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Canonical Correlation Analysis to Determine the Best Traits for Indirect Improvement of Wheat Grain Yield under Terminal Drought Stress

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ABSTRACT

Selection based on the traits affecting grain yield is used for its indirect improvement. The objective of the present study was to determine the quantity and mechanism of effects of agro-morphological and physiological traits on grain yield of bread wheat under terminal drought conditions. Thirty six advanced lines of wheat were evaluated in a Randomized Complete Block Design with three replications during three sequential growing seasons 2010-2013 under rainfed conditions. Stepwise regression, path analysis, and canonical correlation analysis were conducted. All three components of yield had a significant positive effect on grain yield. The first canonical variable of predictive traits (U_1) and yield components (V_1) were studied. In general, selection for shorter vegetative stage and longer grain filling period is recommended to improve wheat grain yield per plant under rainfed conditions. Also, the desirable lines were those that had high amounts of biomass, average plant height and spike length, and low amount of canopy temperature. These types of lines are expected to produce higher numbers of grain per plant (not per spike) and 1000-grain weight, simultaneously, and thus higher grain yield per plant.

Keywords: Canonical variables, Path analysis, Rainfed conditions, Yield components.

INTRODUCTION

Drought is an important threat to global food production, which is a growing problem caused by an increasing world population. In wheat cultivation in a Mediterranean climate, it is mainly the flowering stage and grain-filling period that are exposed to drought stress, also known as terminal drought (Blum, 1998; Reynolds *et al.*, 2005). Drought stress reduces wheat yield at all growth stages, but its negative effect on grain yield during flowering and grain filling is too severe (Farooq *et al.*, 2014). Severe drought and moisture stresses are the major factors for low wheat productivity under rainfed conditions with an average of 1.2 t ha^{-1} as compared to 3.6 t ha^{-1} under irrigation in Iran (Najafian *et al.*, 2010). One potential solution would be to improve wheat to increase yield under drought stress conditions (Passioura, 2006). However, low heritability of yield and complex mechanisms of drought tolerance cause slow progress in improving yield. Therefore, wheat grain yield should be improved indirectly by improving those plant characteristics that have a big effect on yield (Akram *et al.*, 2008). Hence, it is necessary to identify the quantity, path, and quality of relationships between different traits and grain yield under these conditions (Villegas *et al.*, 2007). In fact, characteristics that prevent or reduce damage to crops caused by drought stress should be recognized then assessment made of each one's role and impact on drought tolerance. In this regard,

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selection indices using some phenological, morphological, and physiological traits with high genetic variability, heritability, and correlation with grain yield can be applied (Lonbani and Arzani, 2011).

Estimating simple correlation coefficient between grain yield and its components is not in itself an adequate method to develop an understanding of the importance of these components in determining yield (Ali and Shakor, 2012). A high correlation can be the result of other traits that affect these traits and, so, quantification and incomplete interpretation of these correlations can lead to mistaken selections (Cruz and Regazzi, 1997). In this case, application of path analysis provides a better understanding of associations between traits. With this method, correlation of yield and effective traits can be partitioned into direct and indirect effects which can help in correct designing of breeding programs (Ali and Shakor, 2012). Canonical correlation analysis is another important method for developing an understanding of associations between traits (Dunteman, 1984). This technique identifies and quantifies correlation between two sets of traits (Lorencetti *et al.*, 2006). In this analysis, the correlation estimates are made between linear combinations of one set of variables and linear combinations of another set of variables. These pairs of linear combinations are termed canonical variables, and their correlations are termed canonical correlations (Johnson and Wichern, 1992).

Previous studies have shown that early flowering with appropriate grain filling period associated with grain yield under terminal drought stress conditions (Blum *et al.*, 1983). In this case, grain numbers per plant and 1000-grain weight did not reduce greatly due to stress and large yield loss was prevented. Saeidi and Abdoli (2015) reported that canopy temperature increased in all studied cultivars when they were exposed to post anthesis water deficiency stress. Another research showed that canopy temperature had a negative correlation with grain yield under drought (Saint Pierre *et al.*, 2010). Crops that maintain a low canopy temperature and thus delay stomata closure have a longer period for photosynthesis and thus produce higher grain yield. In Roohi *et al.* (2015) experiment, under water stress condition, the high yielding genotypes had lower canopy temperature (by 1.23°C) than low yielding ones. Hence, canopy temperature can be used as a screening tool for predicting high wheat yield in drought stress conditions (Olivares-Villegas *et al.*, 2007). On the other hand, drought-resistant plants have certain physiological characteristics that enable them to store more water in plant tissue under water deficit condition. Thus, Relative Water Content (RWC) is an appropriate indicator of plant water status and is widely used to identify drought resistance in plants (Liu *et al.*, 2003).

In breeding programs to increase grain yield, it is particularly important to make selections based on components and traits affecting yield. The objective of the present study was to determine quantity and mechanisms of the effects of some agro-morphological and physiological traits on grain yield of bread wheat under terminal drought conditions to make recommendations for use of effective traits for indirect improvement of wheat grain yield.

MATERIALS AND METHODS

Plant Materials, Experimental Design and Field Site Description

Sixteen lines and cultivars of wheat (*Triticum aestivum* L.) (Table 1) were crossed pairwise in 2003 and eight F_1 populations were formed. These populations were managed simultaneously in bulk and then superior lines were selected in several generations using the method of pedigree. Finally, in the present study, evaluation of the 36 advanced lines was done in a Randomized Complete Block Design with three replications at the research farm of the Agricultural Faculty of University of Zanjan, Iran (36° 41' N longitude, 48° 27' E latitude, and 1,620 m in elevation) during three sequential growing seasons in 2010-

2013 under rainfed conditions. Each plot consisted of four rows 2 m long. The inter row and interplant spacings were 25 and 5 cm, respectively. The soil of the research farm was a loamy calcareous soil (Typic Calcixerepts).

Environmental Characteristics

Precipitation and average air temperatures of University of Zanjan during the study years and their long-term averages are given in Table 2. The long-term averages of annual precipitation was 311.9 mm. Investigation of precipitation and temperature averages shows that, at the end of the growth season, which coincided with the reproductive stage, plants were subjected to conditions of reduced precipitation and rising temperature that constituted drought stress conditions.

Evaluated Traits

In the present experiment, six traits were measured including days to heading, grain filling period, plant height, spike length, biomass and canopy temperature against yield and yield components i.e. number of spikes per plant, number of grains per spike, and 1,000-grain weight. In May of each year, to correctly estimate the relationships between the traits, 5 typical plants were randomly tagged from each plot and evaluations were made for traits per plant in these plants. Canopy temperature was measured by a handheld infrared thermometer, Model Mini-Temp. Raytek at 9 to 11 am.

Statistical Analyses

The simple correlation coefficients between the evaluated traits were estimated by SPSS (ver. 20) software. For path analysis of yield and its components (number of spikes per plant, number of grains per spike and 1,000-grain weight), stepwise regression analysis was performed, by SPSS (ver. 20), then, direct and indirect effects of yield components on grain yield were calculated and a path diagram was plotted.

Canonical correlation analysis was started with two sets of data, including vectors of observations for all variables. The canonical correlation was obtained by creating ***U*** as a *p*-dimensional vector of predictor variables and *V* as a *q*-dimensional vector of the dependent variables. The purpose was to achieve a linear combination of predictor variables with maximum correlation with a linear combination of dependent variables, with linear combinations of the following (Johnson and Wichern, 1992):

$$U= a'x= a_1x_1+a_2x_2+\dots+a_px_p \quad (1)$$

$$V= b'y= b_1y_1+b_2y_2+\dots+b_qy_q \quad (2)$$

Canonical correlation analysis was made using SAS (ver. 9.1) software. In this analysis, the set of traits including days to heading, grain filling period, plant height, spike length, biomass and canopy temperature was considered under predictor traits while yield components were applied as the set of dependent traits.

RESULTS

Phenotypic Correlation Coefficients

Grain yield had a significant positive correlation with biomass per plant (0.94**), number of spikes per plant, 1000-grain weight and grain filling period, and a negative correlation with number of grains per spike, plant height, days to heading, and canopy temperature. The correlation of this trait with spike length was also negative and negligible (Table 3).

Stepwise Regression and Path Analysis

All three components of yield appeared in the final regression equation as follows and

Table 1. Pedigree of wheat lines used in this study.[a]

Number	Pedigree	Origin	Number	Pedigree	Origin
1	14 Gene Bank Material	URBYI 81	9	Turkey/3/TG10//Maya	BWYT-B_2 Zanjan
2	C-75-5	-------	10	Fengek 15/Sefid	on farm
3	Sabalan	-------	11	288 Gene Bank Material	BWYT-A_2 Zanjan
4	Azar 2	-------	12	Arman	11th FAWWON
5	Sardari	-------	13	288 Gene Bank Material	BWYT-A_3 Zanjan
6	Son64/4/WRSL/MIDA/…	On farm	14	F6 Maragheh	PWYT(u)
7	Bows/Gene//Shahi	URBYT 78	15	F6 Maragheh	PWYT(u)
8	Tan 200/Kauz	5th WON-SA	16	Ogusta/Sefid	On farm

[a] URBWYT: Uniformity Regional Bread Wheat Yield Trial; WON-SA: Wheat Observation Nursery-Semi Arid; BWYT-A: Bread Wheat Yield Trial-A; BWYT-B= Bread Wheat Yield Trial-B, PWYT: Preliminary Wheat Yield Trial.

Table 2. Precipitation and average air temperature at the research farm of University of Zanjan during the years of experiment and their long-term averages.

Month	2010-2011		2011-2012		2012-2013		Long-term Average	
	Precipitation (mm)	Average temperature (°c)	Precipitation (mm)	Average temperature (°c)	Precipitation (mm)	Average temperature (°c)	Precipitation (mm)	Average temperature (°c)
October	6.4	14.8	36.6	11.7	22.6	12.9	22.6	13.2
November	0.0	6.4	45.4	2.2	46.0	6.9	32.1	6.2
December	21.7	2.1	9.4	0.1	30.9	1.7	27.7	0.5
January	33.7	-4.1	27.9	-1.5	35.5	0.9	28.9	-2.5
February	12.0	0.5	34.4	-2.4	19.8	3.5	29	-0.3
March	30.2	5.0	53.8	1.9	29.4	7.4	45.6	5.0
April	89.8	11.3	71.8	11.5	14.1	11.3	57.8	11.0
May	32.3	15.8	60.9	16.3	49.2	14.6	41.9	15.9
June	18.4	21.6	24.1	20.2	0.5	20.6	11.4	21.1
July	38.3	24.3	19.1	23.0	0.0	24.1	6.3	24.4
August	8.7	22.6	5.0	24.6	4.6	22.5	4.0	24.0
September	1.5	18.7	4.3	18.9	0.0	19.7	4.6	19.7
Total	293	----	392.7	---	252.6	---	311.9	---

Table 3. The phenotypic correlation coefficients among the studied traits.[a]

	DH[a]	GFP[b]	PH[c]	SL[d]	B/P[e]	CT[f]	S/P[g]	G/S[h]	GW[k]	Y/P[l]
DH	1	-0.02	-0.01	0.17	-0.35**	0.07	-0.38**	0.31**	-0.19	-0.30**
GFP	-0.02	1	-0.74**	-0.14	0.38**	-0.68**	0.23*	-0.36**	0.63**	0.45**
PH	-0.01	-0.74**	1	0.28**	-0.38**	0.84**	-0.30**	0.51**	-0.69**	-0.48**
SL	0.17	-0.14	0.28**	1	-0.07	0.25**	-0.08	0.40**	-0.45**	-0.11
B/P	-0.35**	0.38**	-0.38**	-0.07	1	-0.64**	0.81**	-0.31**	0.40**	0.94**
CT	0.07	-0.68**	0.84**	0.25**	-0.64**	1	-0.49**	0.47**	-0.72**	-0.70**
S/P	-0.38**	0.23*	-0.30**	-0.08	0.81**	-0.49**	1	-0.47**	0.22*	0.82**
G/S	0.31**	-0.36**	0.51**	0.40**	-0.31**	0.47**	-0.47**	1	-0.58**	-0.33**
GW	-0.19	0.63**	-0.69**	-0.45**	0.40**	-0.72**	0.22*	-0.58**	1	0.47**
Y/P	-0.30**	0.45**	-0.48**	-0.11	0.94**	-0.70**	0.82**	-0.33**	0.47**	1

[a] Days to Heading; [b] Grain Filling Period; [c] Plant Height; [d] Spike Length; [e] Biomass per Plant; [f] Canopy Temperature; [g] Number of Spike per Plant; [h] Number of Grains per Spike; [k] 1000-Grain Weight, and [l] Grain Yield per Plant. * and **: Significant at 0.05 and 0.01 probability levels, respectively.

justified 83.6% of the variation in grain yield per plant:

$$Y= -10.093+0.852\ S/P+0.148\ G/S+0.172\ GW \quad (3)$$

that, Y, S/P, G/S and GW are yield per plant, number of spike per plant, number of grains per spike and 1000-grain weight, respectively.

R^2= 0.836 (F= 177.042***), significant at 0.001 probability level

Then, path analysis was done with performance of the three components. All three components had a significant positive effect on grain yield. Number of spikes per plant and 1000-grain weight had a non-significant indirect effect via one another. However, number of grains per spike had high negative indirect effects via other traits, despite a direct effect on grain yield per plant that caused a significant negative correlation between them (Table 4 and Figure 1).

Canonical Correlation Analysis

Statistical parameters of phenological, morphological, and physiological traits studied as predictor traits (X-variable set) and yield components (Y-variable set) are listed in Table 5. Canonical correlation analysis was used to investigate the relationship and the effect of predictor variables on yield components as independent variables. In this analysis, three significant canonical variables were obtained between the two sets of traits such that the first canonical correlation coefficient

Table 4. Direct and indirect effects of yield components on grain yield/plant.

Traits	Direct Effects	Indirect effects[a]			Correlation with Y/P
		S/P	G/S	GW	
S/P	0.89**	-	-0.18	0. 11	0.82**
G/S	0.38**	-0.42	-	-0.29	-0.33**
GW	0.50**	0.19	-0.22	-	0.47**
Residual	0.40				

[a] Symbols are defined under Table 3. * and **: Significant at 0.05 and 0.01 probability levels, respectively

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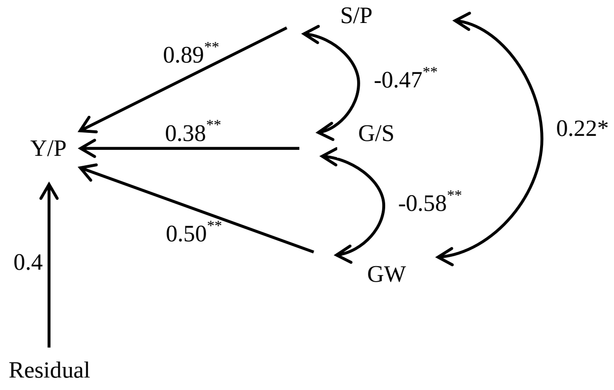

Figure 1. Path diagram of yield components on grain yield of wheat under rainfed conditions.

Table 5. Statistical parameters of predictor traits (X-variable set) and yield components (Y-variable set).

Variable Set	Traits	Mean±SD	Minimum	Maximum
X	Days to Heading (DH)	214.45 ± 2.91	207.00	221.50
	Grain Filling Period (GFP)	29.53 ± 4.16	20.50	41.50
	Plant Height (PH) (cm)	71.03 ± 13.29	42.06	97.55
	Spike Length (SL) (cm)	10.46 ± 0.843	8.18	12.53
	Biomass/Plant (B/P) (gr)	14.17 ± 5.43	4.61	28.50
	Canopy Temperature (CT) (°c)	20.45 ± 4.40	13.20	29.13
Y	Number of Spike/Plant (S/P)	6.80 ± 2.41	2.20	14.00
	Number of Grain/Spike (G/S)	27.01 ± 5.89	14.57	43.65
	1000-Grain Weight (GW) (gr)	32.45 ± 6.60	21.66	49.72

Table 6. Canonical correlation analysis.

	Canonical correlation	Squared canonical correlation	Eigenvalu e	Proportio n	Cumulativ e	Approximate *F* value	*Pr> F*
1	0.906	0.820	4.563	0.790	0.790	23.03	< 0.0001
2	0.724	0.524	1.100	0.190	0.980	10.59	< 0.0001
3	0.320	0.102	0.114	0.020	1.000	2.88	0.0264

was greater than all and equal to 0.906 (Table 6). The standard canonical coefficients were calculated since the evaluated traits were not assessed in the same units (Table 7). The first canonical variable of predictive traits (U_1) was more highly affected by biomass per plant. Variables of canopy temperature, plant height, spike length, days to heading and plant height were affected to a lesser degree in this canonic variable. This canonical variable determined a weighted difference of plant biomass and grain filling period on the one hand and canopy temperature, spike length, days to heading and plant height on the other. The first canonical variable of yield components (V_1) was mainly influenced by number of spikes per plant

Table 7. Standardized canonical coefficients.

X-Variable set[a]	Canonical variables			*Y*-Variable set	Canonical variables		
	U_1	U_2	U_3		V_1	V_2	V_3
DH	-0.123	0.185	0.642	S/P	0.803	0.804	0.053
GFP	0.052	-0.349	0.786	G/S	0.217	0.541	1.234
PH	-0.106	0.213	1.384	GW	0.641	-0.560	0.892
SL	-0.134	0.361	0.114				
B/P	0.674	0.952	-0.161				
CT	-0.227	0.456	-1.050				

[a] Symbols are defined in Table 5.

and 1,000-seed weight and number of grains per spike was of secondary importance. The effect of some of these variables was different on the other canonical variables.

The correlation coefficient between the original and canonical variables was calculated to interpret the results of canonical correlation analysis (Tables 8 and 9). U_1 as an own canonical variable and V_1 as an opposite canonical variable had the most positive and negative correlations with biomass per plant and canopy temperature, respectively. Traits of plant height and days to heading were evaluated with negative coefficients and grain filling period had a positive coefficient correlation with the first canonical variables in secondary importance. V_1 as an own canonical variable and U_1 as an opposite canonical variable had higher positive correlations with number of spikes per plant and 1,000-grain weight. Number of grains per spike with a negative coefficient was in secondary importance in terms of correlation with the first canonical variables.

The proportion of total standardized variance of *X*, *Y*-variable sets justified by their own and opposite canonical variables was also calculated by canonical redundancy

Table 8. The correlation coefficients between the *X*, *Y*-variable sets and their own canonical variables.

X-Variable set[a]	Canonical variables			*Y*-Variable set	Canonical variables		
	U_1	U_2	U_3		V_1	V_2	V_3
DH	-0.40	-0.05	0.61	S/P	0.84	0.43	-0.34
GFP	0.56	-0.51	0.39	G/S	-0.53	0.49	0.69
PH	-0.63	0.59	0.01	GW	0.69	-0.70	0.19
SL	-0.30	0.55	0.24				
B/P	0.93	0.36	0.05				
CT	-0.82	0.37	-0.25				

[a] Symbols are defined in Table 5.

Table 9. The correlation coefficients between the *X*, *Y*-variable sets and the opposite canonical variables

X-Variable set[a]	Canonical variables			*Y*-Variable set	Canonical variables		
	V_1	V_2	V_3		U_1	U_2	U_3
DH	-0.36	-0.04	0.20	S/P	0.76	0.31	-0.11
GFP	0.51	-0.37	0.13	G/S	-0.48	0.35	0.22
PH	-0.57	0.43	0.00	GW	0.62	-0.51	0.06
SL	-0.27	0.40	0.08				
B/P	0.84	0.26	0.02				
CT	-0.75	0.27	-0.07				

[a] Symbols are defined in Table 5.

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Table 10. The Proportions of total standardized variance of *X, Y*-variable sets explained by their own and opposite canonical variables.

X-Variable set				*Y*-Variable set			
Canonical variables	Variance explained	Canonical variables	Redundancy	Canonical variables	Variance explained	Canonical variables	Redundancy
U_1	0.42	V_1	0.34	V_1	0.49	U_1	0.40
U_2	0.20	V_2	0.11	V_2	0.30	U_2	0.16
U_3	0.11	V_3	0.01	V_3	0.21	U_3	0.02

analysis (Table 10). As can be seen, 49% of the total variance of *Y*-variable set was justified by the three first canonical variables belonging to V_1. Redundancy of the first canonical variable of predictor variables (U_1) with yield components set (Y-variable set) was 40%. That is, linear combination U_1 alone could justify 40% of the total variance of the variable set. This canonical variable also justified 42% of the total variance of yield components (X-variable set).

DISCUSSION

Indirect selection of grain yield via its components is one of the most effective strategies for plant breeding. Success in grain yield improvement depends on an understanding of the complex relationships between yield and its components. Yield components have positive or negative correlations with each other and improvement of a component is usually associated with a reduction in the other components (Ahmad *et al.*, 2007). In the present experiment, as was expected, all three of the yield components had a significant direct effect on grain yield per plant and that the direct effect of number of spikes per plant was higher than evaluations of the other two. Results determined that this trait had little indirect effects from number of grains per spike and 1000-grain weight on grain yield per plant. In other words, by making selection according to higher number of spikes per plant, indirect increase in grain yield per plant can be expected without reducing other yield components in the evaluated lines. Okuyama *et al.* (2004) also stated that number of spikes is an important trait for higher grain yield under normal and drought conditions. One-thousand-grain weight was also determined as having no indirect effect on grain yield via other components. Since the yield component which is formed last is 1000-grain weight and that the drought stress in the experimental area is a terminal drought stress that mainly affects the trait, it is expected that the selection to increase 1,000-grain weight would have a great effect on grain yield per plant in the region. Although drought affects all phases of plant growth, the grain filling period is the most sensitive to stress and 1,000-grain weight is affected the most by this stress (Pradhan *et al.*, 2012). Other researchers have also considered number of spikes per plant and 1,000-grain weight as important elements affecting grain yield under rainfed conditions (Zaefizadeh *et al.*, 2011; Waqar-Ul-Haq and Akram, 2010). In contrast, the number of grains per spike was negatively correlated with 1,000-grain weight. Therefore, increasing the number of grains per spike under this drought stress condition creates a negative indirect effect on grain yield per plant via 1,000-grain weight loss, due to limitations of assimilates, that counterbalance its positive direct effect. Moghaddam *et al.* (1997) reported a negative correlation between the two yield components and determined a positive direct effect of number of grains on grain yield that was mainly counterbalanced by its negative indirect effect *via* 1,000-grain weight. In

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general, according to these results and the range of traits of evaluated lines, it is recommend that in rainfed conditions such as those in the experimental area, increase in grain yield per plant be made indirectly through number of spikes per plant and 1,000-grain weight.

However, the canonical correlation analysis of yield components, as independent variables, with predictor variables revealed that U_1 linear combination of these variables can explain about half of the variations of yield components. Evaluations of linear combinations U_1 and V_1 determined that increasing biomass and decreasing canopy temperature lead to increased number of spikes per plant and 1,000-grain weight and decreased number of grains per spike while, as previously mentioned, all three results can lead to an increase in grain yield per plant. Increasing the duration of grain filling period and decreasing days to heading, plant height, and spike length can cause the same result with less intensity. Reynolds *et al.* (2005) and Rodrigues *et al.* (2007) also stated that in drought stress conditions, remobilization has an important role in grain filling and increased biomass production will follow more yield. Positive relationship between biomass and grain yield has been shown in several studies (Shearman *et al.*, 2005; Taheri *et al.*, 2013). Winkel (1989) reported that the most sensitive stage of wheat to drought stress is duration between heading to anthesis and that the best varieties for drought tolerance are those that produce higher biomass before anthesis and have increased assimilate aggregation in their stem. Earlier heading is one mechanism through which a plant can escape the harmful effects of terminal stress and increase the grain filling period (Bajji *et al.*, 2004; Khokhar *et al.*, 2010). Under the dry land conditions, according to the range of the traits in the evaluated lines, those lines are the most suitable that can quickly pass through their vegetation period before terminal drought stress occurs and, at this stage of growth with relatively good water conditions before anthesis, produce more tillers. So, rather than increasing plant height, such plants accumulate more assimilates in their stems and leaves and increase biomass. Accordingly, these lines will be able to remobilize assimilates accumulated in stems and leaves of each tiller to grains of the same tiller in the grain filling period to increase 1,000-grain weight and thus improve yield per plant. In such circumstances, shorter spikes and fewer grains per spike and a longer grain filling period will produce plants with more successful grain filling with assimilates accumulated in the stems and leaves. Lines with a shorter vegetative period and a longer grain filling period will have a better opportunity for remobilization of assimilates from stems, without an increase in maturity period (Blum, 1998). However, if such plants can maintain a low canopy temperature, then, their stomata will remain open longer, allowing increased photosynthesis, leading to more production of assimilates and thus more successful grain filling (Balota *et al.*, 2008; Munjal and Rana, 2003).

CONCLUSIONS

In general, to improve grain yield per plant in wheat breeding programs under rainfed conditions, selection for shorter vegetative stage and longer grain filling period is recommended. Also, desirable lines are those that have large biomass, high average plant height, long spike length, and low canopy temperature. These types of lines are expected to produce higher number of grain per plant (not per spike) and 1,000-grain weight, simultaneously, and thus higher grain yield per plant.

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تجزیه همبستگی کانونیک برای تعیین بهترین صفات برای اصلاح غیرمستقیم عملکرد دانه گندم تحت شرایط تنش خشکی آخر فصل

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چکیده

برای اصلاح غیرمستقیم عملکرد دانه از گزینش برمبنای صفات مؤثر بر آن استفاده می‌شود. هدف از انجام پژوهش حاضر تعیین مقدار و چگونگی تأثیر صفات اگرومورفولوژیک و فیزیولوژیک بر عملکرد دانه گندم نان تحت شرایط تنش خشکی آخر فصل بود. ۳۶ لاین پیشرفته گندم درقالب یک طرح بلوک‌های کامل تصادفی با سه تکرار در طول سه سال زراعی متوالی ۱۳۸۹-۱۳۹۲ تحت شرایط دیم ارزیابی شدند. رگرسیون گام‌به‌گام، تجزیه علیت و تجزیه همبستگی کانونیک انجام گردید. هر سه جزء عملکرد اثر مثبت معنی‌داری بر عملکرد دانه داشتند. اولین متغیر کانونی صفات پیش‌بین (U_1) و اجزای عملکرد (V_1) بررسی شدند. درکل، برای اصلاح عملکرد دانه در بوته گندم تحت شرایط دیم، گزینش برای دوره رویشی کوتاه‌تر و و دوره پرشدن دانه طولانی‌تر پیشنهاد می‌شود. همچنین، لاین‌های مطلوب آنهایی هستند که بیوماس نسبتاً زیاد، ارتفاع بوته و طول سنبله متوسط و دمای کنوپی پایین دارند. انتظار می‌رود که اینگونه لاین‌ها به‌طور همزمان تعداد دانه در بوته (نه در سنبله) و وزن هزاردانه بیشتر و در نتیجه عملکرد دانه در بوته بیشتری تولید نمایند.