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*Research Article*

# Comparing Relationships among Yield and Its Related Traits in Mycorrhizal and Nonmycorrhizal Inoculated Wheat Cultivars under Different Water Regimes Using Multivariate Statistics

**Armin Saed-Moucheshi,[1] Mohammad Pessarakli,[2] and Bahram Heidari[1]**

[1] *Department of Crop Production and Plant Breeding, Shiraz University, Shiraz 71441 65186, Iran*
[2] *School of Plant Sciences, The University of Arizona, Tuscan, AZ 85721, USA*

Correspondence should be addressed to Mohammad Pessarakli; pessarak@email.arizona.edu

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Multivariate statistical techniques were used to compare the relationship between yield and its related traits under noninoculated and inoculated cultivars with mycorrhizal fungus (*Glomus intraradices*); each one consisted of three wheat cultivars and four water regimes. Results showed that, under inoculation conditions, spike weight per plant and total chlorophyll content of the flag leaf were the most important variables contributing to wheat grain yield variation, while, under noninoculated condition, in addition to two mentioned traits, grain weight per spike and leaf area were also important variables accounting for wheat grain yield variation. Therefore, spike weight per plant and chlorophyll content of flag leaf can be used as selection criteria in breeding programs for both inoculated and noninoculated wheat cultivars under different water regimes, and also grain weight per spike and leaf area can be considered for noninoculated condition. Furthermore, inoculation of wheat cultivars showed higher value in the most measured traits, and the results indicated that inoculation treatment could change the relationship among morphological traits of wheat cultivars under drought stress. Also, it seems that the results of stepwise regression as a selecting method together with principal component and factor analysis are stronger methods to be applied in breeding programs for screening important traits.

## 1. Introduction

Bread wheat (*Triticum aestivum* L.) is one of the most widely cultivated and important food crop in the world. Development of high yielding wheat cultivars is the major objective of breeding programs [1]. On the other hand, targeted efforts to breed genotypes for improved mycorrhizal symbiosis result in increased yield in crops under a wide range of environmental conditions and contribute toward sustainability of agricultural ecosystems in which soil-plant-microbe interactions will be better exploited. Screening genotypes via molecular biology and traditional breeding techniques can increase productivity of symbioses and eventually result in increased economic yield of crop plants [2].

Arbuscular mycorrhizal (AM) fungi colonize the roots of most monocotyledons and dicotyledons, including important crops such as rice, maize, and wheat despite their different root architecture and cell patterning. In nature, mineral nutrient acquisition and water uptake by plant roots are often assisted by symbioses with beneficial AM fungi. During this intimate association, the extraradical hyphal mycelium acquires minerals from the soil beyond the zone accessible by the roots. Inside the root, a considerable proportion of the minerals is delivered to the host in exchange for carbohydrates [3]. However, a few breeding programs and physiological researches have examined the morpho-physiological effects of mycorrhizal inoculation on wheat cultivars under drought stress. The benefit arising from the mycorrhizal symbiosis was not proportional to the extent of the root colonization in durum wheat genotypes; because various genotypes showed various responses to mycorrhizal inoculation [2, 4].

Aiming to providing methods in order to attain higher production, breeders have used important yield components as selection criteria to perform higher yields via indirect selection [5, 6]. Kumbhar et al. [7] illustrated high efficiency of tiller and kernel production on wheat yield. Grain weight/spike has been reported as the most closely variable

contributing to grain yield, and it has often been used in selecting high yielding wheat genotypes [7]. 1000-grain weight has been shown as the main yield component for 20% of variation in wheat grain yield. Moghaddam et al. [8] found a negative correlation between plant height and grain yield of wheat due to the lower number of grains/spike. The results of Leilah and Al-Khateeb [9] showed that number of spike per square meter, 100-grain weight, grain weight/spike, and biological yield were the most effective variables influencing grain yield. The study of O. Alizadeh and A. Alizadeh [10] showed that using mycorrhizal inoculation caused better nutrient elements uptake in plant and generated plant growth regulators for increasing yield and yield components in corn. When *Azospirillum* and *Mycorrhiza* were used as biofertilizers in study conducted by Ardakani et al. [11], significant effects on wheat yield and its related traits were found. Statistical techniques have important roles in detecting relationship among plants' traits and between the yield and its related components. One of the basic statistical methods to study the relationships between traits is simple correlation coefficient analysis [12]. Estimating correlation coefficients of different variables with grain yield is a suitable technique to decisions about the relative importance of these characters and their values as selection criteria [13]. On the other hand, the correlation coefficient may not give enough information about the relationship between different variables as much as statistical multivariate methods give. Therefore, other statistical techniques such as multiple regressions, factor analysis, principal component analysis, cluster analysis, and path coefficient analysis have been defined as appropriate techniques for interpreting these relationships in crop plants [13, 14]. The multivariate statistical analyses can provide more insights on the deep structure of data and traits' relationships.

Attempts to identifying an ideal model for producing high-yielding wheat plants under different water regimes using mycorrhizal symbiosis in wheat breeding have rarely been made. This study was conducted to clarify and interpreting the relationship between wheat grain yield and its related components under drought conditions and mycorrhizal symbiosis with aiming to provide theoretical foundations guiding wheat breeders for researching the association of the main yield components and their influences on wheat plant productivity.

## 2. Materials and Methods

*2.1. Experimental Procedures.* The experiment was carried out in the greenhouse of Crop Production and Plant Breeding Department, College of Agriculture, Shiraz University, Shiraz, Iran, in 2010. Maximum, minimum, and the mean temperatures of this area were 20.9, 4.4, and 11°C, respectively, with 47.3% relative humidity and 602 mm annual rainfall. A factorial experiment based on completely randomized design with three replications was used. The studied factors were four water regimes (100%, 75%, 50%, and 25% of field capacity), three wheat cultivars (Darab 2 as a semi-resistant cultivar; Shiraz and Falat as sensitive cultivars), and mycorrhizal inoculation, including inoculated and noninoculated (control) treatments. The fungus used in this experiment was *Glomus intraradices* Schenck and Smith, provided by the Department of Soil Science, Shiraz University, Shiraz, Iran. Mycorrhizal inoculums were prepared through the trap culture in maize (*Zea mays* L.) with spores of *G. intraradices*. The mixture of trap culture medium was obtained from autoclaved soil/quartz sand (<1 mm) (4 : 1, v/v).

The soil samples used for planting were collected from Bajgah, Fars, Iran (1810 m asl; longitude 29°50′ and latitude 52°46′). The soil samples were air-dried, passed through 2 mm sieve, and mixed uniformly. The physicochemical properties of the soil were sandy loam, fine, mixed, mesic, calcixerollic xerochrepts, field capacity 25.3%, pH 7.9 (soil: distilled water, 1 : 1), electrical conductivity 0.5 d S $m^{-1}$, carbonate calcium equivalent 11.6%, total organic matter 1.34%, total Kjeldahl nitrogen 0.06%, Olsen phosphorus 15 mg $kg^{-1}$, extractable potassium 240 mg $kg^{-1}$, and DTPA-extractable Fe, Cu, Mn, and Zn were 5, 2, 11.3, and 1.7 mg $kg^{-1}$, respectively [15]. The day/night air temperature of the greenhouse was 25/15.

The pots were filled with 5 kg washed and sieved soil (mentioned previously) without purification or sterilization to simulate the real soil field properties. 150 mg N $kg^{-1}$ soil (urea 46%) and some micronutrient elements such as Zn, Fe, Ca, and K up to 5 mg $kg^{-1}$ were applied in each pot. The seeds were treated with ethanol 98% for about 20 s, washed three times with distilled water, and kept at 20°C for a week. About 5 cm of surface soil of each pot was removed and in mycorrhizal treatments, 50 g inoculums (containing spore numbers of 8 $g^{-1}$ substrate and root colonization of 85 percent) were placed and incorporated with the remaining soil. Then, 3 cm of the removed soils was added to each pot; afterwards eight seeds were planted at equal distances in each pot. Finally, the rest of the removed soils were added to the pots. After germination, seedlings were thinned to four plants per pot.

Pots were daily weighed and based on the decreasing weight of each pot; decalcified water was added to each pot up to desired field capacity (FC) until the date of applying water regimes' treatments. The water regimes were started at the tillering stage. The temperature during the experiment ranged from 15 to 28°C, with a 16/8 h light/dark period.

*2.2. Leaf Area Measurements.* Plants' leaves diameter were measured with a ruler, and leaves areas (X11) were calculated using the following equation [16, 17]:

$$\text{Leaves area}\left(\text{cm}^2\right) = \text{maximum leaf length} \times \text{leaf width} \times 0.75. \quad (1)$$

*2.3. Total Chlorophyll Content.* Total chlorophyll contents of the flag leaves (X8) were determined according to Iqbal et al. [6] procedure. Total chlorophyll content was extracted in 80% cold acetone, and the absorbance of the extractions was measured spectrophotometrically at 645 and 663 nm. Total chlorophyll was determined based on the following standard formula [18]:

$$\text{Chl T}\left(\text{mg mL}^{-1}\right) = 20.2 \times \left(A_{645}\right) + 8.02 \times \left(A_{663}\right), \quad (2)$$

where, $A$ is the spectrophotometer reading at 645 and 663 wavelengths (nm), and Chl T is total chlorophyll content.

*2.4. Agronomic Traits.* Grain yield (Y), tiller numbers (X1), spike length (X2), spikelet/spike (X3), spike weight/plant (X4), grains/spike (X5), grain weight/spike (X6), 100-grain weight (X7), biological yield (X9), and root weight (X10) were determined after the plants were harvested.

*2.5. Statistical Analyses*

*2.5.1. Simple Correlation Coefficients.* Pearson simple correlation coefficients were calculated, and the matrix of these correlations was studied [19].

*2.5.2. Multiple Linear Regressions.* A multiple linear regression model was used for determining relative contribution of related components to the grain yield (Y) variations by applying the following equation [19]:

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + \cdots + b_ix_i, \quad (3)$$

where, $y$ is the dependent variable (yield), the $x$'s are independent variables (measured traits) affecting dependent one, $a$ is the intercept coefficient, and the $b$'s are the related coefficients of independent variables in predicting the dependent variable.

*2.5.3. Stepwise Regression.* Stepwise regression [20] was used in order to determine the most important variables significantly contributed to total yield variability.

*2.5.4. Factor Analysis.* The factor analysis method is consisted of the reduction of a large number of correlated variables to a much smaller number of uncorrelated variables. After extracting main factors, the matrix of factor loading was used to a varimax orthogonal rotation, and the communality or variance of uncorrelated variables was estimated by the highest correlation coefficient in each array as suggested by Seiller and Stafford [21].

*2.5.5. Principal Components Analysis.* Principal components analysis is a mathematical procedure used to classify a large number of variables (items) into major components and determine their contribution to the total variation. The first principal component is accounted for the highest variability in the data, and each succeeding component accounts for the highest remaining variability as possible [22].

*2.5.6. Path Analysis.* Path coefficient analysis was performed using simple Pearson correlation coefficients using grain yield/plant as dependent variable and the other characters as influential variables. The direct and indirect effects of influential variables on grain yield were calculated according to proposed method of Dewey and Lu [23].

*2.5.7. Cluster Analysis.* Cluster analysis was used for arranging variables into different clusters to find the clusters that their cases within are more similar and correlated to one another comparing to other clusters. This procedure was performed using a measure of similarity levels and Euclidean distance [24, 25].

All statistical analyses were performed using SAS-9.1 [26] and Minitab-14 packages.

## 3. Results

*3.1. Simple Correlations.* Table 1 shows the minimum and maximum values, arithmetic mean, standard deviation, and standard error of means for all the estimated variables of wheat, separately for the inoculated and noninoculated plants. Results of simple correlation analysis (Table 2) show that all variables for either inoculated or noninoculated cultivars have a significant positive correlation with grain yield. The highest correlation with yield under both inoculated and noninoculated conditions was recorded for spike weight/plant ($r = 0.998$ for inoculated and 0.993 for noninoculated conditions). Overall, correlation coefficients with grain yield were higher in the inoculated plants than that of the noninoculated ones.

*3.2. Path Coefficients.* The correlation coefficients were partitioned into direct and indirect effects in both inoculated and noninoculated plants (Tables 3 and 4). The highest direct effect (1.023 for the inoculation and 1.013 for the noninoculation) on yields for both conditions belonged to the spike weight/plant, while direct effects of the other variables were relatively low. The indirect effects of the spike weight/plant for both conditions were negative. Except for the spike weight/plant, the other variables had high indirect effects on the grain yield. Spikelets/spike showed the lowest direct contribution to the grain yield variations for both conditions but the highest indirect contribution through other variables.

*3.3. Multiple Linear Regressions.* Regression coefficients and the probability of the estimated variables in predicting the wheat grain yield separately for the inoculated and noninoculated conditions are presented in Table 5. Based on these results, the predicting model equations for the grain yield/plant (Y) are formulated as follows.

*Model for Inoculated Condition*

$$\begin{aligned} Y = {} & 0.539 - 0.116X1 - 0.0202X2 - 0.0081X3 + 0.962X4 \\ & + 0.0109X5 - 0.780X6 - 0.00698X7 - 0.00423X8 \\ & + 0.0131X9 + 0.0840X10 - 0.00080X11, \end{aligned} \quad (4)$$

where, Y is the grain yield, X1 is the tiller numbers, X2 is the spike length, X3 is the spikelet/spike, X4 is the spike weight/plant, X5 is the grains/spike, X6 is the grain weight/spike, X7 is the 100-grain weight, X8 is the total chlorophyll contents of the flag leaves, X9 is the biological yield, X10 is the root weight, and X11 is the leaf area.

Table 1: Basic statistics (minimum and maximum values, arithmetic mean, standard deviation (SD) and standard error of mean (SE mean)) for the measured variables of wheat under inoculation (In) and noninoculation (non-In) conditions and different water levels.

| Variables | Situation | Mean | SE mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|---|
| X1 | In | 1.6940 | 0.1250 | 0.7490 | 1.000 | 3.0000 |
| | Non-In | 1.6940 | 0.1300 | 0.7500 | 1.000 | 3.0000 |
| X2 | In | 8.9910 | 0.2060 | 1.2380 | 6.696 | 12.000 |
| | Non-In | 7.4190 | 0.1960 | 1.1750 | 5.270 | 10.200 |
| X3 | In | 17.493 | 0.3690 | 2.2150 | 12.65 | 23.000 |
| | Non-In | 14.667 | 0.3190 | 1.9120 | 12.00 | 20.000 |
| X4 | In | 5.4720 | 0.5440 | 3.2660 | 0.392 | 12.480 |
| | Non-In | 4.1710 | 0.4530 | 2.7160 | 0.243 | 9.3760 |
| X5 | In | 17.110 | 1.4300 | 8.5600 | 3.000 | 33.000 |
| | Non-In | 13.060 | 1.2100 | 7.2900 | 2.000 | 29.000 |
| X6 | In | 0.2479 | 0.0212 | 0.1271 | 0.094 | 0.5780 |
| | Non-In | 0.2128 | 0.0194 | 0.1162 | 0.059 | 0.5150 |
| X7 | In | 29.246 | 0.8660 | 5.1970 | 20.00 | 41.282 |
| | Non-In | 27.976 | 0.8660 | 5.1970 | 18.73 | 40.012 |
| X8 | In | 60.810 | 3.0200 | 18.090 | 22.12 | 97.930 |
| | Non-In | 51.770 | 3.0200 | 18.130 | 21.83 | 101.71 |
| X9 | In | 11.410 | 1.0700 | 6.4300 | 2.500 | 25.800 |
| | Non-In | 10.490 | 1.1100 | 6.6700 | 2.300 | 22.400 |
| X10 | In | 0.8701 | 0.0742 | 0.4449 | 0.167 | 1.9480 |
| | Non-In | 0.7365 | 0.0713 | 0.4278 | 0.110 | 1.9480 |
| X11 | In | 74.520 | 2.3000 | 13.830 | 51.03 | 100.76 |
| | Non-In | 71.500 | 2.5800 | 15.480 | 30.30 | 102.45 |
| Y | In | 4.9750 | 0.5120 | 3.0720 | 0.200 | 11.600 |
| | Non-In | 3.8150 | 0.4320 | 2.5930 | 0.133 | 8.7000 |

X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grains/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, X11: leaves area, and Y: grain yield.

*Model for Noninoculated Condition*

$$\begin{aligned} Y = {} & -0.089 - 0.0061X1 - 0.0103X2 + 0.0032X3 + 0.978X4 \\ & + 0.0119X5 - 1.51X6 - 0.00451X7 - 0.00316X8 \\ & - 0.0109X9 + 0.119X10 + 0.00486X11, \end{aligned} \tag{5}$$

where, Y is grain yield, X1 is the tiller numbers, X2 is the spike length, X3 is the spikelet/spike, X4 is the spike weight/plant, X5 is the grains/spike, X6 is the grain weight/spike, X7 is the 100-grain weight, X8 is the total chlorophyll contents of the flag leaves, X9 is the biological yield, X10 is the root weight, and X11 is the leaf area. The formulas explained 99.5% and 99.2% ($R^2$) of the total variations of the grain yields for the inoculated and noninoculated conditions, respectively, and the remaining 0.5% and 0.8% are probably due to residual effects. The $t$-test for the variables revealed that the spike weight/plant and grain weight/spike contributed significantly in grain yields of both conditions, while the grains/spike, leaf area and root weight were significant only for the noninoculated condition.

*3.4. Stepwise Regression.* Tables 6 and 7 show the entered or removed variables from the established model by stepwise regression separately from inoculated and noninoculated conditions. The partial and cumulative determination coefficient ($R^2$), the probability value of entered variables to the model or removed variables from models, and standard error of the variables are also presented in these Tables (Tables 6 and 7). Under the inoculated condition, spike weight/plant, grains/spike, grain weight/spike, and total chlorophyll content of the flag leaf were entered into the model, and none were removed; while, under the noninoculated condition, seven variables, including spike weight/plant, grains/spike, grain weight/spike, total chlorophyll content of the flag leaf, biological yield, root weight, and the leaf area were entered into the model, and there were no variables to be removed. According to the results, 99.75% and 99.91% of the total variations in the grain yields were explained by the selected variables under the inoculated and noninoculated conditions, respectively. Due to their low relative contributions, the other variables were not included in the models. Therefore, based on the final step of stepwise regression analyses, the equations for prediction of grain yield (Y) were computed as follows.

*Final Model under Inoculated Condition*

$$\begin{aligned} Y = {} & 0.07776 + 0.95104X4 + 0.01332X5 - 0.99926X6 \\ & - 0.00472X8, \end{aligned} \tag{6}$$

Table 2: A matrix of simple correlation coefficients ($R$) for the measured variables of wheat under inoculation (In) and noninoculation (non-In) conditions and different water levels.

| | | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | X11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X2 | In | 0.633** | | | | | | | | | | |
| | Non-In | 0.611** | | | | | | | | | | |
| X3 | In | 0.569** | 0.622** | | | | | | | | | |
| | Non-In | 0.625** | 0.562** | | | | | | | | | |
| X4 | In | 0.649** | 0.724** | 0.609** | | | | | | | | |
| | Non-In | 0.492** | 0.484** | 0.627** | | | | | | | | |
| X5 | In | 0.598** | 0.757** | 0.615** | 0.784** | | | | | | | |
| | Non-In | 0.553** | 0.576** | 0.602** | 0.563** | | | | | | | |
| X6 | In | 0.663** | 0.544** | 0.444** | 0.564** | 0.537** | | | | | | |
| | Non-In | 0.448** | 0.392* | 0.415* | 0.555** | 0.615** | | | | | | |
| X7 | In | 0.508** | 0.614** | 0.590** | 0.786** | 0.676** | 0.402* | | | | | |
| | Non-In | 0.688** | 0.467** | 0.668** | 0.566** | 0.494** | 0.381* | | | | | |
| X8 | In | 0.728** | 0.638** | 0.647** | 0.686** | 0.686** | 0.545** | 0.602** | | | | |
| | Non-In | 0.762** | 0.565** | 0.506** | 0.528** | 0.654** | 0.335* | 0.645** | | | | |
| X9 | In | 0.743** | 0.819** | 0.708** | 0.679** | 0.747** | 0.457** | 0.553** | 0.727** | | | |
| | Non-In | 0.680** | 0.701** | 0.642** | 0.711** | 0.721** | 0.538** | 0.533** | 0.758** | | | |
| X10 | In | 0.594** | 0.580** | 0.468** | 0.599** | 0.576** | 0.510** | 0.579** | 0.527** | 0.500** | | |
| | Non-In | 0.533** | 0.484** | 0.448** | 0.602** | 0.533** | 0.503** | 0.601** | 0.490** | 0.554** | | |
| X11 | In | 0.406* | 0.473** | 0.179ns | 0.517** | 0.493** | 0.424* | 0.386* | 0.146ns | 0.283ns | 0.415* | |
| | Non-In | 0.370* | 0.278ns | 0.486** | 0.658** | 0.564** | 0.713** | 0.468** | 0.421* | 0.492** | 0.491** | |
| Y | In | 0.625** | 0.721** | 0.601** | 0.998** | 0.789** | 0.533** | 0.782** | 0.668** | 0.678** | 0.594** | 0.515** |
| | Non-In | 0.468** | 0.466** | 0.620** | 0.993** | 0.554** | 0.525** | 0.556** | 0.510** | 0.689** | 0.601** | 0.655** |

* and **: Significant at 5%, 1% level of probability. ns: not significant.
X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grains/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, X11: leaves area, and Y: grain yield.

Table 3: Path coefficient (direct and indirect effects) of the measured variables attributed on grain yield variation of wheat in inoculation condition and different water levels.

| Variables | Effects via | | | | | | | | | | | Direct effect | Indirect effect | Y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | X11 | | | |
| X1 | ***−0.028*** | −0.005 | −0.004 | 0.664 | 0.019 | −0.023 | −0.007 | −0.02 | 0.019 | 0.007 | −0.002 | ***−0.028*** | **0.653** | 0.625 |
| X2 | −0.018 | ***−0.007*** | −0.004 | 0.741 | 0.024 | −0.019 | −0.009 | −0.018 | 0.021 | 0.007 | −0.002 | ***−0.007*** | **0.728** | 0.721 |
| X3 | −0.016 | −0.004 | ***−0.006*** | 0.623 | 0.019 | −0.016 | −0.009 | −0.018 | 0.018 | 0.006 | −0.001 | ***−0.006*** | **0.607** | 0.601 |
| X4 | −0.019 | −0.005 | −0.004 | ***1.023*** | 0.025 | −0.02 | −0.011 | −0.019 | 0.017 | 0.007 | −0.003 | ***1.023*** | **−0.025** | 0.998 |
| X5 | −0.017 | −0.005 | −0.004 | 0.802 | ***0.032*** | −0.019 | −0.01 | −0.019 | 0.019 | 0.007 | −0.003 | ***0.032*** | **0.756** | 0.788 |
| X6 | −0.019 | −0.004 | −0.003 | 0.577 | 0.017 | ***−0.035*** | −0.006 | −0.015 | 0.011 | 0.006 | −0.002 | ***−0.035*** | **0.567** | 0.532 |
| X7 | −0.015 | −0.004 | −0.004 | 0.804 | 0.021 | −0.014 | ***−0.014*** | −0.017 | 0.014 | 0.007 | −0.002 | ***−0.014*** | **0.796** | 0.782 |
| X8 | −0.021 | −0.005 | −0.004 | 0.702 | 0.022 | −0.019 | −0.009 | ***−0.027*** | 0.018 | 0.006 | −0.001 | ***−0.027*** | **0.694** | 0.667 |
| X9 | −0.021 | −0.006 | −0.005 | 0.695 | 0.024 | −0.016 | −0.008 | −0.020 | ***0.025*** | 0.006 | −0.002 | ***0.025*** | **0.652** | 0.677 |
| X10 | −0.017 | −0.004 | −0.003 | 0.613 | 0.018 | −0.018 | −0.008 | −0.015 | 0.012 | ***0.013*** | −0.002 | ***0.013*** | **0.580** | 0.593 |
| X11 | −0.012 | −0.004 | −0.002 | 0.529 | 0.016 | −0.015 | −0.006 | −0.004 | 0.007 | 0.005 | ***−0.005*** | ***−0.005*** | **0.519** | 0.514 |

X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grains/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, and X11: leaves area.

where, Y is grain yield, X4 is the spike weight/plant, X5 is the grains/spike, X6 is the grain weight/spike, and X8 is the total chlorophyll contents of the flag leaves.

*Final Model under Noninoculated Condition*

$$Y = -0.19463 + 0.9767X4 + 0.01208X5 - 1.54441X6 - 0.00407X8 - 0.01094X9 + 0.09707X10 + 0.00505X11, \quad (7)$$

where, Y is grain yield, X4 is the spike weight/plant, X5 is the grains/spike, X6 is the grain weight/spike, X8 is the total chlorophyll contents of the flag leaves, X9 is the biological yield, X10 is the root weight, and X11 is the leaf area.

*3.5. Factor Analysis.* The first two of the twelve factors accounted for 59.2% and 60.1% of the total variations of the inoculated and noninoculated conditions, respectively (Table 8). The first factor was included for yield and spike weight/plant for both conditions, and it could explain 47.6% and 49.5% of the total variations in the dependent structure for the inoculated and noninoculated conditions, respectively; therefore, it can be named as grain yield factor. The

Table 4: Path coefficient (direct and indirect effects) of the measured variables attributed on grain yield variation of wheat in noninoculation condition and different water levels.

| Variables | Effects via | | | | | | | | | | | Direct effect | Indirect effect | Y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | X11 | | | |
| X1 | ***−0.004*** | −0.003 | 0.000 | 0.503 | 0.018 | −0.03 | −0.006 | −0.017 | −0.019 | 0.01 | 0.01 | ***−0.004*** | **0.471** | 0.467 |
| X2 | −0.002 | ***−0.004*** | 0.000 | 0.495 | 0.018 | −0.026 | −0.004 | −0.013 | −0.019 | 0.009 | 0.007 | ***−0.004*** | **0.469** | 0.465 |
| X3 | −0.002 | −0.002 | ***0.001*** | 0.641 | 0.019 | −0.028 | −0.006 | −0.012 | −0.018 | 0.009 | 0.013 | ***0.001*** | **0.620** | 0.621 |
| X4 | −0.002 | −0.002 | 0.000 | ***1.013*** | 0.018 | −0.037 | −0.005 | −0.012 | −0.019 | 0.012 | 0.018 | ***1.013*** | **−0.02** | 0.993 |
| X5 | −0.002 | −0.003 | 0.000 | 0.576 | ***0.032*** | −0.041 | −0.004 | −0.015 | −0.02 | 0.01 | 0.016 | ***0.032*** | **0.522** | 0.554 |
| X6 | −0.002 | −0.002 | 0.000 | 0.567 | 0.02 | ***−0.067*** | −0.003 | −0.008 | −0.015 | 0.01 | 0.02 | ***−0.067*** | **0.591** | 0.524 |
| X7 | −0.003 | −0.002 | 0.000 | 0.579 | 0.016 | −0.026 | ***−0.008*** | −0.015 | −0.015 | 0.012 | 0.013 | ***−0.008*** | **0.563** | 0.555 |
| X8 | −0.003 | −0.002 | 0.000 | 0.54 | 0.021 | −0.023 | −0.006 | ***−0.023*** | −0.021 | 0.009 | 0.011 | ***−0.023*** | **0.532** | 0.509 |
| X9 | −0.003 | −0.003 | 0.000 | 0.727 | 0.023 | −0.036 | −0.005 | −0.017 | ***−0.027*** | 0.011 | 0.013 | ***−0.027*** | **0.716** | 0.689 |
| X10 | −0.002 | −0.002 | 0.000 | 0.616 | 0.017 | −0.034 | −0.005 | −0.011 | −0.015 | ***0.020*** | 0.013 | ***0.020*** | **0.581** | 0.601 |
| X11 | −0.002 | −0.001 | 0.000 | 0.673 | 0.018 | −0.048 | −0.004 | −0.01 | −0.014 | 0.009 | ***0.028*** | ***0.028*** | **0.626** | 0.654 |

X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grains/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, and X11: leaves area.

Table 5: The regression coefficient ($B$), standard error (SE), $T$ value, and probability of the estimated variables in predicting wheat grain yield by the multiple linear regression analysis under inoculation (In) and noninoculation (non-In) conditions and different water levels.

| Predictor | | DF | $B$ | SE | $T$ | $P$ |
|---|---|---|---|---|---|---|
| Constant | In | 1 | 0.5394 | 0.49180 | 1.10 | 0.284 |
| | Non-In | 1 | −0.0893 | 0.20870 | −0.43 | 0.672 |
| X1 | In | 1 | −0.1164 | 0.08245 | −1.41 | 0.171 |
| | Non-In | 1 | −0.0061 | 0.04145 | −0.15 | 0.884 |
| X2 | In | 1 | −0.0202 | 0.05014 | −0.40 | 0.691 |
| | Non-In | 1 | −0.0103 | 0.02030 | −0.51 | 0.618 |
| X3 | In | 1 | −0.0082 | 0.02037 | −0.40 | 0.693 |
| | Non-In | 1 | 0.0032 | 0.01477 | 0.22 | 0.830 |
| X4 | In | 1 | 0.9617 | 0.01927 | 49.90 | 0.001 |
| | Non-In | 1 | 0.9780 | 0.01041 | 93.96 | 0.001 |
| X5 | In | 1 | 0.0110 | 0.00699 | 1.56 | 0.131 |
| | Non-In | 1 | 0.0120 | 0.00389 | 3.07 | 0.005 |
| X6 | In | 1 | −0.7802 | 0.34490 | −2.26 | 0.033 |
| | Non-In | 1 | −1.5139 | 0.24110 | −6.28 | 0.001 |
| X7 | In | 1 | −0.0070 | 0.00979 | −0.71 | 0.483 |
| | Non-In | 1 | −0.0045 | 0.00538 | −0.84 | 0.411 |
| X8 | In | 1 | −0.0042 | 0.00318 | −1.33 | 0.196 |
| | Non-In | 1 | −0.0032 | 0.00196 | −1.61 | 0.120 |
| X9 | In | 1 | 0.0131 | 0.01165 | 1.12 | 0.273 |
| | Non-In | 1 | −0.0109 | 0.00541 | −2.01 | 0.056 |
| X10 | In | 1 | 0.0840 | 0.09246 | 0.91 | 0.373 |
| | Non-In | 1 | 0.1195 | 0.05402 | 2.21 | 0.037 |
| X11 | In | 1 | −0.0008 | 0.00318 | −0.25 | 0.803 |
| | Non-In | 1 | 0.0049 | 0.00177 | 2.74 | 0.011 |

X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grains/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, and X11: leaves area.

second factor included spike length and biological yield for the inoculated condition which accounted for 11.6% of the total variability in the dependent structure, and it was considered as the spike length (Table 9). Under the noninoculated condition, the second factor accounted for 10.6% of the total variability and was consisted of total chlorophyll content of the flag leaf; therefore it could be named as total chlorophyll factor. The first two factors of the inoculated and noninoculated conditions are graphically depicted in Figures 1(a) and 1(b).

Table 6: Relative contribution (partial and model $R^2$), $F$ value, and probability in predicting wheat grain yield by the stepwise procedure analysis under inoculation condition and different water levels.

| Step | Variables entered | Variable removed | Partial $R^2$ | Model $R^2$ | $P$ value ER | Parameter estimate | Standard error | $P$ value $M$ |
|---|---|---|---|---|---|---|---|---|
| 1 | $x4$ | — | 0.9957 | 0.9957 | <.0001 | 0.95104 | 0.01458 | <.0001 |
| 2 | $x6$ | — | 0.0012 | 0.9969 | 0.0009 | −0.99926 | 0.27170 | 0.0009 |
| 3 | $x5$ | — | 0.0003 | 0.9972 | 0.0809 | 0.01332 | 0.00549 | 0.0212 |
| 4 | $x8$ | — | 0.0003 | 0.9975 | 0.0445 | −0.00472 | 0.00225 | 0.0445 |

X4: spike weight/plant, X5: grains/spike, X6: grain weight/spike and X8: total chlorophyll content of flag leaf.
$R^2$ : coefficient of determination, $P$ value ER: $P$ value for entered or removed variables, and $P$ value $M$: $P$ value for final model.

Table 7: Relative contribution (partial and model $R^2$), $F$ value, and probability in predicting wheat grain yield by the stepwise procedure analysis under noninoculation condition and different water levels.

| Step | Variables entered | Variable removed | Partial $R^2$ | Model $R^2$ | $P$ value ER | Parameter estimate | Standard error | $P$ value $M$ |
|---|---|---|---|---|---|---|---|---|
| 1 | $x4$ | — | 0.9963 | 0.9963 | <.0001 | 0.9767 | 0.00947 | <.0001 |
| 2 | $x6$ | — | 0.0013 | 0.9975 | 0.0002 | −1.54441 | 0.21063 | <.0001 |
| 3 | $x9$ | — | 0.0005 | 0.998 | 0.0088 | −0.01094 | 0.00460 | 0.0245 |
| 4 | $x5$ | — | 0.0004 | 0.9985 | 0.0060 | 0.01208 | 0.00342 | 0.0014 |
| 5 | $x11$ | — | 0.0002 | 0.9987 | 0.0261 | 0.00505 | 0.0016 | 0.0038 |
| 6 | $x8$ | — | 0.0002 | 0.9989 | 0.0169 | −0.00407 | 0.00138 | 0.0064 |
| 7 | $x10$ | — | 0.0001 | 0.9991 | 0.0475 | 0.09707 | 0.04682 | 0.0475 |

X4: spike weight/plant, X5: grains/spike, X6: grain weight/spike, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, and X11: leaves area.
$R^2$: coefficient of determination, $P$ value ER: $P$ value for entered or removed variables, and $P$ value $M$: $P$ value for final model.

*3.6. Principal Component.* The data presented in Table 10 and Figures 2(a) and 2(b) demonstrated that the increase in the number of components was associated with a decrease in eigenvalues. According to the results, the estimated wheat variables grouped into two main components that accounted for 72.4% and 70.3% of the total variations of the grain yields for the inoculated and noninoculated conditions, respectively. PC1 was moderately correlated with spike length ($r = -0.311$), spike weight/plant ($r = -0.33$), grains/spike ($r = -0.316$), biological yield ($r = -0.305$), and grain yield ($r = -0.325$) in the inoculated plants and with spike weight/plant ($r = -0.315$), biological yield ($r = -0.324$), and yield ($r = -0.309$) under the noninoculated condition. PC2 for the inoculated condition was moderately correlated with spikelets/spike ($r = -0.373$) and total chlorophyll content ($r = -0.371$), while it was highly correlated with the leaf area ($r = 0.737$). In the noninoculated plants PC2 was moderately correlated with the spike length ($r = -0.329$), grain weight/spike ($r = 0.382$), total chlorophyll ($r = -0.355$), leaf area ($r = 0.477$), and yield ($r = 0.307$). PC1 accounted for about 63.5% and 60% of the variations in the grain yields; while PC2 explained 8.9% and 10.3% of the variations in the grain yields under the inoculated and noninoculated conditions, respectively. The first two components and their contributions in the variables for both conditions are graphically presented in Figures 3(a) and 3(b).

*3.7. Cluster Analysis.* Hierarchical cluster analysis showed the similarity distance ranged between 72%–86% under the inoculated condition and 65%–82% under the noninoculated condition. The examined variables of wheat cultivars could be agglomerated into four and three clusters, respectively (Figures 4(a) and 4(b)). As the important variables affecting wheat grain yield, spike weight/plant, and 100-grain yield under the inoculated condition and the spike weight/plant, grain weight/spike, and the leaf area under the noninoculated condition were grouped together with the wheat grain yield into the third cluster.

Tables 11(a) and 11(b) outline the overall results of determining the most important variables affecting wheat grain yield for separately inoculated and noninoculated conditions.

## 4. Discussion

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- and high-yielding crop plants (ideotype). The knowledge of association and relationship between grain yield and its components under water deficit conditions would improve the efficiency of breeding programs by identifying appropriate indices to select wheat cultivars [27]. Because of wide variations in grain yield under normal and water stress conditions, simulating performance of wheat under soil moisture deficit represents special challenges for wheat modelers [28]. The results of the present study showed that spike weight/plant had the highest positive correlation with grain yield of wheat genotypes under both inoculated and noninoculated conditions. As well as spike weight/plant, other variables showed high positive correlations with yield. Based on the correlation coefficient analysis, all the variables had a high contribution with the wheat grain yield, but spike weight/plant was the most effective variable for both conditions. Moghaddam et al. [8]

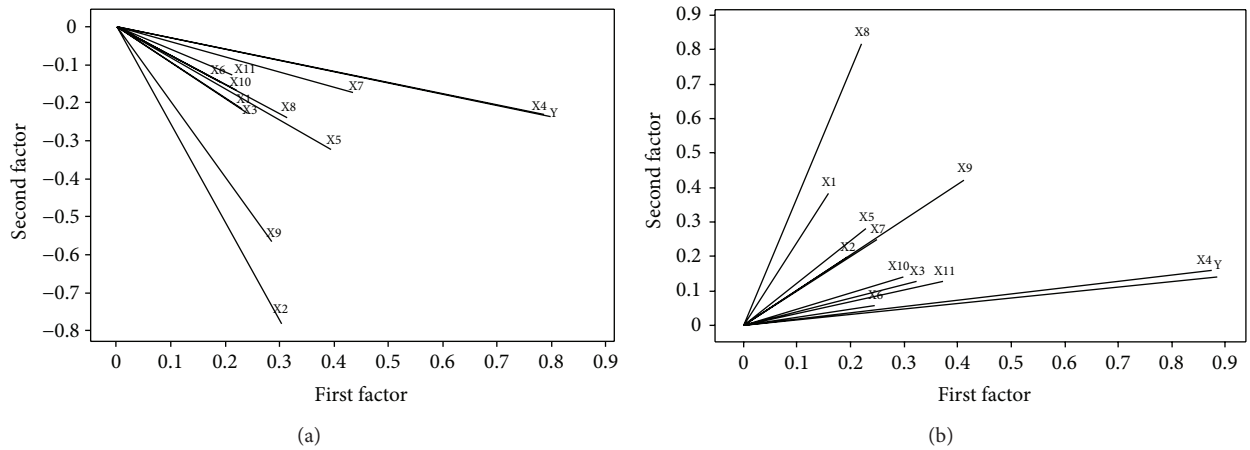


Figure 1: (a) Variables loading by factor analysis and varimax rotation with first two factors under inoculation condition and different water levels. X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grain number/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, X11: leaves area, and Y: grain yield. (b) Variables loading by factor analysis and varimax rotation with first two factors under noninoculation condition and different water levels. X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grain number/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, X11: leaves area, and Y: grain yield.

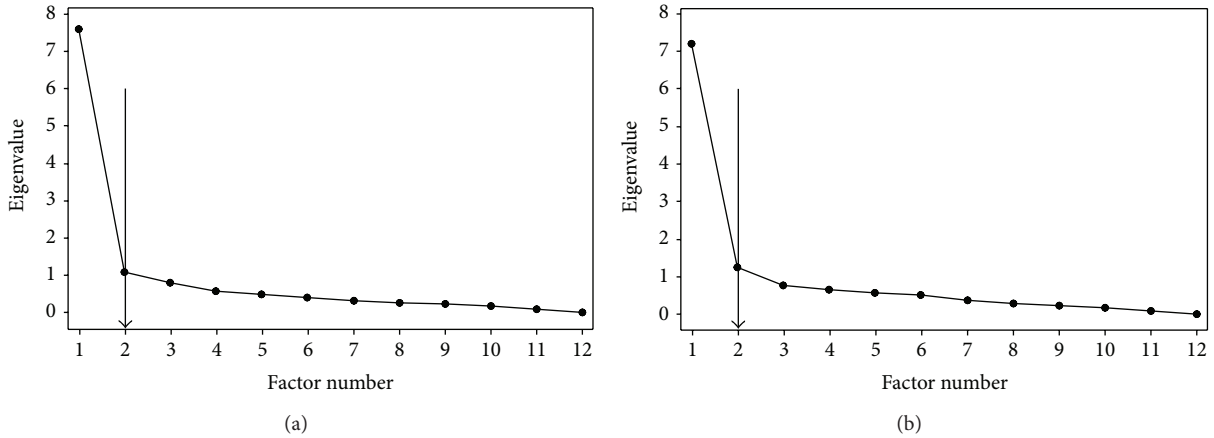


Figure 2: (a) Scree plot showing eigenvalues in response to the number of components for the estimated variables of wheat under inoculation condition and different water levels. (b) Scree plot showing eigenvalues in response to the number of components for the estimated variables of wheat under noninoculatin condition and different water level.

showed a negative correlation between the plant height and the grain yield. These investigators [8] attributed that increase in stem height caused the lower number of grains/spike. Kumbhar et al. [7] and Mohamed [29] had shown that grain weight/spike, biological yield, and the number of spikes were closely related to grain yield. In the study of Leilah and Al-Khateeb [9] grain yield had a high positive correlation with the number of spikes, number of grains/spike, 100-grain weight, weight of grains/spike, and the biological yield. In the study of Heidari et al. [1], grain yield was correlated positively with each of the biological yield, spikes/$m^2$, harvest index, and the grain weight/spike, while there was no correlation between the grain yield and the heading date or maturity. The differential relations of yield components to the grain yield may be attributed to environmental effects on plant growth [9, 30].

Since simple correlation coefficient can only determine the linear relationship between two related variables, but it cannot show how multiple variables are related to one another contributing to dependent variable (yield); path analysis was used for dividing the correlation coefficient of variables with yield into their direct and indirect effects via other variables. Spike weight/plant had the highest direct effect on grain yield under either condition. Path analysis shows that direct effect of biological yield, under inoculation condition, is positive, while, under noninoculated condition, it is negative, which is probably due to the effect of AM symbiosis on higher uptake of nutrient elements. The results also show that biological yield of the inoculated plants is significantly higher than those in noninoculated ones. Higher biological yield, under noninoculated condition, causes more consumption of plant energy and nutrient elements for more vegetative growth,

Table 8: Rotated (Varimax rotation) factor loadings and communalities for the estimated variables of wheat based on factor analysis technique for inoculation and noninoculation conditions and different water levels.

| Variables | Inoculation | | Communality | Noninoculation | | Communality |
|---|---|---|---|---|---|---|
| | Factor 1 | Factor 2 | | Factor 1 | Factor 2 | |
| X1 | 0.230 | −0.216 | 0.014 | 0.159 | 0.384 | 0.543 |
| X2 | 0.303 | −0.782 | −0.479 | 0.194 | 0.196 | 0.390 |
| X3 | 0.240 | −0.229 | 0.011 | 0.324 | 0.127 | 0.451 |
| X4 | 0.788 | −0.230 | 0.558 | 0.875 | 0.157 | 1.032 |
| X5 | 0.395 | −0.324 | 0.071 | 0.230 | 0.280 | 0.510 |
| X6 | 0.192 | −0.146 | 0.046 | 0.246 | 0.056 | 0.302 |
| X7 | 0.434 | −0.174 | 0.260 | 0.250 | 0.247 | 0.497 |
| X8 | 0.313 | −0.239 | 0.074 | 0.220 | 0.817 | 1.037 |
| X9 | 0.286 | −0.566 | −0.280 | 0.411 | 0.421 | 0.832 |
| X10 | 0.222 | −0.167 | 0.055 | 0.299 | 0.138 | 0.437 |
| X11 | 0.213 | −0.126 | 0.087 | 0.374 | 0.126 | 0.500 |
| Y | 0.800 | −0.235 | 0.565 | 0.885 | 0.140 | 1.025 |
| Latent roots | 2.118 | 1.397 | 3.514 | 2.338 | 1.268 | 3.606 |
| Factor variance (%) | 47.60 | 11.60 | 59.20 | 49.50 | 10.60 | 60.10 |

X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grains/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, X11: leaves area, and Y: grain yield.

Table 9: Summary of factors loading for the estimated variables of wheat with mycorrhiza inoculation or noninoculation under different water levels.

| | Characters | | Loading | % total communality | Factor name | Characters | | Loading | % total communality | Factor name |
|---|---|---|---|---|---|---|---|---|---|---|
| Inoculation | Factor 1 | | 2.120 | 47.60% | Yield | Factor 2 | | 1.397 | 11.60% | Spike length |
| | | X4 | 0.788 | | | | X2 | −0.782 | | |
| | | Y | 0.800 | | | | X9 | −0.566 | | |
| Noninoculation | Factor 1 | | 2.340 | 49.50% | Yield | Factor 2 | | 1.268 | 10.60% | Ch T flag |
| | | X4 | 0.875 | | | | X8 | 0.817 | | |
| | | Y | 0.885 | | | | — | — | | |

X2: spike length, X4: spike weight/plant, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, and Y: grain yield.

resulting in decreasing grain yield, but inoculation of the mycorrhizal fungus compensated this problem by higher nutrient elements uptake from the soil. Based on the path coefficient analysis of wheat grain yield, Kumbhar et al. [7], Mohamed [29], and Leilah and Al-Khateeb [9] reported that the biological yield, harvest index, grains weight/spike, number of spikes/$m^2$, and 100-grain weight have the greatest impact in relation to the wheat grain yield. In the study of Heidari et al. [1], number of grains/spike had the largest direct and positive effect on the grain yield.

Linear regression analysis revealed that spike weight/plant and grain weight/spike are variables that significantly contributed in grain yield for both conditions, while the grains/spike, leaves area, and root weight were significant only for the noninoculated condition, so, these are variables determined as the most effective variables contributing to the grain yield by this statistical method. These results show that inoculation can affect relationship between the traits, and it can be useful for the breeding programs. Results of this study for regression analysis, under the noninoculated condition, are relative similar to the other studies such as Kumbhar et al. [7] and Leilah and Al-Khateeb [9] which showed that spike length, number of spikes/$m^2$, grain weights/spike, and the biological yield have contributed significantly to the grain yield. Asseng et al. [30] reported that increased kernel number had improved the potential yield of wheat under certain environmental conditions limited by water supply.

Stepwise regression analysis is a multiple statistical method that can screen or select the most important variables through a dependent variable such as the grain yield. Based on this method, spike weight/plant, number of grains/spike, grain weight/spike, and total chlorophyll content of the flag leaf are the most important variables contributing to the yield under the inoculated condition. Under the noninoculated condition, in addition to the four mentioned variables for the inoculated condition, three other variables, including the biological yield, root weight, and the leaves area are important. Relatively differences between the selected models by stepwise regression for the inoculated and noninoculated conditions show effectiveness of the root colonization on

Table 10: (a) Eigenvalues and the correlation matrix for the estimated variables of wheat using principal component procedure for inoculated wheat cultivars under different water levels. (b) Eigenvalues and the correlation matrix for the estimated variables of wheat using principal component procedure for noninoculated wheat cultivars under different water levels.

(a)

| Variables | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 | PC9 | PC10 | PC11 | PC12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X1 | −0.293 | −0.092 | −0.452 | −0.003 | −0.018 | −0.290 | −0.573 | 0.035 | −0.080 | 0.271 | −0.455 | 0.020 |
| X2 | −0.311 | −0.011 | 0.003 | −0.397 | 0.243 | −0.005 | 0.373 | 0.420 | −0.313 | −0.345 | −0.392 | 0.006 |
| X3 | −0.271 | −0.373 | 0.087 | −0.061 | 0.116 | 0.771 | −0.285 | −0.096 | 0.228 | −0.125 | −0.095 | 0.004 |
| X4 | −0.33 | 0.132 | 0.260 | 0.104 | −0.295 | −0.113 | −0.045 | 0.270 | 0.327 | −0.034 | −0.021 | −0.716 |
| X5 | −0.316 | 0.041 | 0.145 | −0.202 | −0.010 | −0.051 | 0.426 | −0.622 | 0.137 | 0.409 | −0.281 | −0.021 |
| X6 | −0.248 | 0.138 | −0.614 | 0.190 | −0.418 | 0.352 | 0.358 | 0.125 | −0.113 | 0.126 | 0.188 | 0.023 |
| X7 | −0.287 | 0.055 | 0.440 | 0.359 | −0.035 | 0.111 | −0.135 | −0.027 | −0.716 | 0.202 | 0.080 | 0.010 |
| X8 | −0.294 | −0.371 | −0.103 | 0.164 | −0.194 | −0.329 | 0.025 | −0.408 | −0.081 | −0.626 | 0.162 | 0.018 |
| X9 | −0.305 | −0.297 | −0.036 | −0.439 | 0.186 | −0.173 | −0.050 | 0.153 | −0.012 | 0.314 | 0.660 | −0.019 |
| X10 | −0.262 | 0.151 | −0.152 | 0.537 | 0.716 | −0.070 | 0.138 | 0.028 | 0.228 | −0.006 | 0.087 | −0.009 |
| X11 | −0.191 | 0.737 | −0.074 | −0.327 | 0.075 | 0.104 | −0.314 | −0.273 | −0.050 | −0.276 | 0.198 | 0.003 |
| Y | −0.327 | 0.136 | 0.298 | 0.085 | −0.273 | −0.125 | −0.027 | 0.268 | 0.362 | −0.008 | −0.006 | 0.697 |
| Eigenvalue | 7.620 | 1.072 | 0.805 | 0.574 | 0.481 | 0.390 | 0.326 | 0.248 | 0.236 | 0.167 | 0.080 | 0.001 |
| Proportion | 0.635 | 0.089 | 0.067 | 0.048 | 0.04 | 0.032 | 0.027 | 0.021 | 0.02 | 0.014 | 0.007 | 0.000 |
| Cumulative | 0.635 | 0.724 | 0.791 | 0.839 | 0.879 | 0.912 | 0.939 | 0.96 | 0.979 | 0.993 | 1.000 | 1.000 |

X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: Spike weight/plant, X5: grains/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, X11: leaves area, and Y: grain yield.

(b)

| Variable | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 | PC9 | PC10 | PC11 | PC12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X1 | −0.290 | −0.379 | 0.041 | −0.261 | 0.056 | −0.044 | −0.481 | 0.345 | 0.221 | 0.440 | −0.323 | 0.001 |
| X2 | −0.264 | −0.329 | 0.198 | 0.407 | −0.235 | 0.435 | −0.178 | −0.560 | −0.062 | 0.146 | 0.043 | 0.003 |
| X3 | −0.290 | −0.101 | −0.217 | 0.048 | 0.532 | 0.499 | 0.211 | 0.211 | 0.339 | −0.111 | 0.329 | −0.001 |
| X4 | −0.315 | 0.296 | −0.358 | 0.288 | −0.054 | −0.118 | −0.119 | 0.085 | −0.161 | 0.161 | 0.041 | −0.715 |
| X5 | −0.298 | −0.015 | 0.428 | 0.089 | 0.124 | −0.074 | 0.664 | 0.145 | −0.249 | 0.348 | −0.230 | −0.024 |
| X6 | −0.255 | 0.382 | 0.526 | −0.183 | −0.004 | 0.196 | −0.370 | 0.24 | −0.324 | −0.159 | 0.338 | 0.047 |
| X7 | −0.284 | −0.184 | −0.350 | −0.519 | 0.110 | 0.117 | 0.058 | −0.250 | −0.550 | −0.240 | −0.208 | 0.006 |
| X8 | −0.290 | −0.355 | 0.056 | −0.076 | 0.037 | −0.623 | 0.035 | −0.167 | 0.044 | −0.026 | 0.601 | 0.015 |
| X9 | −0.324 | −0.135 | 0.128 | 0.348 | −0.028 | −0.197 | −0.055 | 0.180 | 0.122 | −0.703 | −0.393 | 0.020 |
| X10 | −0.274 | 0.068 | −0.095 | −0.312 | −0.752 | 0.169 | 0.295 | 0.137 | 0.319 | −0.062 | 0.094 | −0.014 |
| X11 | −0.263 | 0.477 | 0.145 | −0.247 | 0.241 | −0.135 | −0.035 | −0.539 | 0.449 | 0.029 | −0.223 | −0.020 |
| Y | −0.309 | 0.307 | −0.390 | 0.292 | −0.058 | −0.120 | −0.068 | 0.066 | −0.131 | 0.209 | 0.007 | 0.697 |
| Eigenvalue | 7.200 | 1.231 | 0.764 | 0.661 | 0.550 | 0.501 | 0.360 | 0.267 | 0.210 | 0.166 | 0.088 | 0.000 |
| Proportion | 0.600 | 0.103 | 0.064 | 0.055 | 0.046 | 0.042 | 0.030 | 0.022 | 0.017 | 0.014 | 0.007 | 0.000 |
| Cumulative | 0.600 | 0.703 | 0.766 | 0.821 | 0.867 | 0.909 | 0.939 | 0.961 | 0.979 | 0.993 | 1.000 | 1.000 |

X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grains/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, X11: leaves area, and Y: grain yield.

interrelationship of the variables. Leilah and Al-Khateeb [9] reported that the weight of grains/spike, harvest index, biological yield, number of spikes/$m^2$, and lastly spike length can explain 98.1% of the grain yield variations of wheat. Also, Mohamed [29] found that spike length, spike number, grain numbers/spike, spike weight, and straw yield are associated significantly with wheat grain yield. Heidari et al. [1] showed that the most important components for grain yield based on this method are grain weight/spike, spikes/$m^2$, and spikelets/spike.

Factor analysis showed that spike weight/plant under both inoculated and noninoculated conditions, spike length, and biological yield for the inoculated condition, and total chlorophyll content of the flag leaf for the noninoculated condition had the highest relative contribution to wheat grain yield (Table 9). Such results can be recognized by means

Table 11: (a) Wheat characteristics identified as crucial in wheat grain yield with each one of the used statistical techniques under inoculation condition and different water levels. (b) Wheat characteristics identified as crucial in wheat grain yield with each one of the used statistical techniques under noninoculation condition and different water levels.

(a)

| Variables | *R* | Reg | Step | FA | PC | Path | Cluster | Total score |
|---|---|---|---|---|---|---|---|---|
| X1 | x | | | | | | | 1 |
| X2 | x | | | x | x | | | 3 |
| X3 | x | | | | x | | | 2 |
| X4 | x | x | x | x | x | x | x | 7 |
| X5 | x | | x | | x | | | 3 |
| X6 | x | x | x | | | | | 3 |
| X7 | x | | | | | | x | 2 |
| X8 | x | | x | x | x | | | 4 |
| X9 | x | | | | x | | | 2 |
| X10 | x | | | | | | | 1 |
| X11 | x | | | | x | | | 2 |

X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grains/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, X11: leaves area and Y: grain yield.
*R*: correlation analysis, Reg: multiple linear regression, Step: stepwise multiple regression, FA: factor analysis, PC: principal component analysis, path: path coefficient analysis, and cluster: cluster analysis.

(b)

| Variables | *R* | Reg | Step | FA | PC | Path | Cluster | Total score |
|---|---|---|---|---|---|---|---|---|
| *X*1 | x | | | | x | | | 2 |
| *X*2 | x | | | | x | | | 2 |
| *X*3 | x | | | | | | | 1 |
| *X*4 | x | x | x | x | x | x | x | 7 |
| *X*5 | x | x | x | | | | | 3 |
| *X*6 | x | x | x | | x | | x | 5 |
| *X*7 | x | | | | | | | 1 |
| *X*8 | x | | x | x | x | | | 4 |
| *X*9 | x | | x | | x | | | 3 |
| *X*10 | x | x | x | | | | | 3 |
| *X*11 | x | x | x | | x | | x | 5 |

*X*1 = Tiller numbers/plant, *X*2 = Spike length, *X*3 = Spikelets/spike, *X*4 = Spike weight/plant, *X*5 = Grains/spike, *X*6 = Grain weight/spike, *X*7 = 100 − Grain weight, *X*8 = Total chlorophyll content of flag leaf, *X*9 = Biological yield/plant, *X*10 = Root weight, *X*11 = Leaves area, Y = Grain yield.
*R* = Correlation analysis, Reg = Multiple linear regression, Step = Stepwise multiple regression, FA = Factor analysis, PC = Principal component analysis, Path = Path coefficient analysis, and Cluster = Cluster analysis.

of Figures 2(a) and 2(b). Similar results were obtained by Mohamed [29] who stated that factor analysis had classified the ten wheat variables into two main groups which accounted for 80.79% of the total variability in the dependence structure. Leilah and Al-Khateeb [9] showed that biological yield, harvest index, weight of grains/spike, spike length, and number of spikes/$m^2$ had a high relative contribution to wheat grain yield.

Results of the principal component analysis revealed that, under the inoculated condition, spike length, spike weight/plant, grains/spike, biological yield, number of spikelets/spike, and total chlorophyll are important variables affecting grain yield, and under the noninoculated condition, spike length, spike weight/plant, biological yield, grain weight/spike, total chlorophyll, and leaves area are the most important factors. Harvest index, biological yield, spike diameter, number of spikes/$m^2$, spike length, grain weights/spike, and 100-grain weight in the study of Leilah and Al-Khateeb [9] were the most important factors in contributing to the yield. Also, Yin et al. [31] stated that the grain yield was divided into three components, namely, number of spikes/$m^2$, number of kernels/spike, and 1000-kernel weight.

Hierarchical cluster analysis showed that, under the inoculated condition, grain yield, spike weight/plant, and 100-grain yield are highly important variables for contributing to yield, while, under the noninoculated condition grain yield, spike weight/plant, grain weight/spike, and leaves area are highly important variables. Hierarchical cluster analysis method starts with the calculation of the distance of each variable in relation to other variables. Groups are then formed by the process of agglomeration division. In this process, all variables start individually in groups of one. The close groups are then gradually merged until finally all variables come to a single group. Repeated splitting of the groups will result in all

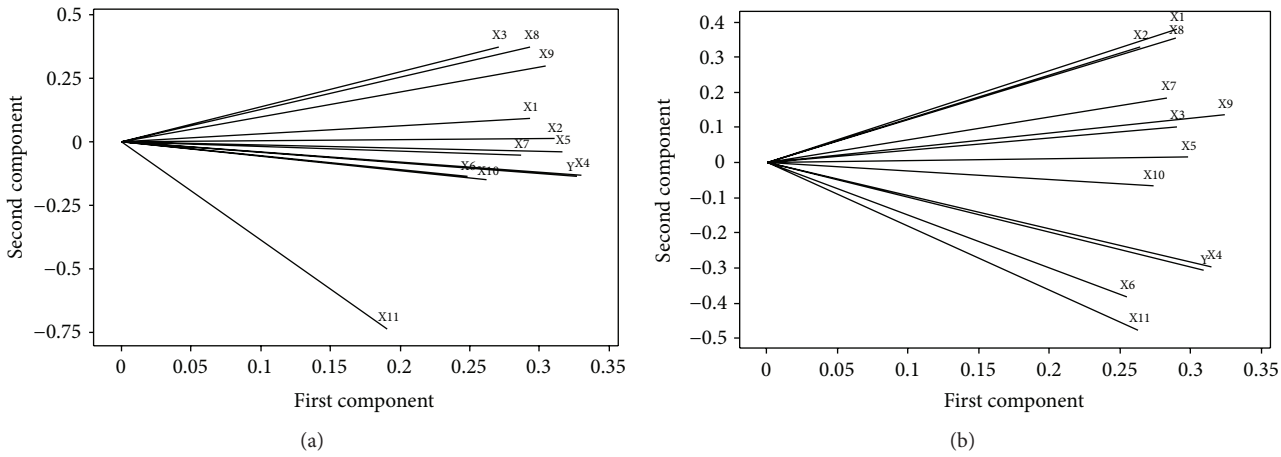


Figure 3: (a) Variables loading by principal component analysis with first two components under inoculation condition and different water levels. X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grain number/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, X11: leaves area and Y: grain yield. (b) Variables loading by principal component analysis with first two components under noninoculation condition and different water levels. X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grain number/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, X11: leaves area and Y: grain yield.

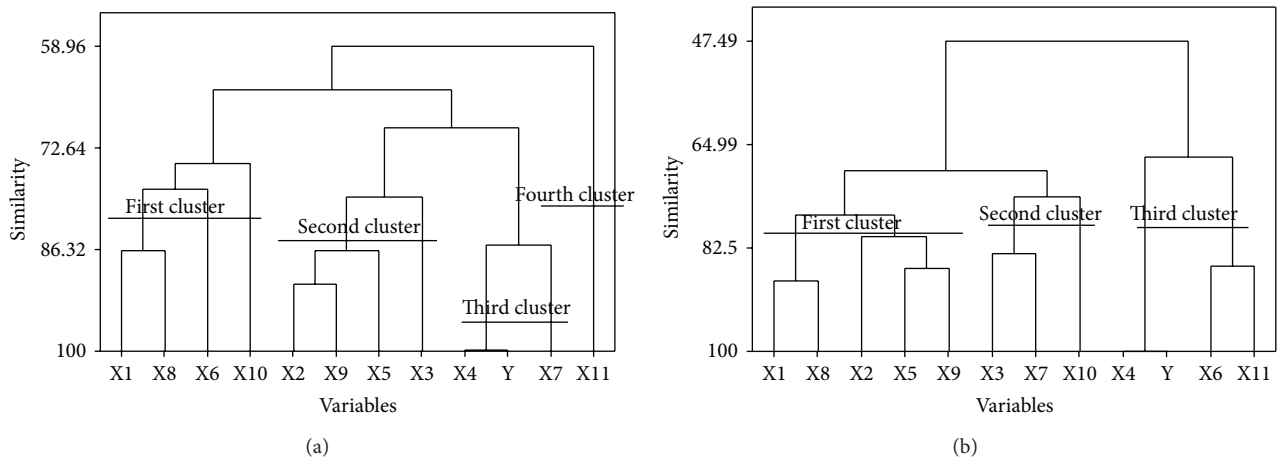


Figure 4: (a) Similarity levels of the estimated twelve wheat variables using the hierarchical cluster analysis under mycorrhizal inoculation and different water levels. X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grain number/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, X11: leaves area and Y: grain yield. (b) Similarity levels of the estimated twelve wheat variables using the hierarchical cluster analysis under noninoculation condition and different water levels. X1: tiller numbers/plant, X2: spike length, X3: spikelets/spike, X4: spike weight/plant, X5: grain number/spike, X6: grain weight/spike, X7: 100-grain weight, X8: total chlorophyll content of flag leaf, X9: biological yield/plant, X10: root weight, X11: leaves area and Y: grain yield.

the evaluated variables being in groups of their own. In the study of Leilah and Al-Khateeb [9] results proved that 100-grain weight, weight of grains/spike, harvest index, and the biological yield were the variables most closely related to the grain yield.

It has been well established that AM symbiosis protects host plants against negative effects of drought stress due to nutritional, physical, and cellular improvements [32]. In addition, the AM symbiosis increases host plant growth due to improved plant nutrient and water uptakes via external hyphae in inoculated roots [33]. The beneficial effects of different mycorrhizal fungi on plant growth, under drought conditions, have been demonstrated in wheat [34] and other plant species [35, 36]. Mouchesi et al. [37] showed higher production of yield and its related traits under inoculated condition in compare to noninoculated one due to higher uptake of nutrient elements and water by mycorrhizal roots.

## 5. Conclusions

The multiple statistical procedures which have been used in this study showed that, under water stress condition and mycorrhizal inoculation, spike weight/plant and total chlorophyll content of the flag leaf are the most important

variables contributing to wheat grain yield, while for the noninoculated condition, grain weight/spike and chlorophyll content of the flag leaf, grain weight/plant, and leaves area are also important. Therefore, spike weight per plant and chlorophyll content of the flag leaf can be used as selection criteria in the breeding programs for both the inoculated and the noninoculated wheat cultivars under different water regimes, and also grain weight per spike and leaf area can be considered for the noninoculated condition. Furthermore, the results indicated that root inoculation with the mycorrhizal fungus changed the relationship among morphological traits of wheat cultivars under drought stress.

Overall, the results indicate that mycorrhizal symbiosis can relatively change the impact of important yield-related traits through production of wheat grain yield which is due to the effect of mycorrhizal symbiosis on water and nutrient elements uptakes by root. Also, plant breeders can consider fewer variables as selection criteria under mycorrhizal symbiosis than nonmycorrhizal condition to find higher yielding cultivars in their breeding programs.

Also, using different statistical techniques for determining important traits contributing to grain yield of wheat showed that simple correlation cannot distinguish important variables. On the other hand, since path analysis uses results of simple correlation, it is not suitable for using it in selecting important variables. Similar to the results of correlation and path analysis, cluster analysis and multiple regression analysis could not clearly distinguish important traits either. It seems that the results of stepwise regression as a selecting method together with principal component and factor analysis are stronger statistical methods to be applied in breeding programs for screening important traits.

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