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DETERMINING HERITABILITY, RELIABILITY AND STABILITY OF GRAIN YIELD AND YIELD-RELATED COMPONENTS IN DURUM WHEAT (*TRITICUM DURUM* L.)

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Abstract

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The major objectives of the study were to (1) evaluate genotypic yield performances of eighteen durum wheat genotypes, (2) determine their reliability and stability parameters and (3) estimate variance components and heritability of yield and yield-related traits. Eighteen durum wheat genotypes were evaluated in two conditions (rainfed and well watered) in Ilam and Gachsaran agricultural research stations of Iran during from 2009 to 2011 to identify patterns of genotype by environment interactions and their stabilities in terms of seed yield and yield-related components. Seed yield and its components are affected by plant genotype and environmental conditions. There were significant differences between genotypes of one or two years at each location for all the traits. Significant differences among years or between conditions were obtained in terms of all traits. Genotypes x environment interactions at all the traits were highly significant. Thus, the stabilities of eighteen durum wheat genotypes were different for all the traits. According to the stability parameters, G6 and G12 genotypes were stable for grain yield. Genotypes, GA//2*CHEN/ ALTAR84 and SHAG_26/SNITAN were considered as having high adaptability to both rainfed and irrigated conditions while OUASERL -1(G5) and OSSL-1/4/MRBSH/3/RABI//GS/CR/5/ HNA (G8) were considered as having low adaptability to both rainfed and irrigated conditions. The estimates of heritability values with limited phenotypic variance definition were 0.006, 0.163, -0.025, 0.396, 0.327, 0.346 and -0.075 for grain yield, plant height, test weight, thousand kernel weight, peduncle length, spike length, and number of grains per spike ranged respectively. The heritability with complete phenotypic variance definition were 0.001, 0.025, -0.006, 0.040, 0.114, 0.164 and -0.024 for the same traits, respectively. Moderate or low heritability values estimated for all the traits showed that family selection method could be used instead of individual selection in the breeding programs for improving grain yield and its components.

Key words: Durum Wheat, Gachsaran, GE Interaction, Grain Yield, Heritability, Reliability, Stability

Introduction

Durum wheat is one of the most important cereal crops, which are better adapted to semi-arid conditions. Durum wheat is grown on 10% of the world wheat area. It occupies approximately 11 million ha in the Mediterranean basin. The world's durum wheat acreage is concentrated in the Middle East, North Africa, the former USSR, the North American Great Plains, India, and Mediterranean Europe (Karimizadeh et al.,

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2011). In spite of its low acreage, durum wheat is an economically important crop because of its unique characteristics and products. Iran has had an important durum-breeding program in recent years, supported by the CIMMYT and ICARDA. Increasing the genetic potential of yield and its stability are major objectives of durum wheat breeding programs in Iran and other countries. Improved cultivars substantially contribute to increase durum wheat production. However, durum wheat yields in most production regions seem to be no more than the potential yields of the cultivars and far below the theoretical maximum yields (Rharrabti et al., 2003). Although durum wheat breeding programs have some priorities in common, the major objective of increasing the genetic potential of yield for most, if not for all, can be achieved through breeding for higher yield or eliminating improper factors that reduce yield. Ensuring the stability of high yield cultivars under unfavorable conditions is the main problem facing breeders producing improved different cultivars. The adaptability of a cultivar over diverse environments is usually tested by the degree of its interaction with different environments under which it is planted (Cooper et al., 1999).

The improved genotypes are evaluated in multi-environmental trials (MET) to test their performance across different environments and to select the best genotypes in specific environments (Karimizadeh and Mohammadi, 2010). In most cases, GE interaction is observed, complicating selection for improved yield. Evaluating stability of performance and range of adaptation has become increasingly important for breeding programs. Therefore, interpretation of GE interaction can be aided by statistical modeling. A large number of statistical procedures have been developed to enhance breeder's understanding of GE interaction, stability and adaptation (Sabaghnia et al., 2008). Flores et al (1998) compared 6 univariate stability procedures with 16 nonparametric and multivariate methods to analyze GE interactions. Mohebodini et al. (2006) and Dehghani et al. (2008) used 19 univariate stability methods for yield stability analysis. They declared that the univariate stability procedures and especially regression-based procedures are good estimators of yield stability.

Several stability analysis methods have been proposed to address the GEI interaction and study each cultivar's performance relative to other cultivars in different environments. They are based either on joint regression or in principal components analysis (Bernardo, 2002). Each method results in a corresponding stability parameter (index) as means for effective genotype/cultivar classification. Finlay and Wilkinson (1963) regression coefficient (bi), Eberhart and Russel (1966) deviation from regression (S_{di}^2), Shukla (1972) stability variance (σ_i^2) and Kang (1993) yield stability parameter (YSi), are some of the most widely used stability parameters. The additive main effects and multiplicative interaction (AMMI) model has been suggested as efficient means in determining stable and high yielding genotypes (Zobel and Gauch, 1988). AMMI partitions the overall variation into genotype main effects (G), environment main effects (E) and genotype environment (GEI) effects and utilize principal components analysis (PCA) to study GEI. In AMMI analysis, genotypes having low absolute values in the principal components are regarded as stable, while their mean performance could be predicted from the main effect model. Thus the use of the absolute values of the first principal component (IPCA1) or in combination with the second (IPCA2) were proposed as stability parameters (Gauch and Zobel, 1996).

In many crops, a variation of genotypes in time to reproductive stage is a source of genotype × environment interaction and requires appropriate consideration. In general, unfavorable conditions in time to reproductive stage differently affects productivity and growing of commercial cultivars in production areas. Thus, genotypes least effected from changed environmental conditions especially in reproductive stage can remain present in yield performance. The effect of unfavorable environmental conditions on yield performance is stronger in drought areas. The reliability index as proposed by Kataoka (1963) for economic analysis can be used for estimating on the basis of the distribution of yield values observed across test environment, the lowest yield expected for a given genotype and a specified probability of negative events (Eskridge,1990).

Heritability, a measure of the phenotypic variance attributable to genetic causes, has predictive function of breeding crops (Songsri et al., 2008). It provides an estimate of the genetic advance a breeder can expect from selection applied to a population under certain environment. The higher the heritability estimates, the simpler are the selection procedures (Khan et al., 2008). High genetic advance coupled with high heritability estimates offers the most effective selection criteria for selection (Larik et al., 2000). The magnitude of genetic inheritance and expected genetic advance are important for the prediction of response to selection in diverse environments and provide the basis for planning and evaluating breeding programs (Ahmad et al., 2006; Ahmed et al., 2007). High heritability alone is not enough to make sufficient improvement through selection generally in advance generations unless accompanied by substantial amount of genetic advance (Bhargava et al., 2003). The utility of heritability therefore increases when it is used to calculate genetic advance, which indicates the degree of gain in a character obtained under a particular selection pressure. Thus, genetic advance is yet another important selection parameter that aids breeder in a selection program (Shukla et al., 2004). Phenotypic and genotypic variance, heritability and genetic advance have been used to assess the magnitude of variance in wheat breeding material (Bhutta, 2006). The main aim was to identify the traits, which can be used as selection markers under irrigated and non-irrigated conditions.

Khan and Naqvi (2011) determined heritability among the traits under irrigated and non-irrigated conditions. Result of this research showed that a higher value of heritability (0.89) for spike length was obtained in non-stressed condition with low genetic advance. Phenotypic and genotypic coefficient of variation was very close. Higher broad sense heritability for spike length was obtained in irrigated condition. Other researchers had reported similar result (Kashif and Khaliq, 2004). A supervised feature selection algorithm was applied to determine the most important features contributing to wheat grain yield by Bijanzadeh et al. (2010). Four hundreds seventy-two fields (as records) from different parts of Iran, which were different in 21 characteristics (features), were selected for feature selection analysis. The feature selection algorithm selected 14 features as the most effective features on grain yield. These features included culture type, location, soil texture, 1000 kernel weight, nitrogen supply, irrigation regime, biological yield, the organic content of the soil, the amount of rainfall, genotype, plant height, and spike number per unit area (Bijanzadeh et al., 2010). Farshadfar et al. (2011) studied specific and general combining ability as well as and the genetic properties of agronomic and physiological characters in bread wheat. In the other research Nouri et al. (2011), evaluated 11 durum wheat-breeding lines and 3 checks based on grain yield, agronomic traits and drought tolerance indices under rainfed and irrigated conditions in the west of Iran. A positive and significant correlation was observed between yield under irrigated (Yi) and rainfed (Yr) conditions and mean productivity (MP), geometric mean productivity (GMP), and stress tolerance index (STI). Based on principle component analysis a significantly positive correlation was observed between stress susceptibility index and tolerance (Nouri et al., 2011). Heritability estimates showed that broad sense heritability of traits such as stomata resistance, stoma-density, and stoma-dimension in under and over surface of flag leaf; plant height, grains/spike and 1000-grain weight were higher than those of other characters were. Broad sense heritability of grain yield, biomass, harvest index, fertile tiller and leaf area was moderate (Rashidi, 2011). Sharma and Sharma (2007) reported high heritability values for grain yield/plant also they were estimated high GCV (genetic coefficient of variation) for number of effective tillers, grain yield/plant, harvest index and 1000 grain weight.

The objectives of our study were to (i) examine the influence of genotype, environment and genotype x environment interactions on seed yield and certain yield components of eleven durum wheat genotypes, (ii) evaluate seed yield and certain agronomic traits of durum wheat genotypes, (iii) determine their stability parameters, (iv) predict the broad sense heritability in terms of certain traits observed and (v) determine genotypes with high reliability and yield, depending on the differential genotypic responses to environments.

Material and Methods

Trials were conducted in 2008-2009, 2009-2010 and 2010-2011 growing seasons at Gachsaran and Ilam agricultural research stations. Gachsaran station situated at 710 meters altitude above sea level with longitude 50° 50' east and latitude 30° 20' north is located in south-western of Iran and Ilam station situated at 975 meters altitude above sea level with longitude 33° 47' east and latitude 36° 26' north is located in western of Iran. Some regional climatic data including average temperature and rainfall for three growth seasons in Ilam (first year) and Gachsaran (second and third years) stations is in Table 1. Soil texture of experimental site is silty clay loam and 20 years average of rainfall was 460 mm. In this study, eighteen durum wheat genotypes including BCR//MEMO/GOO/3/STJ7(G1), ALTAR84/STN / WDZ-2(G2), DON-MD 81-36 (G3), STJ3 // BCR / LKS4 (G4), OUASERL -1 (G5), GA // 2*CHEN/ ALTAR84(G6), AGAR1 /5/ SHEA /STK // BIT3 /KYP/4/ CHAH88 (G7), OSSL-1/4/ MRB-SH /3/ RABI//GS/CR /5/ HNA(G8), DA-6BLACK-AWNS /3/ BCR// MEMO/ GOO(G9), D86135/ACO89 // PORRON_4 /3/ SNITAN (G10), DUKEM /3/ RUFF/ FGO//AV79 /6/ CGEN/ALTAR84/4/…(G11), SHAG_26/SNITAN(G12), GEDIZ/FGO/ /GTA/3/ SRN_1/4/ TOTUS/5ENTE/… (G13), CMH82A.1062 /3/ GGOVZ394 // SBA81/ PLC /4/ AAZ-1/…(G14), SOOTY-9 / RASCON-37 /3/ SOOTY-9/ TARRO-1// AJAIA-2 (G15), LLARETA INIA/3/STOT// ALTAR 84/ALD /4/…(G16), MRB5 (G17) and DEHDASHT check cultivar (G18) were planted in two set (well-watered and rainfed conditions) by using a randomized complete block design for 3 years. Plots were planted at a seeding rate of 300 seed per m^2 by WINTERSTEIGER AG trial drilling machine on 25 November 2009 and 28 November 2010. Plot size was containing six rows (7.03 m long) with row differences of 17.5 cm. Fertilizers were applied 80 kg ha^{-1} of nitrogen and 80 kg ha^{-1} of phosphorus as 40.40.0 compose at planting time, 80 kg ha^{-1} of nitrogen as ammonium nitrate (half of the top dressed fertilizer) was given at tillering, and the other half of the top dressed fertilizer was given at swollen stage. No disease was shown during growth period, and weed control was made by chemical method (Topic and Granstar poisons). After physiological maturity, plots were harvested by WINTERSTEIGER AG trial thrasher machine. Regional climatic data during growth seasons (Mean of November 2009 to June 2010 and November 2010 to June 2011) is shown in Table 1.

In this study replicates of conditions and years of eighteen genotypes, the following linear model estimated variance components:

$$X_{ijkl} = \mu + G_i + B_{jkc} + C_k + Y_i + GC_{ik} + GY_{ic} + CY_{kc} + GYC_{ikc} + E_{ijkc} \quad (1)$$

Where; X_{ijkc} = Observed value, μ = general mean, G_i = effect of genotype, B_{jkc} = effect of replication (block), C_k = effect of condition, Y_i = effect of year, GC_{ik}, GY_{ic}, CY_{kc} and GYC_{ikc} = effects of Genotype x Condition, Genotype x Year, Condition x Year, and Genotype x Condition x Year interactions, respectively. E_{ijkc} = residual effects or experimental error. Additionally, g, r, c and y are number of genotypes, replications, conditions

Table 1
Regional climatic data including average temperature and rainfall for three growth seasons from 2008-2009 to 2010-2011

	2008-09 Season (Ilam)		2009-10 Season (Gachsaran)		2010-11 Season (Gachsaran)	
	Average temperature	Rainfall, mm	Average temperature	Rainfall, mm	Average temperature	Rainfall, mm
November	12	119.3	17.6	43.6	18.1	13.7
December	6.8	13.4	9.6	96.3	8.9	83.9
January	4.9	14.4	8.4	44.9	7.3	151.4
February	8.5	49	12.3	24.1	11.8	136.8
March	11.2	28.4	15.6	51.6	15.2	7.9
April	14.7	46.9	30.1	41.2	30.3	14.8
May	22.4	2.7	26.9	0	25.6	2.1
June	28.3	-	30.6	0	31.2	0
Total	-	274.1	-	301.7	-	410.6

and years, respectively (in this study, g = 18, r = 4, c = 2 and y = 3).

Variance components were estimated using expected mean squares of the analysis of variance as pointed out in Table 2. Nine different components of variance were calculated using their appropriate MS contributing them. For example, genotypic and genotype x condition components were estimated using below equations:

$$\sigma_G^2 = \frac{M_5 - M_6 - M_7 + M_8}{rcy} \quad (2)$$

$$\sigma_{YC}^2 = \frac{M_3 - M_4 - M_8 + M_9}{rg} \quad (3)$$

Other components were estimated by below equations that are simpler than last equations:

$$\sigma_{GY}^2 = \frac{M_7 - M_8}{rc} \quad (4) \qquad \sigma_{GC}^2 = \frac{M_6 - M_8}{ry} \quad (5)$$

$$\sigma_{GYC}^2 = \frac{M_8 - M_9}{r} \quad (6)$$

Two types of heritability were estimated as with complete and limited phenotypic variance definition as suggested by Gordon et al. (1972). These were calculated using the following equations:

Heritability with complete phenotypic variance definition (h_1^2)

$$h_1^2 = \frac{\sigma_G^2}{\sigma_R^2 + \sigma_Y^2 + \sigma_C^2 + \sigma_{YC}^2 + \sigma_G^2 + \sigma_{GY}^2 + \sigma_{GC}^2 + \sigma_{GYC}^2 + \sigma_E^2} \quad (7)$$

Heritability with limited phenotypic variance definition (h_2^2)

$$h_2^2 = \frac{\sigma_G^2}{\sigma_G^2 + \sigma_{GY}^2 + \sigma_{GC}^2 + \sigma_{GYC}^2 + \sigma_E^2} \quad (8)$$

All the terms at the denominators and nominators are estimates of the variance components determined in this study.

AMMI's stability value (ASV) was calculated using as suggested by Purchase (1997):

$$ASV = \sqrt{\frac{SSIPC\ 1}{SSIPC\ 2}(PC1)^2 + (PC2)^2} \quad (9)$$

Where, ASV is the AMMI's stability value, SS, sum of squares, IPCA1, interaction of principal component analysis one, IPCA2, interaction of principal component analysis two.

The reliability index: The reliability index as proposed by Kataoka (1963) can be calculated by the following expression:

$$I_i = m_i - Z(P)S_i \quad (10)$$

Table 2
Source of variation, calculated mean squares (MS) and their expected values

Source	Degree of freedom	MS	Expected Mean Square
Conditions (C)	c-1	M	$\sigma_e^2 + g\sigma_R^2 + r\sigma_{GYC}^2 + ry\sigma_{GC}^2 + rg\sigma_{YC}^2 + rgy\sigma_C^2$
Years (Y)	y-1	M_2	$\sigma_e^2 + g\sigma_R^2 + r\sigma_{GYC}^2 + rc\sigma_{GY}^2 + rg\sigma_{YC}^2 + rgc\sigma_Y^2$
C × Y	(c-1)(y-1)	M_3	$\sigma_e^2 + g\sigma_R^2 + r\sigma_{GYC}^2 + rg\sigma_{YC}^2$
Block in Y/C	yc (r-1)	M_4	$\sigma_e^2 + g\sigma_R^2$
Genotypes (G)	g-1	M_5	$\sigma_e^2 + r\sigma_{GYC}^2 + rc\sigma_{GY}^2 + ry\sigma_{GC}^2 + ryc\sigma_G^2$
G × C	(g-1)(c-1)	M_6	$\sigma_e^2 + r\sigma_{GYC}^2 + ry\sigma_{GC}^2$
G × Y	(g-1)(y-1)	M_7	$\sigma_e^2 + r\sigma_{GYC}^2 + rc\sigma_{GY}^2$
G × Y × C	(g-1)(y-1)(c-1)	M_8	$\sigma_e^2 + r\sigma_{GYC}^2$
Error	yc (g-1)(r-1)	M_9	σ_e^2

Where mi = mean yield, Si = square root of the environmental variance (S^2) and Z(P) = percentile from the standard normal distribution for which the cumulative distribution function reaches the value P. The Z(P) can assume the following values depending on the chosen P level: 0.675 for P = 0.75; 0.840 for P = 0.80; 1.040 for P = 0.85; 1.280 for P = 0.90; and 1.645 for P = 0.95. P values may vary between 0.95 (for subsistence agriculture in favorable cropping regions) to 0.70 for modern agriculture in most favorable regions (Annicchiarico, 2002).

Stability analysis was applied for each trait using the stability parameters as proposed by Finlay and Wilkinson (1963), Francis and Kannenberg (1978) and AMMI stability value (ASV) parameters (Purchase, 1997). These parameters are public indices that use by plant breeders since ten years ago, also there is not necessary to display their formulas here. For calculation of stability parameters used of macro program that wrote in MATLAB software.

Results and Discussion

Analysis of variance

Analysis of variance of was conducted to determine the effects of year, condition, genotype, and interactions among these factors, on grain yield of durum wheat genotypes (Table 3). The effects of years (Y) were significant (P<0.01), the conditions (C) effects were also significant (P > 0.01) and their interactions (Y × C) were highly significant (P<0.01). The main effect of genotypes was high significant (P<0.01), the genotype by year interaction (G × Y), genotype by condition interaction (G × C) and three way interactions (G × Y × C) were highly significant (P<0.01). Grain yield is a quantitative trait, which expression is the result of genotype, environmental effect and GE interaction (Huhn and Leon, 1985). Complexity of these traits is a result of diverse processes that occur during plant development. Cooper and Byth (1996) explained that the larger the degree of GE interaction, the more dissimilar the genetic systems controlling the physiological processes conferring adaptation to different environments. The combined analysis of variance indicated that the main effects of year (Y), condition (C) and genotype (G) were significant for all traits studied (Table 3). The Y × C interaction was only significant for thousand kernel weight, peduncle length and number of grains per spike. The G × Y interaction was significant for the all traits excluding plant height and test weight. On the other hand, the interaction between genotype and condition (G × C) was highly significant for the all traits

Table 3
Results of analysis of variance (Mean squares) for grain yield and yield components observed from trials conducted in three years and two conditions

Source	DF	Yield (Kg.ha^{-1})	Plant height	Test weight	Thousand Kernel Weight	Peduncle length	Spike length	Number of grains per spike
Conditions (C)	1	474419121**	437.2^{ns}	3830 **	2390.9**	766.4**	22.8**	5877.1**
Years (Y)	2	2937488^{ns}	23035.4**	2936.5**	**5099.5	56.2^{ns}	8.8*	9583.8**
YÍC	2	4935481*	998.04*	801.0**	674.81**	482.4**	2.14^{ns}	282.16*
Block in Y/C	18	3800980	958.42	119.9	68.44	118.49	3.03	125.16
Genotypes (G)	17	761629**	387.33**	15.8*	67.67**	70.75**	3.50**	156.43**
GÍC	17	643519*	115.5**	19.2*	7.9*	29.7**	1.06**	33.4*
GÍY	34	654194*	159.0**	16.7*	11.9**	11.7**	0.88**	**237.1
GÍYÍC	34	583348*	27.88**	11.89^{ns}	5.59*	11.7**	0.68**	34.1*
Error	306	224298	6.94	12.3	4.33	0.9	0.04	14.1
Total	431	-	-	-	-	-	-	-
CV%	-	13.4	3.3	4.8	6.2	4.4	2.9	8.5

* and ** = Significant in 0.05 and 0.01 probability levels
ns = Not significant

excluding plant height. In addition, triple interaction (G × L × Y) was found significant for all of the traits, except thousand-kernel weight (Table 3).

Agronomic performance of durum wheat genotypes

Comparisons were made between durum wheat genotypes used in terms of important agronomical traits in the study. Eighteen durum wheat genotypes were significantly different from the traits observed (Table 4). According to the results obtained over years in rainfed condition, the mean values of genotypes for grain yield, plant height, test weight, thousand kernel weight, peduncle length, spike length, and number of grains per spike ranged between 1747.5 and 2240.3 $kg.ha^{-1}$, 71.8 and 88.2 cm, 65.4 and 71.9 kg/100 liters, 27.9 and 34.8 g, 17.8 and 22.4 cm, 6.1 and 7.8 cm, 37.0 and 44.9 grains per spike, respectively. Result in well watered condition comprised with rainfed condition in Table 4. The values of previous traits were between 3596.1 and 4780.8 kg/ha^{-1}, 70.5 and 93.3 cm, 71.9 and 78.1 kg/100 liters, 31.7 and 38.6 g, 19.7 and 26.7 cm, 7.0 and 8.5 cm, 45.1 and 55.2 grains per spike, respectively. Genotypes, G12, G6 and G14 in watered condition and G6, G18 and G16 in rainfed condition were higher in grain yield than the others were. The lowest yielding genotypes were G8 and G9 in watered and rainfed conditions respectively. G8 (OSSL-1/4/MRBSH/3/RABI//GS/CR /5/HNA) and G9 (DA-6 BLACK AWNS/3/BCR//MEMO/GOO) which were also lowest mean values in the other traits measured. In general, the highest yielding genotypes had the highest means in terms of agronomical traits (Table 4). Similar results were obtained in previous local studies also (Nouri et al., 2011; Karasu et al., 2009; Farshadfar et al., 2011). In 2010, most of the genotypes gave higher mean values in terms of number of grains per spike, thousand kernel weight, test weight and grain yield relative to re-

Table 4
Mean of agronomical traits for eighteen genotypes tested at two conditions over three years during 2008-2011

Entry	Grain yield		Plant height		Test weight		Thousand Kernel Weight		Peduncle length		Spike length		Number of grains per spike	
	Rainfed	Watered	Rainfed	Watered	Rainfed	Watered	Rainfed	Watered	Rainfed	Watered	Rainfed	Watered	Rainfed	Watered
G1	1938.2	4094.3	72	78.7	71.5	75.3	34.8	38.6	19.1	21.2	6.6	7.4	37	45.2
G2	1879.6	3882.3	88.2	93.3	70.2	76.1	30	34.9	21.3	24	6.9	7	39	48.5
G3	1859	4023.6	86	78.1	69.5	75.9	29.2	34.7	19.1	21.3	6.7	7.3	39.4	45.5
G4	1995.8	3933.4	77.6	86.1	71	76.7	32.2	36.5	17.8	18.5	6.8	7.8	41.6	45.8
G5	2093.8	3924.6	77.6	85.1	71.7	77.3	30.9	37.3	22.3	23.8	7.7	8.5	38.5	52.1
G6	2240.3	4739.6	76.8	78.6	65.4	78.1	27.9	33.2	19.5	19.7	7.2	7.4	49.8	55.2
G7	2030.8	3864.9	73.9	81.1	69	75	29.1	34.4	18.5	18.5	7.5	7	39.1	47.5
G8	2112.3	3596.1	71.8	75.2	68.5	71.9	30.9	38	22.4	24.5	6.1	6.9	40.5	45.5
G9	1747.5	3930.9	73.6	73.3	67.2	72.7	29.1	32.3	17.9	20.5	6.4	7.1	38.8	44.7
G10	1929	4044.3	75.3	79	69.9	76	30.2	31.7	18.2	21.6	7	7.2	39.6	50.5
G11	2117.7	4194.4	78.4	77.9	71.9	77.6	28.9	34.4	19.4	26.2	7.1	8.1	40.9	49.8
G12	1834.7	4780.8	84.1	82.3	70.5	76.4	31.1	34.8	19.7	26.7	6.7	7.4	41	47
G13	2159.3	4284.6	81.9	79.7	70.4	76.3	30.1	36.2	20.7	26.5	7.1	7.2	40.1	45.2
G14	2010.8	4482.3	82.3	82.1	71.1	76.7	31.3	35	19.9	22	7.1	7	44.9	48.6
G15	2090.3	4040.6	74.5	79.4	69.1	75.3	31.1	33.9	20.7	22.8	6.8	7.5	41.1	48.5
G16	2150.3	4440.2	74.7	70.5	71	76.3	30.4	35	20.9	23.2	6.7	7.2	38.1	45.6
G17	2131.6	4085.7	77.2	78.6	70.5	75.1	33.9	37.4	19.1	22.5	7.3	8	38.3	45.1
G18	2178.4	3883	77.9	78.2	71	76	34.1	38.5	21.9	24.1	7.8	8.5	39.2	48.4

sults of 2009 and 2011. The highest means for the other traits were obtained in 2009 or 2011. Temperature and precipitation are important environmental factors that have a great impact on durum wheat yield. Temperature and precipitation could be the underlying factors that have contributed to the year effect in this research. Therefore, temperature and precipitation differences at growing season of durum wheat between 2009 and 2011 years were considered (Table 1). In general, 2009 and 2011 seasons were substantially drier than 2010. On the other hand, temperatures at growing season of durum wheat plant were slightly changed across the years. These climatic conditions likely contributed to most of the differences observed among years.

Stability parameters of durum wheat genotypes

Genotype × environment interaction in multiple-condition and multiple-year trials can be partitioned in to G × C, G × Y and G × C × Y interactions. Our results indicated that performances of genotypes in terms of traits studied were different at each condition and year. Therefore, G × C, G × Y and G × C × Y interactions were found significant (Table 3). For example, all the genotypes, except G4, G2 and G17 were high yielding in rainfed condition at first year, while differences between genotypes were not significant in rainfed condition in this year. Although, all genotypes had higher yield in 2009 and 2010 years than 2011 year. The genotypes G4, G8, G3 and G12 gave higher grain yield relative to the other genotypes in 2009 at well watered condition. The significant G × Y and G × C interactions reflected changes in the rank of the genotypes for grain yield (Table 4). The first trait measured in the study was the plant height observed at pre-harvesting time. The mean plant heights of genotypes were ranged between 70.5 and 93.3 cm. Among genotypes used in the study, G2 gave the tallest plants while G16 had the shortest plants. The regression coefficients (bi) of genotypes for plant height ranged between 0.45 (G10) and 1.31 (G15). The genotypes G6, G12, G17 and G18 had regression coefficients near to 1 (Table 5). In this research, Coefficient of variation (CV) used as a first type of stability parameter. According to Coefficient of variation statistics, genotypes G6, G12, G2 and G14 were the most stable genotypes based on environmental coefficient of variation (CV) for plant height trait (Table 5). The ASV as described by Purchase (1997) is comparable with the other stability parameters of AMMI model in the study of GE interaction. Table 5 indicates the ASV values of the AMMI model for each genotype in each trait. Results of ASV parameter for plant height trait showed that genotypes G6, G9 and G18 were the most stable genotype. The second trait measured in the study was test weight that measured at post-harvesting time. Result of three stability parameters showed that genotypes G15, G4, G2 and G6 were most stable genotypes for test weight by ASV parameter and genotypes G5, G6, G17 and G12 had smallest CV of Fransis and Kanneberg (1978), also these genotypes were best genotypes for this test weight trait. The regression coefficients (bi) of genotypes for test weight ranged between 0.38 (G8) and 1.34 (G17). The genotypes G14, G15 and G18 had regression coefficients near to 1. These genotypes could be considered as having high adaptability to all environments.

The third trait measured in the study was thousand-kernel weight that measured at post-harvesting time. Result of stability parameters showed that genotypes G13, G4 and G2 were most stable genotypes for thousand kernel weight by ASV parameter and genotypes G18, G15, G17 and G2 had smallest CV of Fransis and Kanneberg (1978), also these genotypes were best genotypes for thousand kernel weight trait. The regression coefficients (bi) of genotypes for thousand kernel weight ranged between 0.58 (G17) and 1.28 (G11). The genotypes G8 and G10 had regression coefficients equal 1.

The fourth trait measured in the study was peduncle length that measured at pre-harvesting time. Result of AMMI stability value (ASV) showed that genotypes G18, G6 and G14 were most stable genotypes for thousand-kernel weight by this parameter. The values of ASV parameters had significant differences and ranged between 1.81 to 22.03. Genotypes G18 and G15 had smallest CV of Fransis and Kanneberg (1978), also these genotypes were best genotypes for peduncle length trait. The coefficients of variation of genotypes were ranged between 8.38 and 24.22. The regression coefficients (bi) of genotypes for peduncle length ranged between 0.48 (G3) and 1.46 (G11). The genotypes G1, G12 and G15 had regression coefficients

Table 5
Stability and reliability parameters of durum wheat genotypes (means of rainfed and well watered conditions)

Entry	Grain yield				Plant height				Test weight				Thousand Kernel Weight				Peduncle length				Number of grains per spike			
	ASV	CVi	bi	Ii	ASV	CVi	bi	Ii	ASV	CVi	bi	Ii	ASV	CVi	bi	Ii	ASV	CVi	bi	Ii	ASV	CVi	bi	Ii
G1	21.79	29.03	1.14	1698	1.42	13.15	1.08	44.7	1.67	15.78	0.51	59.3	0.79	23.5	0.77	20.8	3.48	11.71	1.03	8.3	1.68	21.08	0.98	32.5
G2	7.81	26.31	1.11	1634	4.22	11.92	1.05	55.2	0.7	20.98	1.21	89.7	1.58	17.9	1.1	26.7	7.67	9.92	1.31	7.1	10.82	17.86	0.51	29.5
G3	39.22	28.64	0.82	1566	3.05	12.97	0.73	42.6	0.73	19.36	0.87	93.6	1.6	23.2	1.09	19.7	0.31	11.62	0.48	5.8	9.92	20.91	0.68	33.5
G4	31.17	38.68	1.17	1523	3.36	17.52	1.12	34.7	0.55	15.79	0.96	67.5	0.58	31.4	0.83	15.3	7.79	24.22	0.85	5	11.68	25.6	0.8	48.9
G5	58.89	36.85	1.25	1398	2.08	16.69	1.21	27.9	0.78	12.99	0.92	62.2	1.42	28	0.88	11.5	9.38	13.14	0.82	2.7	12.04	23.65	0.78	45.3
G6	7.28	23.52	1.01	1482	0.38	10.65	0.99	36.8	0.77	12.16	0.91	69.3	1.01	24.7	0.95	11.9	1.96	12.1	0.95	3.3	0.44	21.78	0.99	43
G7	32	26.18	0.89	1607	1.51	11.86	0.51	50.3	1.12	15.38	0.62	97.1	0.48	21.3	0.89	23.9	16.57	11.03	1.16	6.6	26.95	19.85	1.17	30.1
G8	53	26.8	0.73	1571	1.18	12.14	0.63	43.5	0.49	18.01	0.38	90.6	1.76	18.1	1	20.2	13.99	9.99	1.3	5.9	25.83	17.99	0.8	17
G9	29.96	35.63	0.92	1710	0.43	16.14	0.84	69.2	0.78	22.05	0.92	86.4	0.22	20.9	1.1	34.5	10.87	10.88	1.43	8.5	29.15	19.58	0.78	25.8
G10	17.36	32.88	0.84	1626	2.07	14.89	0.45	53.7	0.72	20.37	0.85	63.3	1.29	32.9	1	25.8	14.51	14.69	1.3	6.9	0.99	26.44	0.91	39
G11	31.09	26.81	1.03	1876	2.55	12.14	0.96	99.3	0.86	18.76	0.97	39.6	1.29	18.7	1.28	51.2	22.03	10.18	1.46	9.8	4.21	18.32	0.83	44.8
G12	6.75	22.06	1.02	1503	1.14	11.99	1.05	30.8	1.49	14.1	1.08	55.5	1.61	19.2	1.13	13.1	7.38	11.53	1.03	4.7	4.59	24.36	0.88	47
G13	16.49	30.83	0.95	1731	1.41	13.97	0.88	73.2	0.13	15.49	0.96	79.1	1.25	25.9	0.65	36.7	15.2	12.49	0.85	8.9	1.8	22.48	0.82	34.6
G14	25.51	26.12	1.03	1684	0.92	11.83	0.96	64.5	1.17	16.87	0.99	84.1	0.68	30.7	0.63	31.8	2.39	14	0.82	8	3.63	25.19	1.1	40.9
G15	16.72	30.59	1.25	1546	3.64	13.86	1.31	38.9	0.25	22.78	1.02	71.3	0.92	14.7	0.7	17.6	3.49	8.93	0.99	5.5	1.61	16.08	1.24	28
G16	17.53	37.44	1.1	1518	2.81	16.96	1.14	33.6	0.9	21.7	1.04	82.6	0.31	17.9	0.67	14.7	11.7	9.94	0.87	4.9	0.21	17.9	1.02	48.5
G17	7.78	34.59	1.08	1777	1.06	15.67	1.02	81.7	1.07	13.85	1.34	93.7	1.18	18.7	0.58	41.4	12.36	10.18	0.75	9.7	2.32	18.33	1.24	41.7
G18	64	31.85	1.11	1737	0.63	14.43	1.05	74.2	0.82	15.42	1.01	96.2	0.48	13	0.66	37.2	1.81	8.38	0.86	9	1.61	15.08	1.58	47

ASV= AMMI Stability Value, CV_i = Coefficient of Variance of Francis and Kannenberg (1978), b_i = Correlation coefficient of Finlay and Wilkinson (1963), Ii = Reliability index equal 1. These genotypes could be considered as having high adaptability to all environments.

The fifth trait measured in the study was number of grains per spike that measured at pre-harvesting time. Result of AMMI stability value (ASV) showed that genotypes G16, G6 and G10 were most stable genotypes for number of grains per spike by this parameter. The values of ASV parameters had significant differences and ranged between 0.21 to 29.15. Genotypes G18, G16 and G2 had smallest Coefficient of variance; also, these genotypes were best genotypes for number of grains per spike trait. The coefficients of variation of genotypes were ranged between 15.08 and 26.44. The regression coefficients (bi) of genotypes for peduncle length ranged between 0.51 (G2) and 1.58 (G18). The genotypes G1, G6 and G16 had regression coefficients equal 1. These genotypes could be considered as having high adaptability to all environments for this trait.

Result of AMMI stability value (ASV) for grain yield showed that genotypes G2, G6, G12 and G17 were most stable genotypes by this parameter. The values of ASV parameters had significant differences and ranged between 6.75 to 58.89. Genotypes G6, G12 and G14 had smallest coefficient of variance; also, these genotypes were best genotypes for yield stability. The coefficients of variation of genotypes were ranged between 22.06 (G12) and 36.85 (G5) for grain yield. The regression coefficients (bi) of genotypes for ranged between 0.73 (G8) and 1.25 (G5 and G15). The genotypes G6, G11 and G12 had regression coefficients equal 1 also these genotypes could be considered as having high adaptability to all environments.

The reliability index (Ii) for traits in durum wheat genotypes

Making assumption that the technological level of agriculture and field conditions in three years in this research falls between subsistence agriculture and modern agriculture, we took (P) = 0.8, which corresponds to a Z(P) = 0.84 to be inserted in equation 10 (see material and methods section). The reliability index (Ii) did not rank the genotypes and exist in Table 5 for each genotype across the test environment. Table 5 shows that for grain yield, the top three reliable genotypes were G5, G6 and G12. The reliability index of genotypes were ranged between 1398 (G5) and 1876 (G11) for grain yield. It is not surprising that genotypes G6 and G12 appear as the most reliable genotypes because of the regression coefficient analysis (bi coefficient close to 1.0), smallest ASV and CVi parameters. For plant height trait, genotypes G4, G6 and G14 had smallest Ii index and were most reliable genotypes. The reliability index of genotypes were ranged between 30.8 (G12) and 99.8 (G11) for plant height trait. For test weight trait, genotypes G11 and G12 had smallest Ii index and were most reliable genotypes. For thousand-kernel weight trait, genotypes G1 and G12 had smallest Ii index and were most reliable genotypes for this trait. For peduncle length trait, genotypes G5 and G6 had smallest Ii index and were most reliable genotypes for this trait and finally for number of grains per spike trait, genotypes G8 and G15 had smallest Ii index and were most reliable genotypes for this trait.

Components of variance and heritability

Heritability and gene action of yield and yield components were estimated in a Golia x Cumhuriyet 75 cross using generation mean analysis (Erkul et al., 2010). The additive-dominance model was valid for spike length, number of spikelets per spike, thousand kernel weight, fertile tiller number, and grain yield. On the other hand, the six-parameter model was fitted for explaining genetic variation for number of kernels per spike, number of kernels per spikelet, and single spike yield. Heritability estimates and genetic advances were low for number of kernels per spike, thousand kernel weight and grain yield; medium for spike length, number of kernels per spikelet; high for number of spikelet per spike, spike yield and fertile tiller number (Erkul et al., 2010). In Rashidi et al. (2011) research, heritability estimates of durum wheat traits showed that broad sense heritability of traits such as stomatal resistance, stoma-density, and stoma dimension in under and over surface of flag leaf; plant height, grains/spike and 1000-grain weight were high, but heritability of traits such as grain yield, biomass, harvest index, fertile tiller and leaf area were moderate.

Estimated components of variance contributing to G × E interaction were found significant for all traits investigated (Table 6). The largest sources of G × E interaction (the G × Y and G × C variance components) for plant height were equal 0.60 approximately. The genetic variance for plant height also had a significantly high value. Also, the C (condition) and Y (year) variance components into total (phenotypic) variance were significantly high level. Thus for plant height, heritability with complete phenotypic variance definition was low (0.025), but heritability with limited phenotypic variance definition was relatively higher value (0.163). These results validate results of the Yagdi and Sozen (2011) and Abinasa et al. (2011) studies and are inconsistent with the results of the Khan and Naqvi (2010) research. Abinasa et al. (2011) reported plant height and number of kernels per spike showed the highest phenotypic and genotypic coefficients of variations and genetic advance, whereas, days to maturity and test weight had the lowest values. Plant height exhibited highest heritability value of 98.3% while number of spikelet per spike showed minimum value of 36.4%.

For test weight, condition variance component was the largest component of the total variance, and year variance component had second large contribution. However, the genetic variance component (G) was smaller than the other components. The heritability as h_1^2 and h_2^2 for test weight were -0.006 and -0.025, respectively. Test weight was one of the attributes with the smallest heritability in this study. These results validate results of the Yagdi and Sozen (2011) and Abinasa et al. (2011) studies. For the thousand-kernel weight, year (Y) and year × condition (Y × C) variance components were larger than the other components. Heritability with complete phenotypic variance definition was very low level (0.040). Heritability with limited phenotypic variance was moderate or high level (0.396). These results with the results of the study Rashidi et al. (2011) are consistent and are inconsistent with the results of the Yagdi and Sozen (2009) study. The largest source of total variance for thousand-kernel weight was the Y variance component, followed by the Y × C, C, E and R variance components.

For peduncle length trait, the highest proportion into phenotypic variance had the R variance compo-

Table 6
Estimates of variance components and heritability of certain agronomical traits for eighteen durum wheat genotypes tested at two conditions during 2009 to 2011

Estimates	Grain yield	Plant height	Test weight	Thousand Kernel Weight	Peduncle length	Spike length	Number of grains/ spike
Variance component							
σ_y^2	-14366.9	152.13	14.8	30.68	-2.97	0.04	63.19
σ_C^2	2173207	-3.2	14	7.92	1.31	0.09	24.96
σ_{YC}^2	10770.15	0.26	9.47	8.4	4.9	-0.02	1.9
σ_R^2	198704.6	52.86	5.98	3.56	6.53	0.17	6.17
σ_G^2	1969.33	5.86	-0.34	2.23	1.71	0.09	-3.33
σ_{GY}^2	8855.75	16.39	0.6	0.79	0.13	0.03	25.38
σ_{GC}^2	5014.25	7.3	0.61	0.19	1.5	0.03	-0.06
σ_{GYC}^2	89762.5	5.24	-0.1	0.32	2.7	0.16	5
σ_e^2	224298	6.94	12.3	4.33	0.9	0.04	14.1
Heritability							
h_1^2 (full)	0.001	0.025	-0.006	0.04	0.114	0.164	-0.024
h_2^2 (limited)	0.006	0.163	-0.025	0.396	0.327	0.346	-0.075

nent, followed by the Y × C, Y, and G × Y × C variance components. Both heritability values (h_1^2 and h_2^2) were moderate to high values (0.114 and 0.327 respectively). The most important components of the phenotypic variance for spike length were the R, G × Y × C variance components. Heritability with complete phenotypic variance definition (h_1^2) was moderate (0.164) due to significantly higher Y × C interaction. However, heritability with limited phenotypic variance was moderate or high level (0.346). These results validate result of Khan and Naghvi (2011) research and in contrast to results of Yagdi and Sozen (2009). The number of grains per spike trait, the highest proportion into phenotypic variance had the Y variance component, followed by the G × Y, and C variance components. Both heritability values (h_1^2 and h_2^2) were low values (-0.024 and -0.075 respectively).

The G × Y × C variance component was found to be the most important source of total variance for grain yield. The second and third largest sources of total variance were the C and G variance components, respectively. The smallest heritability estimates in the study were obtained from seed yield with 0.001 and 0.006 (h_1^2 and h_2^2 respectively). Grain yield is a quantitative character. It is called complex character because many genes control it. The variation within a quantitative character is due to its complex inheritance and to the influence of the environment (Fehr, 1978). As a result, low or moderate heritability for all characters were found in the present study.

Conclusion

In conclusion, this study has provided evaluation of the environmental and agronomic performance of certain durum genotypes. In addition, heritability of some agronomical traits was predicted using phenotypic variance components in the study. The G × Y, G × C and G × Y × C effects were significantly found for grain yield and the other traits studied. Temperature and precipitation were environmental factors that had a major impact on durum wheat yield. In general, 2010 was substantially drier than 2009 and 2011 growing seasons. These climatic conditions likely contributed to most of the differences observed among years. Stability analysis, demonstrated that there were two stable genotypes (G6 and G12) for grain yield whereas some genotypes were considered as having high adaptability to the favorable environments and the other genotypes to the unfavorable environment conditions. The Genotype × Environment (G x E) variance components were the most important source of total or phenotypic variance for all traits observed. Thus, the heritability estimates for all characters were found low or moderate levels. In summary, the low heritability and large G × E interactions indicated that grain yield, test weight and number of grain per spike are not inherited quantitatively in durum wheat. In contrast, other traits such as 1000-kernel weight, peduncle length and spike length are inherited quantitative attributes. Selection progress for improved durum yield and yield components will be small but possible. Thus, using family selection method could increase success in breeding programs for improved grain yield.

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