in the two seasons were subjected to statistically analyzed according to the technique of analysis of variance (ANOVA) for the alpha lattice design developed by Patterson and Williams (1976) (Table 1).

Table 1. Form of analysis of variance for alpha lattice design

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
Replications	r-1	SS_r	MS_r	
Blocks (within replications, ignoring treatments)	rs-r	SS_b	MS_b	
Treatments (adjusted for blocks)	t-1	SS_t	MS_t	F_0
Error	rt-rs-t+1	SS_e	MS_e	
Total	tr-1	SS_T	-	

The arrangement of treatments in alpha lattice into groups gave possibility the data analysis as a randomized complete block experiment. Statistical calculations were carried out with the use of the program SPSS (2009).

The linear model of observations in alpha design is of the form:

$$y_{ijk} = \mu + t_i + r_j + b_{jk} + e_{ijk}$$

where y_{ijk} denotes the value of the observed trait for i-th treatment received in the k-th block within j-th replicate (superblock), t_i is the fixed effect of the i-th treatment ($i = 1,2,\dots,t$); r_j is the effect of the j-th replicate (superblock) ($j = 1,2,\dots,r$); b_{jk} is the effect of the k-th incomplete block within the j-th replicate ($k = 1,2,\dots s$) and e_{ijk} is an experimental error associated with the observation of the i-th treatment in the k-th incomplete block within the j-th complete replicate.

3- Simple correlation and regression coefficients

To analyze the relationships between grain yield and yield components accurately, simple correlation and regression analysis was performed for all cultivars using MINITAB (2005) 14 software statistical package. The data collected for the two years were combined then subjected to estimate correlation and regression coefficients among measured characteristics (Steel, 1997).

3- Path coefficient analysis

Path coefficient analysis was made on the basis of phenotypic correlation coefficients taking grain yield as effect and the remaining estimated characters as cause. Direct and indirect effects of component characters on grain yield were worked out using path coefficient analysis (Dewey and Lu, 1959) using OpenStat software version 1.9, a computer program, as suggested by William (2007).

4- Stepwise multiple linear regression

Stepwise multiple linear regression procedure was used to determine the variable accounting for the majority of total yield variability. Stepwise program computed a sequence of multiple linear regression in a stepwise manner using MINITAB (2005) 14 software statistical package. At each step, one variable was added to the regression equation. The added variable was the one that induced the greatest reduction in the error sum of squares. It was also the variable that had the highest partial correlation with the dependent variable for fixed values of those variables already added. Moreover, it was the variable which had the highest F-value. To detect presence of multicolinearity, value of variance inflation factor (VIF) among all independent variables is often used (Hair, 1995). [VIF= $1/(1- R_i^2)$), where $R_i^2$is the coefficient of determination for the prediction of the i^{th} variable by the predictor variables]. Thus, large VIF's values (above 10) indicate high colinearity (Hair, 1995). The above mentioned multivariate procedures were applied to the data over both seasons of the experiment including plant characteristics namely: days to 50% heading (x_1), plant height (x_2), number of tillers plant^{-1}(x_3), , number of spikelets spike^{-1} (x_4), number of grains spike^{-1} (x_5), spike length (x_6), 1000-grain weight (x_7), harvest index (x_8) and grain yield plant^{-1} (Y).

RESULTS AND DISCUSSION

Means of Wheat Yield and its Components

Basic statistical parameters: mean values, standard error, minimum and maximum values and coefficient of variation, for the six cultivars under investigation of all studied traits are presented in (Table 2). In the present investigation, there was a considerable variation with regard to all characteristics under study (Table 2). The results shown in Table 1 show that the coefficient of variation was the highest for harvest index, followed by number of tillers per plant. Heading date had the lowest value, followed by, number of grains per spike and plant height. Thousand grain weight, spike length, number of spikletes per spike and grain yield per plant showed moderate values for the coefficient of variation (Table 2). Coefficient of variation also known as 'relative variability' calculated as percentage is a measure of how much variability exists for selection. Similar results have been reported by Abd El-Mohsen, (2012), Ashmawy, (2010) and Mohamed, (2005).

Table 2. Basic statistical parameters for yield and yield components in barley: mean values, standard error, minimum values (Min) maximum values (Max) and coefficient of variation (CV)

Character	Mean	SE	Min.	Max.	CV%
Days to 50% heading (x_1)	82.14	2.14	83.21	92..44	8.35
Plant height (cm) (x_2)	95.36	3.09	74.34	119.53	10.38
Number of tillers plant^{-1}(x_3)	9.81	0.43	6.27	22.10	14.22
Number of spikletes spike^{-1}(x_4)	19.02	0.71	16.77	26.87	12.10
Number of grains spike^{-1}(x_5)	46.87	1.34	30.99	70.54	9.19
Spike length (cm) (x_6)	9.94	0.40	9.27	15.04	12.97
1000-grain weight (g) (x_7)	44.97	1.55	37.41	60.20	11.09
Harvest index (%)(x_8)	47.25	2.29	38.11	49.57	15.55
Grain yield plant^{-1}(g) (y)	15.89	3.85	11.87	41.35	13.27

Means of grain yield varied between 11.87 and 41.35 g per plant. Plant height ranged from 74.34 to 119.53 cm. days to 50% heading was between 83.21 and 92.44 day, whereas the number of tillers per plant was between 6.27 and 22.10. The number of spikletes per spike, number of grains per spike, thousand grain weight, spike length and harvest index were between 16.77 and 26.87, 30.99 and 70.54, 37.41 and 60.20 g, 9.27 and 15.04 cm, 38.11 and 49.57 %, respectively (Table 2). Such considerable range of variations provided a good opportunity for yield improvement.

Analysis of variance

Statistical analysis according to the technique of analysis of variance (ANOVA) for both successive seasons of alpha lattice design for studied traits are summarized in Tables 3 and 4. Based on the results obtained, statistical analysis revealed that the genotypes included in the study had highly significant variation ($p \leq 0.01$) for all traits under study. It could be concluded that differences between wheat cultivars may be due to genetical differences between cultivars and indicating considerable amount of variation present in these material and revealing a high level of diversity among the cultivars for these traits. This provides evidence for sufficient variability and selection on the basis of these traits can be useful. Selection for seed yield can only be effective if desired genetic variability is present in the genetic stock. The varietal differences in growth, yield and yield components obtained in this study are in agreement with those obtained by El-Sarag and Ismaeil (2013), Abd El-Kreem and Ahmed (2013) , Baloch, (2013).

Table 3. Mean squares of the 9 traits of bread wheat for 2010/2011 season

SOV	df	Days to 50% heading	Plant height (cm)	No of tillers plant^{-1}	Spike length (cm)	No of spikelets spike^{-1}	No of grains spike^{-1}	1000-grain weight (g)	Harvest index (%)	Grain yield plant^{-1} (g)
Replications	2	56.37^{ns}	145.36*	120.21*	5.83**	6.81**	8.01**	37.77**	4.86**	77.26**
Blocks	9	30.22^{ns}	90.45*	75.45*	3.85**	4.22**	4.56**	25.45**	3.12*	43.45**
Genotypes	19	215.49**	373.25**	1278.98**	8.07**	5.58**	9.45**	78.31**	55.81**	88.21**
Error	29	20.69	38.15	31.20	0.66	0.74	1.21	6.25	1.45	10.15

** = Significant at 1% level. * = Significant at 5% level. ns = Non-Significant

Table 4. Mean squares of the 9 traits of bread wheat for 2011/2012 season

SOV	df	Days to (50%) heading	Plant height (cm)	No of tillers plant^{-1}	Spike length (cm)	No of spikelets spike^{-1}	No of grains spike^{-1}	1000-grain weight (g)	Harvest index (%)	Grain yield plant^{-1} (g)
Replications	2	44.29^{ns}	167.33*	154.36**	4.02*	6.14**	7.25*	53.22**	4.86**	66.80**
Blocks	9	16.71^{ns}	95.64*	68.75*	2.95**	3.66**	5.49**	31.74**	2.82*	44.57**
Genotypes	19	224.33**	365.98**	1245.32**	7.26**	5.09**	11.45**	86.32**	66.81**	60.34**
Error	29	22.62	40.47	27.51	0.90	0.95	1.69	6.02	1.72	11.91

** = Significant at 1% level. * = Significant at 5% level. ns = Non-Significant

Simple correlation and regression analysis

Correlation analysis is widely used in statistical evaluations and it shows efficiency of relationship between two variables. According to the data presented in Table 5, the correlation coefficient (r values) for number of tillers plant^{-1}, number of spikelets per spike, number of grains per spike , 1000-grain weight, spike length and harvest index were positively significantly correlated with grain yield plant^{-1} indicating that increase in these characters would increase the grain yield per plant. When we look at the relationship among traits, the results of the correlation coefficients revealed that the number of tillers plant^{-1}, spike length, number of spikelets spike^{-1}, harvest index and 1000-grain weight had the highest significant positive correlation with grain yield plant^{-1}, r= 0.603**, r=0.672**, r=0.619**, r= 0.640** and r=0.634**, respectively (Table 5), indicating dependency of yield on these characters. Other traits including plant height and days to 50% heading showed significant and negative 'b' values suggesting that grain yield would be decreased with the increase of both characters.

Based on simple regression analysis, linear regression of number of tillers plant^{-1}, spike length, number of spikelets spike^{-1}, number of grains per spike, thousand grain yield and harvest index it leads to increase the grain yield plant^{-1} by 0.67, 0.52, 0.32, 0.30, 0.64 and 0.63 units, respectively.

Positive and significant association (r=0.603**) between tillers plant^{-1} and grain yield plant^{-1} revealed that increase in tillers plant^{-1} will increase correspondingly increase grain yield plant^{-1}. About 36% of total variability in grain yield plant^{-1} was due to its association with tillers plant^{-1}; while regression coefficient indicated that one tiller increase will simultaneously give increase of 0.67 g in grain yield plant^{-1}. The correlation between harvest index and grain yield plant^{-1} showed significantly positive association (r=0.640**) which indicated that increase in harvest index will markedly increase grain yield plant^{-1}. The coefficient of determination (R^2) revealed that 41% of total variability in grain yield plant^{-1} was due to its association with harvest index; while regression coefficient showed that a unit increase in harvest index will result in an increase of 0.63 g in grain yield plant^{-}

Presence of highly significant and positive correlation between number of tillers plant^{-1}, spike length, number of spikelets spike^{-1}, number of grains per spike, thousand grain yield and harvest index with grain yield plant^{-1} shows that the results of regression analysis are in harmony with correlation results, while, days to 50% heading and plant height reduce the grain yield plant^{-1} by 0.008 and 0.11 units, respectively.

Kashif and Khaliq (2004) reported that yield components like tillers plant^{-1} had significantly contributed towards grain yield development. They also noted that grains spike^{-1} and 1000-grain weight were main contributors to grain yield in wheat. It was also reported that grain yield plant^{-1} showed significantly positive association with number of productive tillers plant, plant height, 1000-grain weight and spike length at genotypic and phenotypic levels (Aycicek and Yildirim, 2006). Majumder, (2008) had shown that spikes number per plant, number of grains per spike, spike length, 100-grain weight and harvest index were the most important characters which possessed positive association with grain yield. However, Mohammed, (2009) showed a negative correlation between plant height and grain yield. Baloch, (2013) suggested that major portion of total variability in grain yield plant^{-1} was attributable to traits such as tillers plant^{-1}, spike length and harvest index.

Table 5. Correlation (r), regression coefficients (b) and coefficient of determination (R^2) of various traits in wheat cultivars

Character association	Correlation coefficient (r)	Regression coefficient (b)	Coefficient of determination (R^2)
Days to 50% heading *vs* grain yield plant^{-1}	-0.090^{ns}	-0.02	0.008
Plant height *vs* grain yield plant^{-1}	-0.330^{ns}	-0.19	0.11
Number of tillers plant^{-1} *vs* grain yield plant^{-1}	0.603**	0.67	0.36
Number of spikelets spike^{-1} *vs* grain yield plant^{-1}	0.672**	0.52	0.45
Number of grains spike^{-1} *vs* grain yield plant^{-1}	0.619**	0.32	0.38
Spike length *vs* grain yield plant^{-1}	0.539**	0.30	0.29
1000-grain weight *vs* grain yield plant^{-1}	0.634**	0.64	0.40
Harvest index *vs* grain yield plant^{-1}	0.640**	0.63	0.41

**Significant at $P < 0.01$ and ns = non-significant according to the t-test, respectively.

Path coefficient analysis

Knowledge of correlation alone is often misleading as the correlation observed may not be always true. Two characters may show correlation just because they are correlated with a common third one. In such cases, it becomes necessary to use a method which takes into account the causal relationship between the variables, in addition to the degree of such relationship. Path coefficient analysis measures the direct influence of one variable upon the other, and permits separation of correlation coefficients into components of direct and indirect effects. Portioning of total correlation into direct and indirect effects provide actual information on contribution of characters and thus form the basis for selection to improve the yield.

The result of correlation coefficients was partitioned into direct and indirect effects through various yield contributing characters. The estimates of direct and indirect effects of the eight attributes on grain yield are presented in Table 6. Path coefficient analysis was carried out using coefficient of all the traits with grain yield plant^{-1} (Table 6).

Table 6. Path coefficient analysis of eight characters on grain yield plant^{-1} in wheat over the two years

Traits	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	Grain yield plant^{-1} (g)
Days to (50%) heading (x_1)	***(- 0.404)***	-0.128	-0.140	0.233	0.061	0.230	-0.071	0.210	-0.090
Plant height (cm) (x_2)	0.135	***(-0.290)***	0.378	-0.532	0.123	-0.488	0.135	0.209	-0.330
No. of tillers plant^{-1} (x_3)	-0.092	-0.167	***(0.589)***	-0.045	-0.122	0.359	0.209	-0.101	0.603**
Spike length (cm) (x_4)	-0.067	-0.047	0.371	***(-0.398)***	0.270	0.384	0.264	-0.105	0.672**
No. of spikelets spike^{-1} (x_5)	-0.196	0.231	0.325	-0.084	***(-0.533)***	0.715	-0.052	0.213	0.619*
No. of grains spike^{-1} (x_6)	-0.050	-0.06	0.300	-0.104	-0.041	***(0.409)***	-0.056	0.130	0.539**
1000-grain weight (g) (x_7)	-0.103	-0.019	-0.028	0.387	-0.115	-0.114	***(0.316)***	0.310	0.634**
Harvest index (%) (x_8)	-0.150	0.149	0.211	0.148	-0.192	0.262	-0.122	***(0.489)***	0.640**

Italic and bold figures denotes direct effects while regular figures denotes indirect effects; Residual effect = 0.097

Based on path analysis, maximum positive direct effect on grain yield plant^{-1} was contributed mostly by number of tillers plant^{-1} (0.589), followed by harvest index (0.489), number of grains spike^{-1} (0.409), and 1000-grain weight (0.316). This means that a slight increase in one of these traits may directly contribute to grain yield. Similar results were reported by Dhonde, (2000), Satya, (2002) and Khan and Dar (2010). The positive direct effects of spikes number, grains number and thousand-kernel weight were previously reported in wheat (Fellahi, 2013**;** Iftikhar, 2012; Pirdashti, 2012). On the other hand, the maximum negative direct effect was exhibited by number of spikelets spike^{-1} (-0.533), followed by days to 50% heading (-0.404), spike length (-0.398) and plant height (-0.290). Residual effects (0.097) indicated that eight characters included in this study explained high percentage of variation in grain yield. Also, indicated that in addition to the previous variables, there are also other factors to justify grain yield changes.

Days to 50% heading vs. grain yield

Direct effect of days to 50% heading was negative with non significant correlation. The negative direct effect of days to 50% heading on grain yield per plant was (-0.404). The selection of this trait will be ineffective. Although, indirect effect *via* spike length, number of grains spike^{-1} and harvest index was positive and high and these traits could be selected for yield improvement. Some authors also indicated the negative effect of days to 50% heading on grain yield (Yildirim, 1996 and Narwal, 1999).

Plant height vs. grain yield

Plant height directly affected the grain yield in negative direction (Table 6). The negative direct effect of plant height was moderate (-0.290), and its correlation with grain yield plant^{-1} was negative but non-significant. Similar results were reported by Chowdhry, (1986) and Ali, (2008). It is due to high percentage of dry matter accumulation towards the height of the plant in tillers plant^{-1} affecting the grain yield. Indirect effects of plant height via, days to 50% heading, tillers plant^{-1}, number of spikelets spike^{-1}, 1000-grain weight and harvest index was positive whereas it was negative through spike length and grains spike^{-1} (Table 6).

Tillers per plant vs. grain yield

A close view of results (Table 6) indicated that number of productive tillers plant^{-1} exhibited a high positive direct effect and highly significant correlation coefficient indicating the true relationship. Therefore direct selection through this trait will be effective for yield improvement. The correlation between tillers per plant (0.603) and the grain yield is almost equal to its direct effect (0.589), thus it shows true relationship and direct selection for higher number of tillers plant^{-1} would be enough to increase grain yield. Singh and Chaudhary (1979) suggested that if the correlation coefficient between a causal factor and the effect (i.e. grain yield) is almost equal to its direct effect, then correlation explains the true relationship and direct selection through this trait will be effective.

he indirect effect of this trait *via* number of grains per spike was also positive and high while it was negative through days at 50% heading, plant height, spike length, spikelets spike^{-1} and 1000-grain weight. These results are similar to those obtained by Simane (1998), Ali, (2008) and Abd El-Mohsen, (2012).

Spike length vs. grain yield

Spike length is a character of considerable importance, as the larger spike is likely to produce more grains and eventually higher yield plant^{-1}. Direct effect was negative and moderate and correlation coefficient was positive and highly significant between spike length and grain yield plant^{-1}. This was mainly due to the indirect positive effect of number of grains spike^{-1} and the indirect selection for this trait will be effective to improve yield.

Number of spikelets per spike vs. grain yield

Number of spikelets spike^{-1} had negative direct effect on grain yield plant^{-1} and had maximum positive indirect effect through number of grains spike^{-1} and number of tillers plant^{-1}. These results are congruent with the finding of Subhani and Chowdhry (2000), Tamman, (2000), Shahid, (2002) and Lad, (2003).

Number of grains per spike vs. grain yield

Number of grains per spike directly affected the grain yield plant^{-1} in positive direction (Table 6). The positive direct effect of number of grains per spike was highly great (0.409), and its correlation with grain yield plant^{-1} was positive and highly significant.

It is evident that grain yield can be increased reliably by increasing of number of grains spike^{-1}. The direct selection for this trait will be effective. Basirat (1994) suggested that the highest direct effect on grain yield is related to number of grain spike^{-1}. Mohammad, (2002), Aycicek and Yildirim (2006), Ali, (2008) and Mollasadeghi and Shahryari (2011) also reported positive direct effect of number of grains spike^{-1} and its positive association with grain yield in wheat genotypes and these findings support the present results. The indirect effect *via* number of tillers plant^{-1} was also positive.

Thousand grain weight vs. grain yield

Thousand grain weight exhibited positive direct effect on grain yield plant^{-1} (0.316). Selection for this trait will be rewarding for yield improvement. Aycicek and Yildirim (2006) also reported positive but small direct effects of 1000-grain weight on grain yield in wheat. Soghi, (2006) by examining relationship between yields with yield components of 19 advanced wheat lines showed that direct effect of one-thousand grain weight was little.

Harvest index vs. grain yield

Harvest index directly affected the grain yield plant^{-1} in positive direction (Table 6). The positive direct effect of number of grains per spike was highly great (0.489), and its correlation with grain yield plant^{-1} was positive and highly significant. These results are in agreement with earlier study by Majumder, (2008). Gashaw, (2007) reported that the harvest index had strong positive direct effect with grain yield.

Stepwise multiple linear regression

In order to remove effect of non-effective characteristics in regression model on grain yield, stepwise regression was used. In stepwise regression analysis, grain yield plant^{-1} (Y) as dependent variable and other traits as independent variables were considered. Accepted variables and their relative contributions are shown in Table 7.

The results showed that number of tillers per plant, harvest index, number of grains per spike, and 1000-grain weight with R^2 = 97.29%, had justified the maximum of yield changes (Table 7 and Figure 1). It is observed from the results in Table 7 that number of tillers plant^{-1} was the most important character followed by harvest index, number of grains spike^{-1} and weight of 1000 grains. The relative contributions in the total variation of grain yield were 58.06%, 18.10%, 11.40% and 9.73 % for the above mentioned characters, respectively. Due to their low relative contributions, the other variables were not included in the model. Consequently, based on the final step of stepwise regression analyses, the best prediction equation was formulated as follows :

$$Y = 3.89 + 0.19\, x_3 + 1.24\, x_8 + 0.\ 45\, x_5 + 0.36\, x_7$$

Where, Y, x_1, x_2, x_3 and x_4 are grain yield plant^{-1}, number of tillers plant^{-1}, harvest index, number of grains spike^{-1} and 1000-grain weight, respectively. Existence of significant R square in a successful regression equation indicates the effectiveness of these traits to increase grain yield. Therefore, these traits were considered as the main grain yield components. The unexplained variation (2.71% of the total) may be due to variation in other yield components. A positive regression coefficient of the four variables implies that defining a logical index selection with these variables, considering their correlation coefficients with grain yield, might be a good strategy for increasing grain yield in wheat.

The results of this analysis are in agreement with Fellahi, (2013) who found that spikes number per plant, grains number per spike, thousand kernel weight and days to heading with R^2 = 97.4%, had justified the maximum of yield changes. Soleymanfard, (2012) reported that 75% variation in grain yield was due to spikes m^2, 1000 grain weight and plant height. Shamsi, (2011) who found that spike number, grains number per spike and thousand-kernel weight were introduced into stepwise regression model, accounting for 98% of grain yield variance. Efyoni and Mahloji (2005) used stepwise regression analysis in

42 lines and for bread wheat, and showed that the grain yield period, the number of grains per spike, the number of spikes per m^2 and plant height entered into regression model sooner than other traits and were the most effective traits on grain yield.

Table 7. Relative contribution (partial and model R^2), regression coefficient (b), standard error (SE), t-value, variance inflation factor (VIF) and probability value (P) in predicting wheat grain yield by the stepwise procedure analysis

Step	Variable entered	Partial R^2	Model R^2	b	SE	t	VIF	P-value
1	Number of tillers plant^{-1} (x_3)	0.5806	0.5806	0.19	0.091	30.25	2.38	0.001
2	Harvest index (x_8)	0.1810	0.7616	1.24	0.025	16.13	1.22	0.002
3	Number of grains spike^{-1} (x_5)	0.1140	0.8756	0.45	0.047	10.27	1.88	0.009
4	1000-grain weight (x_7)	0.0973	0.9729	0.36	0.088	7.32	1.11	0.007

Constant = 3.89, R^2 = 0.9729, R^2 (adjusted) = 0.9605

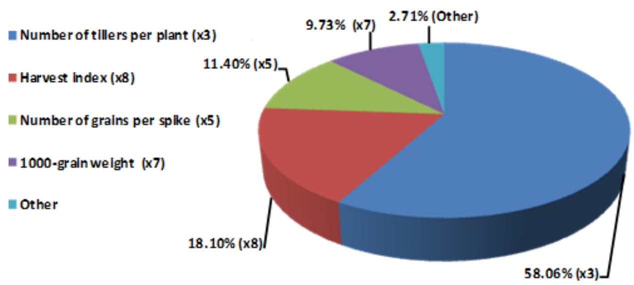

Figure 1. The relative contributions for yield components

The multiple statistical procedures which have been used in this study showed that the number of tillers plant^{-1} (x_3), harvest index (x_8), Number of grains spike^{-1} (x_5) and 1000-grain weight (x_7) were the most important yield variables to be considered for these cultivars. These procedures were shown at Table 8 for all studies variables. Thus, high yield of wheat plants based on these cultivars can possibly be obtained by selecting breeding materials with high values of these traits.

Table 8. Wheat characteristics identified as crucial in grain yield with each one of the used statistical techniques

Characteristics	Statistical procedures				Frequency
	Simple correlation	Simple linear regression	Path analysis	Stepwise regression	
Days to (50%) heading (x_1)					0
Plant height (cm) (x_2)					0
No. of tillers plant^{-1} (x_3)	√	√	√	√	4
Spike length (cm) (x_4)	√	√			2
No. of spikelets spike^{-1} (x_5)	√	√			2
No. of grains spike^{-1} (x_6)	√	√	√	√	4
1000-grain weight (g) (x_7)	√	√	√	√	4
Harvest index (%) (x_8)	√	√	√	√	4

CONCLUSION

Based on the results obtained in this study, the following conclusions could be drawn:-

This study has shown the existence of considerable variation among the cultivars under study. Results of the study showed that these cultivars may provide good source of material for further breeding program. The multiple statistical procedures which have been used in this study showed that simple correlation and regression analysis cannot distinguish important variables affecting grain yield, the final judgment cannot be done on the basis of these methods as such, it is necessary to use multivariate statistical methods in breeding programs for screening important traits in wheat. An over all, it is logical to conclude that number of tillers plant^{-1}, number of grains spike^{-1}, 1000-grain weight and harvest index were the major contributors towards grain yield since these four characters had high correlation and also high direct effect thus direct selection for these four character should be major concern for plant wheat breeder. Hence using such devices will create opportunity to make better selection of suitable genotypes in wheat improvement programs and to get high yielding genotypes. Information from this study would be valuable to wheat breeder for developing high yielding cultivars for wheat.

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