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Genotype-environment interaction of barley DH lines in terms of morphological and physical traits of the stem and the degree of lodging

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A b s t r a c t. The study presents results of investigations concerning the effect of environmental conditions on the morphological and physical traits of the stalk and the degree of lodging in barley (*Hordeum vulgare*). The object of the experiments were doubled haploid lines (DH) obtained from F_1 hybrids between the hulled DH line RK63/1 and the hull-less breeding line 1N86. The DH lines, the initial forms, F_1 and F_2 hybrids were examined in the course of a three-year field experiment. The length, diameter and thickness of the stem wall, the elasticity of the stem (Young's modulus) and the degree of lodging were analyzed in the study. A significant effect of the year, genotype and the genotype x year (G x E) interaction on the variability of the investigated traits was found. The evaluation and testing of the comparisons between the hulled and hull-less barley lines showed that hulled genotypes were characterized by a significantly thicker and longer stem, a bigger elasticity and a lower degree of lodging. The size and direction of changes between the hulled and hull-less lines in terms of the traits analyzed depended on environmental conditions.

K e y w o r d s: *Hordeum vulgare,* G x E interaction, DH lines, Young's modulus, lodging

INTRODUCTION

Resistance to lodging is one of the basic properties of cereal cultivars, which determines their commercial suitability. In barley, losses in grain yields caused by lodging may in some years reach as high as 60%. Lodging, in cereal, is most frequently connected with the permanent damage of the stem or the root system as a result of adverse conditions during growth, such as strong winds or heavy rainfall. Apart from environmental conditions, resistance to lodging is also determined by genetic factors specific to individual cereal species or cultivars (Doliński *et al.,* 1996a; b; Jeżowski, 1996). Studies conducted so far showed that the resistance of barley to lodging is connected with the morphological and physical structure of the stem (Zeniščeva, 1986; Jeżowski, 1981; 1996; 1999; 2000; Jeżowski and El-Bassam, 1985; Vasquez and Sanchez-Menge, 1989; Doliński, 1995).

The majority of barley cultivars belong to forms with a hulled grain. Hull-less cultivars, although rarely grown, exhibit several advantageous properties, especially from the point of view of their usability for feed. Grain devoid of hulls is characterized by the higher content of protein and better digestibility, and is a valuable component of feeds in the feeding of monogastric animals (Kapała and Rybiński, 1996; Rybiński *et al*., 1996). One of the defects of hull-less cultivars, however, is their increased susceptibility to lodging (Rybiński *et al*., 1996).

The aim of this study was: 1) to investigate the differences between the hulled and hull-less forms of barley in terms of the morphological and physical properties of the stem and the degree of lodging, 2) to determine to what extent the observed variability of these traits was dependent on environmental conditions.

MATERIAL AND METHODS

The experimental material consisted of hulled and hull-less doubled haploid lines (DH) of barley (*Hordeum vulgare*) of common origin. The lines were obtained using the *H. bulbosum* method (Kao and Kasha, 1970; Adamski, 1979) from F_1 hybrids of the hulled strain RK63/1 with the hull-less strain 1N86. Forty six DH lines (23 hulled and 23 hull-less) and paternal genotypes were investigated in a three-year field experiment (1999–2001). Each year the experiment was carried out in a complete randomized block design with three replications. Plots with an area of 4 m^2 were each sown with seeds of the genotypes analyzed at a

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density of 330 seeds per 1 m^2. At the stage of full maturity the degree of lodging was assessed using a 1–9 scale, where 1 denotes the absence of lodging and 9 – complete lodging. After harvesting, the length, diameter and the thickness of the stem walls were measured. Moreover, the elasticity of the stem's sclerenchyma tissue was measured by Young's modulus evaluated by the ultrasound method (Gawda and Haman, 1983; Jeżowski, 1996); in this paper it is treated shortly simply as stem elasticity.

Data obtained from the experiments was analyzed statistically using the two-way analysis of variance taking into consideration the years, genotypes and the genotype x year interaction. Moreover, contrasts (comparisons) were estimated and tested between the group of hulled lines and the group of hull-less lines as well as the groups of DH lines and parental genotypes, and between parental genotypes.

RESULTS AND DISCUSSION

The average values of the investigated traits of the hulled and hull-less DH lines and their parental genotypes are presented in Table 1. The analysis of variance showed a significant ($P < 0.01$) variation of the genotypes investigated in terms of the morphological and physical properties of the stem, as well as the degree of lodging (Table 2). The effect of environmental conditions (years) on all the traits analyzed, except for the thickness of the stem wall, turned out to be significant. Moreover, a significant genotype x year (G x E) interaction was found for all the traits investigated.

These results are consistent with the results of similar studies concerning the variability of characteristics determining resistance to lodging in barley and other cereals (Jeżowski 1981; 1996; Jeżowski and El-Bassam, 1985; Jeżowski *et al*., 1987; Skubisz, 1989; Skubisz and Müller, 1991; Doliński, 1995; Doliński *et al.*, 1996a; b).

Table 3 presents the evaluation of contrasts between the hulled and hull-less barley genotypes and their test results. Initial lines RK63/1 and 1N86 were characterized by the similar lengths of the stem, but differed significantly in terms of the diameter and thickness of the stem walls, stem elaticity and resistance to lodging. The hull-less strain – 1N86 - exhibited a smaller diameter and thickness of stem wall, a lower elasticity and a higher susceptibility to lodging than did RK63/1. A comparison of the hulled DH lines with the hull-less lines showed that hulled lines had significantly longer and thicker stems, both in terms of the diameter and thickness of their walls. The stem elasticity of hulled lines was significantly higher than that of the hull-less lines; the hulled lines were also characterized by a lower susceptibility to lodging. A comparison of hulled lines with the parental form RK63/1 showed that although the lines were characterized by longer stems, they were more elastic and more

Table 1. Mean values of studied traits in hulled and naked barley DH lines and parental genotypes examined in 3-year experiment

Trait	Year of experiment	DH lines		Parental genotypes	
		Hulled	Naked	RK 63/1	1N86
Stem length (cm)	1	84.43	76.26	74.00	77.67
	2	82.26	80.46	76.33	78.33
	3	78.40	77.90	81.67	79.33
	mean	81.70	78.21	77.33	78.44
Stem diameter (mm)	1	2.83	2.62	2.88	2.64
	2	2.80	2.61	2.77	2.69
	3	2.70	2.52	2.80	2.61
	mean	2.78	2.58	2.81	2.64
Stem wall thickness (mm)	1	0.21	0.20	0.23	0.20
	2	0.22	0.20	0.21	0.21
	3	0.20	0.20	0.22	0.21
	mean	0.21	0.20	0.22	0.21
Young's modulus (MPa)	1	25.73	26.60	28.15	26.14
	2	28.42	25.22	29.90	25.70
	3	28.15	25.09	29.06	24.28
	mean	27.43	25.64	29.02	25.37
Lodging grade	1	2.00	2.96	3.00	4.21
	2	3.14	5.53	3.00	5.00
	3	2.53	5.24	4.33	4.33
	mean	2.56	4.48	3.44	4.51

T a b l e 2. Analysis of variance for traits determining lodging resistance in barley

Source	d.f.	Stem length (cm)	Stem diameter (mm)	Stem wall thickness (mm)	Young's modulus (MPa)	Lodging grade
Year	2	21.91**	4.83**	0.99	3.12*	138.01**
Genotype	47	10.53**	13.41**	10.86**	14.89**	8.71**
Genotypex Year	94	3.44**	2.49**	2.29**	5.15**	4.46**

d.f. – degree of freedom, *P < 0.05, **P < 0.01.

T a b l e 3. Contrasts between DH lines and parental genotypes and their G x E interaction for stem traits determining lodging resistance in barley

Contrast	Stem length (cm)	Stem diameter (mm)	Stem wall thickness (mm)	Young's modulus (MPa)	Lodging grade
DH hulled – DH naked					
Estimate	2.49	0.20	0.01	1.79	–1.02
F-statistic for:					
estimate	272.36**	524.34**	364.16**	410.59**	194.77**
G x E interaction	36.85*	50.31**	28.39**	135.30**	107.01**
DH hulled – RK 63/1					
Estimate	4.37	–0.03	–0.01	–1.59	–0.88
F-statistic for:					
estimate	29.22**	0.01	0.14	8.83*	5.19*
G x E interaction	1.84	0.79	3.42*	0.97	0.33
DH naked – 1N86					
Estimate	–0.23	–0.06	–0.01	0.27	–0.03
F-statistic for:					
estimate	0.07	2.58	4.56*	3.72	7.00**
G x E interaction	1.02	0.54	2.05	2.64	0.98
1N86 – RK 63/1					
Estimate	–1.11	–0.17	–0.01	–3.65	1.07
F-statistic for:					
estimate	0.52	11.75**	4.33*	–23.89**	6.68*
G x E interaction	1.34	0.89	1.92	2.27	4.20

* P < 0.05, **P < 0.01.

resistant to lodging. Hull-less lines in terms of the traits analyzed were in general similar to the parental form with the hull-less grain (1N86) and significant differences were observed only in the case of the thickness of the stalk wall. These results indicate that it is possible to obtain – as a result of gene recombination – homozygous lines with an improved resistance to lodging.

The size of differences between the hulled and hull-less DH lines depended on environmental conditions, as evidenced by the significant effects of the interaction of the main effects with the years analyzed for all the traits. Differences between initial lines the RK63/1 and 1N86, as well as these genotypes and the hulled and hull-less groups of DH lines, respectively, were similar in individual years. A significant interaction with environmental conditions was found only in the contrast between the hulled DH lines and the hulled strain RK63/1 in terms of the thickness of the stalk wall. This means that the reaction to the environmental conditions of the hulled and hull-less lines was similar to the reaction of the parental form with the hulled grain and the parental form with the hull-less grain, respectively.

The results of the investigations presented confirmed, from the observations, the higher susceptibility to lodging of the hull-less barley genotypes in comparison to the hulled ones. The smaller diameter and thickness of the walls characterized stems of the hull-less lines; moreover, the walls were less elastic.

The results obtained clearly indicate that the genotypes characterized by higher values of Young's modulus which is a measure of stem elasticity (or more exactly – the elasticity of the stem sclerenchyma tissue) exhibited lodging to a lesser degree. The relationship between elasticity and improved resistance to lodging was also shown by other authors examining the resistance of cereals and other plants

to lodging (Neean, 1975; Mc Randal, 1980; Oda *et al*., 1966; Skubisz, 1978; 1989; Doliński, 1990; 1995; Rybiński *et al*., 1996). The close dependency between the degree of lodging and Young's modulus results from the fact that this index is a product of the physical properties of the mechanical tissue of the stem (sclerenchyma) (Multamäki, 1962; Baier, 1965; Jeżowski, 1978; Skubisz, 1989; Skubisz and Müller, 1991).

CONCLUSIONS

On the basis of the present study the following conclusions may be drawn:

1. Barley genotypes with hulled grain are characterized by higher stem elasticity and higher resistance to lodging than hull-less genotypes.

2. The morphological and physical traits determining resistance of barley to lodging are dependent on genetic and environmental factors, as well as the interaction of genotypes with environments.

3. Environmental factors have a significant effect on the size and direction of differences between the hulled and hull-less lines of barley in terms of traits determining resistance to lodging.

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