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Original Contribution

VARIABILITY, HERITABILITY, AND CORRELATIONS AMONG GRAIN YIELD AND RELATED TRAITS IN HULLESS BARLEY ACCESSIONS

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ABSTRACT
The aim of the present study was to investigate the variability, heritability and correlation between grain yield and yield-related traits of hulless accessions of spring barley under Southeast Bulgarian conditions. The research work was conducted in the experimental field of the Institute of Agriculture - Karnobat, South-eastern Bulgaria during the 2016 and 2017 growing seasons. The trail consisted of 20 six-rowed hulless barley accessions from ICARDA. A significant variation of grain yield and yield-related traits among the studied hulless barley accessions was found. The values of broad-sense heritability were from 1.81% for grain yield to 81.84% for the number of spikelets per spike. The number of spikes per plant had a direct positive effect on grain yield of hulless spring barley in both growing seasons. In a condition of water stress (the second year of study), the weight of grains per spike shows the highest direct effect on grain yield. Since the number of spikes per plant and weight of grains per spike had low heritability, these traits can be used as additional traits for selection for improving grain yield in the hulless barley breeding program of hulless barley only if the selection be practiced in later generations in replicated trials.

Key words: hulless barley, broad-sense heritability, correlation, path analysis

INTRODUCTION

Barley is used mainly for malting and for animal feed, but there is an increasing interest in this crop for human food and industrial uses. Using of naked barley for human food has many advantages due to its high content of protein, soluble dietary fiber, and beta-glucan in grain (1).

Although undoubted nutritional benefactions of that type of barley hulless trait have been associated with decreased yield seed weight and seedling emergence (2). Lower yield compared to hulled barley is the main factor limiting the growing of hulless barley as an alternative to hulled barley.

For any breeding program, aiming yield improvement the information for genetic variability of agronomically important traits, their heritability and associations is essential.

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Heritability of traits is important in determining its response to selection. The broad-sense heritability is a relative magnitude of the genotypic and phenotypic variance of a trait and it gives information for total variation accounted to genotypic effect (3).

Yield in crops has a complex control mechanism and depends on the interaction between different yield components and the environmental effects. The low heritability of grain yield complicates the selection of high-yielding varieties. Selection efficiency may be increased by using various traits correlated with yield. Therefore, knowledge about the association of characters with grain yield is very important. Path coefficient analysis has been used in the indication of traits for indirect selection of barley genotypes with improved yield (4).

The growing conditions have a great effect on phenotype expression of traits and environmental characteristics can be the causes of a correlation, once two traits are differently influenced by environmental conditions (5).

Information for heritability and about the relationship between yield and yield contributing traits for hulless spring barley in agro-ecological conditions of Bulgaria is limited. The present study was undertaken to investigate the variability, heritability and association between grain yield and yield-related traits of hulless accessions of spring barley under Southeast Bulgarian conditions.

MATERIAL AND METHOD

The research work was conducted during the 2016 and 2017 growing seasons in the experimental field of the Institute of Agriculture - Karnobat, Southeastern Bulgaria. The soil was slightly acid (pH is 6.2) Pellic Vertisol.

The average temperature and precipitation during the experimental period are shown in **Figures 1 and 2.** The sum of precipitation for the period was 329 mm in 2016 and 184 mm in 2017. Hence, the quantity of precipitation was with 90 mm higher in the first growing season and it was with 55 mm lower during the vegetation period of the second year compared to the long-term average precipitation (239 mm for the period from February to July) for this location. In almost all months the average temperatures were higher or close to the long-term values.

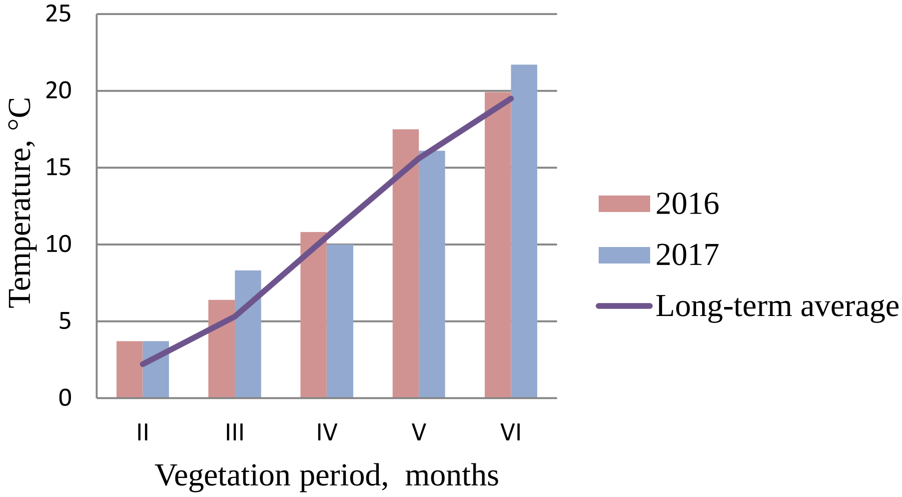

Figure 1. Mean monthly temperature, °C during vegetation period (2016 and 2017) in Karnobat

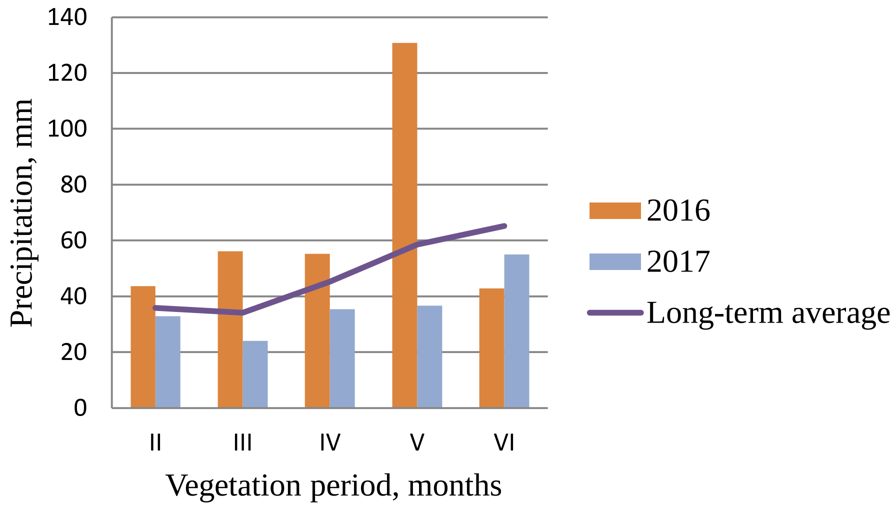

Figure 2. Monthly precipitation sums, mm during vegetation period (2016 and 2017) in Karnobat

The trail consisted of 20 six-rowed barley accessions from ICARDA – 17 from International Naked Barley Yield Trail for high *input* conditions – 2014 (INBYT-14-HI-1, INBYT-14-HI-3, INBYT-14-HI-4, INBYT-14-HI-5, INBYT-14-HI-6, INBYT-14-HI-7, INBYT-14-HI-8, INBYT-14-HI-9; INBYT-14-HI-10, INBYT-14-HI-11, INBYT-14-HI-13,

INBYT-14-HI-14, INBYT-14-HI-16, INBYT-14-HI-17, INBYT-14-HI-16, INBYT-14-HI-18, INBYT-14-HI-19) and 3 from International Naked Barley Observation Nursary – 2014 (INBON-14-HI-3, INBON-14-HI-12, INBON-14-HI-21).

The experiments were organized in a Randomized Complete Block Design with 3 replications on plots of 3.6 m^2.

The traits: number of spikes per plant, plant height (cm), spike length (cm), number of spikelets per spike, number of grains per spike, weight of grains per spike (g), was measured on 25 randomly selected plants in each replication for each genotype. Grain yield (t/ha) and 1000-grain weight (g) were determined on plot basis.

Analysis of variance and Pearson's linear correlation coefficients among traits was computed by using SPSS 17.00 for Windows (6). The estimates of the component of variance due to genotype, year, and genotype by year interaction were expressed as % of the total sum of squares remaining after removing sums of squares due to replication and error from the analysis of variance. The phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were determined as low - <10%, medium - 10 - 20%, and high - > 20% (7). Broad-sense heritability (h_{bs}) was calculated as the ratio of the genotypic variance to the phenotypic variance. Heritability estimates were grouped into the following categories: low <40%, medium - 40-59%, high - 60-79% and very high heritability >80% (8). The path analysis performed by using the statistical software GENES (9) was used to split correlations between grain yield (dependent variable) and other traits into direct and indirect effects.

RESULTS

The effects of genotype, year and genotype by year interaction were significant for all the traits in this study **(Table 1)**. The significant genotypic effect showed the existence of genetic variability among hulless barley accessions for studied traits. The effect of genotype was highest for spike length and number of spikelets per spike. The year had a high impact on the weight of grains per spike, number of grains per spike, number of spikes per plant and plant height. The influence of genotype was greater than the influence of year and genotype by year interaction for 1000-grain weight. A moderate genotypic effect (32.15%) is nearly equal to the effects of the year and genotype by year interaction (36.30% and 31.55%) for grain yield was observed.

Table 1. *The percentage of sums of squares for grain yield and yield-related traits of accessions of spring hulles barley*

Source of variation	SP	PH	SL	SNS	GNS	GWS	TGW	GY
G	12.90**	22.76**	77.68**	84.58**	9.34**	8.43**	52.90**	32.15**
Y	73.80**	68.59**	8.08**	0.06*	80.51**	81.97**	16.22**	36.30**
GxY	13.30**	8.65**	14.24**	15.36**	10.15**	9.60**	30.87**	31.55**

*, ** significant at 0.05 and 0.01 level, respectively; SP – number of spikes per plant; PH – plant height; SL - spike length; SNS – number of spikelets per spike; GNS - number of grains per spike; GWS - weight of grains per spike; TGW – 1000-grain weight; GY - grain yield;

Mean, minimum and maximum values and coefficient of variation (CV, %) of grain yield and yield-related traits of hulless barley accessions in 2016 and 2017 are presented in **Table 2**. The comparison of mean values showed a reduction in all studied traits in 2017. The average number of spikes per plant was 2.74 in 2016 and 1.72 in 2017. The mean plant height of studied accessions in 2017 was about 26 cm lower than in 2016. Low differences in values of spike length and number of spikelets per spike between the two years were observed. The average number of grains per spike was with 27 grains lower in 2017 compared to 2016. Spikelet sterility was relatively high also in 2016 when only 74 % of spikelets were produced grains. The average weight of grains per spike in 2017 was 44% lower compared to 2016. The average 1000-grain weight in 2016 was 42.68 g and varied from 36.05 g to 48.83 g and in 2017 the average value was 38.61 g with a range from 27.40 g to 48.78 g. Grain yield varied from 1.45 t/ha to 3.39 t/ha in 2016 and from 0.84 t/ha to 2.54 t/ha in 2017. The average grain yield in 2017 was with 35.7% (or 0.82 t/ha) lower than in 2016.

Table 2. *Descriptive statistics of grain yield and yield-related traits of 20 hulles accessions of spring barley*

Traits	Year	Mean	Min.	Max.	CV, %
Number of spikes per plant	2016	2.74	2.35	3.34	9.52
	2017	1.72	1.40	2.61	11.79
Plant height, cm	2016	88.10	65.11	98.97	8.72
	2017	62.46	46.40	79.81	11.48
Spike length, cm	2016	9.47	8.46	10.62	6.16
	2017	9.08	8.00	10.12	6.85
Number of spikelets per spike	2016	72.68	63.96	80.50	6.79
	2017	72.55	62.28	80.79	7.06
Number of grains per spike	2016	53.89	39.06	64.48	11.00
	2017	26.66	17.09	41.14	16.14
Weight of grains per spike, g	2016	2.38	1.78	2.96	11.70
	2017	1.05	0.58	1.66	17.55
1000-grain weight, g	2016	42.68	36.05	48.83	7.24
	2017	38.61	27.40	48.78	11.68
Grain yield, t/ha	2016	2.30	1.45	3.39	17.97
	2017	1.48	0.84	2.54	19.73

The phenotypic coefficient of variation (PCV) varied from 7.10% for number of spikelets per spike to 20.97% for grain yield **(Table 3)**. The values of PCV were considered as high for grain yield (20.97%), while traits weight of grains per spike (12.73%), number of grains per spike (11.81%) and plant height (10.07%) had moderate PCV values. Lower PCV values were observed for number of spikes per plant (9.85%), 1000-grain weight (9.27%), number of spikelets per spike (7.10%) and spike length (6.69%). All the traits showed the relatively low genotypic coefficient of variation (GCV) ranged from 1.74% for number of spikes per plant to 7.92% for plant height. The difference between the PCV and GCV was high for grain yield, number of spikes per plant, grain number and weight of grains per spike. The difference was low for spike length and number of spikelets per spike. This indicated a low effect of environment on the phenotype expression of the traits and high possibility for effective selection based on the phenotype.

Table 3. *Mean values (2016-2017), genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), broad-sense heritability (h_{bs}) of studied traits*

Traits	Mean	PCV, %	GCV, %	h_{bs}, %
Number of spikes per plant	2.23	9.85	1.74	3.11
Plant height, cm	75.28	10.07	7.92	61.97
Spike length, cm	9.27	6.69	6.04	81.70
Number of spikelets per spike	72.82	7.10	6.42	81.84
Number of grains per spike	40.28	11.81	3.51	8.84
Weight of grains per spike, g	1.72	12.73	4.87	14.63
1000-grain weight, g	40.65	9.27	5.98	41.64
Grain yield, t/ha	1.89	20.97	2.82	1.81

Low heritability values were observed for grain yield (1.81%), number of spikes per plant (3.11%) number of grains per spike (8.84%) and weight of grains per spike (14.63) which indicate that selection of these traits could be complicated **(Table 3)**. Heritability was medium for the 1000-grain weight (41.64%), high for plant height (61.97%) and very high for spike length (81.70%) and for number of spikelets per spike (81.84%).

The phenotypic correlation coefficients between yield-related traits and grain yield traits for 2016 and 2017 are presented in **Table 4**. Grain yield of naked barley accessions in 2016 showed a positive correlation with the number of spikes per plant (r=0,764), weight of grains per spike (r=0,560) and 1000-grain weight (r=0,503). In 2017 grain yield had a positive correlation with the number of spikes per plant (r=0,791), plant height (r=0.498), number of grains per spike (r=0.712) and weight of grains per spike (r=0.842). Positive and significant correlations of weight of grains per spike with number spikes per plant (r=0.643) and number of grains per spike (r=0.596) in 2016 and with number of spikes per plant (r=0.562), number of spikelets per spike (r=0,508) and number of grains per spike (r=0.935) in 2017 were observed. The number of grains per spike was accosted with number of spikelets per spike in both years of study (r=0.599 in 2016 and r=0.509 in 2017). The number of spikes per plant also correlated with plant height (r=0.526), number of spikelets per spike (r=0.458) and number of grains per spike (r=0.472) in 2017.

Table 4. *Phenotypic correlations among the traits in 2016 (above diagonal) and 2017 (below diagonal)*

Traits	SP	PH	SL	SNS	GNS	GWS	TGW	GY
SP	-	0.230	0.182	0.068	0.422	0.643**	0.354	0.764**
PH	0.526*	-	0.058	-0.105	-0.043	0.284	-0.041	0.272
SL	-0.081	-0.132	-	0.599**	0.167	0.046	-0.034	0.165
SNS	0.458*	0.438	0.390	-	0.229	0.247	0.069	0.162
GNS	0.472*	0.294	-0.094	0.509*	-	0.596**	0.029	0.186
GWS	0.562**	0.403	-0.079	0.508*	0.935**	-	0.422	0.560*
TGW	0.039	0.073	-0.113	-0.185	0.250	0.431	-	0.503*
GY	0.791**	0.498*	-0.183	0.364	0.712**	0.842**	0.291	-

*, **: significant at 0.05 and 0.01 level, respectively; SP – number of spikes per plant; PH – plant height; SL - spike length; SNS - number of spikelets per spike; GNS - number of grains per spike; GWS - weight of grains per spike; TGW – 1000-grain weight; GY - grain yield;

The direct and indirect effects of studied traits along with their phenotypic correlation coefficients with grain yield for each of the two years are presented in **Tables 5**. Path coefficient analysis in 2016 revealed that the number of spikes per plant had the highest positive direct effect on grain yield (0.716) followed by 1000-grain weight (0.336). The maximum positive indirect effect was recorded by weight of grains per spike (0.460) via number of spikes per plant. In 2017 the highest positive direct effect resulted from weight of grains per spike (1.202) followed by the number of spikes per plant (0.337). The number of grains per spike (-0.380), 1000-grain weight (-0.287) and number of spikelets per spike (-0.223) had a highly negative direct effect on grain yield in the conditions of 2017. The maximum positive indirect effect was observed for number of grains per spike (1.124) via weight of grains per spike.

Table 5. *Direct and indirect effect of studied traits on grain yield in 2016 and 2017*

Traits	Year	Direct effect	Indirect effect							Total effect
			SP	PH	SL	SNS	GNS	GWS	TGW	
SP	2016	0.716	-	0.018	0.004	0.01	-0.027	-0.021	0.119	0.764
	2017	0.337	-	-0.003	0.006	-0.102	-0.180	0.676	-0.011	0.791
PH	2016	0.079	0.165	-	0.001	-0.016	0.003	-0.009	-0.014	0.272
	2017	-0.006	0.177	-	0.010	-0.098	-0.112	0.485	-0.021	0.498
SL	2016	0.020	0.130	0.005	-	0.090	-0.012	-0.002	-0.011	0.165
	2017	-0.078	-0.027	0.001	-	-0.087	0.036	-0.095	0.032	-0.183
SNS	2016	0.149	0.049	-0.008	0.012	-	-0.015	-0.008	0.023	0.162
	2017	-0.223	0.154	-0.003	-0.030	-	-0.194	0.611	0.054	0.364
GNS	2016	-0.063	0.301	-0.003	0.003	0.034	-	-0.019	0.010	0.186
	2017	-0.380	0.159	-0.002	0.007	-0.114	-	1.124	-0.072	0.712
GWS	2016	-0.032	0.460	0.020	0.001	0.037	-0.037	-	0.142	0.560
	2017	1.202	0.189	-0.002	0.006	-0.113	-0.356	-	-0.124	0.842
TGW	2016	0.336	0.255	-0.003	-0.001	0.010	-0.002	-0.014	-	0.503
	2017	-0.287	0.013	0.001	0.008	0.041	-0.095	0.518	-	0.291

SP – number of spikes per plant; PH – plant height; SL - spike length; SNS - number of spikelets per spike; GNS - number of grains per spike; GWS - weight of grains per spike; TGW – 1000-grain weight; GY - grain yield;

DISCUSSION

The development of high-yielding varieties depends on the existing genetic variation for yield-related traits and grain yield. The information about the relationships between grain yield and yield-related traits across different environments could improve the efficiency of a hulless barley breeding program. The genetic parameters give information about the expected selection response of yield and yield components and can be used in specifying the most appropriate breeding techniques.

Studies of genetic variability and association of the traits of hulled barley have already been reported (10-12), but few studies have evaluated the heritability and interrelationships among important characters of hulless barley in different years. In this research, significant variation was found between 20 hulless genotypes of spring barley for grain yield and 7 yield-related traits. High variability among genotypes for desirable traits indicates an opportunity for s selection of superior genotypes.

The conditions of the year had a high effect on the variation of weight of grains per spike, number of grains per spike and number of spikes per plant. There were considerable differences in meteorological conditions between two years of the experiment. The amount of precipitation was higher in the first year and extremely low in the second year compared to the long-term quantity of rainfalls for the barley vegetation period. Rainfalls are typically very irregularly distributed during vegetation of spring barley and, usually, drought stress is a serious problem for spring barley production in this region of the country. A reduction of mean values of traits was observed as a result of drought stress in the second year of the field trial. The highest reduction was found in number of grains per spike (51%), followed by the number of spikes per plant (37%) and weight of grains per spike (37%). Grain yield was with 36% lower in the second year of study. Previous studies have shown that drought stress decrease barley grain yield by reducing the number of spikes, grain number per spike and grain weight (13-17). Drought stress in an thesis reduces grain number per unit area due to lower fertilization caused by pollen sterility and/or ovule abortion (18). Water deficit during the early vegetative phase and the stem elongation stage induces a reduction number of tillers and the number of grains per spike and during grain filling period decreases grain weight (19).

Selection efficiency depends on the value of heritability of desired traits. The heritability is affected by the type of genetic materials and environment since the traits are a result of the interaction of genes and growing seasons (20). In this study, high and very high heritability estimates were found only for plant height, spike length and number of spikelets per spike. The lowest heritability was observed for grain yield. Low heritability of grain yield in hulled barley was found (21-23). Moreover, it was concluded that seasonal effects may seriously obstruct the selection of barley genotypes with improved grain yield (24). Moderate values of heritability of yield were reported in hulless barley (25, 26). Low heritability of yield found in our study indicates that the selection of genotypes based on yield alone might not be effective in this particular environment. Yield components should also be considered during selection for improvement of grain yield. This determines the importance of correlations of grain yield with other plant traits in the selection of high-yielding genotypes. In this research, a positive and significant correlation of grain yield with number of spikes per plant, weight of grains per spike and 1000-grain weight under the condition without water deficit was observed. The significant positive correlation of hulled barley grain yield with grain filling period, biological yield, harvest index, number of seed/spike, number of seed/m^2, 1000-seed weight and number of spikes/m^2 was reported (27).

The traits number of spikes per plant, plant height, and number of grains per spike and weight of grains per spike had significant and positive correlation coefficients with grain yield in water deficit in the present study, indicating its importance for the selection of drought-tolerant and high-yielding hulless barley. A positive association between barley grain yield and plant height in a drought environment was also reported (28, 29). In this study, a correlation between grain yield and weight of 1000 grains in water deficiency was not found, while some authors (30, 31) reported an association between grain yield and 1000-grain weight under drought stress.

The results of path analysis showed that tilling capacity (number of spikes per plant) had a significant and positive direct effect on grain yield of hulless barley in both years of the experiment. A positive direct effect of the number of spikes per m^2 on grain yield of naked barley was reported (32). Similar results for hulled barley were found (33, 34). In our study weight of grains per spike had the highest direct effect on hulless barley grain yield under drought conditions in the second year of study. Change in the magnitude of direct and indirect effects on barley yield in different growing years was noted (35). Differences in correlations between yield and yield-related traits in consecutive growing seasons were reported in hulled barley (36). Changes in correlation coefficients were observed in hulless barley genotypes under two irrigation treatments – normal and drought stress (37).

CONCLUSION

The results indicated significant variation for grain yield and yield-related traits among the studied hulless barley accessions. Conditions of the year had a high effect on the variation of weight of grains per spike, number of grains per spike and number of spikes per plant. The effect of genotype was highest on variation of spike length and number of spikelets per spike. The estimates for broad-sense heritability ranged from 1.81% for grain yield to 81.84% for the number of spikelets per spike. The number of spikes per plant had a direct positive effect on grain yield of hulless spring barley in both years of study. In a condition of water deficit weight of grains per spike shown the highest direct effect on grain yield. Since the number of spikes per plant and weight of grains per spike had low heritability, these traits can be used as additional traits for selection for improving grain yield in a breeding program of hulless barley only if the selection be practiced in later generations in replicated trials.

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