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Statistical analysis of durum wheat yield under semi-warm dryland condition

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Abstract

Eight statistical procedures including simple and combined variance, covariance analyses, coefficients of genetic variation, broad sense heritability and genetic advance, simple correlation, stepwise multiple linear regression and path analysis were used to study the relationship between grain yield of spring-type durum wheat and its components under semi-warm dryland condition of Iran. In order to identify relationship of some agronomical traits including yield components with grain yield of durum genotypes, 24 durum wheat genotypes were studied in RCBD design with 3 replications during 2004-2005 and 2005-2006 wheat growing season in Gachsaran Dryland Agricultural Research Station in the southwest of Iran. The results showed that the measured traits varied in genotypic and phenotypic coefficients of variations, heritability and genetic advance. Thousand kernel weight had positive significant correlation coefficient and great positive direct effect on grain yield, so it can be considered as indirect selection criteria for better yield in durum breeding programs. The spike number per square meter (S/m²) through direct effect on grain yield and via thousand kernel weight can be defined as another indirect selection criterion. Meanwhile, decreasing and nullifying the negative indirect effect of kernel number per spike by decreasing seed weight should be considered in direct selection for thousand kernel weight and spike number per square meter. It can be concluded that differences among genotypes for days to heading, spike number per square meter, flag-leaf area, flag-leaf weight and grain yield were mainly controlled by environmental variance. The existence of high heritability for growth vigor, days to maturity, plant height, peduncle length, number of kernel per spike, flag leaf senescence, spike length, thousand kernel weight and test weight traits, indicated that effective selection can be done on these traits through breeding programs.

Keywords: Drought; yield analysis; path analysis; stepwise regression; durum wheat.
Abbreviations: VIG: growth vigor at five-leaf stage; PLH: plant height; PD: peduncle length (one week after heading); Pub: pubescence of stem at heading time; DHE: days to heading; SL: spike length; FLS: flag leaf senescence; DMA: days to physiological maturity; FLA: flag leaf area; FLW: flag leaf weight; TKW: thousand kernel weight; K/S: kernel number per spike; S/m²: number of spike per square meter; TW: test weight (hectoliter); GY: grain yield

Introduction

Among all cultivated wheats, *Triticum aestivum* and *Triticum durum* are the most important cereal crops in the world. Durum wheat is a minor crop, grown on only 8 to 10% of all wheat cultivated area. In spite of its low acreage, durum wheat is an economically important crop because of its unique characteristics and end products. It is generally considered the hardiest of all wheats. Durum kernels are usually large, golden amber, and translucent. These characteristics, along with its protein content and gluten strength, make it suitable for manufacturing of diverse food products. Pasta is the most common durum's end product consumed in Europe, North America, and the former USSR. Products other than pasta are also made from durum wheat. Couscous, made from durum semolina, is consumed mainly in North Africa. Flat bread made from durum wheat and bulgur are part of the main diet in Jordan, Lebanon, and Syria. Durum wheat is one of the most extensively cultivated crops under dryland conditions in the Mediterranean environments, where water stress and high temperature are the main constraints limiting productivity (Araus et al., 2002), although this condition offers an opportunity for the production of high-quality durum (Borghi et al., 1997). Selection for genotypes with increased productivity under drought conditions has been an important aspect of many breeding programs. The biological basis for drought tolerance is still poorly understood. Also, drought stress is highly heterogeneous space (between and within sites), and time (over the seasons and years), and is unpredictable. This makes it difficult to identify or simulate a representative drought stress condition. In addition to the complexity of drought itself (Passioura, 2007), plant responses to drought are complex and different mechanisms are adopted by plants when they encounter drought (Jones, 2004). Different methods have been employed to identify crops that are productive under drought condition. Yield loss is the main concern of plant breeders, hence, they emphasize on yield performance under drought condition. But yield is a complex trait and is the result of environmental factors as well as interaction of many minor-effect characteristics by low heritability especially under dryland condition (Blum, 1988). So, yield improvement through direct selection method is difficult. The morpho-physiological trait based breeding approaches has merit over breeding solely on the basis of grain yield. If the morpho-physiological traits affecting yield

Table 1. Mean, standard error, genetic variation coefficient, broad sense heritability and genetic advance of traits of different durum wheat genotypes.

Trait	Mean	Standard error	Genetic variation coefficient (CV_g %)	Broad sense heritability (%)	Genetic advance (%)	F(G)	F (G*E)
VIG	6.8	0.062	4.0	51.8	5.9	2.06*	0.1 ns
PLH	82	0.992	7.9	88.7	15	1.79*	1.79 ns
PD	16.6	0.274	15	76.6	27	6.08**	2.24*
DHE	101	0.933	1.2	21.6	1.1	1.49 ns	4.66**
DMA	133	1.049	1.5	64.9	2.4	4.42**	6.58**
TKW	41.6	0.411	5.2	56.9	8.1	3.13**	2.61**
K/S	44.4	0.548	6.2	53.4	9.4	2.80**	2.33**
S/m^2	210	2.913	5.5	24.6	5.6	1.52 ns	2.47*
FLA	25.3	0.480	3.2	8.9	2.0	1.13 ns	1.55 ns
FLW	2.1	0.052	2.9	8.4	1.7	1.11 ns	1.83 ns
FLS	130	1.188	1.9	72.4	3.4	5.43**	3.23**
SL	6.9	0.075	3.6	60.6	5.8	2.61**	1.05 ns
Pub	3.0	0.050	8.6	37.1	11	1.98*	2.86**
TW	81.3	0.242	1.3	48.8	1.9	2.09**	1.17 ns
GY	3848	67.05	2.3	7.4	1.3	1.10 ns	1.39 ns

VIG: growth vigor, PLH: plant height, PD: peduncle length, DHE: days to heading, DMA: days to maturity, TKW: thousand kernel weight, K/S: number of kernel per spike, S/m^2: spike number per square meter, FLA: flag leaf area, FLW: flag leaf weight, FLS: flag leaf senescence, SL: spike length, Pub: pubescence of stem, TW: test weight (hectoliter), GY: grain yield.

are found as indirect selection criteria with higher heritability and easily and rapidly screened. The efficiency of selection will increase especially in early generations or when the yield may not be properly evaluated (Royo et al., 2003). A great number of physiological traits have the potential to improve crop performance under abiotic stress (Araus et al., 2002; Condon et al., 2004; Richards, 2006). The existence of correlation between different traits with grain yield under drought stress shows compatibility with drought conditions is not unexpected (Richards et al., 2003). Selection of drought tolerant genotypes in wheat requires a simple and non-destructive method (Gusta and Chen, 1987). The results of research by Moghadam et al. (1993) showed that although there are positive correlation between grain yield and some of its components, but the existence of negative correlations has caused different efficiency of selection for some components that are not in the same direction of increasing the wheat yield. Increase in one component usually causes the decreasing of other components. Furthermore, although a number of morpho-physiological traits have proved associated with yield of wheat under semi-arid conditions; their contribution to selection can be adversely affected by the fact that this association may be environment-specific. In modeling of durum yield, different statistical techniques have been used, including correlation, path analysis and stepwise regression. Correlation coefficient is an important statistical procedure to evaluate breeding programs for high yield, as well as to examine direct and indirect contribution of the yield variables (Mohamed, 1999). Dissecting the correlation coefficient into direct and indirect effects can be done through path analysis technique (Dewey and Lu, 1959). Path analysis has been used in many studies on wheat (Mohamed, 1999; Leilah and Al-Khateeb, 2005). Stepwise multiple linear regression proved to be more efficient than the full model regression to determine the predictive equation for yield (Naser and Leilah, 1993; Mohamed, 1999). The aim of the present study was to evaluate several traits linked to drought adaptation in the advanced durum lines under subtropical dry-land conditions.

The specific research objectives pursued were (i) to distinguish the best traits associated with yield under drought (ii) evaluate the genetic diversity for drought adaptation among the studied lines under drought stress in terms of yield, phenology and physiological attributes (iii) discern inherent mechanisms contributing to a higher performance under drought and (iv) assessment of the feasibility of utilizing secondary selection criteria to identify high-yielding durum genotypes.

Materials and methods

Field experiments

In this study, 24 durum wheat genotypes were studied in subtropical Gachsaran Dryland Agricultural Research Station (Southwest of Iran) in years 2004-2005 and 2005-2006. Plot size was 5 × 6 m rows (6.0 m2) with a 20 cm row space. The study was conducted under dry-land condition in a randomized complete block design (RCBD) with three replications. The studied agronomic traits were growth vigor (VIG) in five-leaf stage, plant height (PLH), peduncle length (PD) (one week after heading), pubescence of stem (Pub) at heading time, days to heading (DHE), spike length (SL), flag leaf senescence (FLS), days to physiological maturity (DMA), flag leaf area (FLA), flag leaf weight (FLW), thousand kernel weight (TKW), kernel number per spike (K/S), number of spike per square meter (S/m^2), test weight (hectoliter) (TW) and grain yield (GY). Plants were fertilized with nitrogen at the rate of 50 kg/ha urea and phosphorus at the rate of 120 kg/ha ammonium phosphate. Proper management practices were adopted throughout the growing seasons to ensure good crop growth.

Statistical analysis

Simple and compound variance and covariance analyses were done on grain yield and other traits. Variance, coefficients of genetic variation, broad sense heritability and genetic advance of traits were calculated using Burton and Divine,

Table 2. A matrix of simple correlation coefficients (r) for the estimated fifteen variables of durum wheat.

Trait	GY	TKW	S/M^2	K/S	VIG	PLH	PD	DHE	DMA	FLA	LW	LS	SL	Pub	TW
GY	1														
TKW	0.76**	1													
S/m^2	-0.12	0.33	1												
K/S	-0.23	-0.52**	-0.25	1											
VIG	0.07	0.02	-0.25	-0.59**	1										
PLH	-0.29	-0.20	0.15	0.46**	0.94**	1									
PD	-0.84**	-0.54**	0.19	-0.02	0.17	0.95**	1								
DHE	-0.82**	-0.41*	0.40	-0.34	-0.98**	0.83**	0.00	1							
DMA	-0.54**	-0.66**	0.05	0.10	-0.85**	0.45*	0.54**	0.25	1						
FLA	-0.32	-0.46*	0.83**	-0.71**	-0.80**	0.65**	0.17	0.40	0.81**	1					
FLW	-0.65**	-0.22	-0.16	-0.52**	-0.43*	0.11	0.90**	0.03	0.40*	0.40	1				
FLS	-0.22	-0.47*	0.04	-0.12	-0.76**	0.59**	0.58**	0.17	0.99**	0.68**	0.02	1			
SL	-0.32	0.21	-0.54**	0.52**	0.31	-0.82**	-0.81**	-0.29	-0.38	-0.08	-0.52**	-0.50*	1		
Pub	-0.64**	-0.40	0.07	0.041	-0.25	-0.47*	-0.36	-0.68**	0.32	-0.02	-0.02	0.24	0.32	1	
TW	-0.46*	0.28	-0.23	0.01	0.40	0.25	0.29	0.24	-0.21	-0.04	-0.66**	-0.91**	0.28	-0.08	1

GY: grain yield, TKW: thousand kernel weight, S/m^2: number spike/m^2, K/S: number of kernel per spike, VIG: growth vigor, PLH: plant height, PD: peduncle length, DHE: days to heading, DMA: days to matyrity, FLA: flag leaf area, FLW: flag leaf weight, FLS: flag leaf senescence, SL: spike length, Pub: pubescence of stem, TW: test weight (hectoliter).

Table 3. Relative contribution (partial and model R^2) in predicting durum wheat grain yield, F-value and probability by the stepwise procedure analysis.

Characters entered into the model	Regression coefficient	Standard error	Partial R^2	Model R^2	TOL	F	Significant probability
TKW	99.35	4.66	57.3	57.3	0.68	1454.2	0.000
S/m^2	19.33	0.74	22.8	80.1	0.47	1674.6	0.000
K/S	95.78	4.45	17.4	97.5	0.44	1462.7	0.000

(1953) and Johnson and Moss, (1979) methods. For simple correlation analysis, a matrix of simple correlation coefficients between grain yield and its components were computed (Snedecor and Cochran, 1981). Stepwise multiple linear regression procedure was used to determine the variable accounting for the majority of total yield variability. Stepwise program computed a sequence of multiple linear regression in a stepwise manner. At each step, one variable was added to the regression equation. The added variable was the one that induced the greatest reduction in the error sum of squares. It was also the variable that had the highest partial correlation with the dependent variable for fixed values of those variables already added. Moreover, it was the variable which had the highest F-value. Path coefficient analysis was made on the basis of phenotypic correlation coefficients taking grain yield as effect and the remaining estimated characters as cause. Direct and indirect effects of component characters on grain yield were worked out using path coefficient analysis (Dewey and Lu, 1959) using PATH2 software. Appropriate statistical analyses were done using GenStat and SPSS packages.

Results and discussions

According to the data presented in Table 1, the measured traits had a relatively low diversity among the studied durum lines. The genetic variation coefficient, which expresses the amount of existing genetic variation as a percentage of the general mean, are of great importance for genetic improvement programs. The genetic variation coefficient shows the range of genetic variation for a trait, in view of its improvement potential (Valois et al., 1980). In our study, it ranged from 1.2% for days to heading (DHE) to 15% for peduncle length (PD). This low range indicates that there is not enough genetic variance available for yield increasing by improving measured traits among the studied genotypes. The lower coefficient of genetic variation of test weight, DHE and leaf senescence characteristics might be because of heat-forced maturity at the end of growing season. Grain yield also had low genetic variation coefficient (2.3%). Broad sense heritability ranged from 7.4% for grain yield to 88.7% for PLH traits. Broad sense heritability estimates were quite high for seedling growth vigor (VIG), plant height (PLH), days to maturity (DMA), peduncle length (PD), thousand kernel weight (TKW), number of kernel per spike (K/S), flag leaf senescence (FLS), spike length (SL) and test weight (TW), which are important criteria for selection in wheat breeding programs under drought condition (Chowdhry et al., 1992; Pecetti et al., 1992). For days to heading (DHE), spike number per square meter (S/m2), flag leaf area (FLA) and weight (FLW) and grain yield, estimates of the heritability were low, due to a larger contribution of the environmental variance in the phenotypic expression. Similarly, Yagdi et al. (2007) reported quite low broad sense heritability estimations for grain yield (5.6%) in durum wheat. They also reported low heritability for spike length (35.5%), plant height (9.1%) and grain number per spike (3%), which are in contrast with the findings of our study. Being low heritability for DHE, S/m2, FLA, FLW and yield traits in this study suggested that additive and/or dominant gene effects are not playing important role, but environmental variance had significant effect on these traits. For VIG, DMA, PLH, PD, K/S, FLS, SL, TKW and TW traits, existence of higher heritability in our study indicated that effective selection can be done in breeding programs (Aydogan and Yagdi, 2004). Simple correlation coefficients of variables with each other are presented in Table 2. Results showed that DHE, DMA, PD, FLW, Pub and TW had significantly negative correlation with grain yield, but TKW was positively correlated with yield. Similar results for DHE (Annicchiarico and Pecetti, 1995; Ceccarelli et al., 1991) and TKW (Leilah and Al-Khateeb, 2005) were reported under drought condition for wheat. The higher yield of genotypes with longer life cycle in the region seems attainable through longer grain filling via a delay of maturity (Annicchiarico and Pecetti, 1995). In contrast to our findings, other studies showed that early heading and early maturity in semi-arid locations are considered as indicators of increased tolerance to drought (Blum et al., 1989; Pecetti et al., 1994). The differential relations of yield components to grain yield may be attributed to environmental effects on plant growth (Asseng et al., 2002). Table 3 shows the data representing partial and cumulative R^2 as well as the probability for the accepted limiting three variables in durum grain yield prediction. These variables are TKW (57.3%), spike number per square meter (S/m2) (22.8%) and kernel number per spike (K/S) (17.4%). According to the results, 97.5% of the total variation in grain yield could be attributed to these three variables. The other variables were not included in the analysis, due to their low relative contributions. The average TKW of genotypes during two-year experiment was 41.6 g, which is varied from 28.6 to 52.2. There was a significant difference among the genotypes in both years for TKW. The interaction of this trait with year was significant. Broad sense heritability and genetic advance for TKW were 56.9 and 8.12 percent, respectively. TKW had positive and significant genetic correlations with grain yield. Genetic correlation of this trait with other yield components namely the number of spikes per unit area and the number of grains per spike was 0.33 and -0.52, respectively. Genetic correlation analysis of TKW showed that it had a considerable direct effect on grain yield. Also, its indirect effect through number of spike per unit area on grain yield was positive. TKW's indirect effect through other yield components (such as number of kernel per spike) was estimated negatively high. Positive correlation between grain yield and TKW is consistent with the findings of Fonseca and Paterson, (1968), Tahir et al. (1986), Moghaddam et al. (1993) and Shoran, (1995). In contrast, Ehdaei et al. (1988) reported negative correlation between TKW and grain yield. Fonseca and Paterson, (1968) reported negative indirect effect of kernel number per spike on TKW, which is similar with the results of this study. Shoran, (1995) reported direct and indirect effects of TKW on grain yield through two other yield components were poor and negligible. Fonseca and Paterson, (1968) reported the broad sense heritability for thousand kernel weight and its genetic advance about 84 and 19.9 percent, respectively. Ozkan et al. (1997) reported both of heritability and genetic gain for TKW 44 percent. Mahmoud and Shahid, (1991) mentioned heritability and genetic advance for TKW were 91 and 14 percent, respectively. Average number of spike per unit area in two-years was 210, which ranged from 163 to 334. However, there was no significant difference among the genotypes for this character. Interaction effect of genotype × environment (G × E) for number of spikes per unit area was significant. Broad sense heritability and genetic advance of this trait were 24.6 and 5.6 percent of the average, respectively. Genetic correlation between the number of spikes per unit area and grain yield was small and negligible. Genetic correlation analysis of spike number to its direct and indirect effects on grain yield indicated that this trait, similar to TKW, had high genetic direct effect on grain yield. Its genetic indirect effect through TKW on grain yield was positive, whereas indirectly reduced grain yield by decreasing

Table 4. Path coefficient (direct and indirect effects) of the estimated yield attributes on grain yield variation of wheat.

Variables	Effect
Effect of TKW	
Direct effect of TKW on GY	1.273
Indirect effect via S/M^2	0.551
Indirect effect via K/S	-1.064
Total	0.761
Effect of S/m^2	
Direct effect of GY	1.656
Indirect effect via TKW	0.757
Indirect effect via K/S	-2.535
Total	-0.121
Effect of K/S	
Direct effect of K/S on GY	2.029
Indirect effect via TKW	-1.192
Indirect effect via S/M^2	-2.069
Total	-1.231
Residual	0.354

Table 5. Durum wheat characteristics identified as crucial in wheat grain yield with each one of the used statistical techniques.

Trait	Simple correlation	Stepwise regression	Path analysis
TKW	√	√	√
S/m^2	√	√	√
K/S	√	√	√
PD	√		
DHE	√		
DMA	√		
FLW	√		
Pub	√		
TW	√		

kernel number per spike. In the report of Fonseca and Paterson, (1968) correlation of number spike per unit area with grain yield and its direct effect on yield were estimated positive and its indirect effects through the number of kernel per spike was negative and through TKW was negligible. Shoran, (1995) reported positive and significant correlation for this trait with grain yield. Positive correlation between spike per plant with grain yield by Mahmood and Shahid, (1991) and lack of significant genetic correlation of this trait with grain yield by Moghaddam et al. (1993) were reported. Average number of kernel per spike in two-year study was 44.4 ranged from 29.5 to 62.5. Genotype and interaction effect of G × E for this trait were significant. Its heritability and genetic advance were 53.4 and 9.4 percent of the average, respectively, which are lower than the findings of Ozkan et al. (1997), Shahid and Mahmood, (1991), Shoran, (1995) and Fonseca and Paterson, (1968). Genetic correlation of kernel number with grain yield was negatively significant. There was a negative and significant genetic correlation between this trait and TKW. Existence of negative correlation between kernel number and grain yield is consistent with the findings of Fonesca and Paterson (1968), Sinha and Khanna (1975), Ehdaei et al. (1988), Shoran (1995), Ozkan et al. (1997) and Moghaddam et al. (1993). Genetic correlation analysis of kernel number to its direct and indirect effects on grain yield showed that it had a high and positive direct effect of on grain yield. Whereas, its indirect genetic effects through two other yield components on grain yield was negatively significant. In wheat, both grain weight and grain number appeared to be sensitive to heat stress, as they declined with increasing temperature (Ferris et al., 1998). Physiologists have often suggested that the identification and selection of physiological and/or morphological traits is an effective approach to breeding for higher yield, and could be a valuable strategy for use in conjunction with normal methods of plant breeding. A range of traits has been suggested that could be utilized to increase the yield of parental germplasm or be used as indirect selection criteria, especially for improving yield under abiotic stress conditions.

Conclusions

The multiple statistical procedures which have been used in this study showed that TKW, number of spike per unit area were the most important yield variables to be considered under drought condition. This was clear with all used statistical procedures (Table 5). Thus, high yield of durum wheat plants under drought and heat conditions in Gachsaran, Iran can possibly be obtained by selecting breeding materials with high values of these traits. Hence, we concluded that TKW and number of spike per unit area are good measurement for heat and drought tolerance, because these traits could identify tolerant genotypes. These traits are preferred for breeding purposes as they have the advantages of combining the effects of many different factors without having to know physiological basis of each factor. However, we suggest that breeders do not generally select for specific traits to improve yield under drought principally because drought is unpredictable from year to year and this also means that the physiological responses to drought are also complex and unpredictable. These make breeding for drought resistance particularly slow and difficult.

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