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PHENOTYPIC DIVERGENCE FOR MORPHOLOGICAL AND YIELD-RELATED TRAITS AMONG SOME GENOTYPES OF DURUM WHEAT UNDER DROUGHT STRESS AND NON-STRESS CONDITIONS

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Abstract: Drought stress is the most important factor restricting crop production in the majority of agricultural fields in the world. Durum wheat is generally grown in arid and semi-arid areas and drought often causes serious problems in its production. Fourteen durum wheat genotypes were evaluated under semi-arid Mediterranean climatic conditions in two non-stressed and water-stressed conditions. Data on fourteen agronomic traits are presented to assess the phenotypic diversity and to investigate the relationships between grain yield and other important yield components in durum wheat. The coefficient of variation (CV) for all the genotypes ranged from 0.71% to 17.62% in non-stressed environment and ranged from 1.38% to 23.70% in water-stressed environment. Clustering based on durum wheat genotypes separated the measured traits into three main groups under non-stressed environment. Peduncle length, agronomic score and plant height were the most related traits with grain yield. Such clustering in water-stressed environment indicated that growth vigor, thousand kernel weight, test weight or hectoliter and agronomic score were the most associated traits with grain yield. Cluster analysis assigned the durum wheat genotypes to at least two major groups in non-stressed conditions and three major groups in water-stressed conditions. Therefore, it seems that for improving grain yield performance in non-stressed conditions, genotypes G1, G3, G4, G6, G8 and G13 and in water-stressed conditions, genotypes G3, G8, G10 and G14 are good candidates. Finally, for improving grain yield performance in both humidity conditions, genotypes G3 and G8 can be used.

Key words: durum wheat, drought stress, multivariate analysis, phenotypic diversity.

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Introduction

Durum wheat (*Triticum turgidum*L. subsp. *durum* (Desf.)) is one of most cultivated crops under dryland conditions in the Mediterranean areas and is an important source of human nutrition in the alimentation of world population. The need and importance of durum wheat areincreasing day by day due to increase in human population and durum wheat represents 10% of the wheat grown globally, occupying about 11 million hectares in the Mediterranean areas (Karimizadeh et al., 2013). Drought stress is one of the most important factors which affect the production of durum wheat in the arid and semi-arid areas because rainfall and temperatures in such areas show large and unpredictable fluctuations within and between growing seasons. Developing new improved cultivars with suitable advantages under water stress conditions is a basic challenge for durum wheat breeding programs (Mir et al., 2012). The high grain yield and high protein concentration with desirable milling and baking qualities have been the main breeding targets in durum wheat improvement programs (Schulthess et al., 2013).

The genetic potential of different genotypes available to plant breeders can be exploited only if systematic evaluation for various traits is undertaken. Possible segregations in morphological traits are essential for genetic improvement programs and genetic diversity of durum wheat genotypes could be evaluated using morphological variation (De Vita et al., 2010). Description of the morphological traits has been used for genetic diversity analyses and cultivar development. The success of durum wheat cultivation in developing countries is due to its good ability to perform well under drought-stress, marginal and poor environmental conditions where other crops would fail (Marti and Slafer, 2010). The drought stress can strike at any time; most crop cultivars are most susceptible to yield losses due to limited water supply during flowering period. The ability of a genotype to produce high yield over a wide range of stress and non-stress environmental conditions is essential for an ideal cultivar. Although drought may occur at any stage of durum wheat development in Mediterranean regions, climatic frequency studies have identified one major period when drought is most likely to occur (Mohammadi et al., 2011) and it is when the durum wheat is in the grain filling phase.

Grain yield of durum wheat is a complex quantitative trait that results in the actions and interactions of various traits. Cluster analysis could be used as a statistical tool to bring information about appropriate cause and effect relationship between yield and yield components. Grain yield is the primary factor affecting the economical value in durum wheat and breeding efforts in increasing seed yield are being conducted. For effective selection, information on nature and magnitude of variation in plant materials, association of different traits with grain yield and among themselves isnecessary. Some researchers reported an association betweenplant height and grain yield (Anwar et al., 2009; Akram et al., 2008); between grain number per spike and grain yield (Dogan, 2009; Aycicek and Yildirim, 2006); between biological yield and yield (Leilah and Al-Khateeb, 2005); between number of tillers per plant and grain yield (Khan et al., 2003).

In the past decades, the narrowing of the genetic base exploited for the plant breeding and the need to introduce further genetic variation have become matters of concern and evaluation of exotic plant materials, especially from the Mediterranean basin, has been undertaken (Pecetti et al., 2001). Such plant materials of durum wheat were largely exploited in the past in some areas for direct utilization and/or for broadening the genetic base in breeding programs (Schulthess et al., 2013). Most of above-mentioned investigations of exotic gene pools in Mediterranean areas have been mainly devoted to agronomical traits. The present work refers to the evaluation of some new durum wheat genotypes belonging to the ICARDA (International Center for Agricultural Research in the Dry Areas) collection carried out in Northern Syria. Fourteen agronomic traits were considered in this investigation to assess the distinctiveness and the level of phenotypic variation. The generated information could be useful for (i) identifying genotypes as possible sources of parental materials and (ii) identifying traits which may be useful in breeding higher-yielding genotypes in non-stressed and water-stressed environments.

Material and Methods

This research data set involves fourteen durum wheat genotypes tested in two non-stressed and water-stressed environments. In the non-stressed environment, supplemental irrigation (about 30 mm) was performed in stem elongation period (1 March) and twice in the grain filling period (1 and 15 May). On the mentioned dates, there was no rain and durum wheat was influenced by drought stress according to local experience. The non-stressed conditionwas considered to be a favorable condition in order to have a better estimation of the optimum environment. In the water-stressed environment, there was no supplemental irrigation during growth period and natural stress was applied. This calcification was based on the dataset of previous years and local farmers' reports. Some of climatic properties in Gachsaran location during durum wheat growth period are given in Table 1. Of fourteen durum wheat used, 13 were from the ICARDA durum wheat improvement program and one was check cultivar, Dehdasht, typically grown by Iranian farmers (Table 2). In each environment, a completely randomized block design with four replicates was used. The experiments were managed according to local practice under dryland conditions in growing season 2012–2013 at Gachsaran (30°20′N; 50°45′E) with altitude 710 m above sea. Soil texture was silty clay loam with Regosols type based on the FAO soil classification system. Plots were 6 m^2 with six rows each 6 m long and 20 cm between cultivated rows. Plants were fertilized with nitrogen at the rate of 50 kg ha^{-1} urea and phosphorus at the rate of 120 kg ha^{-1} ammonium phosphate. The measured agronomic traits were growth vigor or vigority (VGA) at the five-leaf stage, plant height (PLH), peduncle length (PL) which was measured one week after heading, agronomic score (A.S), days to heading (DHE), spike length (SL), days to physiological maturity (DMA), thousand kernel weight (TKW), test weight or hectoliter (TW) and grain yield (GY). The harvested plot size was 4 m^2 (four 5.5-m rows at the centre of each plot). Mean grain yield was estimated for each genotype ineach environment.

Table 1. Some of climatic properties in Gachsaran during durum wheat growth period.

Average of climatic indices	Mar.	Apr.	May	June	July
Mean daily temperature (°C)	10.8	14.5	20.1	23.6	20.9
Minimum temperature (°C)	10.9	13.9	21.9	24.5	26.2
Maximum temperature (°C)	25.3	27.1	36.9	40.1	41.4
Maximum relative humidity (%)	55	69	37	31	34

The datasets were first tested for normality by the Anderson and Darling normality test using Minitab version 14 (2005) statistical package. Data from each trial were subjected to analysis of variance (ANOVA) using appropriate models and SAS 9.1 (SAS, 2004) package. Cluster analysis was used to arrange a set of variables (genotypes and traits) into clusters. Its objective was to sort variables into groups, so the magnitude of association was strong between members of the same cluster and weak between members of different clusters. Each cluster described the class to which its members belonged and this description maybe abstracted through use of the particular to the general class or type. The cluster analysis was performed using a measure of similarity levels and Euclidean distance (Eisen et al., 1998) using Minitab version 14 (2005) package.

Table 2. The pedigree and yield performance of 14 durum wheat genotypes.

Genotype code	Pedigree	YP	YS
G1	Dehdasht	3838	2413
G2	LILE/3/SORA/2*PLATA_12//SOMAT_3CDSS02Y00114S-0Y-0M-7Y-0Y	3090	2089
G3	BCRIS/BICUM//LLARETA INIA/3/DUKEM_12/ 2* RASCON _21CDSS99B01189T-0TOPY-0M-0Y-81Y-0M-0Y-1M-0Y	4032	2573
G4	ZHONG ZUO/2*GREEN_3//SORA/2*PLATA _12/ 10 /PLATA _10/6/ MQUE/4/USDA 573 //QFN/AA _7 /3/ALBA-D/5/AVO/HUI /7/ PLATA_13 /8/THKN E E_11/9/CHEN/ ALTAR 84/3/HUI/ POC// BUB/RU FO /4/ FNFOOTCDSS 02Y00213S-0Y-0M-30Y-0Y	4025	2327
G5	PLATA_6/GREEN_17//SNITAN/4/YAZI_1/AKAKI_4//SOMAT_3/3/AUK/GUIL//GREENCDSS02Y00369S-0Y-0M-16Y-0Y	3154	2356
G6	TOPDY_18/FOCHA_1//ALTAR 84/3/AJAIA_12/F3 LOCAL(SEL.ETHIO .135 .85)//PLATA_13/4/SOMAT_3/ GREEN _22 CDSS02Y00394S-0Y-0M-13Y-0Y	3835	2428
G7	RASCON_33/TISOMA_2/3/CANELO_8//SORA/2*PLATA_12/4/SOMAT_4/INTER_8CDSS02Y00802T-0TOPB-0Y-0M-19Y-0Y	3028	2268
G8	RISSA/GAN//POHO_1/3/PLATA_3//CREX/ALLA/4/STOT// ALTAR 84/ALD/5/ARMENT//SRN_3 /NIGRIS_4/3/ CANELO_9.1CDSS02Y01145T-0TOPB-0Y-0M-10Y-0Y	3773	2702
G9	SORA/2*PLATA_12//SOMAT_3/3/STORLOM/4/BICHENA/AKAKI_7CDSS02Y01279T-0TOPB-0Y-0M-28Y-0Y	3531	2212
G10	SOOTY_9/RASCON_37//STORLOMCGSS02Y00006S-2F1-12Y-0B-3Y-0B-2Y-0B	3502	2514
G11	CHEN_1/TEZ/3/GUIL//CIT71/CII/4/SORA/PLATA_12/5/STOT//ALTAR 84/ALD/9/USDA595/3/D67.3/ RABI CRA/4/ ALO/5/ HUI/YAV_1/6/ ARDEN TE/7/HUI/YAV79/8/ POD_9CDSS02B 00022S-0Y-0M-41Y-4M-04Y-0B	3475	2347
G12	ADAMAR_15//ALBIA_1/ALTAR 84/3/SNITAN /4/SOMAT _4/INTER _8CDSS02B00296S-0Y-0M-17Y-2M-04Y-0B	3509	2142
G13	1A.1D 5+10-6/2*WB881//1A.1D 5+10-6/3*MOJO/3/SOOTY _9/RASCON_37/9/USDA595 /3/D67.3/RABI// CRA/4/ALO/5/ HUI/YAV_1/6/ARD ENTE/7/HUI/YAV79/8/POD_9CDSS 02B00650S-0Y-0M-3Y-2M-04Y-0B	3768	2392
G14	1A.1D 5+10-6/2*WB881//1A.1D 5+10-6/3*MOJO /3/SOOTY _9/RASCON_37/9/USDA595/3/ D67.3/RABI// CRA/4/ALO/5/ HUI/YAV_1/6/ ARDENTE/7/HUI/YAV79/8/POD_9 CDSS02B00650S-0Y-0M-7Y-3M-04Y-0B	3538	2539

Results and Discussion

Analysis of variance for grain yield performance and other measured traits in both non-stressed and water-stressed environments indicated highly significant differences among fourteen durum wheat genotypes (results are not shown). The average grain yield in non-stressed environment was 3,578.38 kg ha^{-1} and the mean yield performance in water-stressed environment was 2,378.64 kg ha^{-1} (Tables 3 and 4). The maximum grain yield in non-stressed environment was 4,032.25 kg ha^{-1} while the minimum grain yield in water-stressed environment was 3,028.00 kg ha^{-1} (Table 3).

Table 3. Descriptive statistics for estimated traits/variables of durum wheat in non-stressed conditions.

Trait/Variable	Mean	Std. deviation	Minimum	Maximum	CV(%)
Vigority	3.91	0.48	3.00	4.75	12.18
Days to heading	109.04	1.82	106.50	111.75	1.67
Days to physiological maturity	144.05	1.02	142.25	146.00	0.71
Plant height	86.52	3.08	82.25	91.75	3.56
Spike length	6.61	1.13	3.50	8.50	17.03
Peduncle length	37.45	2.70	31.50	42.25	7.21
Agronomic score	3.84	0.68	2.75	4.75	17.62
Test weight	311.91	4.30	302.75	317.75	1.38
Thousand kernel weight	31.80	2.23	27.75	36.25	7.01
Grain yield	3,578.38	323.33	3,028.00	4,032.25	9.04

Table 4. Descriptive statistics for estimated traits/variables of durum wheat in water-stressed conditions.

Trait/Variable	Mean	Std. deviation	Minimum	Maximum	CV(%)
Vigority	3.63	0.45	2.75	4.50	12.32
Days to heading	108.96	1.71	106.25	111.50	1.57
Days to physiological maturity	143.16	1.97	139.25	145.50	1.38
Plant height	77.96	3.47	71.75	83.75	4.46
Spike length	7.66	2.15	6.00	14.25	28.03
Peduncle length	21.95	2.55	18.50	28.00	11.61
Agronomic score	3.14	0.74	2.25	4.75	23.70
Test weight	344.84	7.14	335.25	357.50	2.07
Thousand kernel weight	26.80	1.95	24.25	31.50	7.28
Grain yield	2,378.64	169.65	2,089.00	2,702.25	7.13

The coefficient of variation (CV) for all the genotypes ranged from 0.71% to 17.62% in non-stressed environment and it ranged from 1.38% to 23.70% in water-stressed environment (Tables 3 and 4).The highest CV in both non-stressed and water-stressed environments was observed in agronomic score (A.S) and spike length (SL) traits (Tables 3 and 4). The maximum grain yield in non-stressed environment was 2,702.25 kg ha^{-1} while the minimum grain yield in water-stressed environment was 2,089.00 kg ha^{-1} (Table 4). The lowest CV in both non-stressed and water-stressed environments was observed in days to heading (DHE), days to physiological maturity (DMA), and test weight (TW) traits (Tables 3 and 4). The mentioned CV values of these durum wheat genotypes indicated the presence of sufficient genetic variability to ensure positive response to crop improvement programs as selection and hybridization processes.

Clustering based on durum wheat genotypes separated the measured traits into three main groups in non-stressed environment (Figure 1). There were VGA, SL and TW traits in one cluster, DHE, DMA and TKW traits in the same cluster, and PLH, PL, AS and YLD traits in the other cluster in non-stressed environment (Figure 1).

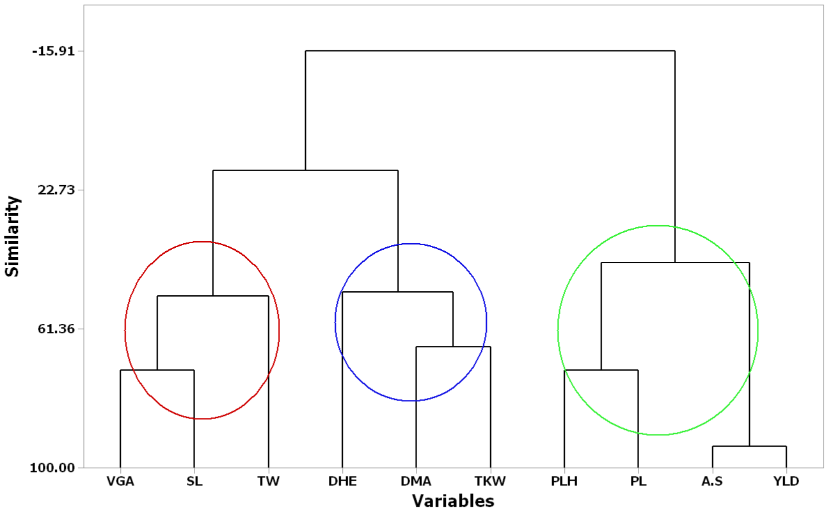

Figure 1. Similarity levels of the estimated traits (variables) in 14 durum wheat genotypes using the hierarchical cluster analysis in non-stressed conditions.

Legend: vigority (VGA), plant height (PLH), peduncle length (PL), agronomic score (A.S), days to heading (DHE), spike length (SL), days to physiological maturity (DMA), thousand kernel weight (TKW), test weight or hectoliter (TW) and grain yield (GY).

Therefore, it seems that peduncle length, agronomic score and plant height were the most related traits with grain yield while some other important traits like thousand kernel weight, test weight or hectoliter and days to physiological maturity were grouped in the other clusters. Similar findings were reported for agronomic score (Mohammadi et al., 2012), plant height (Khan et al., 2013), and peduncle length (Zarei et al., 2013) in non-stressed environment. In contrast, some other researchers indicated that high association between grain yield and yield component traits in wheat such as harvest index (Ghaderi et al., 2009), biological yield (Kandic et al., 2009), number of spikes per unit (Leilah and Al-Khateeb, 2005), number of grains per spike (Khan et al., 2010) and 1000 kernel weight (Mohammadi et al., 2012). However, selection based on some identified traits regardless of interactions among them and with grain yield components may mislead the plant breeders to accomplish their main breeding purposes (Garcia del Moral et al., 2003).

Clustering of the measured traits of durum wheat genotypes in water-stressed environment indicated that VGA, TKW, YLD, A.S and TW traits were grouped as one cluster, PLH, AS and PL traits were grouped as the other cluster, and DHE and DMA traits were grouped as the other cluster (Figure 2). Thus, it seems that growth vigor, thousand kernel weight, test weight or hectoliter and agronomic score were the most associated traits with grain yield while some other important traits like spike length and days to physiological maturity were grouped in the other clusters. Similar results for 1000 kernel weight (Mollasadeghi et al., 2011; Shamsi et al., 2011) and test weight or hectoliter (Mohammadi et al., 2012) were reported under drought conditions for wheat.

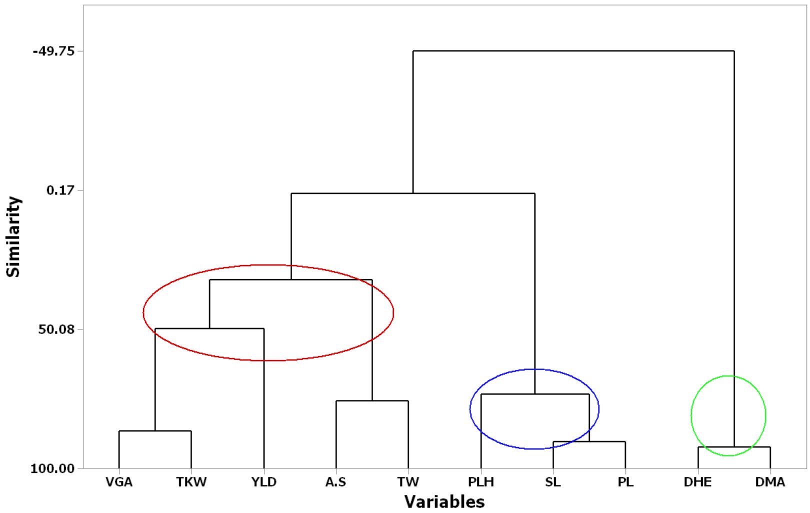

Figure 2. Similarity levels of the estimated traits (variables) in 14 durum wheat genotypes using the hierarchical cluster analysis in water-stressed conditions.

Legend: vigority(VGA), plant height (PLH), peduncle length (PL), agronomic score (A.S), days to heading (DHE), spike length (SL), days to physiological maturity (DMA), thousand kernel weight (TKW), test weight or hectoliter (TW) and grain yield (GY).

In contrast to our findings, other studies showed that plant height (Zarei et al., 2013) and biological yield (Abderrahmane et al., 2013) in semi-arid conditions are considered as indicators of increased tolerance to drought stress. The observed differential relations of yield components to grain yield of durum wheat may be attributed to environmental effects on plant growth. However, results were in agreement with the reports of Mollasadeghi et al. (2011) and Mohammadi et al. (2012) that indicated that TKW and TW traits had the greatest effect on grain yield and suggested that these traits should be are primary selection criteria for improving grain yield in durum wheat in low rainfall conditions.

Clustering based on studied traits separated the durum wheat genotypes into two main groups (Figure 3). There were G1, G3, G4, G6, G8 and G13 genotypes in one group and genotypes G2, G5, G7, G9, G10, G11, G12 and G14 in the other cluster. Therefore, there is a significant difference between evaluated genotypes for morphological traits. Cluster 1 which included Dehdasht (G1) had high mean yield under non-stressed conditions while cluster 2 which included the other remaining genotypes did not have high mean yield in such environmental conditions (Figure 3).

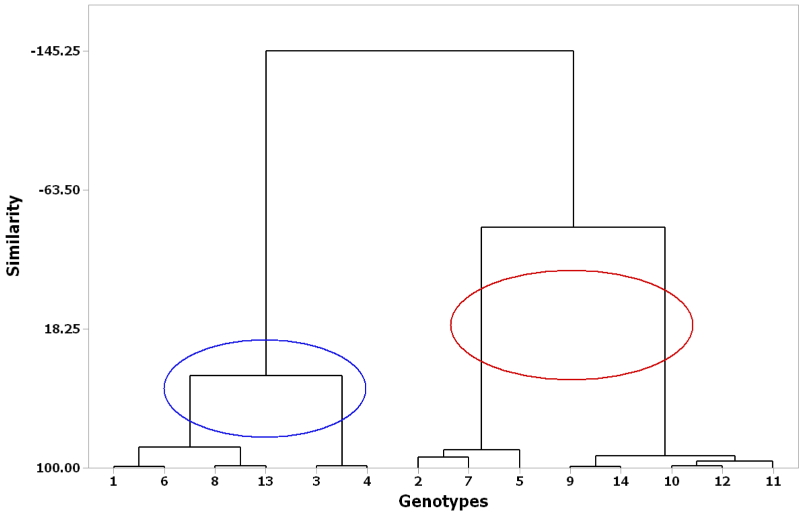

Figure 3. Similarity levels of the estimated 14 durum wheat genotypes using the hierarchical cluster analysis in non-stressed conditions.

Therefore, it seems that for breeding grain yield in non-stressed conditions, genotypes G1, G3, G4, G6, G8 and G13 are good candidates. Clustering according to measured traits separated the durum wheat genotypes into three main groups (Figure 4). The genotypes G1, G4, G5, G6, G11 and G13 were grouped as one cluster; the genotypes G2, G7, G9 and G12 were grouped as one cluster; and the genotypes G3, G8, G10 and G14 were grouped as another cluster (Figure 4). Cluster 1 which included G1 (Dehdasht) showed relatively moderate grain yield performance under water-stressed conditions while cluster 2 which included genotypes G3, G8, G10 and G14 had high mean yield and cluster 3 which included the other remaining genotypes indicated low mean yield in water-stressed environmental conditions (Figure 4). Therefore, it seems that for genetic improvement of high grain yield in durum wheat in water-stressed conditions, genotypes G3, G8, G10 and G14 are good candidates. It should be noticed that the local check cultivar (Dehdasht) had good performance only in non-stressed conditions and could not produce high yield in water-stressed conditions.

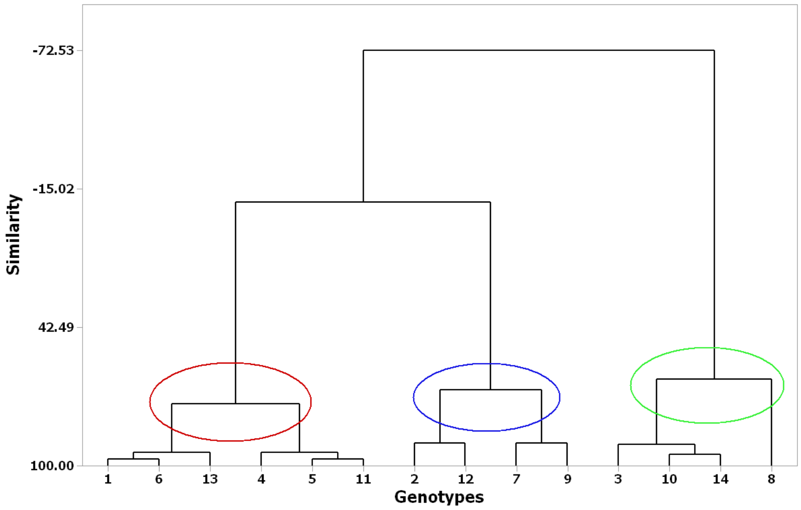

Figure 4. Similarity levels of the estimated 14 durum wheat genotypes using the hierarchical cluster analysis in water-stressed conditions.

Variation due to durum wheat genotypes was significant for all traits in two environmental conditions (non-stressed and water-stressed conditions). This suggested that the observed differences in durum wheat genotypes were sufficient to provide some facilities for selecting the most favorable genotypes to improve yield performance as well as drought tolerance. For a trait to be considered as a selection criterion in grain yield improvement program it must be associated with grain yield and it is therefore, essential to determine whether grain yield was associated with a particular trait. We found that peduncle length and plant height were the most related traits with grain yield and had high contribution to increasing grain yield in non-stressed conditions. Cluster analysis results proved that the above-mentioned traits were the variables most closely related to grain yield. This is in agreement with the previous reported investigation on durum wheat under the favorable conditions (Yagdi, 2009; Khan et al., 2013). These results suggest that selections should be based on the peduncle length and plant height for developing new durum wheat cultivars.

The result of this research could be compromised from a broad diversity among studied durum wheat genotypes. It seems that there is a high variation for agronomic score and spike length traits among evaluated genotypes. For some genotypes, some measured traits were high and other traits showed low values and so consideration of few traits is not a suitable way for selecting the best genotypes. Similarly, various traits have interaction between each other, and effects of some traits make main traits such as grain yield. Although, in some areas where drought stress happens less frequently and where wet years predominate, improving grain yield under water-stressed conditions can usually be achieved by selecting for more productivity under non-stressed conditions, but such strategy is not good enough in most arid and semi-arid environments. In contrast, some researchers believe that this strategy as a traditional approach indicates selecting for high yield under non-stressed conditions (Rajaram et al., 1996). Also, selection based on low yield performance decrease under water-stressed conditions with respect to favorable conditions tends to reduce yield under non-stressed conditions (Sio-Se Mardehet al., 2006).

In this research, the association was observed between grain yield and test weight (hectoliter) under water-stressed conditions. Cluster analysis results indicated that the above-mentioned traits were the variables most closely related to grain yield. The grain yield, a major selection criterion versus drought stress, is a complex trait determined by several processes and its genetics are greatly ambiguous (Mir et al., 2012). The traits such as score and test weight (hectoliter) had association with grain yield in dryland condition, indicating its importance for selection drought tolerance as well as higher yield performance. Our findings are in good agreement with the findings of Leilah and Al-Khateeb (2005), Shamsi et al. (2011), Mohammadi et al. (2012) and Zarei et al. (2013). Accordingly, to increase grain yield under dryland conditions, the more focus should be on morphological traits such as growth vigor, thousand kernel weight, test weight and agronomic score traits which have a high correlation with grain yield and also should utilize them in drought tolerance breeding programs.

Cluster analysis based on the phenotypic trait data assigned the durum wheat genotypes to at least two major groups in non-stressed conditions and to three major groups in water-stressed conditions. Genotypes are distributed among all cluster groups, which implied that genetically different genotypes were identified with grain yield performance. It is reasonable to assume that the genetic basis of grain yield and other measured traits in these genotypes is different, which would enable durum wheat breeders to combine these different sources of genetic variability to improve grain yield as well as other measured traits in their breeding programs. Maximum genetic variation is expected from crosses that involve parents from clusters characterized by maximum distance. Crosses between genotypes selected on the basis of special merits are, therefore, expected to provide relatively better genetic recombination in their progenies. Hence, it seems that for improving grain yield performance in non-stressed conditions, genotypes G1, G3, G4, G6, G8 and G13 and in water-stressed conditions, genotypes G3, G8, G10 and G14 are good candidates. It is interesting that genotypes G3 and G8 can be used for obtaining high grain yield performance in both conditions while genotype G1 (local check cultivar; Dehdasht) had good performance only in non-stressed conditions and could not produce high yield in water-stressed conditions.

Conclusion

The cluster analysis used in this study indicated that peduncle length, agronomic score and plant height were the most important yield variables to be considered under non-stressed conditions while growth vigor, thousand kernel weight, test weight or hectoliter and agronomic score were the most important yield variables to be considered under water-stressed conditions. The obtained results could be useful for durum wheat breeders in order to increase grain yield in both normal and rainfed conditions. However, we suggest that durum wheat breeders do not select for specific traits to improve grain yield under drought stress because it is unpredictable and also the physiological responses to drought stress are complex and unpredictable. Finally, for improving grain yield performance in both humidity conditions, genotypes G3 and G8 can be used.

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FENOTIPSKA DIVERGENTNOST MORFOLOŠKIH OSOBINA I KOMPONENTI PRINOSA GENOTIPOVA TVRDE PŠENICE U USLOVIMA STRESA IZAZVANOG SUŠOM I BEZ STRESA

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Rezime

Stres izazvan sušom je najvažniji faktor koji ograničava proizvodnju useva u većini poljoprivrednih oblasti u svetu. Tvrda pšenica se generalno uzgaja u sušnim i polusušnim oblastima i suša često izaziva ozbiljne probleme u njenoj proizvodnji. Ocenjeno je četrnaest genotipova tvrde pšenice u uslovima polusušne mediteranske klime u uslovima bez stresa i u uslovima vodnog stresa. Prikazani su podaci o četrnaest agronomskih osobina, kako bi se procenila fenotipska raznolikost i istražile veze između prinosa zrna i drugih važnih komponenti prinosa kod tvrde pšenice. Koeficijent varijacije (CV) za sve genotipove se kretao od 0,71% do 17,62% u sredinama bez stresa, kao i od 1,38% do 23,70% u sredinama sa vodnim stresom. Grupisanje zasnovano na genotipovima tvrde pšenice je razvrstalo merene komponente u tri glavne grupe u sredini bez stresa. Dužina vršne internodije, agronomska ocena i visina biljke su bile najpovezanije komponente sa prinosom zrna. Takvo grupisanje u sredini sa vodnim stresom je ukazivalo da su vigor rasta, masa hiljadu zrna, probna težina ili hektolitar i agronomska ocena najpovezanije komponente sa prinosom zrna. Klaster analiza je grupisala genotipove tvrde pšenice u najmanje dve velike grupe u uslovima bez stresa i u tri velike grupe u uslovima vodnog stresa. Prema tome, čini se da su dobri kandidati za povećanje prinosa zrna u uslovima bez stresa, genotipovi G1, G3, G4, G6, G8 i G13 i u uslovima sa vodnim stresom, genotipovi G3, G8, G10 i G14. Na kraju, za povećanje prinosa zrna u uslovima oba tipa vlažnosti, se mogu koristiti genotipovi G3 i G8.

Ključne reči: tvrda pšenica, stres izazvan sušom, multivarijaciona analiza, fenotipska raznolikost.

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