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PATH ANALYSIS OF GRAIN YIELD AND YIELD COMPONENTS AND SOME AGRONOMIC TRAITS IN BREAD WHEAT

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Abstract

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Development of new bread wheat cultivars needs efficient tools to monitor trait association in a breeding program. This investigation was aimed to characterize grain yield components and some agronomic traits related to bread wheat grain yield. The efficiency of a breeding program depends mainly on the direction of the correlation between different traits and the relative importance of each component involved in contributing to grain yield. Correlation and path analysis were carried out in 56 bread wheat genotypes grown under field conditions of Maragheh, Iran. Observations were recorded on 18 wheat traits and correlation coefficient analysis revealed grain yield was positively correlated with stem diameter, spike length, floret number, spikelet number, grain diameter, grain length and 1000 seed weight traits. According to the variance inflation factor (VIF) and tolerance as multicollinearity statistics, there are inconsistent relationships among the variables and all traits could be considered as first-order variables (Model I) with grain yield as the response variable due to low multicollinearity of all measured traits. In the path coefficient analysis, grain yield represented the dependent variable and the spikelet number and 1000 seed weight traits were the independent ones. Our results indicated that the number of spikelets per spikes and leaf width and 1000 seed weight traits followed by the grain length, grain diameter and grain number per spike were the traits related to higher grain yield. The above mentioned traits along with their indirect causal factors should be considered simultaneously as an effective selection criteria evolving high yielding genotype because of their direct positive contribution to grain yield.

Keywords: Bootstrap analysis, Grain yield, multicollinearity, *triticum aestivum*, variance inflation factor

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is one of the most important cereal crops which is associated to the development of the major civilizations all over the world. Iran produces about 13.8 million tons of wheat at 2012 growing season, 93% being bread wheat which is grown on a total area of 7.000.000 ha^{-1} with average yield 2 tha^{-1} (FAOSTAT, 2012). The wheat production in Iran is a historical phenomenon and is based on native genetic diversity of the wheat. Selection of suitable parents with desirable traits and making crosses among them is an important way for increased production (Khaliq *et al.*, 2004). Local cultivars were survived from past years until now, expected to contribute in new practices of agriculture and effects of climate changes which have adverse impacts on production, quality and security of human foods (Parry *et al.*, 2004; Atkinson *et al.*, 2008). Unless, local cultivars are not known by high grain yield, adaptability is their benefits for direct use by farmers or as potential plant materials in breeding programs. This strategy is used to improve grain yield in less favorable systems because, grain yield in these conditions is mainly associated to the narrow genetic base of the new improved cultivars (Annicchiarico and Pecetti, 1993; Dehghani *et al.*, 2008).

Uddin *et al.* (1997) reported number of grains per spike, number of tillers and spike length were positively correlated with grain yield whereas, Chowdhry *et al.* (2000) reported that grain yield was positively correlated with plant height, number of tillers and 1000 seed weight. It was reported that positive correlation of grain yield with number of tillers, 1000 seed weight, plant height, and spike length (Shahid *et al.*, 2002). Kashif and Khaliq (2004) concluded that grain yield components like number of spike per plant, number of grains per spike, 1000 seed weight and number of tillers had significantly contributed in grain yield development. According to Topal *et al.* (2004), plant height, spike length, spikelet number per spike, grain number per spike and 1000 seed weight are major components of wheat yield and could be used as selection criteria in breeding programs. It was reported that grain yield showed significant positive association with number of productive tillers per plant (Aycecik and Yildirim, 2006). Some researchers studied correlation coefficients of various grain yield components with grain yield of bread wheat for its genetic improvement (Uddin *et al.*, 1997; Aycecik and Yildirim, 2006; Akram *et al.*, 2008). Several researchers reported that wheat grain yield was positively correlated with 1000 seed weight (Li *et al.*, 2006; Akram *et al.*, 2008).

The correlation and path analysis of yield components are useful tools to determine valuable genotypes (Li *et al.*, 2006). Path analysis is a reliable statistical method, which provides tool to quantify the interrelationship of various grain yield components and indicate whether the influence is directly reflected in the grain yield or take some other path ways to produce an effect. This method provides a critical examination of specific variables producing a given correlation and can be used in defining a selection strategy. Since path analysis was applied by Dewey and Lu (1959) on wheat grass, this method has been used to facilitate selection in other important crops. Uddin *et al.* (1997) reported number of spikelets per spike and number of tiller had the greatest direct effect on grain yield. Shahid *et al.* (2002) and Kashif and Khaliq (2004) concluded that number of grains per spike and 1000 seed weight had most direct effect on grain yield development. According to Topal *et al.* (2004), spike length and grain number per spike are major components of wheat yield which indicated large direct effect on grain yield. The present investigation was conducted to get information on the correlation of grain yield components with grain yield in bread wheat in the present breeding material via simple correlation coefficient analysis and path analysis for effective selection in segregating generations to find out transgressive segregates.

MATERIALS AND METHODS

The research was carried out in the experimental field of Faculty of Agriculture, University of Maragheh (latitude 37°23'S, longitude 46°16'W, altitude 1478 m). The seed of 56 genotypes were sown in a randomized complete block design with three replications. There were six rows 2.5 m long and 0.25 m apart, plot size was 3.75 m^2. Plots were overplanted and thinned to a distance between plants in the row of 10 cm for an established plant density of 16.7 plants m^{-2}. Normal agronomic practices were applied to the experiment through out the growing season. The fertilizer application was performed before sowing, 60 kg ha^{-1} of N, 30 kg ha^{-1} of P and 20 kg ha^{-1} of K were broadcast on the surface and tilled into the soil and the weeds were controlled chemically. Ten plants from each line were tagged randomly to study different post emergence plant traits and data were recorded for stem diameter (SD), plant height (PH), leaf number (LN), leaf length (LL), leaf width (LW), tiller number (TN), internode length (NL), peduncle length (PL), spike length (SL), floret number (FN), spikelet number (SN), grain number (GN), length of awn (AL), grain diameter (GD), and grain length (GL). The number of days to anthesis or flowering (DF), 1000 seed weight (TS) and grain yield (GY) of each plot traits were measured. The area harvested was 2 m^2 and only the middle four rows were harvested to determine grain yield which measured at physiological maturity and yield was adjusted to 12.5% grain moisture content.

The obtained dataset was first subjected for normality test by the Shapiro-Wilk normality test and simple phenotypic correlation coefficients were calculated for all possible pairs using the Pearson correlation coefficient. Correlation coefficients were partitioned into direct and indirect effects using conventional path coefficient analysis (Dewey and Lu, 1959). The stepwise multiple regression model was performed to recognize the predictor variables into first, second and third order paths on the basis of their respective contributions to total variation in grain yield and minimal collinearity. The level of multicollinearity in each path was measured from two common measures, the tolerance value and its inverse and the variance inflation factor (VIF) as suggested by Hair *et al.* (1995). The tolerance value is the amount of variability of the selected independent variable (agronomic traits) not explained by other independent variables, where R^2 is the coefficient of determination for the prediction grain yield by the predictor traits. The VIF factor indicates the extent of effects of other independent variables (traits) on the variance of the selected independent variable and so high VIF values (> 10) or small tolerance values (much lower than 0.1) shows high collinearity (Hair *et al.*, 1995). To estimate the standard error of path coefficients, bootstrap analysis (Efron and Tibshirani, 1993) was performed. For performing all of the mentioned statistical methods, S-Plus version 2000 (MathSoft, 1999), SPSS version 13 (SPSS, 2004) and Minitab version 14 (2005) statistical packages were used.

RESULTS AND DISCUSSION

The results of analysis of variance showed highly significant differences among 56 bread wheat genotypes for all measured traits under study (data not shown). To determine in the most precise manner the interrelation of direct and indirect grain yield components, simple correlations and path coefficient analysis were calculated. According to the simple correlation coefficients (Tab. I) showed there were high positive correlations between grain yield and SN (spikelet number), GD (grain diameter), GL (grain length) and TS (1000 seed weight) traits. The significant correlation blew 0.40 were not consrdered due to relatively low associations which could not be meaningful in breeding efforts. Similarly, Mondal *et al.* (1997) also reported non-significant association of plant height with grain yield but Khan *et al.* (2005) reported a significant negative correlation between number of tillers per plant and grain yield. Also, similar results have been reported that number of tillers per plant had positive genotypic correlation with grain yield (Usman *et al.*, 2006; Anwar *et al.*, 2009). It was reported that grain yield exhibited highly significant positive correlation with number of tillers per plant, number of spikelets per spike (Lad *et al.*, 2003). Kashif and Khaliq (2004) reported that plant height, number of spikelets per spike and 1000 seed weights were positively significantly correlated with grain yield.

Stem diameter had significant positive correlation with leaf width (LW), tiller number (TN), floret number (FN), spikelet number (SN) and grain number (GN) traits (Tab. I). Plant height (PH) showed significant positive correlation with internode length (NL) and peduncle length (PL) where leaf number (LN) had not any positive correlation with the measured traits (Tab. I). Leaf length had positive correlation with spike length (SL) while leaf width (LW) indicated positive correlation with tiller number (TN), spike length (SL), floret number (FN) and spikelet number (SN) traits (Tab. I). Our obtained results are in agreement with those obtained by Aycecik and Yildirim (2006) and Akram *et al.* (2008). According to Anwar *et al.* (2009), the number of spikelets per spike was negatively associated with 1000 seed weight while we did not find any significant correlation. Also, Moghaddam *et al.* (1998) showed a negative correlation between plant height and grain yield, a positive correlation between plant height and number of grains per spike.

Tiller number (TN) showed positive correlation with floret number (FN) and grain number (GN) while spike length (SL) had positive correlation with spikelet number (SN) and length of awn (AL). Floret number (FN) indicated positive correlation with spikelet number (SN) and grain number (GN) where spikelet number (SN) showed positive correlation with grain number (GN) trait (Tab. I). Grain length showed positive correlation with 1000 seed weight trait (Tab. I). Mohamed (1999) had shown that number of spikes and 1000 seed weight were correlated to grain yield. Although we obtained moderate association between 1000 seed weight and grain yield, but this association is not true for all situations such as stressed conditions (Kilic and Yagbasanlar, 2010). Under drought stress conditions, the number of fertile tillers and spikelets in spike are decreased and negative correlation between1000 seed weight and grain yield was observed (Siahbidi *et al.*, 2012). Although, some agronomic traits of wheat have influences on grain yield but the differential relations of grain yield components may be attributed to environmental effects on plant growth (Asseng *et al.*, 2002).

Estimation of direct effects by path analysis (Tab. II), were considered where yield-related traits, as grouped into first, second, and third-order variables, with grain yield (Model II). Analysis of multicollinearity indicated a better understanding of the interrelationships among the measured traits and their relative contribution to grain yield. The results of Tolerance and VIF values for predictor variables indicated low values of Tolerance and VIF Model II. The stepwise regression model in this study is facilitating detection of the actual contribution of each predictor variables in different path components, with negligible confounding effects and interference. The advantage of path analysis with regarding collinearity problems and identifying actual contributions of each component in different path components are similar to those found in other crop studies (maize: Agrama, 1996; potato: Asghari-Zakaria *et al.*, 2007), indicating that this procedure should be very effective in achieving favorable results. Resampling techniques, like bootstrap, provide estimates of the standard error and the distribution of any statistics. To use this procedure, the direct effects, estimated from a set of 1000 bootstrap samples which were in close agreement with observed direct effects (Tab. II). This low standard error in all the direct effects and the low bias values also showed the robustness of path analysis. The T-test of significance, using standard error values, obtained through bootstrap resampling, indicated that all the direct effects were significant (data not shown).

The adjusted coefficient of determination ($R^2 = 0.37$) represents the influence of the TS and SN traits as first-order variables involved in the study of total variability of grain (Tab. III), while the TS had the greater direct effect (0.43) than SN on grain yield. The indirect effect to the TS was low and positive (0.073) via SN while the indirect effect on the SN was relatively low and positive (0.093) via TS. Many attempts have been made to graphically present statistical outputs. The diagram of path analysis (Fig. 1), gives a better understanding of the interrelationships among the various traits and their relative contribution to grain yield. The results of path analysis, when the second-order variables were used as predictors, and the first-

I: *Pairwise correlation coefficients between 18 traits of 56 bread wheat genotypes*

Traits	DF	SD	PH	LN	LL	LW	TN	NL	PL	SL	FN	SN	GN	AL	GD	GL	TS
SD[a]	0.01[b]																
PH	–0.08	0.02															
LN	–0.37	–0.09	0.19														
LL	0.11	0.28	0.17	–0.19													
LW	–0.07	0.54	–0.12	–0.04	0.25												
TN	–0.07	0.47	0.08	0.00	0.27	0.38											
NL	0.20	0.30	0.60	0.00	0.26	–0.06	0.20										
PL	0.05	0.05	0.51	0.19	0.16	–0.06	0.24	0.30									
SL	0.01	0.35	0.30	–0.19	0.48	0.48	0.39	0.22	0.15								
FN	–0.11	0.56	0.06	0.01	0.13	0.50	0.59	0.27	0.23	0.32							
SN	–0.13	0.50	0.05	–0.11	0.05	0.53	0.36	–0.03	0.21	0.42	0.56						
GN	–0.22	0.62	0.02	0.05	0.14	0.44	0.44	0.16	0.11	0.29	0.60	0.72					
AL	0.04	0.29	0.16	–0.09	0.29	0.29	0.24	0.03	–0.11	0.66	0.07	0.34	0.20				
GD	–0.23	0.23	0.10	–0.01	–0.06	0.26	0.29	–0.06	0.24	0.21	0.24	0.42	0.30	0.02			
GL	–0.02	0.09	0.24	–0.07	–0.08	0.07	0.36	0.22	0.36	0.24	0.24	0.21	0.08	–0.09	0.49		
TS	–0.17	0.03	–0.05	–0.05	–0.10	0.15	0.23	–0.13	0.26	0.29	0.08	0.21	0.01	–0.05	0.57	0.53	
GY	–0.10	0.27	0.04	–0.13	–0.04	0.20	0.31	0.02	0.19	0.38	0.35	0.43	0.19	0.21	0.50	0.44	0.50

[a] For trait abbreviations refer to text. [b] Critical values of correlation $P < 0.05$ and $P < 0.01$ (df 47) are 0.27 and 0.35, respectively.

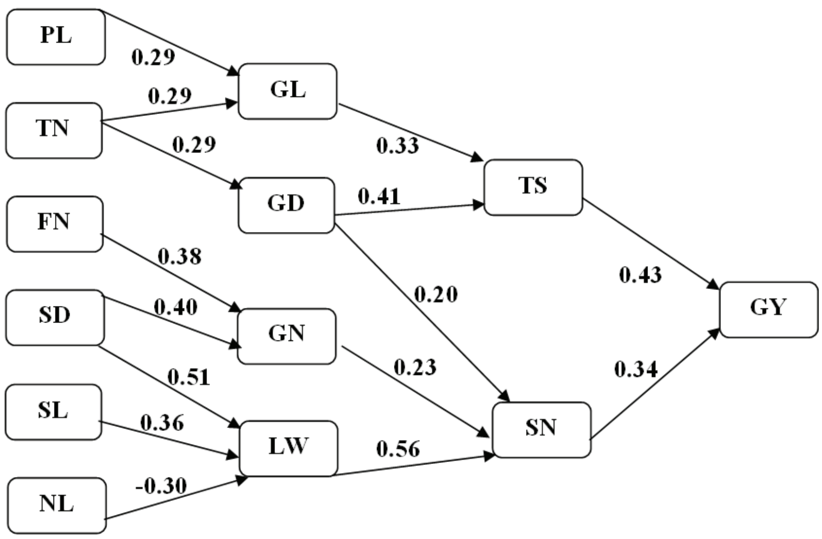
II: *Measures of collinearity values (tolerance and variance inflation factor, VIF) for predictor variables in path analysis and estimation of standard error values of path coefficients using bootstrap analysis*

Predictor variable	Response variable	Adjusted R^2	Direct effect	Collinearity Statistics		Bootstrap factors		
				Tolerance	VIF	Bias	Mean	SE
GY [a]	TS	0.37	0.431	0.954	1.048	–0.010	0.422	0.091
	SN		0.341	0.954	1.048	0.020	0.361	0.115
TS	GD	0.41	0.412	0.759	1.317	–0.002	0.410	0.128
	GL		0.327	0.759	1.317	0.004	0.331	0.117
SN	GN	0.60	0.558	0.769	1.301	–0.002	0.556	0.127
	LW		0.234	0.783	1.277	0.004	0.238	0.099
	GD		0.195	0.891	1.123	0.001	0.196	0.079
GL	PL	0.21	0.294	0.941	1.063	–0.002	0.292	0.106
	TN		0.286	0.941	1.063	–0.006	0.280	0.137
GD	TN	0.09	0.294	1.000	1.000	–0.005	0.289	0.116
GN	SD	0.47	0.404	0.683	1.464	–0.009	0.395	0.101
	FN		0.375	0.683	1.464	0.019	0.394	0.160
LW	SD	0.47	0.505	0.822	1.217	0.000	0.505	0.111
	SL		0.362	0.863	1.159	–0.002	0.360	0.094
	NL		–0.296	0.894	1.119	0.000	–0.296	0.107

[a] For trait abbreviations refer to text

III: *Direct and indirect effects for the predictor variables in path analysis (grouped into first, second and third order variables)*

GY	TS	SN	**SN**	GN	LW	GD
TS	0.431	0.073	GN	0.558	0.104	0.058
SN	0.093	0.341	LW	0.248	0.234	0.052
			GD	0.165	0.062	0.195
TS	GD	GL	**LW**	SD	SL	NL
GD	0.412	0.160	SD	0.505	0.128	–0.090
GL	0.202	0.327	SL	0.178	0.362	–0.064
			NL	0.154	0.079	–0.296
GL	PL	TN	**GN**	SD	FN	
PL	0.294	0.069	SD	0.404	0.211	
TN	0.071	0.286	FN	0.228	0.375	



1: *Path analysis diagram illustrating the interrelationships among various traits contributing to grain yield of bread wheat* order variables as response variables, indicated that GD and GL positively influenced the TS (Tab. III), and accounted for more than 41% of the observed variation in (Fig. 1) and the GN, LW and GD positively influenced SN and accounted for more than 60% of the observed variation. When the third-order variables were used as predictors and second-order variables as response variables the results indicated the PL and TN positively influenced the GL and accounted for about 21% of observed variation while the TN positively influenced GD and accounted for about 9% of the observed variation. Also, the SD and FN positively influenced the GN and accounted for about 47% of observed variation while SD, SL and NL positively influenced LW and accounted for about 47% of the observed variation (Tab. III).

As bread wheat yield depends mainly on three factors: number of grain per spike, 1000 seed weight and number of spikes per unit area, many plant breeders focus on modifying the number of grain per spike and 1000 seed weight of wheat so as to realize high yield, nevertheless, grain yield of wheat is the integration of many variables that affect plant growth throughout the growing period (Leilah and Al-Khateeb, 2005). Among these important components of grain yield, we found only two traits (1000 seed weight and number of spikes) which influence grain yield through first order variable. In order to develop high yielding wheat cultivars, the genetic association between grain yield and its components should be taken into consideration. As grain yield is controlled by multi-genes, progressive accumulation of genes conferring higher yield and the elimination of unfavorable genes through the different breeding methods (Evans and Fischer, 1999). Statistical analysis of agronomic characters via path analysis could be informative in achieving high yielding bread wheat cultivars in genetic improvement programs, because agronomic traits are reflection of genes. Thus, simple correlations may not provide a clear picture of the importance of each component in determining grain yield and using path analysis divides the correlation into direct and indirect effects. The path analysis allows, then, the separation of the direct influences each yield component on grain yield from the indirect effects caused by the real relationships among several components themselves (Khaliq *et al.*, 2004).

For future breeding programs, it is important to determine the available genetic variation for plant structure and yield components in every crop and a better understanding of how yield components influence yield formation can be obtained by using path analysis. It determines the direct and indirect effects of primary, secondary and tertiary traits on yield formation and its main benefit is not only identifying the most important factors directly affecting yield, but also showing how factors affect the yield indirectly through other factors (Kozak and Kang, 2006). Previous studies showed that path analysis provides more information on the interrelationships among yield components than correlation coefficients (Board *et al.*, 1997; Kozak and Kang, 2006; Sabaghnia *et al.*, 2010). Path analysis helps to determine if yield component compensation is occurring and it occurs when two, or more, yield components affecting yield or any other yield component act inversely in their effects.

The statistical methods which have been used in this investigation indicated that the number of spike (0.34) and 1000 seed weight (0.43) were the most important yield variables under non-stressed conditions and this was clear with used statistical procedure. Thus, high yield of wheat in Iran can possibly be obtained by selecting breeding materials with the high number of spike and 1000 seed weight. The other most important yield components in decreasing order were LW (0.56), GD (0.41 plus 0.20), GL (0.33) and GN (0.23) traits in the breeding research to increase grain yield. The importance of TS and SN can be seen for selection, in breeding programs, with the goal of improved wheat grain yield. Selection for above mentioned traits should be emphasized in lines in breeding programs ubder non-stress conditions with the aim of improved wheat grain yield. Given apparent potential for using path analysis, further work is needed to compare multivariate analysis methods with index selection in terms of actual gains achieved from selection.

SUMMARY

Traits variation is primary need of any plant breeding effort which involves the natural evolution and causes sustainable crop production under different environments. The correlation and path analysis of yield components are useful tools to determine valuable genotypes. The statistical methods which have been used in this investigation indicated that the number of spike and 1000 seed weight were the most important yield variables and this was clear with used statistical procedure. Thus, high yield of wheat in Iran can possibly be obtained by selecting breeding materials with the high number of spike and 1000 seed weight. The other most important yield components were GL, GD GN and LW in the breeding research to increase grain yield. The importance of TS and SN can be seen for selection, in breeding programs, with the goal of improved wheat grain yield. Selection for GL, GD GN, LW, TS and SN should be emphasized in lines in breeding programs with the aim of improved wheat grain yield. Given apparent potential for using path analysis, further work is needed to compare multivariate analysis methods with index selection in terms of actual gains achieved from selection.

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