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Variability, heritability and genetic advance of some grain quality traits and grain yield in durum wheat genotypes

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Abstract

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The main priority in durum wheat breeding is the creation of high yielding varieties with improved grain quality. The study were carried out to determine the variability, heritability, genetic advance for the following grain quality traits: protein content (PC), wet gluten (WG), yellow pigment in grain (YPG), sedimentation value (SDS), vitreousness (VS), thousand kernel weight (TKW), test weight (TW) and grain yield (GY) of 24 durum wheat genotypes – 1varieties and breeding lines of different origin: Bulgaria (FCI – Chirpan, DAI – G. Toshevo), Europe, CYMIT – Mexico and ICARDA – Syria. All genotypes were grown under field conditions in competitive variety trial in three replications during three harvest years (2014 – 2016) in the experimental field of Field Crops Institute – Chirpan, Bulgaria. All parameters were evaluated on whole grains on standard methods. Analysis of variance revealed the presence of highly significant ($P \leq 0.01$) variation among genotypes for all studied traits. The Phenotypic Coefficient of Variation (PCV) was generally higher than the Genotypic Coefficient of Variation (GCV) for all studied traits, indicating the influence of the growing season. The greatest PCV was found for sedimentation value (SDS 44.54%), grain yield (GY 16.92%) and yellow pigment in grain (YPG 14.8%) and the greatest GCV was found for the same traits – SDS 43.45%, YPG 14.3% and GY 10.2%. The lowest PCV was found for test weight (TW 1.69%) and protein content (4.66%). The estimated values of broad-sense heritability were found between 52.0% for wet gluten (WG) and 95.2% for SDS sedimentation value. A high level of heritability was also determined for yellow pigment in grain (YPG 92.4%), followed by thousand kernel weight (TKW 72.4%) and protein content (PC 67.2%); moderate level – for test weight (TW 47.4%) and grain yield (GY 36.3%) and relatively low level – for vitreousness (VS 29.1%). The highest genetic advance was calculated for SDS sedimentation value. High heritability and considerable genetic advance for SDS indicated the predominance of an additive gene effect in controlling this trait and reveal the possibility to conduct effective selection. For protein content and thousand kernel weight high heritability was associated with low genetic advance, indicating the influence of dominant and epistatic genes in heritability of this traits and reveal slower breeding progress in their improvement.

Keywords: durum wheat; grain quality traits; heritability; genetic advance

Introduction

Durum wheat is important cereal crop used for human consumption worldwide and represents about 8% of the total wheat production but 80% grows predominantly in Mediterranean climates as well as on the Balkan Peninsula and Bulgaria, too. Durum wheat (*T. durum* Defs.) is a traditional cereal crop in Bulgaria, where the conditions for its cultivation in particular regions are very suitable.

Durum wheat is the preferred raw material for high quality pasta due to specific grain properties of this botanical species guaranteeing quality of end products expected by the traditional consumer (Dexter and Matsuo, 1980; Petrova and Belcheva, 2000a, b). Grain of durum wheat is characterized by a hard and compact endosperm, high vitreousness, high protein and carotenoid content, quality gluten with high extensibility and low elasticity. Major commercial, technological and nutritional traits falling under the attention of breeders and producers of macaroni concern: grain specific weight, vitreousnesss, mass of 1000 grains, content of damaged grain, content of yellow pigments, oxidative potential, protein content, gluten strength and ash content.

Protein content (PC) and gluten strength are the most important characteristics in assessing the culinary quality of pasta products. The link between the quantity and quality of protein with the culinary potential of durum wheat is complex and is influenced by other factors as well. Generally, durum wheat dough high in protein and with stronger gluten are tough and non-sticky and are ideal for processing into pasta with excellent culinary quality (Dexter and Matsuo, 1980; Matsuo et al., 1982; Autran et al., 1986; D'Egidio et al., 1990; Feillet and Dexter, 1996; Dexter and Marchylo, 2000; Sissons et al., 2005; Dexter, 2008). Gluten quality can be successfully determined by its colloidal properties in lactic acid solution. The sedimentation test is well suited for early screening of high gluten and good pasta quality lines of durum wheat since it is more influenced by the genotype than by the environmental conditions (Dexter et al., 1980; Liu et al., 1996; Pena, 2000). Concentration of yellow pigments in the grain is an important trait of durum wheat quality and is due to carotenoids. They contribute to the yellow color of semolina and macaroni.

In Bulgaria, the breeding of durum wheat has a long tradition. Artificial breeding aimed at development of homogeneous and highly productive cultivars was initiated 90 years ago in the Field Crops Institute, formerly Institute of Cotton and Durum Wheat, Chirpan. Different classical breeding methods were successfully applied to develop short-stem and lodging resistant cultivars with higher productivity and grain quality. Most Bulgarian varieties are characterized by very good physical properties of grain, good milling potential and medium culinary potential. In recent years, progress has also been made with regard to end-use quality parameters such as gluten strength and content of endosperm carotenoids (Dechev et al., 2010).

Several microsatellite-based studies have shown moderate to low level of genetic diversity in cultivated durum wheat (Todorovska et al., 2007; Ganeva et al., 2010), highlighting the necessity to improve the present genetic pool. The number of released Bulgarian durum wheat cultivars is lower compared to bread wheat, due to the limited area suitable for cultivation of this crop in the country. This explains the relatively lower diversity in the present-days *T. durum* gene pool. However, the genetic diversity of the modern varieties measured by molecular markers was higher than that of the modern Cypriot cultivars but close to that of Mediterranean ones (Todorovska et al., 2018).

To improve durum wheat quality the efforts of plant breeders should be directed to the creation of cultivars with high protein content, strong gluten and a high content of yellow pigments. One of the most significant problems in this regard is the small differences in the variation of genes controlling these traits in modern durum wheat cultivars (Blanco et al., 1994). This calls for a large number of genotypes of different ecological and geographical origin to be included in the plant breeding programs. Knowledge on variability, heritability and genetic advance is very important for building of appropriate breeding strategy for improvement of these basic for durum wheat traits.

The presence of genetic variability in breeding materials is essential for a broadening the gene pool and therefore for success of plant breeding programs. Heritability is an indicator for transfer of traits of interest from parents to its progeny and is widely used in breeding programs (Falconer, 1981). Heritability estimation gives information about the degree of genetic control in particular traits expression and phenotypic reliability in predicting its breeding value.

The genetic advance (GA) is another important parameter which serves to determine the expected response to selection (Shukla et al., 2004). High genetic advance coupled with high heritability offers the most effective condition for selection (Larik et al., 2000) and indicates the presence of additive genes in the inheritance of trait.

Phenotypic and genotypic coefficients of variations, heritability and genetic advance have been widely used in wheat to assess the magnitude of variance in breeding material, to determine appropriate selection procedures and to predict the breeding advance in improvement of important traits (Zecevic, 2001; Shukla et al., 2004, Clarke et al., 2010).

The present study was conducted to evaluate the variability, heritability and genetic advance for some important grain quality traits and grain yield in a set of durum wheat genotypes – varieties and breeding lines of different origin and to provide necessary genetic information for improvement of grain quality in durum wheat breeding program of FCI – Chirpan, Bulgaria.

Material and Methods

The study includes 24 durum wheat genotypes – cultivars and breeding lines of different origin: Bulgaria (FCI – Chirpan, DAI – G. Toshevo), Europe, CYMMIT – Mexico and

ICARDA – Syria (Table 1). All genotypes were grown under field conditions in competitive variety trial in three replications during three harvest years (2014 – 2016) in the experimental field of Field Crops Institute – Chirpan, Bulgaria. The following parameters have been analyzed: protein content (PC %), wet gluten content (WG %), yellow pigments (YP) in the grain and SDS-sedimentation value. Protein content in the grain has been determined by the Keldahl method (N x 5,7) according to BDS EN ISO 20483: 2006 and of wet gluten according to BDS EN ISO 21415-2: 2008. The gluten strength assessment has been done by sedimentation volume of whole ground grain with protein detergent sodium dodecyl sulfate (SDS) (ICC 151: 1990). The content of the yellow pigments has been determined spectrophotometrically according to BDS EN ISO 11052: 2006. The principle of the method is extraction of pigments with water-saturated n-butanol and reading the optical density of the clear filtrate at a wavelength of 440 nm. The amount of yellow pigments is calculated as ppm DM versus a standard curve with pure β-carotene.

Broad sense heritability (h^2_{BS}) for studied traits was estimated by variance components method based on the combined analyses over three growing seasons. The initial dates were processed by Analyses of variance (ANOVA). Variance components were estimated according to Snedecor and Cochran (1980). Genetic advance was calculated according to Johnson et al. (1955). All studied genetic parameters, formulas for their calculation and designations are presented in Table 2.

For statistical processing of the data software package Statistica 6.0. has been used (StatSoft, Inc. 2002).

Table 1. Names and origin of 24 genotypes used in experiment

Origin	Name
Bulgaria, FCI – Chirpan	Predel, Railidur and advanced breeding lines: D-7557, D-8138, D-8326, M-6433, M-615, M-376, M-431, M-287, DV-8359, D-7864
Bulgaria, DAI – G. Toshevo	Saturn, Severina
Austria	Superdur, Auradur
Hungary	Betadur, Selyemdur
Germany	TD-97
Romania	DF-009114002
ISDN, CIMMYT, Mexico	ISDN/D-8362, ISDN/D-8367, ISDN/D-8370
ICARDA – Syria	D-8308

Table 2. Studied genetic parameters and formulas for their calculation

$\sigma^2_g = (MS_g – MS_{gy})/y$	Genotypic variance
$\sigma^2_{gy} = (MS_{gy} – MS_e)/r$	Variance of interaction between G and Y
$\sigma^2_e = MS_e$	Variance of error
$\sigma^2_{ph} = \sigma^2_g + \sigma^2_{gy}/y + \sigma^2_e)/r$	Phenotypic variance
$h^2_{BS} = (\sigma^2_g / \sigma^2_{ph})$ x 100	Broad sense heritability
GA = k x $(\sigma^2_{ph})^{0.5}$ x h^2_{BS} ($\bar{x} \times 100$)	Genetic advance; K – selection intensity – 2.06
PCV = $\sqrt{}\ \sigma^2_{ph}/ (\bar{x} \times 100)$	Phenotypic coefficient of variation
GCV = $\sqrt{}\ \sigma^2_g/(\bar{x} \times 100)$	Genotypic coefficient of variation
MS_g	Mean squares of genotype (g)
MS_{gy}	Mean squares of interaction (gxy)
MS_e	Mean squares of error
y	Number of years of cultivation
r	Number of replications
$\bar{x}$	Mean value

Results and Discussions

The amount of genotypic and phenotypic variability that exist in a species is of utmost importance for breeding programs. The conducted analysis of variance shows that the mean squares for genotypes, years of cultivation and interaction between them were significant for all studied traits (Table 3). The observed significance differences for all studied traits among all genotypes reveals the presence of genetic variations in chosen sat of genotypes, that can be used for improvement of grain quality traits and yield in durum wheat.

Mean values, ranges and phenotypic and genotypic coefficients of variation of all studied traits for 24 durum wheat genotypes across growing seasons are given in Table 3. The phenotypic coefficient of variation (PCV) was generally higher than the Genotypic Coefficient of Variation (GCV) for all studied traits, indicating the influence of the growing season on the variation of the studied traits. The greatest PCV was found for sedimentation value (SDS 44.54%), grain yield (GY 16.92%), yellow pigment in grain (YPG 14.8%). The greatest GCV was found for the same traits – 1SDS (43.45%), YPG (14.3%) and GY (10.2%). The smaller difference between PCV and GCV was observed for the traits SDS, YPG, PC and TW that is an indicator for less influence of the environment on the phenotypic expression of the respective trait. The biggest difference between PCV and GCV was obtained for traits GY, WG, V and TKW and is therefore associated with greater environmental than genotypic impact on the variation of this traits. On the other hand, the coefficient of variation is used to determine the variability that exists in one population. It is considered, that CV higher than 20% is an indicator of great diversity, value of CV between 10 and 20% – moderate diversity and <10% – low diversity (Deshmukh et al., 1986). In our study the great diversity was obtained for trait SDS – CV 44.54%, followed by moderate diversity for traits grain yield – CV 16.92%, YPG – CV 14.8%. These results reveal the existence of sufficient variability on these important grain quality traits and grain yield among studied genotypes that could be exploited in our breeding program for durum wheat improvement. The lowest PCV was estimated for test weight (TW 1.69%), protein content (4.66%), wet gluten content – CV% (7.32%), TKW (8.10%) and V (8.24%). This is an indicator for low genetic variability and less potential for breeding advance for these traits.

The phenotypic variance of all studied traits and its two main components: genotypic variance (heritable) and environmental variance (non-heritable) are presented in Table 4. The magnitude of genotypic variances was higher than

Table 3. Mean square value of grain quality traits and grain yield of 24 durum wheat genotypes over three years of cultivation

Traits	Year/Environments	Genotype	GxE	Error
Yield	835615***	25423***	16187***	1464
PC	46.56***	2.57***	0.63***	0.01
Wet gluten	237.0***	22.4***	8.4***	0.1
SDS	133.3***	1848.7***	60.8***	2.5
YPG	39.770***	8.393***	0.418***	0.003
V	12752.7*	203.3*	127.0*	9.0
TW	201.9**	9.6**	4.1**	0.1
TKW	490.5***	57.9***	11.8***	0.2

Table 4. Means value and its ranges, variation coefficient of grain quality traits and grain yield of 24 durum wheat genotypes over three years of cultivation

Traits	Min-Max	Mean	CV, %	
			PCV	GCV
Yield	249-460	314.04	16.92	10.2
PC	13.96-16.26	14.79	4.66	3.8
Wet gluten	24.9-32.5	28.68	7.32	5.32
SDS	19.00-74.33	39.72	44.54	43.45
YPG	6.04-10.71	8.06	14.8	14.3
V	62.83-87.33	80.20	8.24	4.44
TW	79.48-83.93	81.82	1.69	1.17
TKW	35.03-45.7	40.23	8.10	6.89

environmental variances (years of cultivation) for the traits PC, SDS, YPG and TKW. The ratio between genotypic and environmental variances at these traits was determined from 1.03 for PC to 10.22 for SDS. This reveals that the genotypic component of variation is the main contributor to total variation in the above traits. The magnitude of environmental variances was higher than genotypic variances for the traits Y, WG, V and TW and indicates that environmental component of variation is the main contributor to total variation for above traits.

Heritability is a measure of the phenotypic variance attributable to genetic causes and has predictive function in plant breeding. It is an indicator for transfer of traits from parents to its progeny. Heritability estimation gives information about the degree of genetic control in particular traits expression and phenotypic reliability in predicting its breeding value. High heritability indicates less environmental influence in the observed variation (Eid, 2009). According to Khan et al. (2009) the higher the heritability estimates, the simpler are the selection procedures. Broad-sense heritability only shows if there is sufficient genetic variation in a population and how the population will respond to selection pressure (Gatti et al., 2005; Milatovic et al., 2010).

In our investigation the highest heritability (H) was obtained for the traits SDS (95%) and YPG (92%); moderate high – for TKW (72%), protein content (67%) and wet gluten (WG) – 52%, (Table 5). The lowest heritability coefficients are determined for grain yield (GY) – 36%, vitreousness (V) – 29%. In many previous studies it has been reported that most grain quality traits in wheat have high heritability values and they can be improved through conventional plant breeding methods (Lukow and McVetty, 1991; Bushuk, 1998; Peterson et al., 1998; Mohammed et al., 2012).

The genetic advance is an important selection parameter in addition to heritability, through which the degree of target traits improvement can be predicted (Shukla et al., 2004). Genetic advance as percent mean was categorized as low (0-10%), moderate (10-20%) and high (≥20%) (Johnson et al., 1955; Falconer and Mackay, 1996). According to Teich (1984) and Chaturvedi and Gupta (1995) low genetic advance indicates slight changes of improvement of target traits in subsequent generations.

In our study the highest genetic advance was found for SDS – 87% and for yellow pigments in grain (YPG) – 28.22%. For all other studied traits a low genetic advance (GA) ranging from 1.64 for TW to 12.61 for grain yield is established. It is considered that high heritability coupled with high genetic advance reveals the additive gene effects while high heritability coupled with low genetic advance indicates the non-additive gene effects for control the particular character. In present study the additive gene effects were found for the traits sedimentation value as an indicator of gluten strength and for yellow pigments in grain. This indicates the possibility of conducting an effective selection of genotype by phenotype in early generations and achieving rapid breeding progress on improvement of these important grain quality traits for durum wheat in environment of Field Crops Institute – Chirpan.

In previous studies it has been found that broad sense heritability for sedimentation value (SDS) in wheat varies from intermediate to high (Zecevic et al., 2001, Clarke et al., 2010), that is confirmed by our results, too. However Akcura (2009) reported low heritability for this trait in Turkish winter durum wheat pure lines.

Several studies have been related to the detection of heritability of yellow pigment concentration in durum wheat (Braaten et al. 1962; Lee et al., 1976; Johnston et al., 1983; Clarke et al., 2005). Clarke et al. (2005) analyzing existing researches summarized that heritability of pigment concentration is high and this permit early generation selection for the trait. Johnston et al. (1983) found that YPG is controlled primarily by additive gene effects. On the other hand Lee et al. (1976) reported for the presence of both additive and non-additive gene effects with a slight preponderance of ad-

Table 5. Component of variance (σ^2), broad-sense heritability (h^2_{BS}) and genetic advance (GA)

Traits	Variance				h^2_{BS} %	GA
	σ^2_{ph}	σ^2_{g}	σ^2_{y}	$\sigma^2_{g} / \sigma^2_{y}$		
Yield	2824.77	1026.22	4907.66	0.21	36	12.61
Protein	0.476	0.32	0.31	1.03	67	6.44
Wet gluten	4.421	2.33	4.15	0.56	52	7.85
SDS	313	297.98	29.15	10.22	95	87.24
YPG	1.44	1.33	0.21	6.33	92	28.22
V	43.72	12.72	59	0.22	29	4.94
TW	1.932	0.916	2	0.46	47	1.64
TKW	10.613	7.68	5.8	1.32	72	12.04

ditive effects in inheritance of this trait. Our results are in accordance with this finding because the calculated genetic advance is not very high. Thus it should be considered that the effective selection for yellow pigment content in the early generations could be complicated.

For the traits protein content and thousand kernels weight the moderate high heritability coefficients were coupled with low to moderate genetic advance. This indicates the presence of non-additive gene action and considerable influence of environment in the expression of these traits. Protein content is one of the most important quality parameters of durum wheat. It is well known that the selection for high protein content is complicated due to existing negative correlation with grain yield and the significant influence of environment on the variation of this trait (Blanco et al., 2006; Würschum et al., 2016). There is contradictory information about heritability of protein content in different environments and sets of used genotypes. Clarke et al. (2000) and Akcura (2009) reported for low to moderate value of heritability coefficient for this trait. While Rapp et al. (2018) using two different durum wheat panels comprising of 159 and 189 genotypes, which were tested in multiple field locations across Europe, determined relatively high heritability of protein content about 75% for both used panels of genotypes. Our results with a much smaller number of genotypes, grown in one location in three consecutive growth seasons, support the finding of the above authors.

The lowest heritability coefficient coupled with lowest genetic advance in our investigation was found for the traits grain yield, wet gluten content and vitreousness. Therefore the influence of non-additive gene actions in inheritance of these traits are prevailing and the effective selection of genotype by phenotype in early generation will be not possible in our conditions. Some authors reported low heritability of GY (Sharma and Smith, 1986), others – for low heritability coupled with high genetic advance (Paul et al., 2006; Mannie et al., 2009), while third authors have found high heritability for this trait in durum wheat in different environments (Rapp et al., 2018). There is also contradictory information about the heritability of wet gluten and vitreousness in durum wheat (Bilgin et al., 2010; Taghouti et al., 2010; Brankovich et al., 2014; Brankovich et al., 2018). According to Baum et al. (1995) the heritability coefficients for vitreousness calculated for irrigated conditions are lower than in dryland conditions for the durum wheat genotypes developed at the International Maize and Wheat Improvement Center – Mexico. Therefore, it should be kept in mind that heritability estimates for each trait can be different, depending upon the genetic material, environment and the method of computation (Blanco et al., 2012).

Conclusion

The presented results reveal the possibility to obtain rapid breeding progress in improvement of one important grain quality trait – SDS as indicator of gluten strength. This is due to the presence of high genetic variability between studied genotypes, genotypic variance greater than the phenotypic one and the estimated high values of heritability and genetic advance suggesting existence of additive genetic effects.

For carotenoids content calculated genotypic variance and heritability were also high, while the genetic advance was a little lower, wherefore at our conditions the effective selection for this trait in the early generations could be complicated.

For the traits protein content and thousand kernels weight the moderate high heritability coefficients were coupled with low to moderate genetic advance and reveal the presence of non-additive gene action.

The lowest heritability coefficient coupled with lowest genetic advance was found for the traits grain yield, wet gluten content and virtuousness suggesting the prevailing of non-additive gene actions. Therefore for these traits the effective selection of genotype by phenotype in early generation will be not possible.

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