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Morphological and yield-related traits of semi-dwarf and mid-tall cultivars of spring barley under Southeast Bulgarian conditions

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Abstract

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The aim of the present investigation was to study some morphological and yield-related traits of semi-dwarf cultivars compared with mid-tall cultivars of spring barley under the agro-meteorological conditions of Southeastern Bulgaria. The study was conducted in 2018 – 2019 on the experimental field of the Institute of Agriculture – Karnobat, Southeastern Bulgaria. Data for plant height, number of internodes, lengths of the first, second, third and, fourth internode, peduncle length, number of spikes per plant, spike length, number of spikelets per spike, number of grains per spike, weight of grains per spike, 1000-grain weight, and weight of grains per plant were recorded. The studied semi-dwarf cultivars showed significantly lower mean values for plant height, number of internodes, length of the first, second, third, and fourth internodes, peduncle length, spike length, number of spikelets and grains per spike, grain weight per spike, and grain weight per plant compared to mid-tall cultivars. No significant differences between semi-dwarf and mid- tall cultivars for the mean number of spikes per plant and 1000-grain weight were found. Higher variation of spike length, plant height, and length of the fourth internode was observed in semi-dwarf than in mid-tall varieties. Grain weight per plant was positively associated with the number of grains per spike and grain weight per spike in semi-dwarf as in mid-tall cultivars.

Keywords semi-dwarf cultivars; mid-tall cultivars; spring barley

Introduction

Winter barley is one of the main grain crops in Bulgaria. Barley grain is used mainly as livestock feed and as well as raw material for the malting industry.

The success of breeding work is largely determined by the used plant genetic resources. Local cultivars and landraces, adapted to specific conditions, are undoubted of great value for breeding. However, the germplasm from other breeding programs should also be used, since such materials have a great potential for barley improvement.

Lodging can cause high reductions of grain yield and quality of barley, and also increases the grain losses during harvesting. Reduction of plant height is one of the most successful approaches to control the lodging. Therefore, semi-dwarf cultivars were introduced in cereal crops, including barley.

Several semi-dwarf genes like *sdw1/denso*, *hcm1* and *uzu* were used in breeding programs for the development of short stature barley cultivars (Kuczyńska et al., 2013). Semi-dwarf cultivars are characterized by a reduced plant height, increased lodging resistance, and higher harvest index. Nevertheless, semi-dwarfing genes have a pleiotropic effect on a range of traits, some with undesirable effects as of late heading and maturity, reduced grain quality, and temperature sensitivity (Wang et al., 2010). Other traits affected include diameter and length of stem internodes, awn length, rachis internodes number and length, grain shape, tiller number, coleoptile length, leaf size, and tolerance to some biotic and abiotic stress factors (Franckowiak, 1986; Kuczyńska et al., 2013; Forster, 2001; Kuczyńska et al., 2014; Chen et al., 2016). The phenotypic expressions of some of these traits could be considerably modified by different environmental factors such as temperature, moisture, and photoperiod. Therefore, before including semi-dwarf cultivars in the barley breeding program it is essential to study those cultivars under particular agro-meteorological conditions. Since there is no information for characteristics of semi-dwarf cultivars under the agro-meteorological conditions of Bulgaria the aim of the present investigation was to study some morphological and yield-related traits of semi-dwarf compared with mid-tall cultivars of spring barley under the agro-meteorological conditions of South-eastern Bulgaria.

Material and Methods

The study was conducted in 2018 – 2019 on the experimental field of the Institute of Agriculture – Karnobat, South-eastern Bulgaria (42°39′ N, 26°59′ E). For the study years, the average air temperature during the growing period of spring barley was higher than the long-term average (Table 1). In particular months of the period, the air temperature was generally higher than long-term average temperatures. Monthly average temperature was slightly below the long-term average only in April 2019. In 2018, the sum of precipitation during the growing period of spring barley exceeded the long-term average with 175.4 mm (Table 1). In 2019, the total precipitation for the vegetation period was lower than the long-term average with 17.0 mm. The most abundant rainfalls were recorded in July and March of 2018. For the studied period, April of 2018 was the month with the lowest precipitation and July and March of 2018 with the highest amount of rainfalls.

Plant material used included 10 semi-dwarf and 10 mid-tall cultivars of spring barley (Table 2).

The field experiment was set up on leached chernozem soil under rainfed conditions. Ten, 1.10 m long rows at 25 cm apart and at a spacing of 5 cm within rows were sown of each cultivar in 3 replications. Twenty random plants from each cultivar and each replication were taken at maturity. Data for plant height (PH, cm), number of internodes (IN), length of the first internode (1st IL, cm), length of the second internode (2nd IL, cm), length of the third internode (3rd IL, cm), length of the fourth internode (4th IL, cm), peduncle length (PL, cm), number of spikes per plant (SP), spike length (SL, cm), number of spikelets per spike (NSS), number of grains per spike (NGS), weight of grains per spike (WGS, g), 1000-grain weight (TGW, g), weight of grains per plant (WGS, g) were recorded.

Table 1. Origin of studied cultivars

Semi-dwarf cultivars			Mid-tall cultivars		
Name	Year of release	Country of release	Name	Year of release	Country of release
Bold	1978	USA	AC Hamilton	1994	Canada
Ishi	2005	USA	AC Lacombe	1991	Canada
Jackson	1985	Canada	AC Malone	1999	Canada
Mahigan	1998	Canada	AC Nadia	1993	Canada
Maranna	1993	USA	AC Stephan	1992	Canada
Niska	1999	Canada	Creel	2005	USA
Tukwa	1996	Canada	Creme	1988	Canada
UC828	1995	USA	Husky	1953	Canada
Vivar	2000	Canada	Olli	1927	Finland
WestBred Barcott	1985	USA	Sophie	1980	Canada

Table 2. Temperature and precipitation and their differences from long-term values (1931-2018) for Karnobat

Month	2018				2019			
	Air temperature, °C		Precipitation, mm		Air temperature, °C		Precipitation, mm	
	Monthlymean	Long-term mean (+/-)	Monthly sum	Long-term sum (+/-)	Monthly mean	Long-term mean (+/-)	Monthly mean	Long-term sum (+/-)
III	6.4	+1.1	121.2	+87.1	8.6	+3.3	8.9	-25.2
IV	19.3	+8.8	6.0	-39.3	10.3	-0.2	52.9	+7.6
V	17.9	+2.3	68.6	+10.1	17.1	+1.5	44.9	-13.6
VI	20.8	+1.2	98.6	+33.4	22.6	+3.0	95.6	+30.4
VII	23.1	+1.1	134.0	+84.1	22.9	+0.9	33.7	-16.2
Mean/Sum	17.5	+2.9	428.4	+175.4	16.3	+1.7	236.0	-17.0

Data were analysed by analysis of variance (ANOVA) and linear correlation analysis using the SPSS19.0 software. The portion of sums of squares (SS) attributed to genotype, year and genotype × year interaction (GxY) was presented as a percentage of the total sums of squares remaining after removing sums of squares due to replication and error. Statistical significance difference at 5% level ($P < 0.05$) among barley cultivars was estimated by Duncan's Multiple Range Test.

Table 3. The portion of sums of squares attributed to cultivar type (semi-dwarf of mid-tall), year, and cultivar type by year interaction as a percentage of the total sums of squares remaining after removing sums of squares due to replication and error

Traits	Cultivar type	Year	Interaction
Plant height	41.56*	57.62*	0.82*
Number of internodes	95.48*	4.02*	0.50ns
Length of the first internode	69.41*	24.03*	6.56 ns
Length of the second internode	72.17*	27.46*	0.37 ns
Length of the third internode	47.94*	50.12*	1.94 ns
Length of the fourth internode	25.10*	73.38*	1.52 ns
Peduncle length	21.59*	78.40*	0.01 ns
Number of spikes per plant	3.10ns	96.90*	0.00 ns
Spike length	84.99*	14.78*	0.23 ns
Number of spikelets per spike	52.69*	46.96*	0.35 ns
Number of grains per spike	4.43*	94.56*	1.01 ns
Grain weight per spike	3.84*	96.01*	0.15 ns
1000-grain weight	0.08 ns	99.33*	0.59 ns
Grain weight per plant	2.47*	97.40*	0.13 ns

*Significant 0.05%

Results and Discussion

The results of the analysis of variance revealed that the cultivar type (semi-dwarf or mid-tall) had a significant effect on the variation of all studied traits except the number of spikes per plant and 1000-grain weight (Table 3). All studied traits were significantly influenced by the year. A significant interaction between cultivar type and the year was found only for the trait plant height indicating a specific reaction in different environments.

A strong influence of the year on the variation of number of grains per spike (94.56%), grain weight per spike (96.01%) and per plant (97.40%), 1000-grain weight (99.33%), and number of spikes per plant (96.90%) was found. The percent of sums of squares for cultivar type (semi-dwarf or mid-tall) was higher than those of the year for the traits number of internodes (95.48%), lengths of first (69.41%) and second (72.17%) internode, spike length (84.99%), and number of spikelets per spike (52.69%).

In semi-dwarf cultivars, the effects of genotype and genotype by year interaction were significant for all traits (Table 4). The influence of the year on the variation of all studied traits was significant except for the length of the first internode. In mid-tall cultivars, a significant effect of genotype, year, and genotype by year interaction for studied traits were observed, except for the number of internodes in which effect of year and genotype by year interaction were nonsignificant. Genotypic effects were considerably higher in semi-dwarf cultivars compared to mid-tall cultivars for traits plant height, spike length, length of the third and fourth internode,

Table 4. The portion of sums of squares attributed to genotype (G), year (Y), and genotype by year interaction (GxY) as a percentage of the total sums of square remaining after removing sums of squares due to replication and error

Traits	Semi-dwarf cultivars			Mid-tall cultivars		
	G	Y	GxY	G	Y	GxY
Plant height	26.08*	71.04*	2.89*	2.09*	96.18*	1.73*
Number of internodes	62.62*	8.36*	29.02*	94.13*	1.77ns	4.10ns
Length of the first internode	35.17*	32.40*	32.43*	36.33*	19.99*	43.68*
Length of the second internode	91.84*	5.12*	3.05*	63.93*	26.97*	9.10*
Length of the third internode	47.68*	2.82ns	49.50*	42.37*	19.35*	38.28*
Length of the fourth internode	62.55*	20.40*	17.05*	53.64*	27.90*	18.47*
Peduncle length	55.50*	35.85*	8.65*	27.98*	66.87*	5.15*
Number of spikes per plant	49.90*	42.65*	7.44*	13.35*	82.92*	3.72*
Spike length	5.89*	92.26*	1.85*	19.08*	77.55*	3.37*
Number of spikelets per spike	75.03*	14.04*	10.93*	61.95*	28.22*	9.83*
Number of grains per spike	17.25*	70.59*	12.16*	20.31*	75.93*	3.76*
Grain weight per spike	15.35*	76.31*	8.34*	17.90*	76.13*	5.97*
1000-grain weight	11.57*	81.11*	7.32*	12.39*	83.84*	3.76*
Grain weight per plant	61.60*	28.39*	10.01*	42.77*	53.41*	3.82*

*Significant 0.05%

and 1000-grain weight. A higher percentage of the sum of squares attributed to genotype for internode number was observed in mid-tall cultivars than in semi-dwarf cultivars.

The mean plant height was 59.63 cm in semi-dwarf cultivars and varied from 46.47 cm for W. Barcott to 67.33 cm for Vivar (Table 5). In mid-tall cultivars, plant height varied from 78.67 cm for AC Lacombe to 85.96 cm for Olli with a mean value of 83.10 cm. The number of internodes was 5.87 in semi-dwarf and 6.55 in mid-tall cultivars. All of the measured internodes of semi-dwarf cultivars were shorter than those of the mid-tall cultivars. The difference between semi-dwarf and medium-high varieties for the length of the internodes was particularly distinct for the length of the last internode with an average of 6.96 cm shorter peduncle in semi-dwarf varieties. Reduction of peduncle length in some of the short-culm barley mutants as *Zeo1.b*, *sdw1* and *uzu1.a* can cause incomplete spike extrusion from the leaf sheath, leading to increased risk of diseases and decline of grain yield and quality (Dockter et al., 2014; Patil et al., 2019). From the studied cultivars, W. Barcott had the shortest peduncle -13.67 cm.

Barley lodging resistance is largely affected by the length of the second basal internode (Madic et al., 2009). The shortest second internode was found in cultivar Maranna (3.27 cm), followed by UC828 (3.82 cm). While longest second internode was measured in cultivars Olli (7.91 cm) and AC Hamilton (7.23 cm).

In short-stature cultivars, compared to the mid-tall varieties higher values of coefficient of variation (CV, %) were observed for plant height and length of the fourth internode.

The number of spikes per plant ranged from 3.85 (Maranna) to 4.38 (Tukwa) in short-stem varieties and from 3.71 (AC Malone) to 4.41 (Sophie) in mid-tall varieties (Table 6). Contrary to the findings of Jia et al. (2011) the results of the present study did not show a statistically significant increase in the number of productive tillers in semi-dwarf genotypes.

Table 5. Mean plant height, number of internodes, lengths of the first, second, third and fourth internode, and peduncle length (2018–2019)

Cultivars	PH, cm	IN	1st IL, cm	2nd IL, cm	3rd IL, cm	4rd IL, cm	PL, cm
Semi-dwarf cultivars							
Bold	47.22f	5.67c	1.85bc	4.34b	5.99g	6.68g	17.42d
Ishi	60.67d	6.00a	2.02ab	5.48a	7.76c	9.45c	17.25d
Jackson	65.80b	6.16a	1.84bc	4.45b	7.19d	9.09cd	19.31ab
Mahigan	65.50b	5.53cd	2.25a	5.85a	9.36a	12.53a	17.62d
Maranna	62.34c	6.03a	1.66c	3.27d	6.22fg	8.59de	18.91bc
Niska	62.03c	6.09a	1.80bc	4.03bc	6.52efg	8.08ef	18.74bc
Tukwa	65.45b	6.12a	1.91bc	4.52b	7.02de	8.87d	19.20ab
UC828	53.53e	5.72bc	1.72c	3.82c	6.19fg	8.01f	18.08cd
Vivar	67.33a	5.97ab	2.18a	5.56a	8.50b	10.61b	20.05a
W. Barcott	46.47f	5.37d	1.83bc	4.09bc	6.62def	9.13cd	13.67e
Mean	59.63	5.87	1.90	4.54	7.14	9.10	18.02
CV, %	13.04	4.65	9.98	18.36	15.44	17.39	9.88
Mid-tall cultivars							
AC Hamilton	84.35b	6.55bcd	2.34abc	7.23b	9.83b	11.12c	23.84e
AC Lacombe	78.67f	6.20e	1.98d	5.53c	8.43de	11.08c	27.41b
AC Malone	85.67a	6.83b	2.51a	5.87c	8.38e	10.10d	24.30de
AC Stephan	82.04d	6.71bc	2.00d	5.66c	8.97cd	10.83c	23.65e
Creel	80.37e	6.81b	2.18bcd	6.86b	9.88b	10.95c	19.30g
Creme	82.43cd	6.23de	2.39ab	5.58c	8.59de	10.94c	26.56c
Husky	82.63cd	6.43cde	2.14bcd	5.92c	9.19c	11.80b	24.93d
Nadia	83.25bc	7.24a	2.03cd	5.86c	8.58de	9.59d	20.79f
Olli	85.96a	6.22de	2.56a	7.91a	11.09a	12.43a	28.20b
Sophie	85.67a	6.25de	2.05cd	5.55c	8.90cde	11.16c	30.80a
Mean	83.10	6.55	2.22	6.20	9.18	11.00	24.98
CV, %	2.89	5.31	9.76	13.47	9.32	7.15	13.74

PH – plant height; IN- number of internodes; 1st IL – length of the first internode; 2nd IL – length of the second internode; 3rd IL – length of the third internode; 4th IL – length of the fourth internode; PL –peduncle length

But given the high effect of the environment on this trait, it is possible for the semi-dwarf varieties to form more tillers in more favourable conditions.

The mean spike length of semi-dwarf cultivars was 7.26 cm and 8.99 cm in mid-tall cultivars. Variation of this trait was significantly higher in short-stature varieties (CV = 19.41%) compared to tall varieties (CV = 7.34%). The mid-tall cultivars showed a higher average number of spikelets and grains per spike, and grain weight per spike and per plant compared to studied semi-dwarf varieties. In the set of semi-dwarf varieties, maximum grain weight per plant was observed in Jackson (7.25 g) followed by Bold (6.19 g). In the mid-tall group, the highest grain weight per plant was found in cultivars AC Stephan (7.83 g) and AC Hamilton (7.18). Thomas et al. (1991) and Laurie et al. (1993) also reported lower grain weight per spike and per plant in semi-dwarf genotypes. The mean weight of 1000-grains was 39.02 g and 39.22 g for semi-dwarf and mid-tall varieties, respectively. A decrease of 1000-grains weight of semi-dwarf barley was found in some studies (Thomas et al., 1991; Laurie et al., 1993) but in the present investigation difference between the two sets of cultivars for this trait was not significant.

Although our findings showed lower values for some of the most important yield-related traits as grain weight per spike and per plant in semi-dwarf cultivars compared to mid-tall cultivars, additional studies of yield on plots are needed to fully assess the yield potential of semi-dwarf varieties under specific agro-climatic conditions. These varieties can show increased grain yields as a result of improved lodging resistance and canopy structure.

The correlation coefficients between the studied traits of two groups of barley cultivars are presented in Table 7. In short-stature cultivars, plant height was positively accosted with the number of internodes (r = 0.82), length of the third internode (r = 0.64), peduncle length (r = 0.69), and number of spikelets (r = 0.85) and grain (r = 0.89) per spike. The number of stem internodes had a positive correlation with spike length (r = 0.73) and the number of spikelets per spike

Table 6. Mean yield-related traits of semi-dwarf and mid-tall cultivars of spring barley (2018-2019)

Cultivars	NS	SL, cm	NSS	NGS	GWS, g	TGW, g	GWP, g
Semi-dwarf cultivars							
Bold	4.12b	4.56f	50.02i	41.38g	2.02b	46.53a	6.19b
Ishi	4.09bc	7.32c	62.52f	44.16e	1.97bc	44.73b	4.76de
Jackson	4.13b	8.20b	77.13a	55.86a	2.42a	39.73d	7.25a
Mahigan	4.06bc	8.15b	68.28c	49.06b	1.95bc	35.78f	5.21cd
Maranna	3.85c	8.84a	71.35b	49.71b	2.09b	37.40e	6.02b
Niska	3.92bc	8.12b	67.81cd	40.29h	1.56d	36.05f	4.62e
Tukwa	4.38a	7.98b	66.92d	47.68c	1.61d	30.93h	5.28c
UC828	4.01bc	6.49d	58.35g	42.97f	1.91bc	42.96c	4.93cde
Vivar	3.91bc	7.77b	64.93e	44.49de	1.90bc	39.93d	6.08b
W. Barcott	4.06bc	5.19e	57.12h	45.08d	1.76cd	36.20f	5.04cde
Mean	4.05	7.26	64.44	46.07	1.92	39.02	5.54
CV, %	3.67	19.41	12.06	10.05	12.86	12.11	14.89
Mid-tall cultivars							
AC Hamilton	4.00bc	9.70a	76.59c	53.30c	2.41a	42.67b	7.18ab
AC Lacombe	3.93bcd	8.27d	63.26f	45.69e	1.94cd	39.27c	5.76de
AC Malone	3.71d	9.26abc	74.94d	55.46b	2.28ab	37.59d	6.05cd
AC Nadia	3.96bcd	9.70a	77.73ab	58.68a	2.38a	37.31d	6.75bc
AC Stephan	3.85cd	9.26abc	78.19a	58.92a	2.50a	37.38d	7.83a
Creel	4.06bc	7.58e	62.73f	43.76ef	2.01bc	42.21b	6.26cd
Creme	3.90bcd	8.82c	69.52e	48.13d	2.39a	45.83a	6.45bcd
Husky	4.07bc	9.41ab	77.37b	47.86d	1.67d	34.51e	4.81f
Olli	4.16ab	9.14bc	69.12e	49.46d	2.02bc	37.70d	6.04cd
Sophie	4.41a	8.81c	68.92e	42.29f	1.78cd	37.68d	5.09ef
Mean	4.00	8.99	71.84	50.35	2.14	39.21	6.22
CV, %	4.75	7.34	8.24	11.84	13.63	8.55	14.56

NS – number of spikes per plant; SL – spike length; NSS – number of spikelets per spike; NGS – number of grains per spike; GWS – grain weight per spike; GWP – grain weight per plant; TGW – 1000-grain weight

Table 7. Correlation coefficients between studied trait in semi-dwarf (above diagonal) and mid-tall (below diagonal) cultivars of spring barley (2018-2019)

	PH	IN	1^{st}	2^{nd}	3^{rd}	4^{rd}	PL	NS	SL	NSS	NGS	GWS	TGW	GWP
PH	1	0.82**	0.18	0.43	0.64*	0.56	0.69*	-0.12	0.85**	0.89**	0.71*	0.29	-0.36	0.28
IN	0.01	1	-0.10	0.28	0.34	0.15	0.61	0.05	0.73*	0.84**	0.54	0.16	-0.40	0.28
1st	0.58	-0.17	1	0.72*	0.75*	0.72*	-0.16	-0.07	-0.23	-0.21	-0.05	0.02	0.13	0.10
2nd	0.33	-0.06	0.59	1	0.87**	0.66*	0.07	0.33	-0.03	0.03	0.15	0.04	0.16	0.10
3rd	0.29	-0.22	0.45	0.94**	1	0.93**	0.05	-0.01	0.24	0.26	0.33	0.09	-0.13	0.06
4rd	0.10	-0.77**	0.28	0.52	0.71*	1	-0.04	-0.27	0.27	0.23	0.32	0.14	-0.13	0.00
PL	0.34	-0.83**	0.12	-0.13	0.02	0.51	1	0.04	0.69*	0.77**	0.65*	0.49	0.06	0.55
NS	0.27	-0.41	-0.18	0.23	0.43	0.51	0.48	1	-0.37	-0.22	0.19	0.13	0.13	0.31
SL	0.58	0.24	0.17	0.03	-0.05	-0.14	0.05	-0.16	1	0.93**	0.57	0.19	-0.42	0.10
NSS	0.43	0.46	0.01	-0.11	-0.16	-0.28	-0.22	-0.30	0.91**	1	0.75*	0.41	-0.35	0.36
NGS	0.21	0.65*	0.06	-0.03	-0.18	-0.52	-0.44	-0.64*	0.71*	0.79**	1	0.79**	-0.12	0.71*
GWS	0.06	0.46	0.18	0.00	-0.17	-0.55	-0.41	-0.65*	0.37	0.42	0.77**	1	0.44	0.88**
TGW	-0.24	-0.18	0.28	0.13	0.03	-0.08	-0.12	-0.15	-0.36	-0.40	-0.22	0.43	1	0.38
GWP	-0.09	0.44	0.00	0.15	0.04	-0.37	-0.48	-0.51	0.24	0.34	0.71*	0.92**	0.36	1

PH – plant height; IN – number of internodes; 1^{st} IL – length of the first internode; 2^{nd} IL – length of the second internode; 3^{rd} IL – length of the third internode; 4^{th} IL – length of the fourth internode; PL –peduncle length; NS – number of spikes per plant; SL – spike length; NSS – number of spikelets per spike; NGS – number of grains per spike; GWS – grain weight per spike; GWP – grain weight per plant; TGW – 1000-grain weight

(r = 0.84). Positive and significant correlations between lengths of first, second, third, and fourth internode were observed. Peduncle length correlated with spike length (r = 0.69) and number of spikelets (r = 0.77) and grain(r = 0.65) per spike. An association between spike length and the number of spikelets per spike (r = 0.93) and between the number of spikelets per spike and the number of grains per spike (r = 0.79) was found. Grain weight per plant showed a positive correlation with the number of grains per spike (r = 0.71) and grain weight per spike (r = 0.88).

In mid-tall cultivars, the number of internodes was negatively associated with the length of the fourth (r = -0.77) and last (r = -0.83) internode and positively associated with the number of grains per spike (r = 0.65). Positive correlations between lengths of second and third (r = 0.94) and between third and fourth internode (r = 0.71) were found. The number of spikes per plant showed a negative correlation with number of grains per spike (r = -0.64) and grain weight per spike (r = -0.65). Spike length was associated with the number of spikelets per spike (r = 0.91) and the number of grains per spike (r = 0.71). An association between number of spikelets per spike and number of grains per spike (r = 0.79) and between number of grains per spike and grain weight per spike (r = 0.77) was observed. Grain weight per plant had a positive correlation with the number of grains per spike (r = 0.71) and grain weight per spike (r = 0.92).

Some previous studies reported a positive correlation between plant height and grain yield in barley (Samarrai et al., 1987; Al-Sayaydeh et al., 2019). According to Richards (1992) and Mirralles et al. (1995) the considerable reduction of plant height may lead to the formation of a very dense canopy and as result creating favourable conditions for the development of foliar pathogens and reduce the uniformity of radiation interception and biomass production. The association between plant height and yield was often observed under water stress, which suggests that under this condition the yield depends on larger stem reserve mobilization (Khan et al., 2010; Abdel-Moneam et al., 2014). The lack of significant correlation between plant height and grain yield in semi-dwarf cultivars in the present study indices the possibility of selecting genotypes with a combination of short stature and high grain yield per plant.

Conclusions

The studied semi-dwarf cultivars had significantly lower mean values for plant height, number of internodes, length of the first, second, third, and fourth internodes, peduncle length, spike length, number of spikelets and grains per spike, grain weight per spike, and per plant compared to mid-tall cultivars.

There was no significant difference between semi-dwarf and mid- tall cultivars for the mean number of spikes per plant and 1000-grain weight.

Considerable higher variation of spike length, plant height, and length of the fourth internode was observed in semi-dwarf than in mid-tall varieties.

In both sets of cultivars, grain weight per plant was positively associated with the number of grains per spike and grain weight per spike.

References

Abdel-Moneam, M. A., Sultan, M. S., Eid, A. A. & El-Wakeel, S. E. (2014). Response of hull-less barley genotypes for high yield potential and stability as affected by different water stress conditions. *Asian Journal of Crop Science*, *6(3),* 202-213.

Al-Sayaydeh, R., Al-Bawalize, A., Al-Ajlouni, Z., Akash, M.W., Abu-Elenein, J. & Al-Abdallat, A. M. (2019). Agronomic evaluation and yield performance of selected barley (*Hordeum vulgare* L.) landraces from Jordan. *International Journal of Agronomy*, *2019,* 1-17, ID9575081.

Chen, G., Li, H., Wei, Y., Zheng, Y. L., Zhou, M. & Liu, C. (2016). Pleiotropic effects of the semi-dwarfing gene uzu in barley. *Euphytica*, *209(3),* 749-755.

Dockter, C., Gruszka, D., Braumann, I., Druka, A., Druka, I., Franckowiak, J., Gough, S. P., Janeczko, A., Kurowska, M., Lundqvist, J., Lundqvist, U., Marzec, M., Matyszczak, I, Müller, A. H., Oklestkova, J., Schulz, B., Zakhrabekova, S. & Hansson, M. (2014). Induced variations in brassinosteroid genes define barley height and sturdiness, and expand the green revolution genetic toolkit. *Plant Physiology*, *166(4),* 1912-1927.

Forster, B. P. (2001). Mutation genetics of salt tolerance in barley: an assessment of Golden Promise and other semi-dwarf mutants. *Euphytica*, *120(3),* 317-328.

Franckowiak, J. D. (2000). Notes on plant height in six-rowed barley and FHB resistance. In: *Proceedings of the Eighth International Barley Genetics Symposium, 2*,107-109.

Jia, Q., Zhang, X.Q., Westcott, S., Broughton, S., Cakir, M., Yang, J., Lance, R. & Li, C. (2011). Expression level of a gibberellin 20-oxidase gene is associated with multiple agronomic and quality traits in barley. *Theor. Appl. Genet.*, *122,* 1451–1460.

Khan, A. J., Azam, F. & Ali, A. (2010). Relationship of morphological traits and grain yield in recombinant inbred wheat lines grown under drought conditions. *Pak. J. Bot*, *42(1),* 259-267.

Kuczyńska, A., Mikołajczak, K. & Ćwiek, **H.** (2014). Pleiotropic effects of the sdw1 locus in barley populations representing different rounds of recombination. *Electronic Journal of Biotechnology*, *17(5),* 217-223.

Kuczyńska, A., Surma, M., Adamski, T., Mikołajczak, K., Krystkowiak, K. & Ogrodowicz, P. (2013). Effects of the semi-dwarfing sdw1/denso gene in barley. *Journal of Applied Genetics*, *54(4),* 381-390.

Laurie, D.A., Pratchett, N., Romero, C., Simpson, E. & Snape, J.W. (1993). Assignment of the denso dwarfing gene to the long arm of chromosome 3 (3H) of barley by use of RFLP markers. *Plant Breeding*, *111(3),* 198-203.

Madić, M., Knežević, D., Paunović, A. & Zečević, V. (2009). Inheritance of stem height and second-internode length in barley hybrids. *Genetika*, *41(3),* 229-236.

Mirralles, D. J. & Slafer, G. A. (1995). Yield, biomass and yield components in dwarf, semi-dwarf and tall isogenic lines of springs wheat under recommended and late sowing dates. *Plant Breeding*, *114*, 392-396.

Patil, V., McDermott, H.I., McAllister, T., Cummins, M., Silva, J.C., Mollison, E., Meikle, R., Morris, J., Hedley P.E., Waugh R., Dockter, C., Hansson, M. & McKim, S. M. (2019). APETALA2 control of barley internode elongation. *Development*, *146(11),* 1-16.

Richards, R. A. (1992). The effect of dwarfing genes in spring wheat in dry environments. I. Agronomic characteristics. *Australian Journal of Agricultural Research, 43*, 517-523.

Samarrai, S. M., Seyam, S. M., Mian, H. R. & Dafie, A. A. (1987). Growth periods, harvest index and grain yield relationships in barley. *Rachis Barley Wheat Newsletter, 6(2),* 21-24.

Thomas, W. T. B., Powell, W. & Swanston, J. S. (1991). The effects of major genes on quantitatively varying characters in barley. 4. The GPert and denso loci and quality characters. *Heredity*, *66(3),* 381-389.

Wang, J., Yang, J., McNeil, D. L. & Zhou, M. (2010). Identification and molecular mapping of a dwarfing gene in barley (*Hordeum vulgare* L.) and its correlation with other agronomic traits. *Euphytica*, *175(3),* 331-342.

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