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ANALYSIS OF SOME AGRONOMIC TRAITS OF DURUM WHEAT UNDER DRYLAND AND SUPPLEMENTAL IRRIGATION CONDITIONS

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Knowledge about the extent of variability and the association among traits are of a high value for any breeding efforts. The objective of this investigation is to evaluate the agro-morphological traits in a set of durum wheat genotypes under supplemental irrigation and dry land conditions. Results showed that principal component (PC) analysis had grouped the measured traits into four main components that altogether accounted for 77% of the total variation under non-stressed condition and 87% under water-stressed condition. With regard to the first four PCs, peduncle length, agronomic score, grain yield, vigority, test weight, days to physiological maturity and thousand kernel weight have shown to be the most important variables affecting the performance of durum wheat under non-stressed condition. In the first four PCs at the water-stressed condition, agronomic score, grain yield, vigority, days to physiological maturity, test weight and peduncle length have been shown to be the important variables under water-stressed condition. The results of factor analysis relatively confirmed the results of PC analysis. Our findings indicated that a selection strategy should take into consideration of agronomic score and days to physiological maturity under non-stressed condition while plant height and spike length under water-stressed condition. Therefore, the above-mentioned traits could be used as indirect selection criteria for genetic improvement of grain yield in durum wheat, especially in early generations of breeding programmes.

Key words: multivariate analysis, morphological traits, grain yield

Wheat (*Triticum* spp.) supports the world food supply, providing 44% of total edible dry matter and 40% of food crop energy consumed in most of the developing countries while durum wheat accounts for the remaining 10% of wheat production (Lantican *et al*. 2005). At present, durum wheat is cultivated mostly in rainfed areas of the Mediterranean regions under stressed environments because most rain falls during autumn and winter, and water deficit appears in spring, resulting in a moderate stress for wheat around flowering, increasing in severity throughout the grain-filling period (Moragues *et al*. 2006; Schulthess *et al*. 2013). Some of the Mediterranean areas are characterised by a dry with terminal drought stress for durum wheat cultivation. The insufficiency of water is an important environmental stress that causes heavy damage in many parts of the world and can reduce grain yield, average yield loss have been estimated to be 17–70% (Nouri-Ganbalani *et al*. 2009).

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There are huge differences among different genotypes of wheat, which are generally the basis for yield performance. Grain yield can be evaluated in terms of three yield components, including number of spikes per unit area, number of grains per spike and grain weight. Environmental conditions affect grain yield and its components; moreover, correlation studies in durum wheat (Garcia del Moral *et al*. 2003) provide additional evidence of the effect that environmental variation has on the association among different traits. Drought stress may cause a reduction in the yield-related traits, but particularly, in the number of spikes per unit area and the number of grains per spike (Abayomi & Wright 1999), while grain weight is negatively influenced by drought stress during grain-filling period (Chmielewski & Kohn 2000). It is necessary to investigate the genetic diversity in the currently used durum wheat genotypes in order to maintain a desirable level of genetic variation for future improvement programs.

The development of high-yielding durum wheat genotypes is a major objective in breeding programmes and the genetic variation for the target selected trait is necessary to have suitable response to selection (Mir *et al*. 2012). Further, these yield components are influenced by environmental fluctuations and some of them like grain per spike number, thousand grain weight, peduncle length, awn length, spike length, kernel number per spike, and grain weight per spike affect the durum wheat tolerance to drought stress (Blum 2010). According to previous investigations, number of grain per spike, thousand seed weight and number of tillers have direct and positive affects on durum wheat yield (Mohammadi *et al*. 2011; Zarei *et al*. 2013). Karimizadeh *et al*. (2012) reported the affect of plant height, number of grains per spike, and number of tiller on yield.

This investigation was performed to clarify the relationship between durum wheat grain yield and its components under non-stressed and water-stressed (drought) conditions. The aim was to provide theoretical foundations to guide durum wheat breeders who are researching the genetic association of the main agronomic traits and their influence in durum-wheat productivity. To achieve this goal, the relationship between grain yield and its components for durum wheat was studied using principal component analysis and factor analysis as multivariate statistical procedures under drought and non-stressed conditions.

Table 1

Coordinates of the eigenvectors of principal components analysis for measured traits of durum wheat genotypes in non-stressed condition

Variable	PC1	PC2	PC3	PC4
VGA	−0.229	0.491	0.290	0.027
DHE	−0.171	−0.551	0.235	−0.083
DMA	0.046	−0.067	0.705	−0.106
PLH	0.304	−0.233	0.055	0.307
SL	−0.142	0.247	0.251	−0.579
PL	0.466	−0.155	−0.083	−0.287
A.S	0.544	0.217	−0.066	0.045
TW	−0.279	0.327	−0.358	0.115
TKW	0.070	0.186	0.388	0.649
GY	0.456	0.351	0.089	−0.182
Eigenvalue	2.66	2.09	1.59	1.37
% Proportion variance	0.27	0.21	0.16	0.14
% Cumulative variance	0.27	0.48	0.63	0.77

Abbreviations: VGA – vigority; DHE – days to heading; DMA – days to physiological maturity; PLH – plant height; SL – spike length; PL – peduncle length; A.S – agronomic score; TW – test weight; TKW – thousand kernel weight; GY – grain yield

MATERIAL AND METHODS

Fourteen durum wheat genotypes (Table 1) were grown under two conditions, including water-stressed (dryland) and non-stressed (supplemental irrigation). Of these durum wheat genotypes used, 13 were from the International Center for Agricultural Research in the Dry Areas (ICARDA) durum wheat breeding programme and one was local check cultivar, Dehdasht. The experiments were laid out in a randomised complete block design with four replications. The size of plot was 1.2 × 6 m rows with 20-cm row spacing. The field experiments were managed based on local practice in growing season 2012–2013. Plants were fertilised with nitrogen at the rate of 50 kg/ha urea and phosphorus at the rate of 120 kg/ha $(NH_4)_3PO_3$. Supplemental irrigation was carried out two times (pollination and grain-filling periods), 30 mm at each time by sprinkler irrigation method. The plant height (PLH), peduncle length (PL) that was measured 1 week after heading, and spike length (SL) were measured based on guarded plants that were randomly selected from each plot. The other measured agronomic traits were growth vigor or vigority (VGA) in five-leaf stage, agronomic score (A.S), days to heading (DHE), days to physiological maturity (DMA), thousand kernel weight (TKW), test weight or hectolitre (TW) and grain yield (GY), which was harvested from plot area of 4 m^2 (four 5-m rows at the centre of each plot).

The obtained datasets were subjected to normality test by the Anderson and Darling method using Minitab 14 (2005). The first PC accounted for as much of the variation in the dataset as possible, and each succeeding PC accounted for as much of the remaining variation as possible. After factors extraction, the matrix of factor loading was subjected to a varimax orthogonal rotation and shows both groupings and contribution percentage to total variation in the dependence pattern. The array of communality, the variance of a trait computed by the common factors together, was calculated by the highest association in each array.

RESULTS

Data presented in Table 1 for non-stressed condition and graphically shown in Figure 1 proved that an increase in the number of PCs was associated with a decrease in eigenvalues and this trend reached its maximum at four components. Accordingly, it is reasonable to assume that the PC analysis had grouped the studied durum-wheat traits into four main components that altogether accounted for 77% of the total observed variation. Results showed the first PC correlated well with PL, A.S and GY and accounted for 27% of the total variation under non-stressed environmental condition (Table 1). Meanwhile, the second PC correlated with VGA, TW and GY traits and accounted for 21% of the detected

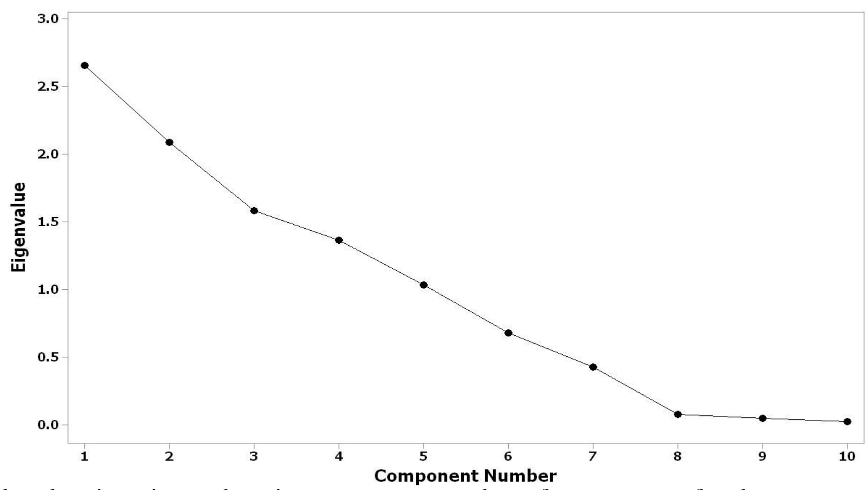

Figure 1. Scree plot showing eigenvalues in response to number of components for the measured traits of durum wheat under non-stressed condition

total variation, while the third PC correlated with DMA and accounted for 16% of the total survived variation (Table 1). Finally, the fourth PC correlated with TKW and accounted for 14% of the total variation in non-stressed condition (Table 1).

With regard to all of the first four PCs, the suggested name for the first PC could be PL while the suggested name for the second PC could be yield (Table 3). Also, the suggested name for the third PC could be physiological maturity while the suggested name for the fourth PC could be TKW (Table 3). The mentioned traits associated with the first four eigenvectors were the variables with the greatest variability and so PL, A.S, GY, VGA, TW, DMA and TKW traits were shown to be the important variables affecting greatly the performance of durum wheat under non-stressed condition. The component loadings refer to the coefficients in each PC or the correlation between the component and the traits and a high correlation between each PC and a trait shows that the trait is associated with the direction of the maximum amount of variation in the dataset. Relatively, similar results were reported by Moragues *et al*. (2006) who stated that the first two PCs were related to the GY components like TKW and the duration of grain-filling period in durum wheat. According to Dogan (2009) and Khan *et al*. (2013), GY, SL and grain-filling duration traits were strongly associated for most of the total observed variance.

Similar to non-stressed condition, data presented in Table 2 for water-stressed condition and graphically shown in Figure 2 indicated that the decreased trend in eigenvalues reached its maximum at four components. Therefore, the PC analysis had grouped the measured durum-wheat traits into four main components that accounted for 87% of the total detected variation. The first PC correlated with VGA and A.S and accounted for 38% of the total variation, while the second PC correlated with PLH, SL and PL and accounted for 23% of the survived total variation under water-stressed condition (Table 2). Meanwhile, the third PC correlated with TKW and TW and accounted for 15% of the total observed variation while the fourth PC involved well with PLH and TKW and accounted for 11% of the total variation of durum wheat genotypes in water-stressed condition (Table 2).

With regard to the first four PCs, the suggested names were VGA, length, TW and TKW, respectively (Table 3). The mentioned traits that associated with the first four eigenvectors were the varia-

T a b l e 2

Coordinates of the eigenvectors of principal components analysis for measured traits of durum wheat genotypes in water-stressed condition

Variable	PC1	PC2	PC3	PC4
VGA	0.367	−0.076	−0.480	0.125
DHE	−0.480	0.049	0.042	0.154
DMA	−0.462	0.119	−0.230	−0.040
PLH	0.004	0.523	0.057	0.456
SL	0.223	0.520	0.128	−0.131
PL	0.212	0.542	0.164	−0.094
A.S	0.435	−0.116	0.260	−0.134
TW	0.271	−0.315	0.254	0.068
TKW	0.250	0.008	−0.535	0.500
GY	0.042	0.164	−0.500	−0.673
Eigenvalue	3.79	2.31	1.50	1.08
% Proportion variance	0.38	0.23	0.15	0.11
% Cumulative variance	0.38	0.61	0.76	0.87

Abbreviations see Table 1

bles with the greatest variability and thus VGA, A.S traits, PLH, SL, PL, TKW and TW traits shown to be the effective variables affecting the performance of durum wheat under water-stressed condition. Our results are in good agreement with the results that were reported by Ahmadizadeh *et al*. (2011) who stated that the first two PCs were more related to the PL, PLH and SL in durum wheat as they were not affected by the values in water-stressed condition.

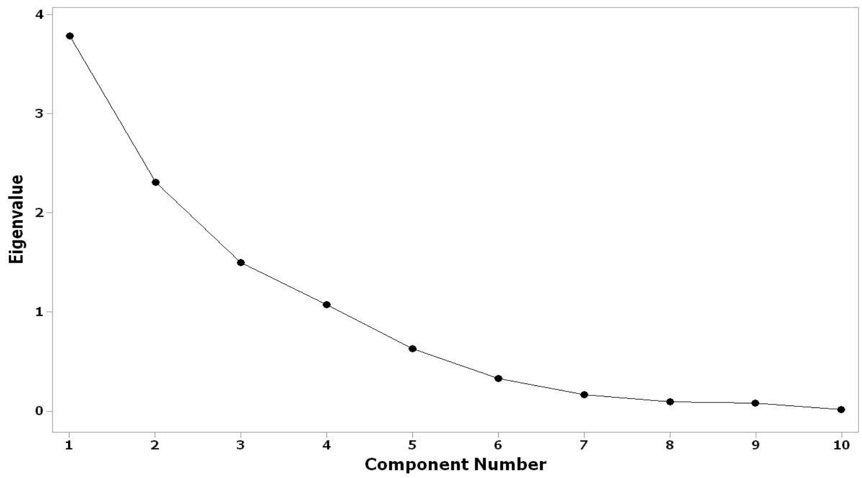

Figure 2. Scree plot showing eigenvalues in response to number of components for the measured traits of durum wheat under water-stressed condition

T a b l e 3

Summary of coordinates of the eigenvectors of principal components analysis for measured traits of durum wheat genotypes in both non-stressed and water-stressed conditions

Non-stressed condition				Water-stressed condition			
Variables	Loading	% Communality	Suggested name	Variables	Loading	% Communality	Suggested name
PC1	2.660	32	Peduncle length	PC1	3.790	52	Vigority
PL	0.466			VGA	0.367		
A.S	0.544			A.S	0.435		
GY	0.456						
				PC2	2.310	85	Length
PC2	2.090	25	Yield	PLH	0.523		
VGA	0.491			SL	0.520		
TW	0.327			PL	0.542		
GY	0.351						
				PC3	1.500	−50	Test weight
PC3	1.590	46	Physiological maturity	A.S	0.260		
DMA	0.705			TW	0.254		
PC4	1.370	−3	1000-kernel weight	PC4	1.080	14	1000-kernel weight
TKW	0.649			PLH	0.456		
				TKW	0.500		
Cumulative	7.710	100			8.680	100	

Abbreviations see Table 1

Data in Table 4 showed that four main factors were accounted for most of the total variation in the dependent structure under non-stressed condition. The first factor included A.S and GY traits; the suggested name for this factor was yield. The second factor included VGA and DMA and it was named the VGA under non-stressed condition (Table 4). The third factor included TW and DMA traits and suggested name was physiological maturity, while the fourth factor included PL trait and it was named as PL under non-stressed condition (Table 6). Data in Table 4 shows that PL had the highest communality and consequently, the high-relative contribution in the performance of durum wheat. Similar results were obtained by Pour-Siahbidi *et al*. (2012) who stated that factor analysis had classified the 14 durum-wheat traits into five main groups that accounted for 84% of the total variability. They have also reported the main contributing traits in the performance of durum wheat were PL, TKW and GY. According to Boveiri *et al*. (2014), first four factors of factor analysis for 18 durum-wheat lines account-

Table 4

Varimax rotated factor loadings and communalities for the traits of durum wheat genotypes in non-stressed condition

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Communality
VGA	−0.005	0.301	0.039	−0.034	0.301
DHE	0.151	−1.031	−0.098	0.024	−0.954
DMA	0.012	0.284	0.267	−0.269	0.294
PLH	0.083	0.135	0.089	−0.556	−0.249
SL	0.004	−0.159	−1.121	0.023	−1.253
PL	−0.224	0.004	−0.016	1.419	1.183
A.S	0.567	−0.156	−0.026	−0.230	0.155
TW	0.107	−0.051	0.197	−0.067	0.186
TKW	−0.137	−0.203	−0.255	0.476	−0.119
GY	0.637	−0.180	0.021	−0.237	0.241

Abbreviations see Table 1

Table 5

Varimax rotated factor loadings and communalities for the traits of durum wheat genotypes in water-stressed condition

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Communality
VGA	0.438	−0.034	−0.743	−0.246	−0.585
DHE	−0.747	−0.253	0.359	0.187	−0.454
DMA	−0.924	−0.139	0.180	−0.166	−1.049
PLH	−0.163	0.454	−0.099	0.109	0.301
SL	0.131	0.935	−0.032	−0.153	0.881
PL	0.257	0.858	0.021	−0.040	1.096
A.S	0.938	0.119	−0.035	0.019	1.041
TW	0.366	−0.087	−0.050	0.098	0.327
TKW	0.080	0.027	−0.988	−0.002	−0.883
GY	−0.067	0.127	−0.087	−0.979	−1.006

Abbreviations see Table 1

ed for 95% of the total observed variance and were strongly associated with GY, SL and grain-filling duration traits.

The first factor, which made the largest contribution to the total variation was composed of the A.S and so was named A.S under water-stressed condition (Table 5). The second factor was composed of SL and PL and this factor was called length factor under water-stressed condition (Table 6). The third factor included DHE trait and suggested name was DHE, while the fourth factor included TW, DHE and PLH and it was named the PLH under water-stressed condition (Table 6). Khayatnezhad *et al*. (2011) stated that factor analysis had classified the 13 durum-wheat traits into five main groups that accounted for 83% of the total variability in the dependence structure of durum wheat under water-stressed condition. They have also reported that the main contributing traits in the performance of durum wheat were peduncle length, thousand grain weight and gain yield. Relatively, similar results were found by Mohammadi *et al*. (2002) and Golparvar *et al*. (2002) in bread wheat. Zarei *et al*. (2013) reported that factor analysis had classified the 15 durum wheat traits in 410 F5 families of durum wheat into four main groups that accounted for 71% of the total variability in the dependence structure of durum wheat under water-stressed condition. They have also reported that the main contributing traits in the performance of durum wheat were PL, SL, PLH and GY.

DISCUSSION

While durum wheat genetic improvement programmes worldwide have achieved meaningful gains in grain, plant breeders agree that future programmes will be realised through an integration of disciplinary investigation and so, there is an urgent requirement to use new traits as well as tools (breeding procedures and statistical methods) (Ahmadizadeh *et al*. 2011). Several investigations suggest that selection for drought stress has the potential to improve genetic yield gains in durum wheat (Mohammadi *et al*. 2011; Karimizadeh *et al*. 2012). In addition, breeding under marginal environments has indicated that some agronomical traits when mea-

Table 6

Summary of factors loading for measured traits of durum wheat genotypes in both non-stressed and water-stressed conditions

Non-stressed condition				Water-stressed condition			
Traits	Loading	% Variance	Suggested name	Traits	Loading	% Variance	Suggested name
Factor 1		27	Yield	Factor 1		38	Agronomic score
A.S	0.567			A.S	0.938		
GY	0.637						
				Factor 2		23	Length
Factor 2		21	Vigority	SL	0.935		
VGA	0.301			PL	0.858		
DMA	0.284						
				Factor 3		15	Days to heading
Factor 3		16	Physiological maturity	DHE	0.359		
DMA	0.267						
TW	0.197			Factor 4		11	Plant height
				DHE	0.359		
Factor 4		14	Peduncle length	PLH	0.109		
PL	1.419			TW	0.098		

Abbreviations see Table 1

sured in drought-stressed condition were associated with yield performance in durum-wheat growing regions worldwide (Zarei *et al*. 2013). Morphological traits associated with increased GY potential in durum wheat include yield components and harvest index (Khan *et al*. 2013). We found, while TKW can be used as a guide to selection, the other traits are less effective. However, large jumps in GY potential will almost certainly need incorporation of diverse plant-genetic sources (De Vita *et al*. 2007; Dogan 2009) to permit evaluation of new yield-determining genes.

The results of this research indicated that the dispersal structure of durum wheat genotypes within the Mediterranean basin affected some of the agronomic traits evaluated herein, because it accounted for most of the observed variation in GY and its components. Our findings also indicated that the structure of dispersal of genotypes affected the association between GY and other agronomic traits. PC analysis PCA revealed that TKW was the yield component most important in defining GY for the genotypes evolved in the non-stressed condition, while for those tested to water-stressed conditions, GY was more based on the SL as well as TKW. The TKW was less important for GY formation in the water-stressed condition than in the non-stressed condition. It has been reported that under non-stressed condition, GY in durum wheat is mainly influenced by TKW. However, this yield component is more important when compared to the other yield components under non-stressed condition (Mohammadi *et al*. 2011). Therefore, our findings suggest that the environmental conditions in which genotypes evolved influenced the relative role of yield components on GY formation in durum wheat.

Nevertheless, DMA was the most important trait in explaining variations in GY in non-stressed conditions, since it explained about 16% of total-observed variability, while DHE was the most important trait in explaining variations in GY in water-stressed conditions, because it explained about 15% of total-survived variation. Similar importance of the above-mentioned phenological characteristics under both non-stressed and water-stressed conditions of Mediterranean regions have been highlighted in several investigations (Loss & Siddique 1994; Motzo & Giunta, 2007; Zarei *et al*. 2013). Under Mediterranean environments, where grain-filling process generally takes place under dry environmental conditions, the limited photosynthesis magnitude has been highlighted in different field crops (Royo *et al*. 1999; Davies *et al*. 2000; Karimizadeh *et al*. 2012).

Both PC analysis and factor analysis show an association between the A.S and total-observed variation under both non-stressed and water-stressed conditions, suggesting a good contribution of A.S to the performance of durum wheat. Increasing GY potential could enable plant breeders to realise the desired increment in drought-stressed tolerance of durum wheat genotypes. Increasing in traits PLH, SL, TKW and PL can improve GY potential in durum wheat genotypes. Golparvar *et al.* (2006), De Vita *et al*. (2007) and Khan *et al*. (2013) have reported relatively similar results for breeding these traits that are emphasised in this research for genetic improvement of GY. Also, the studied durum wheat genotypes would probably have evolved to highlight the most efficient mechanisms for GY production under water-stressed conditions.

CONCLUSIONS

It could be concluded from this study that water stress reduced durum wheat characteristics in all genotypes. Also, our findings indicated that a selection strategy should take into consideration of A.S and DMA under non-stressed condition while PLH and SL under water-stressed condition. Also, TKW and SL could be used in both environmental conditions. These traits are determined by means of multivariate statistical procedures, including principal component analysis and factor analysis. Results of this investigation could give good information and suggestions for future breeding objectives.

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