Correlation and Regression Relationships between Main Grain Quality Characteristics in Bread Winter Wheat

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Summary

The aim of the study was to estimate the correlation and regression relationships between main quality characteristics in winter bread wheat genotypes and to determine criteria for selection that could be used to identify desirable genotypes with high grain quality. The following quality characters of grain were measured: thousand grain weight (TWG, g), test weight (TW, kg/hl), vitreousness (V, %), crude protein content in grain (CP, %), wet gluten content (WG, %), dry gluten content (DG, %), sedimentation value (SV, cm^3), bread making strength index (BSI), gluten weakness (GW, mm) and fermentation value (FV, min). The study revealed positive significant correlation of WG, BSI and DG with CP. WG correlated significantly and positively with BSI, SV and DG. The relationships of FV with SV and DG were also positive. SV correlated positively and significantly with DG. DG and BSC exhibited the highest positive direct effect on CP. DG showed the highest positive direct effect on WG. CP and GW exhibited the highest positive and negative direct effects on the BSI. V and DG had the high positive direct effect on SV. CP and V had the highest positive direct effects on DG. Stepwise regression analysis indicated that, DG and BSI were the most potent predictor variables for CP. DG was the most potent predictor variables for WG, while 72.9% of the total variation in the SV was explained by V and FV. The results of this study will be of benefit for the bread wheat breeding programs.

Key words

correlation, path analysis, regression analysis, wheat, grain, quality characters

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Introduction

Breeding programs are mainly directed toward higher yield and grain quality of common winter wheat. However, it has been reported that there is a negative correlation between yield and quality, thus making it very difficult to obtain a good quality grain in those high yield potential zones (Castillo et al., 2012). Wheat grain quality is a complex trait and depends on several physical, chemical and rheological properties, among which the most important include, e.g., protein content, composition of high-molecular glutenin subunits and grain hardness. The individual contribution of each trait varies depending on specific reaction to environmental conditions (Desheva, 2016). In plant breeding, selection of high-quality wheat is based mainly on the Zeleny sedimentation test, the falling number and the protein content (Rachoń et al., 2011; Salmanowicz et al., 2012; Warechowska et al., 2013; Desheva, 2016; Karaman and Aktas, 2020). The importance of protein content lies in the ability of gluten to produce dough with the desired rheological properties. Viscoelasticity is one of the basic properties of gluten. Therefore, wheat gluten is also very important in bakery products (Ktenioudaki et al., 2010; Boz et al., 2012). Tests like the Pelshenke dough ball test and the sodium dodecyl sulfate (SDS) sedimentation volume (an estimate of the strength of the wheat or quality of gluten and it depends on the degree of hydration of the proteins in the wheat and on their degree of oxidation) can also give valuable information about the baking quality of wheat (Pasha et al., 2007).

Correlations between traits are a measure of the strength of their relationship, and the knowledge of these correlations is important in plant breeding. If two traits are positively correlated, one can be indirectly improved by improving the other. Correlation coefficient is helpful in determining main traits influencing grain protein content and grain yield for indirect selection criteria. However, it provides incomplete information regarding relative importance of direct and indirect effects on individual factors involved (Hussain et al., 2010; Drikvand et al., 2013; Al-Najjar and Al-Zubaidy, 2020). Correlations between traits are dependent on genetic and environmental factors. Correlations themselves express only the degree of traits interrelationships, while path analysis provides an effective means of finding out direct and indirect causes of association (Drikvand et al., 2013).

Regression and correlation are closely related. The amount of correlation between the two variables determines the magnitude of the regression coefficient. Regression to the mean occurs when the correlation between the two variables is not complete. The accuracy of the prediction depends on the strength of the correlation. The higher correlation between variables, the more accurate the prediction (Mousavi and Nagy, 2020).

The aim of the study was to estimate the correlation and regression relationships between main quality characteristics in bread winter wheat and to determine the criteria for selection that could be used to identify desirable genotypes with high grain quality.

Materials and Methods

The study was conducted in three growing seasons (2016/2017, 2017/2018 and 2018/2019) on the experimental field of the Institute of Plant Genetic Resources, Bulgaria. Twenty four winter bread wheat varieties were included in this study (Table 1). The sowings were carried out in the autumn in optimal terms for the region, on soil type meadow-cinnamon resin-like soil, after the predecessor peas. The randomized complete block designs with 3 replications on plots of 10 m^2 were used. The standard technology for cultivation of winter bread wheat was used.

The following quality characters of grain were measured: thousand grain weight (TWG, g), test weight (TW, kg hl^{-1}), vitreousness (V, %), crude protein content in grain (CP, %), wet gluten content (WG, %), dry gluten content (DG, %), sedimentation value (SV, cm^3), bread making strength index (BSI), gluten weakness (GW, mm) and fermentation value (FV, min). Quality analyses were performed at biochemical laboratory of the Institute of Plant Genetic Resources.

TWG, TW and V were determined according to the methods described in BDS ISO 520 (2003), BDS ISO 7971-2 (2000) and BDS 13378 (1976).

CP was estimated by the Kjeldahl method (BDS ISO 1871, 2001).

WG and DG in different flour samples were estimated by the hand washing method (BDS 13375, 1988).

SV of the whole wheat flour was determined using the method described by Pumpyanskiy (1971).

BSI and GW were defined according to BDS 13375 (1988). The whole wheat meal flour of each wheat variety was also tested for FV (Pelchenke et al., 1953).

Average data of three growing seasons were used to calculate the Pearson Correlation Coefficients between all possible combinations. The path coefficient analysis was calculated according to Dewey and Lu (1959). Single regression and stepwise regression analyses were also carried out for the data obtained to test the significance of the independent variables on the dependent variable. The data were analysed using the statistical program IBM SPSS Statistics 22.0.

Results and Discussion

The Pearson phenotypic correlation coefficients for 10 quality parameters of grain are presented in Table 2. The study revealed positive significant correlation of WG (0.893**), BSI (0.610**) and DG (0.913**) with CP. The linear relationship between CP and studied traits showed that a unit increase in the WG, BSI and DG correspondingly increased CP by 0.12%, 0.30% and 0.86%, respectively. The coefficient of determination (R^2) was high between CP and WG and between CP and DG, indicating that 79.71% of CP variance could be predicted from WG and 83.38% from DG (Fig.1). Improvement of crude protein might be possible if the above characters were considered in the selection programme. It was also observed that the association of V (0.387), TW (0.228), FV (0.374), GW (0.164), and SV (0.380) showed non-significant positive association with crude protein, while TWG correlated negatively and non-significantly with crude protein (-0.205). Huang et al. (2006), Kučerová (2006), Ionescu and Stoenescu (2010), Al-Saleh and Brennan (2012), Desheva (2016), Meles et al. (2016) and Karaman and Aktas (2020) in their studies also reported for highly significant positive correlation between CP and WG, which is strongly influenced by the pedoclimatic conditions. A positive correlation between protein content and gluten (both wet and dry) was also reported by Gulia and Khatkar (2015) and Siddiqi et al. (2020). EL-Khayat et al. (2006) and Al-Saleh and Brennan (2012) confirmed a low correlation between test weight and protein content. Drikvand et al. (2013) and Laidig et al. (2017) noted a positive correlation between CP and sedimentation volume (SV). Contrary to our results Shahin et al. (2002), Jochen et al. (2011) and Abdipour et al. (2016) reported for significant phenotypic correlations between crude protein content and sedimentation volume, while Garg et al. (2016) and Siddiqi et al. (2020) reported for no correlation between protein content and SV. Al-Saleh and Brennan (2012) and Brennan et al. (2012) noted a significant positive correlation between protein content and vitreousness and a negative significant correlation with kernel weight. A significant positive correlation of grain protein content with vitreousness was found by Figiel et al. (2011) and Warechowska et al. (2013).

V exhibited significant positive correlations with TW (0.485*), WG (0.567**), FV (0.557**), SV (0.793**) and DG (0.512*) (Table 2). The regression lines between V and studied traits made it evident that the increase of the TW, WG, FV, SV and DG by 1, increased V by 1.591%, 1.923%, 0.161%, 0.972% and 4.88%, respectively. SV with R^2 of 62.85% estimated the maximum of V changes (Fig. 1).

Table 1. Varieties included in the study

№	Plant species	Subspecies	Name of varieties	Origin
1	*Triticum aestivum* L.	var.*erythrospermum* (Koern.) Mansf.	Saturnus	AUT
2	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Dimas	ESP
3	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Ines	CZE
4	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Bohemia	CZE
5	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Baletka	CZE
6	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Seladon	CZE
7	*Triticum aestivum* L.	var.*erythrospermum* (Koern.) Mansf.	Jordao	PRT
8	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Andalou	FRA
9	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Muza	POL
10	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Kobra Plus	POL
11	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Bardotka	CZE
12	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Bazilika	CZE
13	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Nikol	CZE
14	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Bodycek	CZE
15	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Elly	CZE
16	*Triticum aestivum* L.	var.*erythrospermum* (Koern.) Mansf.	Jindra	CZE
17	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	RW Nadal	CZE
18	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Matylda	CZE
19	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Canadair	FRA
20	*Triticum aestivum* L.	var.*ferrugineum* (Alef.) Mansf.	Oropos	GRC
21	*Triticum aestivum* L.	var.*aureum* (Link) Mansf.	Nestor	GRC
22	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Altigo	FRA
23	*Triticum aestivum* L.	var.*lutescens* (Alef.) Mansf.	Aldric	FRA
24	*Triticum aestivum* L.	var.*erythrospermum* (Koern.) Mansf.	Enola	BGR

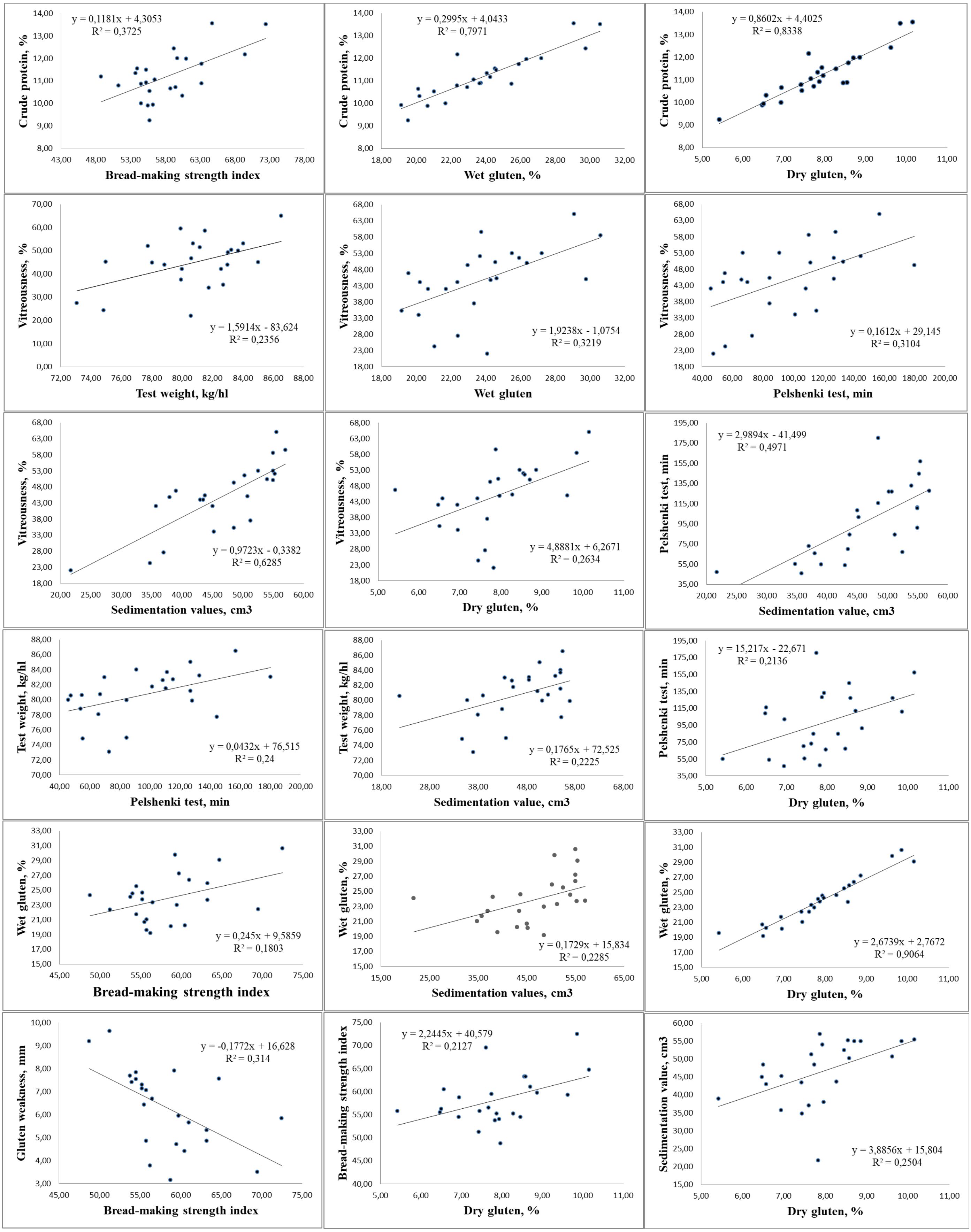

Figure 1. Simple regression relationships between investigated quality characters of 24 bread wheat accessions

Table 2. Pearson correlation coefficients between studied 10 quality parameters of grain in 24 bread wheat genotypes

	CP	V	TWG	TW	WG	FV	GW	BSI	SV	DG
CP	1									
V	0.387	1								
TWG	-0.205	0.024	1							
TW	0.228	0.485*	0.026	1						
WG	0.893**	0.567**	-0.207	0.378	1					
FV	0.374	0.557**	-0.149	0.490*	0.379	1				
GW	0.164	0.161	-0.11	0.141	0.362	-0.21	1			
BSI	0.610**	0.246	-0.106	-0.01	0.425*	0.371	-0.560**	1		
SV	0.38	0.793**	-0.162	0.472*	0.478*	0.705**	-0.105	0.35	1	
DG	0.913**	0.512*	-0.302	0.288	0.952**	0.461*	0.31	0.460*	0.499*	1

crude protein content in grain (CP), vitreousness (V), thousand grain weight (TWG), test weight (TW), wet gluten content (WG), fermentation value (FV), gluten weakness (GW), bread making strength index (BSI), sedimentation value (SV), dry gluten content (DG)

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the $P < 0.05$ level (2-tailed)

In our previous investigation we also noted that the association of V and SV showed significant positive relationship (Desheva, 2016). In contrast with our study Al-Saleh and Brennan (2012) reported for negative correlation with the kernel weight and the test weight.

TW showed significant positive association with FV (0.490*) and SV (0.472*) at phenotypic level. WG correlated significantly and positively with BSI (0.425*), SV (0.478*) and DG (0.952**) (Table 2). The regression lines for evaluated characters showed that the increase of BSI, SV and DG by 1, increased WG by 0.245%, 0.173% and 0.267%, respectively. R^2 of 0.9064 between WG and DG was the highest. This value indicated that 90.64% of the WG variance could be predicted from the DG as variable (Fig. 1).

The associations between sedimentation value and wet gluten content were also illustrated by Pasha et al. (2007), Ralcewicz (2009), Surma et al. (2012) and Siddiqi et al. (2020). Gulia and Khatkar (2015) and Desheva (2016) reported for significant correlation between wet and dry gluten.

The relationships of FV with SV and DG were also positive, respectively 0.705** and 0.461*. GW showed significantly negative association with BSI (-0.560**). SV correlated positively and significantly with DG (0.499*). TWG showed non-significant negative association at phenotypic level with all of the studied parameters except with TW (0.026) and V (0.024) (Table 2). Contrary to our study significantly high positive correlations between test weight and thousand kernel weight were observed by Al-Saleh and Brennan (2012), Warechowska et.al. (2013), Baye et al. (2020) and Karaman and Aktas (2020). Test weight increased linearly with a thousand kernel weight increase. Stronger correlations were found for a variety of larger grains (Warechowska et al., 2013; Upadhyay, 2020).

As stated, path coefficient is the most powerful tool to help analyse nature, extent and direction of selection. It is used to establish the exact relationships in terms of cause and effect, identify the direct, indirect and total (direct plus indirect) causal effects (Khanala et al., 2020). For increasing of given trait in the breeding program, selection and hybridization can be made more effective and accurate by using those traits that have a significant positive correlation coefficient and direct effect on the studied trait (Upadhyay, 2020).

Data presented in Table 3 revealed that characters DG and BSC exhibited the highest positive direct effect on CP, respectively with 0.556 and 0.387, while the highest total positive indirect effect had WG (0.648), following from V (0.566). The direct negative effect of V on the CP was masked from the total positive indirect effect of the rest traits. Therefore DG and BSC could be considered as main components of selection in a breeding program for obtaining higher crude protein in the grain of common winter wheat.

Direct contributions of SV, WG, GW and BSI to V were high and positive, respectively 0.68; 0.592; 0.484 and 0.415. CP exhibited the highest positive direct effect on TWG (0.623), V (0.635) and WG (0.407), while DG (-0.986) showed the highest negative direct effect on TWG. The highest positive and negative direct effects on TW were shown in WG and DG, respectively 1.388 and -1.321. The direct negative effect of DG on the TW was masked from the total positive indirect effect of the rest traits (Table 3).

DG (0.754) showed the highest positive direct effect on WG, like its phenotypic correlation with WG (0.952), implying that there was true association of the two traits. Direct contribution of DG (1.209) on FV was the highest and positive. WG (-0.965) showed the greatest negative direct effect on FV, which was masked from the total positive indirect effect of the rest traits (1.344).

V exhibited positive direct effect on GW however less magnitude was, while BSI showed the highest negative direct effect on the character, like the association between both traits. CP and GW correlated positively and negatively, respectively with BSI and exhibited the highest positive and negative direct effects on the BSI (Table 4).

Table 3. The direct and total indirect effects of independent variables on a dependent variable in 24 accessions from *Triticum aestivum* L.

Independent variables	Dependent variables							
	CP		V		TWG		TW	
	Direct effects	Total indirect effects	Direct effects	Total indirect effects	Direct effects	Total indirect effects	Direct effects	Total indirect effects
CP			-0.424	0.811	**0.623**	-0.828	0.224	.004
V	-0.179	**0.566**			**0.635**	-0.611	-0.009	.494
TWG	0.075	-0.280	0.182	-0.157			0.008	.018
TW	0.04	0.187	-0.004	0.489	0.012	0.014		
WG	0.245	**0.648**	**0.596**	-0.028	0.407	-0.615	**1.388**	-1.010
FV	0.006	0.368	0.156	0.401	-0.037	-0.112	0.515	-.025
GW	0.153	0.012	**0.484**	-0.323	-0.464	0.353	-0.106	.247
BSI	**0.387**	0.225	**0.415**	-0.168	-0.439	0.333	-0.434	.425
SV	-0.004	0.383	**0.678**	0.115	-0.478	-0.187	0.169	.310
DG	**0.556**	0.357	-0.362	1.263	-0.986	0.684	**-1.321**	1.609

crude protein content in grain (CP), vitreousness (V), thousand grain weight (TWG), test weight (TW), wet gluten content (WG), fermentation value (FV), gluten weakness (GW), bread making strength index (BSI), sedimentation value (SV), dry gluten content (DG)

Table 4. The direct and total indirect effects of independent variables on a dependent variable in 24 accessions from *Triticum aestivum* L.

Independent variables	Dependent variables							
	WG		FV		GW		BSI	
	Direct effects	Total indirect effects	Direct effects	Total indirect effects	Direct effects	Total indirect effects	Direct effects	Total indirect effects
CP	0.140	**0.753**	0.022	0.351	0.278	-0.113	**0.620**	-0.010
V	0.144	0.423	0.243	0.314	0.371	-0.210	0.281	-0.035
TWG	0.028	-0.236	-0.016	-0.141	-0.102	-0.009	-0.085	-0.021
TW	0.141	0.237	0.339	0.151	-0.034	0.091	-0.124	0.114
WG			**-0.965**	**1.344**	0.222	0.140	0.194	0.253
FV	-0.149	**0.528**			-0.186	-0.024	-0.057	0.428
GW	0.07	0.293	-0.379	0.169			**-0.774**	0.214
BSI	0.069	0.356	-0.132	0.503	**-0.877**	0.317		
SV	-0.04	**0.518**	0.204	0.501	-0.313	0.208	-0.158	0.508
DG	**0.754**	0.198	**1.209**	-0.747	0.280	0.029	-0.078	0.539

crude protein content in grain (CP), vitreousness (V), thousand grain weight (TWG), test weight (TW), wet gluten content (WG), fermentation value (FV), gluten weakness (GW), bread making strength index (BSI), sedimentation value (SV), dry gluten content (DG)

The table 5 showed that V (0.692) and DG (0.428) had a high positive direct effect on SV indicating the relationship between these traits as good contributors to SV. Direct contributions of FV (0.133) to SV were also positive but with less magnitude and were masked from the total positive indirect effect of the rest traits. CP (0.636) and V (0.589) had the highest positive direct effects on DG

Stepwise regression is a semi-automated process of building a model by successively adding or removing variables based solely on the t-statistics of their estimated coefficients (Hannachi et al., 2013). In our study stepwise regression analysis indicated that DG and BSI were the most potent predictor variables for CP, accounting for 87.9% of its variability. The existence of significant R square in a regression equation indicates the effectiveness of the traits to increase CP (Desheva and Kyosev, 2017). Correlation and path analyses also confirmed that DG and BSI were the main components for obtaining higher crude protein in the grain of common winter wheat. The SV with R^2 = 62.8%, had justified the maximum of V changes. The other variables in this study were not included in the model because of their low relative contributions on V (Fig.1). Stepwise regression fitted model showed that TW increased with the increase of FV, but R square was only 0.240. DG was the most potent predictor variable for WG, accounting for 90.6% of its variability, while SV was the most potent predictor variable for FV (R^2 = 49.7%) (Table 6).

The final stepwise regression model equation developed between BSI and independent variables depicted strong relationship with R^2 of 82.10%. The model showed that BSI increased with the increase of CP and decrease of GW (Table 6).

According to the results, 72.9% of the total variation in the SV was explained by the selected variables V and FV, while the most potent predictor variables for DG were WG and CP. The R^2 value of 92.6% confirmed that our model equation could be used to predict dry gluten (Table 6).

Table 5. The direct and total indirect effects of independent variables on a dependent variable in 24 accessions from *Triticum aestivum* L.

Independent variables	Dependent variables			
	SV		DG	
	Direct effects	Total indirect effects	Direct effects	Total indirect effects
CP	-0.009	0.389	0.277	**0.636**
V	**0.692**	0.101	-0.076	**0.589**
TWG	-0.140	-0.022	-0.059	-0.243
TW	0.073	0.399	-0.117	0.406
WG	-0.168	**0.646**	**0.658**	0.294
FV	0.133	0.571	0.163	0.299
GW	**-0.418**	0.312	0.077	0.219
BSI	-0.238	0.391	-0.024	0.486
SV			0.088	0.412
DG	**0.428**	0.073		

crude protein content in grain (CP), vitreousness (V), thousand grain weight (TWG), test weight (TW), wet gluten content (WG), fermentation value (FV), gluten weakness (GW), bread making strength index (BSI), sedimentation value (SV), dry gluten content (DG)

Table 6. Stepwise regression fitted model to study relationship between grain quality characters of bread wheat

Parameters	Fitted model	R^2	Sum of Squares	df	Mean Square	F	Sig.
CP	CP= 2.515+0.756xDG+0.047xBSI	0.879	22.74	2	11.37	76.49	0.000
V	V= -0.338+0.97xSV	0.628	1661.07	1	1661.07	37.21	0.000
TW	TW= 76.51+0.043xFT	0.240	59.00	1	59.00	6.95	0.015
WG	WG= 2.77+2.674xDG	0.906	208.34	1	208.34	212.94	0.000
FV	FT= -41.499+2.989xSV	0.497	15702.22	1	15702.22	21.75	0.000
BSI	BSI= 30.07+3.731xCP-2.148xGW	0.821	567.00	2	283.50	48.27	0.000
SV	SV= 16.488+0.473xV+0.090xFV	0.729	1281.03	2	640.51	28.26	0.000
DG	DG= -1.534+0.240xWG+0.330xCP	0.926	26.98	2	13.49	131.41	0.000

crude protein content in grain (CP), vitreousness (V), thousand grain weight (TWG), test weight (TW), wet gluten content (WG), fermentation value (FV), gluten weakness (GW), bread making strength index (BSI), sedimentation value (SV), dry gluten content (DG)

Conclusion

The results of our study confirm that to obtain bread wheat genotypes with higher seed quality traits, attention should be focused on selecting traits which have high relative contribution and positive direct effect on seed quality traits. In our study DG and BSI were the main components and the most potent predictor variables for CP. V and FV had the highest relative contribution and positive direct effect for obtaining the higher SV. DG was the most potent predictor variables for WG, while WG and CP had the high relative contribution and positive direct effect on DG. BSI increased with the increase of CP and decrease of GW. The results of this study will be of benefit for the bread wheat breeding programs.

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