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EFFECTS OF SELECTION FOR SHORT STEM ON YIELD AND YIELD COMPONENTS IN BARLEY

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SUMMARY

This investigation deals with the effects of selection for short stem in population lines of the F_4 generation derived from the barley cross between Timura x Osk. 4.208´2-84 developed by the single seed descent and pedigree method.
Direct genetic gain from reducing the stem length was found to be 10.22 % at dense planting (400 kernels/m^2) and 11.47 % at wide-spaced planting (100 kernels/m^2). It was found that stem length had relatively high heritability (0.643 and 0.735). Large negative effects of reducing the stem length at wide-spaced and dense planting were estimated for the grain yield per plant, grain yield per plot and number of fertile tillers. Less pronounced negative effects were found for the grain weight per spike and grain number per spike. Phenotypic and genotypic correlations between stem length and other traits were mostly significant and positive with higher values at dense planting.
Selection for a short stem length was efficient for the improvement of this trait. However, unfavorable correlations have significantly affected undesired expression of other traits, especially grain yield per plant, grain yield per plot and number of fertile tillers.
Any further decrease of plant height should be accompanied by the appropriate selection for other traits, especially grain yield per plant, mass of one grain and harvest index.

***Key-words**: barley, selection criteria, genetic gain, stem length, grain yield, grain yield components*

INTRODUCTION

Stem length in barley breeding is very important as a component of lodging resistance, indirect yield component and source of assimilates. This trait is from medium to high heritability with the dominance degree varying from partial to superdominant (Kovačević, 1981; Lalić et al., 1984).
Hayes et al. (1993) reported that QTL for grain yield are often overlapping with QTL for plant height and lodging resistance. Very strong effects on barley plant height were found for denso dwarf gene (sdw1) (Barua et al., 1993) assigned to the long arm of chromosome 3H (Laurie et al., 1993). Likewise, Börner et al. (1999) mapped two recessive allele, dwarfing mutants gai (GA-ins) and gal (GA-less) in the centromere region and on the long arm of the barley chromosome 2H, respectively. Thomas et al. (1995) and Bezant et al. (1997) found significant QTL effects for grain yield in the region of major denso gene (sdw1).
The possible loss of genes from the population affecting the grain yield depends considerably on the selection criteria applied and the breeding procedures. The availability of reliable selection criteria for the identification of the most productive genotypes represents a crucial point in many breeding programs (Borghi et al., 1998). However, the undesirable correlations of traits whose expression can be considerably affected by the environment, often contributes during selection (particularly for short stem) to the loss of positive gene effects on grain yield.
The objective of this study was to estimate the effects of selection of short stem with respect to grain yield and grain yield components in early generations of the two-rowed winter barley population of the cross Timura / Osk.4.208´2-84.

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MATERIAL AND METHODS

1. Material

The experimental material includes the parents Timura and line Osk.4.208´2-84, 150 lines of the F_4 generation developed by the SSD method and 26 lines developed by the modified pedigree method selected for the short stem from the F_3 generation developed by the SSD method. Timura is a German two-rowed winter barley cultivar originating from the cross Igri / Weihenstephan St 1911, and Osk. 4.208´2-84 is the two-rowed winter barley line selected at the Agricultural Institute Osijek from the cross Osk.4.10´1 /1/ Alpha /2/ Osk.4.5´9 /3/ Union /4/ Sladoran.

Five plants were analyzed from each plot, excluding border and non-competitive plants. Laboratory measurements were made on five randomly selected plants per each plot in three repetitions for the following traits: stem length till the base of spike (cm), grain weight on the primary spike (g), grain number per primary spike, number of fertile tillers per plant, grain yield per plant (g) and total above-ground biomass (g). The average mass of one grain (mg) on the primary spike was calculated by the ratio of the grain weight on the primary spike and the grain number per primary spike. The harvest index was calculated for specific plants and expressed as a percentage. The grain yield per plot was calculated using the sum of grain yield per plants analyzed and other plants from the same plots (in total 16 plants for rare and 20 plants for dense planting).

2. Experiment

The field trial with three repetitions was set up as a randomized block design under dense (400 kernels/m^2) and wide-spaced (100 kernels/m^2) planting densities at the field of the Agricultural Institute Osijek in a one-year experiment.

The main plot at dense planting was a square, 25 x 25 cm with 36 kernels planted at 5 x 5 cm distance, which corresponds to the planting of 400 kernels/m^2.

The main plot at wide-spaced planting was a rectangle, 50 x 80 cm, with 48 kernels planted at 10 x 10 cm distance, which corresponds to the planting of 100 kernels/m^2.

The soil is classified as eutric cambisol with pH in KCl=5.90 and humus content of 2.20 %.

Fertilizers were applied as follows: 96 kg/ha N, 120 kg/ha of P_2O_5 and 80 kg/ha of K_2O.

3. Data analysis

Data were analyzed by the variance analysis followed by the t-test for samples of equal or different size. Based on the variances Vp and Ve from each replication, phenotypic (CVp), environmental (CVe), and genotypic variation coefficients (CVg) were calculated. The phenotypic correlation coefficients were calculated for the lines developed by the SSD method. Heritability in a broad sense (h^2) was calculated by the formula of Mather (1949) where $h^2 = (V_p – V_e)/V_p$. The standard deviation of the heritability value (SE(h^2)) was obtained following Vello and Vencovsky (1974): SE(h^2) = $[(2/n_{1+2}) + (2/n_{2+2})]/ (1- h^2)$, where n_1 and n_2 are the degrees of freedom for the lines and error sources of variation, respectively.

The genetic correlation coefficients (rg) among the traits were estimated for the lines of the F_4 generation developed by the single-seed descent method (SSD), as proposed by Miller et al. (1958) and Searle (1961): **rg= CovgXY / δgX *δgY**

CovgXY - the genetic covariance between traits x and y and

δgX* δgY - the product of the square root of the genetic variance for traits x and y.

The genetic gain (Gs) realized from the selection for short stem length for lines developed by the single-seed descent method (SSD) was estimated for the proportion of 10% selected lines, proposed by Allard (1999), Falconer (1989) as Gs = $i*h^2*\delta_P$ where k is the standardized selection differential, h^2 - the heritability and δ_P - the phenotypic standard deviation.

The correlated response realized from the selection (CRy) for lines developed by the single-seed descent method (SSD) was estimated for the 10% proportion of selected lines as proposed by Falconer (1989): $\mathbf{CRy=i_* h_x h_{y*} r_{a*} \delta_{PY}}$

i - the standardized selection differential for trait x,
h_x and h_y - the square roots of heritability of traits x and y,
r_A - the additive genetic correlation between x and y and
δ_{PY} - the phenotypic standard deviation for y.

RESULTS AND DISCUSSION

The two-rowed winter barley cultivar Timura and the two-rowed winter barley line Osk.4.208´2-84 varied significantly (p=0.05) for stem length and other traits at both planting densities (100 kernels/m^2 and 400 kernels/m^2), except for the grain weight per spike. For the mass of one grain and harvest index, significant differences between parents were only found at dense planting (Table 1).
The heritability in a broad sense (h^2) for stem length varied from 0.643 at dense to 0.735 at wide-spaced planting (Table 2), which corresponds to the results of other authors (Walsh et al., 1976; Valentine, 1979; Powell et al., 1985). Relatively high heritability with lower phenotypic and genotypic variation coefficients for this trait implies the possibility of realizing considerable genetic gain by direct selection and the pedigree method, as suggested by Kovačević (1987).
By selection of 10% lines with the shortest stem at both planting densities, the mean values of most traits under investigation, except the number of grains per spike, were significantly reduced. Namely, all correlations turned out to be significant were positive indicating that reducing the stem length reduction will decrease the mean values of other traits (Table 1). For example, at wide-spaced planting in the F_4 generation, significant genotypic coefficients of correlations varied from r_g=0.30 (p=0.01) between stem length and the number of fertile tillers and mass of one grain to r_g=0.59 (p=0.01) between stem length and grain weight per spike. At dense planting, as compared to wide-spaced one, the higher genotypic correlations were found between stem length and other traits (except for mass of one grain and harvest index, Table 3). In respect to the correlation between stem length and grain yield per plot, these results are in accordance with those of Paroda (1972), and Choo et al. (1980), but not with the results of Hamblin and Donald (1974) and Ali et al. (1978). This can be explained by the influence of the experimental material, environment and the interaction of the genotype x environment as suggested by the results with QTL for plant height and other agronomic traits (Hayes et al. 1993; Hoffman and Dahleen, 2002; Yin et al. 1999, 2002).
For stem length the expected genetic gain for the lines of the F_4 generation developed by the SSD method, based on the selection of 10% lines with the shortest stem, was 6.8 cm (10.22%) at dense, and 8.0 cm (11.47%) at wide-spaced planting (Table 4). The most affected traits selected for a short stem at both planting densities were grain yield per plant, grain yield per plot and number of fertile tillers, while least affected were harvest index and mass of one grain (Table 4). This result suggests caution in selection practice due to the possibility of losing valuable genotypes in the early stages of a breeding program.
To evaluate the effects of selection, the parents Timura (P1) and Osk.4.208´2-84 (P2) were compared with population A (developed by modified pedigree method), and population B (10 % of lines of F_4 generation selected for grain yield from the SSD population), population C (10 % of lines of F_4 generation selected for short stem from the SSD population)(Table 1). Lines selected for high grain yield (population B) were at wide-spaced planting at the level of the taller parent Timura, while at dense planting were at the level of the shorter parent Osk.4.208´2-84. For the other traits (mass of one grain, grain yield per plant and number of fertile tillers), whose significant differences (p=0.05) were found between parents, these lines (population B) were at the level of the parent of higher value at rare planting. At dense planting they were improved, as compared to better parent, for the number of grains per spike, grain weight per spike, mass of one grain, grain yield per plant and harvest index. For the number of fertile tillers, lines were at the level of the parent of higher value (Timura).
Although results suggest the use of a trait such as harvest index, and as it was stated by Hay (1995), who reported that varieties should possess higher biomass production and/or higher partitioning toward the harvested organs (i.e., higher harvest index), Austin et al., (1980.) suggest that for wheat the future improvement of grain yield may not rely on further increasing the harvest index.
High yielding lines (population B) as compared to lines developed by the pedigree method (population A) were characterized by the increased grain yield per plot, stem length grain yield per plant and the number of fertile tillers at both planting densities. At dense planting, high yielding lines (population B)

as compared to lines developed by the pedigree method (population A) were characterized by higher mean values for grain weight per spike, mass of one grain and harvest index. These differences for grain yield components and harvest index were more pronounced at dense planting due to intra-competition within plants, being more pronounced under stressful conditions, such as increased planting density.

Table 1. Mean values for the parents and lines of the F_4 generation after selection for short stem length
Tablica 1. Ostvarena dobit u linija F_4 generacije uzgojenih primjenom odabira biljaka na kraću stabljiku

	P1 Timura	P2 Osk.4.208/2-84	A Pedigree method-(10%-F3 gen.)	B High yielding lines-SSD (najrodnije linije) (10%)	C Lines with a short stem-SSD (linije najniže stabljike) (10%)
Number of lines- *Broj linija*			26	15	15
100 kernels/m^2 (100 zrna/m^2)					
Grain yield per plot, g *Urod zrna po parceli, g*	91,12^C	65,46^D	92.92^B	114.15^A	55.82^E
Stem length, cm *Duljina stabljike, cm*	74,13^A	67,70 ^{B}	67.68^B	73.30^A	63.10^C
Grain number per spike *Broj zrna po klasu*	23,08^B	23,62^A	22.48^C	21.52^D	19.28^E
Grain weight per spike, g *Masa zrna po klasu, g*	1,33^{AB}	1,40^A	1.35^{AB}	1.28^B	1.14^C
Mass of one grain, mg *Masa jednoga zrna, mg*	57,73^D	59,45^B	60.01^A	59.23^B	58.68^C
Grain yield per plant, g *Urod zrna po biljci, g*	7,57^A	5,00^C	6.64^B	7.85^A	5.37^C
Number of fertile tillers per plant *Broj plodnih vlati po biljci*	7,45^A	5,02^D	6.94^B	7.57^A	5.90^C
Harvest index, % *Žetveni index, %*	43,96^A	43,59^{AB}	43.49^{AB}	43.94^A	43.41^B
400 kernels/m^2 (400 zrna/m^2)					
Grain yield per plot, g *Urod zrna po parceli, g*	195,80^C	146,90^D	200.80^B	288.20^A	140.08^E
Stem length, cm *Duljina stabljike, cm*	76,52^A	71,49^B	71.05^B	69.23^C	60.38^D
Grain number per spike *Broj zrna po klasu*	22,40^B	21,52^C	20.52^E	23.14^A	20.96^D
Grain weight per spike, g *Masa zrna po klasu, g*	1,25^B	1,20^B	1.21^B	1.41^A	1.26^B
Mass of one grain, mg *Masa jednoga zrna, mg*	56,02^D	55,84^D	58.69^C	61.17^A	59.87^B
Grain yield per plant, g Urod zrna po biljci, g	4,63^B	3,25^D	4.03^C	5.03^A	3.33^D
Number of fertile tillers per plant *Broj plodnih vlati po biljci*	4,62^A	3,63^C	4.22^B	4.50^A	3.42^C
Harvest index, % *Žetveni index, %*	44,25^B	43,56^C	43.71^C	44.94^A	43.52^C

^{A,B,C,D,E} – any two means having common letters are not significantly different
Test at the level P=0.05.

The pedigree method was successful in selecting for short stem at both planting densities where stem length was at the level or even reduced as compared to the shorter parent (Osk.4.208´2-84) while grain yield was at the level or higher than the high-yielding parent (Timura). Kovačević (l987) found out that the pedigree method was successful for decreasing plant height and increasing grain yield, but it was ineffective for increasing the thousand weight kernel, the grain number per spike and the grain weight per spike.

Very intense selection for the short stem (population C) negatively affected grain yield and yield components. It is rather questioningly to decrease stem length even more when the stature of modern barley is within the range that would optimize yield (Richards, 1992). Any further decrease of plant height should be accompanied by an appropriate selection for other traits, especially grain yield per plant, mass of one grain and harvest index.

Table 2. Analysis of variance, phenotypic and genotypic variation, heritability for stem length under two planting densities for the F_4 generation

Tablica 2. Analiza varijance, fenotipskog i genotipskog varijabiliteta, heritabiliteta za duljinu stabljike kod dvije gustoće sjetve F4 generaciju

Method *Metoda*	Planting density *Norma sjetve*	No. of plants *Broj biljaka*	Variance *Varianca*			Variability (%) Varijabilitet (%)		Heritability *Heritabilitet*
			V_p	V_e	V_g	C_{VP}%	C_{VG}%	$h^2 \pm SE(h^2)$
SSD method	400 kernels/m^2 *(400 zrna/m^2)*	450	36.10	12.87	23.23	9.04	7.24	0.643±0.006
	100 kernels/m^2 *(100 zrna/m^2)*	450	38.20	10.12	28.08	8.86	7.59	0.735±0.005

Table 3. Phenotypic and genotypic correlation coefficients for the lines of the F_4 generation developed by the SSD method

Tablica 3. Fenotipski i genotipski koeficijenti korelacije za linije F_4 generacije uzgojene metodom sjemenka po biljci

Planting density- *Norma sjetve*	Trait- *Svojstvo*	Grain weight per spike	Mass of one grain	Grain number per spike	Number of fertile tillers	Grain yield per plant	Harvest index	Grain yield per plot
		Phenotypic correlation coefficients - *Fenotipski koeficijenti korelacije*						
400 kernels/m^2	Stem length *Duljina stabljike*	0.51**	0.13**	0.55** •	0.33**	0.44**	0.10*	0.44**
100 kernels/m^2		0.43**	0.09	0.44**	0.32**	0.37**	0.04	0.39**
		Genotypic correlation coefficients - *Genotipski koeficijenti korelacije*						
400 kernels/m^2		0.76** ••	0.05	0.66** •	0.55** ••	0.61** ••	-0.04	0.49** ••
100 kernels/m^2		0.59**	0.30** ••	0.55**	0.30**	0.39**	-0.05	0.34**

*, ** significant at P=0.05 and P=0.01, respectively.

, korelacijski koeficijent značajan za P=0,05 i P=0,01*

•, •• significantly higher coefficient of correlation at P=0.05 and P=0.01, respectively.

•, •• značajna razlika između koeficijenata korelacije guste i rijetke sjetve za P=0,05 i P=0,01 unutar populacija

Table 4. Direct and indirect genetic gain from selection of shortest stem length at dense and rare planting based on the selection intensity of 10%.
Tablica 4. Izravna i neizravna genetska dobit od selekcije u gustoj i rijetkoj sjetvi na osnovi izbora 10% linija najkraće stabljike

Traits - *Svojstva*	400 kernels/m^2 (*400 zrna/m^2*)		100 kernels/m^2 *(100 zrna/m^2*)	
	Gs/Gs*	Relatively %	Gs/Gs*	Relatively %
Grain yield per plot, g *Urod zrna po parceli, g*	-41.13	-21.91	-13.95	-18.60
Stem length, cm *Duljina stabljike, cm*	-6.8	10.22	-8.0	11.47
Grain number per spike *Broj zrna po klasu*	-1.93	-8.59	-1.22	-5.88
Grain weight per spike, g *Masa zrna po klasu, g*	-0.15	-11.35	-0.10	-8.04
Mass of one grain, mg *Masa jednoga zrna, mg*	-0.19	-0.32	-0.19	-0.31
Grain yield per plant, g *Urod zrna po biljci, g*	-1.02	-24.01	-1.41	-20.27
Number of fertile tillers per plant- *Broj plodnih vlati po biljci*	-0.81	-19.95	-0.86	-12.11
Harvest index, % *Žetveni index, %*	0.16	0.36	0.23	0.52

Gs - direct and Gs*- indirect genetic gain from selection for each specific trait with selection of 10% lines with the shortest tiller in comparison with the mean value of each trait in the SSD lines
Gs - izravna i neizravna genetska dobit od selekcije za svako svojstvo kod izbora 10% linija najkraće stabljike u odnosu na prosječnu vrijednost pojedinog svojstva SSD linija

CONCLUSION

Having investigated the effects of selection for short stem length in the population of lines of the F_4 generation derived from the barley cross of Timura x Osk.4.208´2-84, the following was found out:

- Selection for a short stem length was efficient for the improvement of this trait. Realised direct genetic gain for the stem reduction was 6.8 cm (10.22%) at dense planting and 8.0 cm (11.47%) at wide-spaced planting.
- The unfavorable correlations significantly affected the undesired expression of other investigated traits. Large negative effects of stem reduction during selection at wide-spaced and dense planting were found out for grain yield per plant (-20.27 and -24.01%), grain yield per plot (-18.60 and –21.91%), and the number of fertile tillers (-12.11 and -19.95%). Less pronounced effects of stem reduction were found for the harvest index (0.52 and 0.36%) and mass of one grain (-2.01 and -0.32%).
- Phenotypic and genotypic correlations between stem length and other traits were mostly significant and positive with higher values at dense planting.
- Any further decrease of plant height should be accompanied by the appropriate selection for other traits, especially grain yield per plant, mass of one grain and harvest index.

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UČINAK SELEKCIJE SNIŽENJA STABLJIKE NA UROD I KOMPONENTE URODA ZRNA JEČMA

SAŽETAK

U radu su istraženi učinci selekcije na kraću stabljiku kod ječma u populaciji linija F_4 generacije izvedene iz kombinacije križanja Timura x Osk.4.208΄2-84 pomoću metode potomstva sjemenke po biljci (SSD) i pedigree metode.
Ostvarena izravna genetska dobit sniženja stabljike bila je 10,22 % u gustoj sjetvi (400 zrna/m^2) i 11,47 % u rijetkoj sjetvi (100 zrna/m^2). Utvrđeno je da je dužina stabljike svojstvo relativno visokog heritabiliteta (0,643 i 0,735). Jaki negativni učinci sniženja dužine stabljike u rijetkoj i gustoj sjetvi procijenjeni su za urod zrna po biljci, urod zrna po parceli i broj plodnih vlati. Manje naglašeni negativni učinci utvrđeni su za masu zrna po klasu i broj zrna po klasu. Fenotipske i genotipske korelacije između dužine stabljike i drugih svojstava bile su uglavnom značajne i pozitivne s višim vrijednostima u gustoj sjetvi.
Selekcija na skraćenje stabljike bila je učinkovita za poboljšanje toga svojstva. Međutim, nepovoljne korelacije značajno su utjecale na neželjenu ekspresiju drugih svojstava, naročito na urod zrna po biljci, urod zrna po parceli i broj plodnih vlati. Daljnje snižavanje visine stabljike trebalo bi biti praćeno i odgovarajućom selekcijom na druga svojstva, posebno urod zrna po biljci, masu zrna i žetveni indeks.

Ključne riječi: ječam, selekcijski kriterij, genetska dobit, dužina stabljike, urod zrna, komponente uroda zrna

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