Original article

Variability, Correlation, and Path Coefficient Analysis of Grain Yield and Yield-Related Traits of Facultative Barley Accessions Grown Under Rainfed Conditions

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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 breeding lines of facultative barley under rainfed conditions and to select lines with desirable agronomic traits for including in further breeding work for the development of facultative barley varieties for Bulgarian environments. The study was conducted during the period of three concessive years from 2016/2017 to 2018/2019 in the experimental field of the Institute of Agriculture - Karnobat, Southeastern Bulgaria. The traits: number of days to heading, plant height, spike length, spikelet number per spike, grain number per spike, grain weight per spike, and grain yield were recorded. The analysis of variance indicated significant differences between 6-rowed facultative barley genotypes in the studied traits. Most of the traits under the study showed a relatively low phenotypic and genotypic coefficient of variation. The estimates for heritability in broad-sense were high for the number of days to heading, grain weight per spike, and 1000-grain weight and very high for plant height and spike length suggesting a possibility for improvement of those traits through selection based on phenotype. Whereas low heritability of grain yield was found indicating that the phenotypic selection could be ineffective under these specific conditions. Grain yield of facultative barley accessions showed a significant positive correlation with spike length, spikelet number per spike, grain number per spike, and grain weight per spike. The traits with the highest positive direct effect on grain yield were grain number per spike and 1000-grain weight while days to heading had a highly negative direct effect on grain yield. A combination of high heritability and high direct on grain yield in 1000-grain weight and days to heading shows that those traits may be used in early-generation selection in breeding of high-yielding facultative lines. The accession TX01D236 had a significantly higher grain yield compared to check varieties and could be included in future breeding work.

Keywords: Facultative barley, Variability, Heritability, Correlation, Grain yield, Yield-related traits.

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INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the most important cereal crops in the world, mostly used for animal feed and malt. In Bulgaria, barley is cultivated mainly as a winter crop under rainfed conditions. The climate in Southeast Bulgaria is sufficiently humid (annual sum of precipitation about 550 mm) with mild winter and dry and hot summer. In those conditions, winter barley has a higher yield performance compared to spring barley. However, there is interest in growing spring barley especially when conditions do not allow timely sowing in the fall or there is a need for recultivation of areas with winter-killed fall-sown crops. Also, spring barley is cultivated in higher altitudes and in other regions where there is a high risk of low temperature-induced crop injury. Crop production under rainfed conditions faces many challenges that are increasing because of climate change, which already resulted in increased average air temperatures and high inter-annual and intra-annual variability of precipitation as well as to climate extremes, such as drought and floods.

In the context of climate change and climate volatility, the facultative growth habit is an advantage as it could give growers maximum flexibility because the same cultivar could be planted in the fall or in the spring. Facultative barley is characterized by high low-temperature tolerance, sensitivity to short-day photoperiod, and no vernalization requirement (von Zitzewitz et al., 2011). However, despite the value of facultative barley, in the Bulgarian cultivar list are included only two old barley cultivars (Veslets and Emon) which suggest that breeding work for the development of new higher-yielding varieties of this type is needed.

In any breeding program, the availability of the genetic variability for the agronomic traits of commercial interest is of fundamental importance (Muñoz-Amatriaín et al., 2014). The assessment of accessions from the new germplasm is provided knowledge for their productive potential and adaptability to the local conditions. The quantifying the magnitude of the variability and extension in which the desirable characters are inherited allowed planning of an effective program of genetic improvement (Tazeen et al., 2009). Knowledge of the interrelationship of the characters is extremely valuable for the breeding strategies, especially when the selection of a trait assists improvement in other correlated characters (Neyhart et al., 2019). The information for the heritability of important characters is essential for most quantitative traits that are strongly influenced by the environment. This shows that studies of the genetic resources of barley are fundamental, especially when considering elite genotypes with good agronomic traits, originating from different plant breeding programs.

The aim of the present study was to investigate the variability, heritability, and correlation between grain yield and yield-related traits of 23 breeding lines of facultative barley from the Texas A&M University breeding program and to select accessions with desirable agronomic traits for including in further breeding work for the development of facultative barley varieties for Bulgarian environments.

MATERIALS and METHODS

Experimental site location

The study was conducted during the period of three concessive years from 2016/2017 to 2018/2019 in the experimental field of the Institute of Agriculture - Karnobat, Southeastern Bulgaria (42° 39' 0" N / 26° 58' 60" E). The soil of the experimental field was slightly acid (pH is 6.2) Pellic Vertisol.

Average temperatures and sums of precipitation during the experimental period are shown in Table 1. The sum of precipitation for the vegetation period compared to the long-term average precipitation for the location was lower in the first year (with 111.3 mm), and third year (with 73.0 mm), and extremely higher in the second year (with 485.9 mm). The average temperatures of growing seasons were higher than the long-term average monthly temperatures.

Tables 1. Average air temperature, monthly sums of precipitation and long-term average data in Karnobat, Southeastern Bulgaria during barley vegetation (2016/2017- 2018/2019)

Months	2016/2017		2017/2018		2018/2019		LT	
	T, °C	P, mm	T, °C	P, mm	T, °C	P, mm	T, °C	P, mm
X	12.1	67.0	12.5	270	14.0	15.4	12.5	44.3
XI	7.5	36.9	8.4	38.8	7.4	68.3	7.1	53.7
XII	0.6	5.7	5.2	93.1	2.4	27.3	2.6	51.2
I	-2.5	28.9	2.5	49.0	2.5	38.9	0.6	36.5
II	3.7	32.9	3.5	81.1	4.3	15.6	2.2	35.8
III	8.3	24.1	6.4	121.2	8.6	8.9	5.3	34.1
IV	10.0	35.4	19.3	6.0	10.3	52.9	10.5	45.3
V	16.1	36.6	17.9	68.6	17.1	44.9	15.6	58.5
VI	21.7	55.0	20.8	98.6	22.6	95.6	19.6	65.2
VII	23.4	40.7	23.1	134	22.9	33.7	22.0	49.9
T, °C	10.1	-	12.0	-	11.2	-	9.8	-
P, mm	-	363.2	-	960.4	-	401.5	-	474.5

T – average air temperature; P – sum of precipitation; LT – long-term average air temperature and sum of precipitation (1931-2019)

Experimental Materials

The trial consisted of 23 six-rowed facultative barley lines and as checks were included six-rowed facultative varieties – Bulgarian variety Veslets and German variety Borwina. The breeding lines were obtained from the USDA National Small Grain Collection and were developed at Texas A&M University. The pedigree of the accessions used in the study is presented in Table 2.

Tables 2. Pedigree of the breeding lines of facultative barley used in the study

№	Breeding line	Pedigree
1	TX01D109	OK95939/OK92911
2	TX01D110	OK95939/OK92911
3	TX01D127	91AB7655/VA92-42-52
4	TX01D132	Robust/TAMBAR 500//OK90813
5	TX01D133	Robust/TAMBAR 500//OK90813
6	TX01D135	ND11116/OK84817
7	TX01D136	ND11116/OK84817
8	TX01D142	M44/VA84-44-342//OK87807
9	TX01D144	M44/VA84-44-342//OK87807
10	TX01D221	87AB9478/WA1997-87//M75/NE86594
11	TX01D234	B1614/92AB561
12	TX01D236	B1614/92AB561
13	TX01D237	B1614/NE92711
14	TX01D242	B1614/NE92711
15	TX01D243	B1614/SC890202
16	TX01D252	W10489-86/92AB561
17	TX01D305	OK96858/OK94848
18	TX01D306	OK96858/OK94848
19	TX01D310	M44/NE90710//ORW11
20	TX01D335	M44/NE90710//OK96887
21	TX01D390	Robust/Excel//WA10489-86/3/86AB474-P-
22	TX01D391	Robust/Excel//WA10489-86/3/86AB474-P-
23	TX02D290	VA72-42-45/SC793556/CI2457

Experimental Design

The experiments were organized in a Randomized Complete Block Design with 3 replications on plots of 3.6 m^2. During the growing seasons, standard plant protection practices were used.

Data Collection

The traits: plant height (cm), spike length (cm), spikelet number per spike, grain number per spike, grain weight per spike (g) were recorded on 25 randomly selected plants in each replication for each genotype. The number of days to heading was recorded as the number of days from the sowing date to the date of the appearance of 50% of spikes. Grain yield (t/ha) and 1000-grain weight (g) were estimated on plot basis.

Statistical analysis

Analysis of variance and Pearson's linear correlation coefficients among traits was computed by using SPSS 17.00 for Windows (SPSS, 2008). The phenotypic coefficient of variation (PCV) and

genotypic coefficient of variation (GCV) were determined as low - less than 10%, medium - between 10 and 20% and high - greater than 20% (Deshmukh et al., 1986). Broad-sense heritability (h^2) 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% (Singh, 2001). The path analysis performed by using the statistical software GENES (Cruz, 2001) was used to split correlations between grain yield (dependent variable) and other traits into direct and indirect effects.

RESULTS and DISCUSSION

Analysis of variance showed a highly significant effect (p<0.01) of genotype, year and genotype x year interaction on the variation of all studied traits (**Table 3**). The phenotypic coefficient of variation (PCV) ranged from 0.89% for number of days to heading to 19.17% for grain yield. PCV values were moderate for grain yield (20.97%) and spike length (14.86%). Low PCV values were observed for plant height (7.87%), number of days to heading (0.89%), spikelet (5.70%) and grain (6.96%) number per spike (6.96%), grain weight per spike (9.88%) and 1000-grain weight (6.60%). All the traits under study except spike length showed the relatively low genotypic coefficient of variation (GCV). The difference between the phenotypic coefficient of variation and the genotypic coefficient of variation was highest for grain yield. This difference was low for plant height and number of days to heading indicating a high possibility for effective selection based on the phenotype.

Low heritability values were observed only for grain yield (14.94%) which suggests that direct selection for yield would be considerably difficult due to the masking effect of the environment (Table 3). Heritability was medium for spikelet number per spike (44.88%) and grain number per spike (45.99%). High values of heritability were found for number of days to heading (63.70%), grain weight per spike (62.89%) and 1000-grain weight (78.58%). Very high heritability was observed for plant height (90.52%) and spike length (91.06%). Low values of broad-sense heritability for barley grain yield were also found by Ahmadi et al. (2016) while other authors reported from medium (Sayd et al. 2019) to high (Al-Tabbal et al., 2012) heritability estimates.

Table 3. Mean squares (MS), phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), and broad-sense heritability (h^2) of studied traits of facultative barley accessions

Traits	MS G	MS E	MS GxE	PCV, %	GCV, %	h^2, %
GY	8.59[*]	165.17[*]	7.30[*]	19.17	7.41	14.94
PH	598.10[*]	8215.27[*]	56.67[*]	7.87	7.49	90.52
DH	34.85[*]	679.59[*]	12.65[*]	0.89	0.71	63.70
SL	10.82[*]	18.76[*]	0.97[*]	14.86	14.18	91.06
SNS	150.25[*]	259.54[*]	82.82[*]	5.70	3.82	44.88
GNS	159.79[*]	2277.10[*]	86.30[*]	6.96	4.72	45.99
GWS	0.58[*]	8.72[*]	0.22[*]	9.88	7.83	62.89
HGW	94.65[*]	448.46[*]	20.27[*]	6.60	5.85	78.58

G – genotype; E – environment; GxE – genotype by environment interaction; [*]significant at 0.01 level; GY – grain yield; PH- plant height; DH – number of days to heading; SL - spike length; SNS - spikelet number per spike; GNS - grain number per spike; GWS - grain weight per spike; TGW – 1000-grain weight;

The mean values of studied traits of facultative barley accessions are presented in **Table 4**. Grain yield of the check varieties Veslets and Borwina was 5.81 t/ha and 5.38 t/ha, respectively. The average grain yield of the accessions varied from 3.23 t/ha (TX02D290) to 6.77 t/ha (TX01D236). Only one accession TX01D236 had a significantly higher grain yield compared to variety Veslets. All other accessions except TX01D242 showed significantly lower grain yield compared to the higher-yielding check Veslets. Plant height of accessions ranged from 74.44 cm (TX01D243) to 111.22 cm (TX01D221). A higher number of days to heading than in Veslets was found in variety Borwina and in TX01D236, TX01D305, TX01D310, TX01D135, and TX01D390. The longest spike (8.01 cm) was measured in variety Borwina while TX01D132 had the shortest spike (4.16 cm). Accessions TX01D236 and TX01D335 had a higher number of spikelets and grains per spike compared to Veslets. The maximum value for grain weight per spike was recorded in TX01D236 (2.77 g) and the minimum value in TX01D243 (1.59 g). The mean 1000-grain weight of check varieties was 46.73 g for Veslets and 46.38 g for Borwina. Most of the studied accessions showed significantly lower 1000-grain weight than checks.

The correlation coefficients between grain yield and yield-related traits are presented in **Table 5**. Grain yield of facultative barley accessions showed a significant positive correlation with spike length (r=0.531), spikelet number per spike (r=0.653), grain number per spike (r=0.676) and grain weight per spike (r=0.704). A positive and significant correlation of number of days to heading with spike length (r=0.480) and 1000-grain weight (r=0.422) was observed. Spike length was accosted with grain weight per spike (r=0.765) and 1000-grain weight (r=0.670). Spikelet number per spike correlated with grain number per spike (r=0.795) and grain weight per spike (r=0.531). A significant association of grain weight per spike with grain number per spike (r=0.644) and 1000-grain weight (r=0.668) was also found.

Tables 4. The mean values of studied traits of 23 facultative barley accessions and check varieties

Accessions	GY	PH	DH	SL	NSS	NGS	GWS	HGW
Veslets	5.81	88.78	190.00	7.12	64.20	52.81	2.35	46.73
Borwina	5.38	90.33	192.89	8.01	65.25	54.49	2.54	46.38
TX01D109	4.16	86.78	187.89	6.76	61.80	52.10	2.16	39.60
TX01D110	4.67	88.67	190.00	5.96	56.69	48.81	2.08	40.34
TX01D127	4.17	82.78	190.00	4.89	66.47	54.38	2.39	39.19
TX01D132	3.47	75.11	187.44	4.16	59.44	43.99	1.75	40.14
TX01D133	4.26	82.78	189.33	6.26	57.87	49.37	2.02	41.45
TX01D135	3.56	80.44	193.67	7.07	63.07	54.66	2.27	40.27
TX01D136	4.39	96.00	188.44	6.41	59.83	51.56	2.30	41.87
TX01D142	5.21	96.11	190.67	6.81	64.97	55.02	2.43	43.86
TX01D144	3.23	100.33	191.22	6.89	60.90	50.81	2.12	43.23
TX01D221	3.74	111.22	192.22	6.40	58.16	51.63	2.19	42.49
TX01D234	5.21	90.44	190.78	7.65	65.92	55.17	2.44	45.07
TX01D236	6.77	93.22	194.11	7.81	70.80	63.04	2.77	47.58
TX01D237	4.57	95.22	189.44	4.87	60.42	54.57	2.12	40.09
TX01D242	5.69	85.78	191.67	7.56	65.45	54.73	2.58	44.50
TX01D243	2.99	74.44	192.78	4.51	61.75	48.39	1.59	36.02
TX01D252	5.13	84.11	192.78	7.31	64.00	50.47	2.19	41.58
TX01D305	3.35	85.00	193.11	6.16	54.00	45.87	2.08	46.70
TX01D306	3.85	94.56	190.11	6.19	54.62	48.38	2.38	47.17
TX01D310	3.26	96.44	193.89	6.90	63.90	51.67	2.23	43.74
TX01D335	5.48	93.44	188.11	5.39	68.05	61.05	2.13	35.83
TX01D390	4.07	96.11	193.11	6.83	61.79	52.81	2.37	45.11
TX01D391	4.56	82.00	191.78	7.29	64.29	54.12	2.34	43.55
TX02D290	3.30	91.78	190.67	4.58	59.17	49.97	1.92	40.89
LSD 0.05	0.14	3.83	2.82	0.49	3.00	3.02	0.38	1.72

GY – grain yield; PH- plant height; DH – number of days to heading; SL - spike length; SNS - spikelet number per spike; GNS - grain number per spike; GWS - grain weight per spike; TGW – 1000-grain weight;

Table 5. Phenotypic correlations among the traits

Traits	PH	DH	SL	SNS	GNS	GWS	HGW
GY	0.091	-0.014	0.531**	0.653**	0.676**	0.704**	0.333
PH		0.083	0.252	-0.051	0.294	0.354	0.317
DH			0.480*	0.198	0.16	0.305	0.422*
SL				0.385	0.377	0.765**	0.670**
SNS					0.795**	0.531**	-0.008
GNS						0.644**	0.030
GWS							0.668**

*, **: significant at 0.05 and 0.01 level, respectively; GY – grain yield; PH- plant height; DH – number of days to heading; SL - spike length; SNS - spikelet number per spike; GNS - grain number per spike; GWS - grain weight per spike; TGW – 1000-grain weight;

Similar correlations between grain yield and yield components that were observed in present study were also reported by Madić et al. (2019), Negash et al. (2019) and Aklilu et al. (2020).

The direct and indirect effects of studied traits on grain yield are presented in **Tables 6**. The path coefficient analysis revealed that the grain number per spike (0.528) had the highest positive direct effect on grain yield followed by 1000-grain weight (0.402). The number of days to heading (-0.400) had a highly negative direct effect on grain yield. A moderate positive direct effect of spike length (0.215) and spikelet number per spike (0.216) on grain yield was found. While the direct effect of plant height (-0.205) was moderate and negative. The maximum positive indirect effect was recorded by spikelet number per spike (0.420) via grain number per spike and by grain weight per spike (0.340) also via grain number per spike.

Table 6. Path analysis showing direct and indirect effect of traits on grain yield

Traits	Direct effect	Indirect effect							Total effect
		PH	**DH**	**SL**	**SNS**	**GNS**	**GWS**	**HGW**	
PH	-0.205		-0.033	0.054	-0.011	0.155	0.004	0.127	0.091
DH	-0.400	-0.017		0.103	0.043	0.085	0.003	0.169	-0.014
SL	0.215	-0.052	-0.192		0.083	0.199	0.009	0.269	0.531
SNS	0.216	0.010	-0.079	0.083		0.420	0.006	-0.003	0.653
GNS	0.528	-0.060	-0.064	0.081	0.172		0.007	0.012	0.676
GWS	0.011	-0.073	-0.122	0.164	0.115	0.340		0.268	0.704
HGW	0.402	-0.065	-0.169	0.144	-0.002	0.016	0.007		0.333

PH- plant height; DH – number of days to heading; SL - spike length; SNS - spikelet number per spike; GNS - grain number per spike; GWS - grain weight per spike; TGW – 1000-grain weight; GY – grain

The results from the path analysis are in agreement with those reported from Zaefizadeh et al. 2011, who also showed highest direct positive effect on yield by number of grains per main spike and highest negative direct effect by days to heading.

The high impact of the heading date on grain yield observed in our study confirmed the importance of this trait for barley adaptability to different stresses such as heat stress, waterlogging, and drought. Our findings support the significance of the number of grains per spike and grain weight for barley grain yield under rainfed conditions.

CONCLUSION

The analysis of variance indicated significant differences between 6-rowed facultative barley genotypes in the studied traits. Most of the traits under the study showed the relatively low phenotypic and genotypic coefficient of variation. The estimates for heritability in broad-sense were high for the number of days to heading, grain weight per spike, and 1000-grain weight and very high for plant height and spike length suggesting a possibility for improvement of those traits through selection based on

phenotype. Whereas low heritability of grain yield was found indicating that the phenotypic selection could be ineffective under these specific conditions. Grain yield of facultative barley accessions showed a significant positive correlation with spike length, spikelet number per spike, grain number per spike and grain weight per spike. The traits with the highest positive direct effect on grain yield were grain number per spike and 1000-grain weight while days to heading had a highly negative direct effect on grain yield. A combination of high heritability and high direct on grain yield in 1000-grain weight and days to heading shows that those traits may be used in early-generation selection in breeding of high-yielding facultative lines. The accession TX01D236 had a significantly higher grain yield compared to check varieties and could be included in future breeding work.

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