Australian Journal of Crop Science

AJCS

AJCS 7(5):609-617 (2013) ISSN:1835-2707

Evaluation of grain yield and some agronomic characters in durum wheat (*Triticum turgidum* L.) under rainfed conditions

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Abstract

In order to identify agronomic and morpho-physiological traits related to drought tolerance in 410 F_5 families of durum wheat an investigation was conducted under rainfed conditions. The relationships between the durum grain yield and the related traits under drought conditions evaluated using several multivariate analyses, including simple correlation, path-coefficient analysis, stepwise regression, factor analysis and cluster analysis. For path coefficient analysis traits were partitioned in two groups one including the traits with the primary effects on grain yield and the other, traits with the secondary effects on grain yield via their effect on the primary traits. Path coefficient analysis indicated that at the primary level biomass had the highest positive direct effect on grain yield (0.584), while at the secondary level the highest direct effect on the number of seed per spike (0.517) belonged to the spike length (0.517) and on the mean grain weight (0.218) was related to peduncle length. Factor analysis revealed four factors. The first factor which accounted for about 0.2735 of the total variation was strongly associated with the number of spikes per plant, the number of tillers per plant, biomass and grain yield. Principal component and cluster analysis exhibited strong relationships between grain yield, above ground biomass, the number of tillers per plant and the number of spikes per plant. Our field screening techniques suggested diversity-dependent strategy based on plant height, the number of tillers per plant, the number of spikes per plant, above ground biomass and harvest index for breeding durum wheat under drought stress condition.

Keywords: yield components; dry land farming; factor analysis; principal component analysis; path-coefficient analysis; cluster analysis.

Abbreviations: PH_Plant height, PED_ peduncle length, FL_ flag leaf length, GY_ grain yield of plant, SpD_ spike density, MGW_ mean grain weight, P/H_ peduncle/plant height, SL_ spike length, HI_ harvest index, NSPP_ number of spikes per plant, NSPS_ number of seed per spike, AL_ awn length, NTPP_ number of tillers per plant, BIO_ biomass, RWC_ leaf relative water content, DF_ degree of freedom**.**

Introduction

Drought stress is the main constraint of the wheat production in many parts of the world. Iran, with about 220 mm of average annual rainfall is located in the dry part of the world except some northern provinces, which are located in the vicinity of the Caspian Sea (Nouri-Ganbalani et al., 2009). In semiarid regions, dry farming is often practiced for wheat production. In these areas, the behavior of the rainfall is highly variable ; the low soil moisture is identified as a major factor limiting crops including wheat production and therefore, breeding for drought resistant wheat is an important task and objective. On the other hand, effective selection criteria for identifying drought resistant genotypes are required (Saba et al., 2001). Durum wheat (*Triticum turgidum* L. sp durum) is cultivated on about 200-300 thousand hectares across arable lands in Iran from which, about 0.65 is under rainfed conditions. This is about 0.05 of total areas devoted to bread wheat in the country. In spite of high genetic yield potential of new varieties of bread wheat, durum wheat has special economic importance because of its genetic resistance to rusts and bunt. Thus, durum wheat can increase the sustainability of farming systems under disease prevailing conditions in rainfed areas under wheat cultivation (Sadeghzadeh and Alizadeh, 2005). Historically, plant breeders have paid insufficient attention to practical aspects of durum wheat (Sharma and Sain 2004). Grain yield is an important trait as it measures the economic productivity in wheat. For this reason, agronomical and breeding studies on increasing seed yield are being conducted intensively. For effective selection, information on nature and magnitude of variation in population, knowledge of correlation among such traits, their contributions towards grain yield and the extent of environmental influence on the expression of these characters are necessary (Yagdi 2009). Selection for grain yield by considering morphological and physiological traits as indirect selection criteria is an alternative breeding approach. This has come to be known as an analytical breeding and implies a better understanding of the factors controlling development (Aparicio et al., 2000). Grain yield is a complex polygenic quantitative trait, hence, selection based on the performance of grain yield alone, is usually not very efficient (Singh and Singh, 1973). Thus, identifying characters contributing to grain yield is important as it increases breeding efficiency; therefore, easily measurable characters along with the high heritability and having useful relationship with grain yield are of the paramount importance to practice indirect selection for the high yield (Gashaw et al., 2007). Different statistical

Table 1. Basis statistics (minimum and maximum values, arithmetic mean, standard deviation (SD) for the estimated variables of durum wheat, and coefficient of variation (CV%) for analysis variance of checks.

Variable	Minimum	Maximum	Mean	Std. Deviation (409DF)	Coefficient of variation *
PH (mm)	576.8	1167.8	892.3	9.19	0.1023
SL(mm)	54.0	119.2	78.5	.817	0.114
PED(mm)	19.2	311.8	136.5	3.83	0.2378
AL (mm)	62.4	151.2	102.2	1.41	0.1469
NTPP	4.40	24.60	12.59	3.04	0.2363
NSPP	3.60	22.20	10.03	2.70	0.2445
BIO(g)	6.07	71.65	29.66	10.15	0.2714
NSPS	10.20	76.60	35.41	7.40	0.1734
MGW(mg)	22.00	37.35	26.07	3.71	0.1329
GY(g)	1.10	20.25	7.20	2.91	0.2985
FL(mm)	153.4	277.4	206.9	1.99	0.1091
RWC	0.2712	0.8605	0.6051	0.753	0.1139
HI	0.544	0.7702	0.2427	0.595	0.0898
P/H	0.03	0.35	0.1514	0.036	0.2097
SpD	13.71	98.17	45.25	8.61	0.2024

* Coefficient of variation was calculated based on ANOVA for checks, whereas standard deviation was calculated based on all of entries for each trait. PH: Plant height, PL: peduncle length, FL: flag leaf length, GY: grain yield of plant, SpD: spike density, MGW: mean grain weight, P/H: peduncle/plant height, SL: spike length, HI: harvest index, NSPP: number of spikes per plant, NSPS: number of seed per spikes, AL: awn length, NTPP: number of tillers per plant, BIO: biomass, RWC: leaf relative water content, DF: degree of freedom.

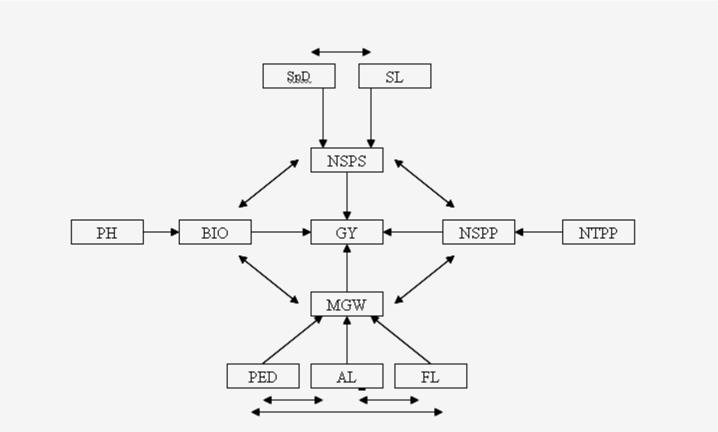

Fig 1. Path coefficient diagram showing the interrelation of traits in primary and secondary levels of grain yield. PH: Plant height, PL: peduncle length, FL: flag leaf length, GY: grain yield of plant, SpD: spike density, MGW: mean grain weight, SL: spike length, NSPP: number of spikes per plant, NSPS: number of seed per spike, AL: awn length, NTPP: number of tillers per plant, BIO: biomass

techniques have been used in modeling the crops yield, including correlation, regression, path analysis, factor analysis, factor components and cluster analysis (Leilah and Al-Khateeb 2005). Correlation studies are useful in measuring the strength and the direction of these relationships among the different characters and grain yield (Gashaw et al., 2007). Path analysis was used in numerous researches with the aim of determining the effects of the important agronomic traits (Naazar et al., 2003; Ahmed et al., 2003). Factor analysis assumed that each of the variables measured depends upon the underlying factors but is also subject to the random errors. The principal factor analysis method was followed in the extraction of the factor loadings (Tadesse and Bekele 2001). The main value of the stepwise selection is that it can be used to select a subset of explanatory variables by using a statistical criterion computed from a dataset (Prost et al., 2008). The principal component analysis reduces the dimension of the original data set without losing the substantial information and often reveals the relationships that were not previously suspected and thereby allows new interpretations or further analysis (Jiang and Thelen 2004). The cluster analysis as a method for classification of varieties under a similar condition with respect to set of variables has gained increased interest in the recent years (Vural and Karasu 2007). The objectives of the present investigation were: (i) to evaluate the associations between yield components and other plant traits with grain yield, (ii) to determine the direct and indirect effects of the yield components and the plant traits on grain yield (iii) to discuss the interrelationships among the examined traits, (iiii) to provide the theoretical foundations to guide wheat breeders who are researching the genetic correlation of the main agronomic characters and their influence on durum wheat productivity under rainfed condition.

Results

Analysis of variance

In an augmented design, instead of grouping the plots, we consider the use of adjacent checks plots for the adjustment of each unreplicated entry. This removes almost all the restrictions on the arrangement of the plots in any precise shape over the area of the trait (IPGRI, 2001). The observations on the check genotypes were first subjected to a simple analysis of variance using a randomized complete block design. Block effect was not significant for any of the measured traits, thus no adjustment was needed for the

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

	(X1)	(X2)	(X3)	(X4)	(X5)	(X6)	(X7)	(X8)	(X9)	(X10)	(X11)	(X12)	(X13)	(X14)	X15)
PH (X1)	1.00														
SL (X2)	.212**	1.00													
PED (X3)	.718**	.065^{ns}	1.00												
AL (X4)	.285**	.267**	.208**	1.00											
NTPP (X5)	.385**	.372**	.189**	.246**	1.00										
NSPP (X6)	.453**	.258**	.273**	.188**	.873**	1.00									
BIO (X7)	.529**	.330**	.377**	.261**	.767**	.843**	1.00								
NSPS (X8)	.097^{ns}	.377**	.049^{ns}	.079^{ns}	.210**	.183**	.311**	1.00							
MGW (X9)	.168**	.073^{ns}	.244**	.215**	.051^{ns}	.042^{ns}	.217**	.061^{ns}	1.00						
GY (X10)	.489**	.343**	.360**	.311**	.669**	.753**	.870**	.355**	.392**	1.00					
FL (X11)	.228**	.347**	.182**	.339**	.150**	.145**	.241**	.225**	.021^{ns}	.232**	1.00				
RWC(X12)	.232**	.106*	0.263**	.174**	.099*	.071^{ns}	.119*	.154**	.176**	.139**	.134**	1.00			
HI (X13)	.100*	-.009^{ns}	.097*	.133**	.032^{ns}	.064^{ns}	.001^{ns}	.174**	.400**	.438**	.066^{ns}	.071^{ns}	1.00		
P/H (X14)	.484**	.01^{ns}	0.948**	.156**	.072^{ns}	.159**	.254**	.018^{ns}	.230**	.257**	.126**	.255**	.070^{ns}	1.00	
SpD (X15)	-.012^{ns}	-.150*	0.021^{ns}	-.046^{ns}	.020^{ns}	.065^{ns}	.156**	.850**	.037^{ns}	.195**	.047^{ns}	.092^{ns}	.139**	.028^{ns}	1.00

$^{*, **, ns}$: $p< 0.05$, $p<0.01$ and $p>0.05$ respectively PH: Plant height, PED: peduncle length, FL: flag leaf length, GY: grain yield of plant, SpD: spike density, MGW: mean grain weight, P/H: peduncle/plant height, SL: spike length, HI: harvest index, NSPP: number of spikes per plant, NSPS: number of seed per spike, AL: awn length, NTPP: number of tillers per plant, BIO: biomass, RWC: leaf relative water content**.**

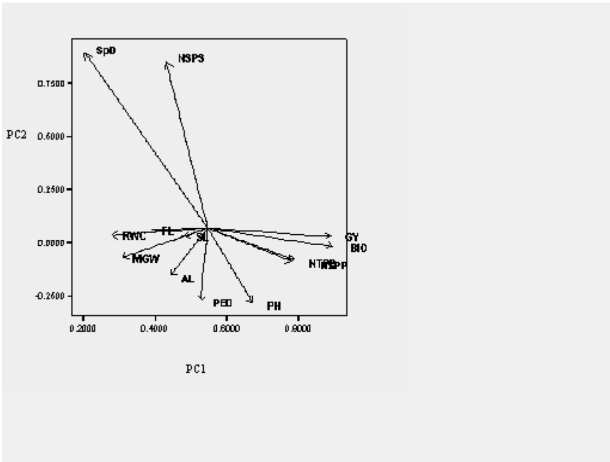

Fig 2. Principal component analysis (PCA) projections on axes 1 and 2, accounting for 0.4931 of total variance, for 410 RILs of durum wheat. PH: Plant height, PL: peduncle length, FL: flag leaf length, GY: grain yield of plant, SpD: spike density, MGW: mean grain weight, SL: spike length, NSPP: number of spikes per plant, NSPS: number of seed per spike, AL: awn length, NTPP: number of tillers per plant, BIO: biomass, RWC: leaf relative water content**.**

entries. Analysis of variance of checks provides information for the further analysis with the entries. This analysis takes into account the variability among blocks, measured by the standard genotypes, according to which the values of entries are adjusted for the comparison. Basic statistics for all the estimated variables are presented in Table 1. The maximum and minimum value of coefficient of variation belonged to grain yield and harvest index, respectively.

Relationship between grain yields and the morpho-physiological characters through the correlation analysis

To study the relationship, simple correlation between each pair of the traits was calculated (Table 2). Based on correlation analysis, all the characters included in the study showed significant positive correlation with grain yield. High significant correlation coefficient was found between GY and PH, NTPP, NSPP, BIO and HI. RWC displayed a weak correlation with GY.

Path coefficient analysis for the determination of the nature of the character association

Although abundant literature is found on the use of path coefficient analysis to evaluate yield in cereals, little information exists on the use of this technique in durum wheat, thus path coefficient analysis was performed to obtain further information on the interrelationship among traits and their direct and indirect effects on grain yield. For this purpose, a cause and effect system was constructed based on the ontogeny of the durum wheat. Although most authors use the result of stepwise regression to perform path analysis, it is appropriate to perform it based on logical relationships between all of the traits. Hence, traits were partitioned in two groups: one group included the traits with the primary effects on GY and the second group consisted of the traits with the secondary effects on GY via their effect on the primary traits. In the primary level, GY was affected by NSPS, NSPP, MGW and BIO, each of them was affected by another trait (Fig. 1). BIO had the highest value of direct effect on GY. In case of NSPS, NSPP and MGW, correlation coefficient was positive, but the direct effects were low compared with BIO, the indirect effects seemed to be the reason of correlation. In such situations, the indirect causal factors must be considered simultaneously (Singh and Chaudhary, 1977). The highest values of the indirect effects on yield belonged to NSPP via BIO. But its direct effect was low indicating that this indirect effect is the main source of correlation. The indirect effect of NSPP through other traits seemed to be negligible. The indirect effects of the traits were towards the increasing yield. At the secondary level of, the direct effect of SpD on NSPS was observed to be high and in positive direction, its indirect effect through SL was negative. The positive direct effect of SL on NSPS was counterbalanced by the indirect effect via SpD rendering its weak positive correlation with NSPS. In case of MGW, the highest value of the direct effect belonged to PED. The correlation coefficients between MGW, PED and AL were almost equal to the corresponded direct effects, indicating that correlation coefficient explained the true relationship between them. The direct effect of FL was negligible compared with the effects of the other traits; however, the deleterious negative direct effect was neutralized by its positive indirect effects. FL through AL was determined to have positive indirect effect at the highest level on MGW, whereas the indirect effects of the other traits remained at the lower values. Path analyses were very useful in clarifying the effects of the yield components and the related traits on grain yield, which were not accurately reflected in simple correlation analyses, thus provided helpful information for durum wheat breeders.

Analysis of factors influencing the yields under drought stress conditions factor analysis

Principal factors were determined as the variables with the highest projection scores on the principal components (Table 4). Factor analysis is a multivariate procedure used to simplify a large set of the characters into a few factors affecting the dependent variable. The magnitude of the influence of a factor is the factor loading for that character. Factor loading greater than 0.5 is usually considered important to the factor (AL-Doss et al., 1997). Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) was 0.645 and Bartlett's test of sphericity was significant (Chi-Square 4375.135, $p<0.000$). The most important factor (factor one), described 0.2732 of the variations among the characters in this study. The sign of the loading indicates the direction of the relationship between the factor and the variable. The values of loading considered in each factors are highlighted in bold in Table 4. The first factor (group) included NTPP, NSPP, BIO and GY. The suggested name for this factor is the factor affecting yield. The second factor included PH and PED which accounted for 0.1557 of the total variability in the dependent structure and it was named the plant height factor. The third factor consisted the NSPS and SpD and was named as the number of seed per spike factor. The fourth factor was named the factor affecting spike features since it contained SL, FL and AL.

Modeling and predicting durum wheat yield using stepwise regression

The results of coefficient of determination (R^2) and coefficient of regression (b) are presented in Table 5 and 6. Multiple regression analysis indicated that biomass (X_7) was the trait most related to yield, since it explained 0.76 of the yield variation (Table 5). Harvest index (X_{13}) entered the equation in the second position, and jointly with biomass accounted for 0.95 of yield variations. The other variables were not included in the analysis due to their low relative contributions. Regression coefficients for the accepted variables are shown in Table 6. The predicted equation for grain yield ($\hat{Y}$) was:

$$\hat{Y} = -5.72 + 0.25X_7 + 0.207X_{13}$$

Exposing the interrelation between the traits using the principal component analysis

Principal component analysis was performed to determine the relationships between yield and its related traits. The first two axes of the principal component analysis explained 0.3538 and 0.1393 of the total variations, respectively. Given that most of the variation could be explained by considering these two axes, we used biplot of axes 1 and 2. The biplot (Fig. 2) represents the eigenvectors of the characteristics that most influence each axis. The length of the projection of each of them on each principal component axis (PC1 and PC2) measures the weight (loading or eigenvalue) of its influence on that axis (Moragues et al., 2006). The first axis was mainly related to GY, NSPP, NTPP and BIO. The second axis was mainly related to SL and NSPS in its positive

Table 3. Path coefficient (direct and indirect effects) of the estimated yield attributes on grain yield variation in durum wheat.

Primary level of grain yield		Secondary level of grain yield							
GY		NSPS		NSPP		MGW		BIO	
NSPS		SL		NTPP		FL		PH	
Direct effect	0.115	Direct effect	0.517	Direct effect	0.87	Direct effect	-0.086	Direct effect	0.529**
Indirect effect via		Indirect effect via		Correlation	0.87**	Indirect effect via		Correlation	0.529**
NSPP	0.043	SpD	-0.139			AL	0.067		
MGW	0.0151	Correlation	0.378**			PED	0.039		
BIO	0.181					Correlation	0.02 ns		
Correlation	0.354**	SpD							
		Direct effect	0.928			AL			
NSPP		Indirect effect via				Direct effect	0.199		
Direct effect	0.232	SL	-0.077			Indirect effect via			
Indirect effect via		Correlation	0.851**			FL	-0.029		
NSPS	0.021					PED	.0453		
MGW	0.010					Correlation	0.215**		
BIO	0.494								
Correlation	0.757**					PED			
						Direct effect	0.218		
MGW						Indirect effect via			
Direct effect	0.248					FL	-0.0156		
Indirect effect via						AL	0.0413		
NSPS	0.007					Correlation	0.243**		
NSPP	0.009								
BIO	0.126								
Correlation	0.390**								
BIO									
Direct effect	0.584								
Indirect effect via									
NSPS	0.035								
NSPP	0.196								
MGW	0.053								
Correlation	0.868**								

*, ** and ns**:** p< 0.05, p<0.01 and p>0.05 respectively. PH: Plant height, PED: peduncle length, FL: flag leaf length, GY: grain yield of plant, SpD: spike density, MGW: mean grain weight, SL: spike length, NSPP: number of spikes per plant, NSPS: number of seed per spike, AL: awn length, NTPP: number of tillers per plant, BIO: biomass.

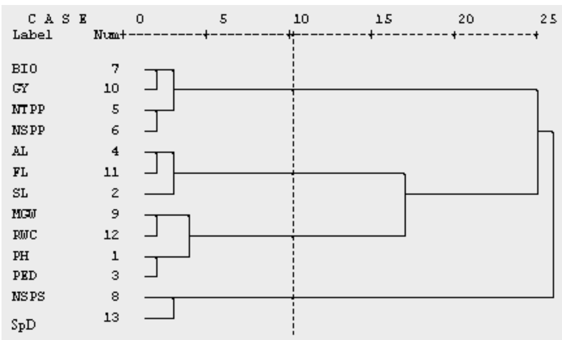

Fig 3. Dendrogram of cluster analysis of 13 quantitative traits of durum wheat using Wards' method. PH: Plant height, PED: peduncle length, FL: flag leaf length, GY: grain yield of plant, SpD: spike density, MGW: mean grain weight, SL: spike length, NSPP: number of spikes per plant, NSPS: number of seed per spike, AL: awn length, NTPP: number of tillers per plant, BIO: biomass, RWC: leaf relative water content**.**

values. Fig 2 shows the strongest relationship between GY and BIO.

Cluster analysis of morpho-physiological traits

Cluster analysis creates groups of samples based on their distances. It seeks objects groups of the same properties which differ at the same time from the next objects group (Švec et al., 2007). Cluster analysis (CA) was chosen to express the reciprocal relations between the effects studied. A dendrogram was constructed on the basis of co-ordinates of principal component analysis. Cluster group rankings were obtained based on Ward's minimum variance. According to the cluster analysis, the variables were divided into four clusters with similarity values above 0.90 (Fig. 3). Discriminant analysis 100% confirmed the results of clustering. Cluster 1 included BIO, GY, NTPP and NSPP, while cluster 2 contained AL, SL and FL. Cluster 3 consisted of MGW, RWC, PH and PED and cluster 4 comprised NSPS and SpD. Our data reflected the tendency of each grouped variables in one cluster to express their close relationships.

Discussion

For a trait to be considered a selection criterion in plant breeding, it must be correlated with yield. It is therefore essential to determine whether or not yield was correlated with a particular trait. The high positive correlation coefficient indicated that selection based on PH, NTPP, NSPP, BIO and HI, have an equal contribution to increase GY. With regard to correlation between GY and PH, the taller genotypes had significantly higher grain yield than dwarf genotypes under rainfed conditions. This is in agreement with the previous reported results on durum wheat under the unfavorable conditions (Sadeghzade and Alizadeh 2005). GY was positively correlated with BIO, as this trait had positive correlation with PH, consequently, the selection of the taller plants leads to a larger amount of above-ground biomass. Also, as the taller plants present higher the number of spikes per plant, the choice of the taller plants with larger above-ground biomass may increase grain yield. NTPP had positive and highly significant correlation with GY. The number of tillers per unit area is one of the yield components in wheat. These results suggest that selections should be based on the number of tillers per plant / per unit area for the developing new wheat varieties. NSPP showed highly significant correlation with GY. Garci´a del Moral et al., (2003) reported that the number of spikes per squares meter in durum wheat was positively related to grain yield under rainfed conditions. Positive and significant association was observed between GY and HI. Some researchers have reported that harvest index is correlated with seed yield and this correlation is desired for wheat breeders (Sharma and Smith 1986; Sharma 1992). Harvest index has been recommended as a selection criterion for increasing yield of cereals. Because the high-yielding lines had increased biomass, while maintaining their MGW and HI, the source and sink were simultaneously increased in these lines. GY and RWC showed a weak correlation. Because of the weak correlation between RWC and GY, it seems that the strategy of drought avoidance by early stomatal closure favouring high water status can be associated with the poor yield potential (Clavel et al., 2006). Path analysis indicated that in the primary level of GY, the high and positive direct effect on grain yield was exhibited by BIO indicating the true relationship between them (Table 3). In this case, the direct selection for the higher BIO would be enough to increase grain yield. This led us to suggest that BIO is easily measured trait that would be valuable in selecting for yield improvement under drought conditions. Kandic et al., (2009) concluded that the traits which mostly accounted for high yield under drought stress were early maturity and above all biomass per plant, which produced the consistent direct and indirect effect on grain yield. At the secondary level of GY, PED had the highest value of direct effect on MGW. FL through AL had the highest indirect effect on MGW. In drought and high temperature conditions after anthesis, photosynthesis and transpiration of awns could play an important role in grain filling (Zaharieva et al., 2003) thus improving mean grain weight. SpD had the highest direct effect on NSPS, but the indirect effect through SL was negative. High positive direct effect of SpD suggests that the direct selection for this trait for high NSPS would be effective. SL had the high direct effect on NSPS, too, but its indirect effect through SpD was negative. These results suggest that NSPS can be enhanced through selection for SpD and SL but in this process we must be care to minimize their probable negative effects. Factor analysis indicated that the selection of the variables in the factor affecting yield (factor 1) could enable breeders to better realize the desired increment in seed yield of durum wheat. Similar results were obtained by Leilah and Al-Khateeb (2005) who stated that factor analysis had classified the nine wheat variables into three main groups which accounted for 0.7444 of the total variability in the dependent structure. Our results based on stepwise regression underline the role of above ground biomass and harvest index in explaining yield variability in durum wheat under rainfed conditions. Biomass was the trait most related to yield, since it explained 0.76 of yield variation. Royo et al., (2006) reported that stepwise regression analysis revealed yield components accounted for 0.875 of yield variations of durum. Principal component analysis (PCA) confirmed that the role of BIO on GY. PCA and regression analysis revealed that BIO was the most important in defining GY for the RILs evolved in the drought conditions. This result suggests that those RILs with higher biomass achieved greater grain yield. Cluster analysis results proved that the NSPP, the NTPP and BIO were the variables most closely related to GY. This result completely confirmed the result of factor analysis.

Material and methods

Field experiment was conducted under rainfed conditions and no fertilizer at the research station of agricultural faculty of Razi University, Kermanshah, Iran (latitude 34˚ 21′, longitude 47˚ 9′, altitude 1319m) during 2008-2009 cropping season. Climate of this region is classified as semi-arid with mean annual rainfall of 450-480 mm.

Plant genetic materials

410 F_5 families (Recombinant inbred lines: RILs) resulting from cross between 'Zardak' and genotype '249' (local variety and genotype of Kermanshah province, Iran, respectively) were used. In terms of the genetic variability remaining within the lines, most is exhausted by the F4 generation. The lines established from F5 or F6 plants are likely to be highly visually uniformed and the environmental variation are lowest by the bulk F2:5 method which makes the selection process more efficient.

Table 4. Factor analysis for the estimated variables of durum wheat using the principal component procedure.

	Components			
Variable	1	2	3	4
PH	0.450	**0.676**	-0.095	0.133
SL	0.293	-0.093	0.044	**0.755**
PED	0.242	**0.812**	-0.069	0.009
AL	0.126	0.317	-0.086	**0.608**
NTPP	**0.898***	-0.011	0.003	0.183
NSPP	**0.949**	-0.066	0.017	0.063
BIO	**0.891**	0.241	0.138	0.153
NSPS	0.183	0.019	**0.927**	0.256
MGW	0.055	0.559	0.060	0.027
GY	**0.803**	0.322	0.199	0.179
FL	0.046	0.137	0.100	**0.794**
RWC	-0.072	0.543	0.156	0.207
SpD	0.039	0.077	**0.962**	-0.144
Eigen Value	4.59	1.81	1.50	1.29
% Total community	27.32	15.57	14.65	13.38
Cumulative variance	27.32	42.89	57.54	70.92
Suggested factor name	factor affecting yield	plant height	seed per spike	factor affecting spike features

PH: Plant height, PED: peduncle length, FL: flag leaf length, GY: grain yield of plant, SpD: spike density, MGW: mean grain weight, SL: spike length, NSPP: number of spikes per plant, NSPS: number of seed per spike, AL: awn length, NTPP: number of tillers per plant, BIO: biomass, RWC: leaf relative water content. *Bold values indicated factor loading considered for naming each factors.

Table 5. Relative contribution in predicting wheat grain yield of durum wheat (partial and model R^2, standard deviation and probability) by stepwise procedure analysis.

Variable entered	Partial R^2	Model R^2	Std. Error of the Estimate	Sig. F Change
BIO (X7)	0.75	0.76	1.43	0.000
HI (X13)	0.19	0.95	0.66	0.000

BIO: biomass, HI: harvest index

Table 6. Regression coefficient (b), standard error (SE), t-value and probability (sig.) of the accepted variables that can be used to predict durum wheat grain yield by the stepwise procedure.

Step	Variable	Coefficient of regression (B)	Standard Error	t	Sig
1	BIO (X7)	0.250	0.004	64.454	.000
2	HI(X13)	0.207	0.006	34.392	.000

t: t statistic-value, Sig: significance probability. BIO: biomass, HI: harvest index

Experimental design

410 RILs were distributed over 9 incomplete blocks each contained 46 RILs and genotypes as checks. The experimental design used was augmented design (Federer and Raghavarao, 1975). Total number of entries in the whole trial was 464 genotypes (including 410 RILs, 2 parents and 4 checks repeated in each block). Each family and checks were planted in 2 rows and in a mixture of clay silty soil. Plant to plant and row to row distances was 5 and 25 cm respectively. The plots were sown on 14 November 2008. 2,4-D was used to control the weeds and where necessary removed by hand.. Plots were hand-harvested at maturity in July 2009. Five plants were selected from the centre of each plot for measurement of the following traits:

Plant height (PH): the height of the main tiller of each plant was measured from the ground level to the tip of spike excluding awns. Peduncle length (PED): the length of peduncle was measured from the flag leaf node to the base of spike. Flag leaf length (FL): distance from base to tip of the flag leaf blade. Grain yield (GY), spike density (SpD), mean grain weight (MGW): mean weight of randomly collected grains, peduncle/plant height (P/H) ratio, spike length (SL), harvest index (HI), the number of spikes per plant (NSPP), the number of seed per spike (NSPS): the number of grains per spike , awn length (AL), the number of tillers per plant (NTPP), above ground biomass (BIO). Leaf relative water content (RWC) was measured as described by Barrs and Weatherley (1962) as:

RWC (%) = [(FW-DW) / (TW-DW)] × 100. Where FW, TW and DW are fresh weight, turgid weight and dry weight of the sample, respectively.

Statistical analysis

Analysis of variance and correlation analysis were done using MSTAT-C and SPSS ver.16 software. Path analysis was done based on logical relationships between GY and other traits in the primary and secondary levels of grain yield to identify direct and indirect path coefficients (Dewey et al., 1959). *Factor analysis*: The array of commonality, the amount of the variance of a variable accounted by the common factors together, was estimated by the highest correlation coefficient in each array as suggested by Seiller and Stafford (1985). The number of factors was estimated using the principal component analysis. The varimax rotation method (an orthogonal rotation) was used in order to make each factor uniquely defined as a distinct cluster of inter-correlated variables. The factor loadings of the rotated matrix, the percentage of variability explained by each factor and the commonalities for each variable were determined. *Stepwise multiple linear regression*: Stepwise regression analysis was developed for the RILs considering GY as the dependent variable and other traits as independent variables. *Principal component analysis*: Principal component analysis was performed on the correlation matrix between means of each RILs to determine the relationships between yield and related traits. *Cluster analysis*: Cluster analysis is driven by the tradeoff between minimizing the Euclidean distance of observation within a cluster and maximizing the Euclidean distance between clusters (Vural and Karasu, 2007), this was done by SPSS software (Ver. 16.0.1, SPSS Inc), to find the natural groups between the lines on the basis of coordinates of principal component analysis.

Conclusion

This paper proposes a strategy to select the traits to be used in breeding programs. The above multivariate analyses led us to suggest that plant height (PH), the number of tillers per plant (NTPP), the number of spikes per plant (NSPP) and above ground biomass (BIO) mainly contributed to a better grain yield in durum wheat under drought conditions. The result obtained from this study could be useful for durum wheat breeders and seed producers in order to increase seed yield in rainfed conditions. It should be taken into consideration that all the investigated traits are quantitative characters and are affected by environmental conditions to a great extent; therefore, the result may be changed from environment to environment.

Acknowledgments

We wish to thank Mr. Reza Mohammadi wheat breeder of Dryland Agricultural Research Institute (DARI) of Iran for his useful help and suggestions on the manuscript.

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