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Genetic analysis of morphological and physical stem characteristics determining lodging resistance in two- and six-rowed barley (*Hordeum vulgare* L.) lines

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A b s t r a c t. The study presents the results of genetic analysis of selected morphological and physical stem characteristics determining lodging resistance in doubled haploid (DH) lines of spring barley produced from F_1 hybrids of the six-rowed variety Klimek with the two-rowed variety Maresi. The DH lines, the initial forms, and F_1 and F_2 hybrids were tested in three-year field trials. Stem length, outside diameter and the thickness of stem walls were analyzed. Lodging rate was observed and stem material elasticity was examined using the ultrasound method. Analysis of variance was conducted for the obtained data and 6-rowed lines were compared with 2-rowed lines in terms of the investigated characteristics. Moreover, on the basis of DH lines and F_1 and F_2 hybrids, genetic parameters determining additive gene effects [d], dominance effects [h] and the effects of non-allelic interaction of loci in the homozygous [i] and heterozygous state [l] were estimated. For the investigated characteristics significant values of parameter [d] were found. Dominance effects turned out to be significant for stem length, stem tissue elasticity and lodging rate. Non-allelic interaction of homo- and heterozygous loci was significant for stem tissue elasticity and lodging rate. A comparison of 6-rowed and 2-rowed lines in terms of the investigated characteristics showed that 6-rowed forms exhibited smaller length and lower elasticity of stems, thinner stem walls and higher lodging rate than 2-rowed lines. It was also found that environmental factors (years) had an effect on both the mean values of the analyzed characteristics and on the difference between the 2- and 6-rowed barley lines.

K e y w o r d s: *Hordeum vulgare*, doubled haploids, Young's modulus, lodging

INTRODUCTION

Lodging resistance in cereals is a major trait affecting yields. Losses caused by lodging in some years may be as high as 60% (Zeniščeva, 1968; 1972; Jeżowski, 1978; 1996). Investigations conducted so far showed that lodging resistance in cereals is connected with the morphological and physical structure of the stem (Jeżowski, 1981a and b; 1999; Jeżowski and El-Bassam, 1985a and b; Doliński, 1995; Vazquez and Sanchez-Mange, 1989; Doliński *et al*., 1996a and b). Studies on lodging in barley concerned basically two-rowed forms. Six-rowed genotypes, primarily of winter barley, are also cultivated, although not as commonly as the two-rowed lines. Multi-rowed cultivars have higher cropping potential than 2-rowed, thus they are of special interest as components for crossing in feed barley breeding. One of the obstacles in this respect might be higher susceptibility to lodging observed in practice in the case of 6-rowed forms.

The aim of this study was to assess genetic determination of characteristics affecting lodging resistance in two- and six-rowed barley lines, taking into consideration the genotype x environment interaction.

MATERIAL AND METHODS

The experiments were conducted over the period of 3 years on 25 doubled haploid (DH) barley lines obtained using the *H. bulbosum* procedure (Kasha and Kao, 1970; Adamski, 1979) from F_1 hybrids of a 2-rowed cultivar Maresi and a 6-rowed cultivar Klimek. Experiments with the DH lines, parental forms, and F_1 and F_2 crosses were conducted throughout the period of the study in a randomized block design in three replications. Seeds were sown onto plots of 4 m^2 in the amount of 330 seeds per 1 m^2. Lodging resistance was assessed at the full maturity stage in a 9-point scale, where 1 denoted no lodging and 9 – the highest lodging rate. Stem length, diameter, and wall thickness were measured after harvest. Stem material elasticity (Young's

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modulus) was determined on the basis of the velocity of ultrasound flow through the sclerenchymal tissue in the middle segment of the stem (Gawda and Haman, 1983; Jeżowski, 1996).

The obtained results were analyzed statistically using a two-way analysis of variance, including years of the study, genotypes, as well as the genotype x year interaction. Comparisons were conducted in terms of the investigated properties between 2- and 6-rowed groups of DH lines, and between these groups and parental forms. Among the analyzed lines, groups of lines with the maximum and minimum values of these properties were identified using the Dunnet test. The additive gene effects [d] and effects of loci interaction in the homozygous stage [i] were assessed on the basis of mean values for all the DH lines, as well as groups of lines with the maximum and minimum values of the properties (Surma *et al*., 1983). Moreover, effects of dominance [h] and dominant gene interactions [l] were estimated using data concerning DH lines and F_1 and F_2 hybrids (Surma *et al*., 1984).

RESULTS AND DISCUSSION

Mean values for the investigated stem parameters and lodging rate in DH lines, their initial forms and F_1 and F_2 crosses are presented in Table 1. A large range of values found in the population of DH lines, considerably exceeding the range of variability in the parental forms, was observed. The analysis of variance showed that the investigated DH lines differed from one another significantly in terms of all the analyzed morphological and physical stem characteristics, as well as in the lodging rate. The effect of environmental conditions (years) on the variability in the investigated parameters turned out to be significant for stem length, Young's modulus and lodging rate, whereas it did not have any significant effect on stem diameter and wall thickness. In the case of all the investigated characteristics except for stem diameter, the genotype x environment interaction was significant (Table 2).

T a b l e 1. Mean values for the studied stem characteristics and lodging rate of barley DH lines derived from Maresi x Klimek hybrids

Stem characteristics	Year	DH lines			Initial forms		Hybrids	
		max.	min.	mean	Maresi	Klimek	F_1	F_2
Stem length (cm)	1	95.71	62.90	76.43	68.64	72.75	70.18	70.56
	2	100.01	65.01	80.64	72.35	79.41	72.11	71.53
	3	99.01	66.21	80.57	76.48	80.57	79.44	79.44
Stem diameters (mm)	1	3.98	2.71	3.25	2.55	3.40	3.01	3.20
	2	4.00	2.85	3.22	3.04	3.33	3.15	3.23
	3	3.90	2.80	3.22	3.03	3.37	3.16	3.07
Stem wall thickness (mm)	1	0.27	0.16	0.21	0.216	0.233	0.216	0.233
	2	0.27	0.17	0.21	0.213	0.216	0.210	0.227
	3	0.25	0.17	0.20	0.207	0.203	0.213	0.217
Stem tissue elasticity (MPa) (Young's modulus)	1	54.32	24.02	38.90	37.50	41.80	37.34	42.94
	2	54.36	19.23	34.53	35.45	35.35	36.11	36.51
	3	58.05	18.67	35.90	32.26	34.42	36.73	36.29
Lodging rate	1	9.00	1.00	4.28	2.33	2.33	2.67	2.00
	2	9.00	1.00	6.03	6.00	6.33	3.00	2.67
	3	9.00	1.00	5.27	6.00	5.67	4.00	3.67

T a b l e 2. Analysis of variance for the studied stem characteristics and lodging rate of barley DH lines derived from Maresi x Klimek hybrids

Source of variation	Degrees of freedom	Mean square				
		Stem length	Stem diameters	Stem wall thickness	Stem tissue elasticity (Young's modulus)	Lodging rate
Year	2	434.7**	0.02	0.0003	407.7**	57.5**
Line	24	543.6**	0.30**	0.0041**	823.9**	47.8**
Year x line	48	15.00**	0.02	0.0002**	25.6**	3.00**
Error	148	5.80**	0.01	0.0001	3.1**	0.64**

**P<0.01.

Table 3 contains estimates of comparisons between groups of DH lines differing in the ear row number and between these groups and the initial forms Maresi and Klimek in terms of the investigated characteristics, together with the results of testing for the interactions of these differences with the years. It can be seen that the parental forms differed significantly in terms of all the investigated parameters except for stem wall thickness: the 6-rowed cultivar Klimek in comparison to the 2-rowed cultivar Maresi had a significantly longer, thicker and more elastic stem. A comparison of these cultivars in terms of the lodging rate showed that the 6-rowed cultivar Klimek was more susceptible to lodging. As a result of the assessment of comparisons between the 6-rowed and 2-rowed DH lines it was found that the 6-rowed forms had shorter, thinner and less elastic stems and exhibited lower resistance to lodging. Six-rowed lines in comparison to the 6-rowed initial cultivar Klimek exhibited significantly smaller stem diameter, smaller stem wall thickness and lower stem material elasticity, but on the other hand they were more resistant to lodging. In contrast, the 2-rowed forms, even though they did not differ from the 2-rowed parental cultivar Maresi in terms of lodging resistance, in comparison to Maresi had longer stems, with larger diameters and bigger stem material elasticity. Table 3 presents also the results of testing the significance of interactions of the investigated differences between the groups of lines with the years of the study. It turned out that the years of the study did not have any significant effect on the size of all the analyzed differences in relation to the length of the stem, as well as the thickness of its walls. For the other characteristics, a significant interaction was found for the contrast of 2-rowed DH lines from cv. Maresi and for the Klimek – Maresi contrast in relation to stem thickness. A significant interaction was also found for the contrast of 6-rowed DH lines with 2-rowed DH lines and for the contrast of 2-rowed DH lines with cv. Maresi in terms of stem tissue elasticity. In the case of lodging rate for all the compared groups of genotypes a significant interaction was found with the years of the study. The obtained results show that the reaction of the investigated barley forms to changing environmental conditions is not uniform, which results in the size and direction of differences between the groups of investigated genotypes in terms of the analyzed characteristics varying in the years of the study. The occurrence of the genotype x environment interaction was reported in earlier papers by these authors (Jeżowski, 1978; 1981a and b; 1999; Jeżowski *et al*., 1987 a, b; 1988), as well as by other researchers (Zeniščeva, 1968; Stanca, 1989; Powell, 1985; Vazquez and Sanchez-Menge, 1989).

T a b l e 3. Estimates of contrasts between two-rowed (DH2) and six-rowed (DH6) barley doubled haploids and parental genotypes (Maresi. Klimek) and results of testing their interaction with the environment with regard to stem characteristics and lodging rate

Stem charactersistics		Contrast			
		DH6 – DH2	DH6 – Klimek	DH2 – Maresi	Klimek – Maresi
Stem length	estimate	-1.31**	0.96	7.35**	5.10**
	interaction	ns	ns	ns	ns
Stem diameters	estimate	0.02	-1.12**	0.35**	0.49**
	interaction	ns	ns	**	**
Stem wall thickness	estimate	-0.01**	-0.01**	0.00	0.01
	interaction	ns	ns	ns	ns
Stem tissue elasticity (Young's modulus)	estimate	-6.47**	-4.31**	4.28**	2.12**
	interaction	*	ns	*	ns
Lodging rate	estimate	1.80**	-1.35**	0.55	1.00*
	interaction	*	**	*	**

*P<0.05, **P<0.01, ns – non-significant.

Table 4 presents the estimation of genetic parameters for the investigated stem parameters and the lodging rate, as well as the measures of interactions of these parameters with the environment (years). Additive gene effects [d] for all the analyzed characteristics were significant. The interaction of these effects with the environment also turned out to be significant for such parameters as stem wall thickness and stem material elasticity (Young's modulus). Estimates of parameter [h] were statistically significant in the case of stem length, stem tissue elasticity, as well as lodging rate. A significant dominance x environment interaction was found only for mechanical elasticity of stem tissue. Estimates of effects of epitasis interaction of loci in the homo-[i] and heterozygous state [l] showed they affected stem length, its elasticity and lodging rate, while only for stem elasticity these effects exhibited interactions with the environment.

T a b l e 4. Estimates of genetic parameters and result of testing their interaction with the environment for stem characteristics and lodging rate in barley

Parameter	Stem length		Stem diameters		Stem wall thickness		Stem tissue elasticity (Young's modulus)		Lodging rate	
	estimate	interaction	estimate	interaction	estimate	interaction	estimate	interaction	estimate	interaction
[d]	12.79**	ns	0.46**	ns	0.03**	**	15.23**	**	3.01**	ns
[I]	2.86**	**	0.04**	ns	0.01**	ns	2.11**	**	-0.74**	ns
[h]	-16.20**	**	-0.14**	ns	0.07**	ns	8.80**	*	-7.70**	ns
[l]	10.90	ns	0.01**	ns	-0.06**	ns	-8.40**	*	5.70**	ns

*P< 0.05, **P< 0.01, ns – non-significant.

Similar results concerning gene effects were obtained for crosses of 2-rowed barley forms (Jeżowski *et al*., 1993; 2001; 2003; Jeżowski, 1996; 1999). In those studies it was shown that lodging rate and stem diameter, stem wall thickness and stem material elasticity were determined primarily by additive gene action. Thus, it may not be excluded that genetic determination of characteristics connected with lodging resistance is similar in 2-rowed and multi-rowed barley forms. Further studies concerning this problem might confirm this hypothesis. However, already at this stage of research it needs to be stressed that at similar morphological and physical stem structure 6-rowed forms may be more susceptible to lodging than 2-rowed forms due to their bigger weight of seeds per ear and morphological structure of multi-rowed ears that is favourable in terms of water storage capacity.

CONCLUSIONS

1. Two-rowed barley forms exhibit bigger stem tissue elasticity and higher lodging resistance than 6-rowed forms.

2. Variability in morphological and physical traits of the stem determining lodging resistance is dependent on the genotype and the environment, as well as on the interaction of these factors. Stem diameter and stem wall thickness turned out to be the most stable parameters under various environmental conditions.

3. Environmental conditions affect the range and direction of variability between 2- and 6-rowed barley lines in terms of stem tissue elasticity and lodging rate.

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