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INHERITANCE OF STEM HEIGHT AND SECOND-INTERNODE LENGTH IN BARLEY HYBRIDS

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Stem height and second (basal) internode are highly important components of lodging resistance in barley. A diallel crossing of five divergent barley genotypes (KG-1/90, NS-293, Jagodinac, KG-15 and KG-10/90) was carried out in order to examine the modes of inheritance of stem height and second-internode length. The dominance of a parent with a higher stem was the prevailing mode of stem height inheritance in most of the combinations in F_1 and F_2 generations, the degree of dominance ranging from partial to superdominance. Partial dominance mostly occurred in the inheritance of second-internode length in most crossing combinations.

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An analysis of genetic variance components showed that the dominant gene effect was the most contributing factor to the inheritance of stem height. Additive effect genes prevailed in the inheritance of second-internode length in the F_1 generation. Both additive and dominant gene effects played an important role in the F_2 generation.

Key words: barley, inheritance, second-internode length, stem height

INTRODUCTION

Stem height plays a substantial role in attaining high grain yields. It is a very important component of lodging resistance in barley. Therefore, breeding programmes are focused on developing cultivars that will have short, strong, elastic stems tolerant of high plant densities. Internode length is a highly significant contributing factor to stem height. Importantly, lower internodes should be short. PRZULJ and MOMCILOVIC (1995) deem it necessary to focus breeding efforts not only on stem height reduction, but also on creating an anatomical structure that will provide sufficient strength to the stem.

Stem height reduction is an essential step due to the great problem of lodging resistance of barley. However, the established positive correlations demand caution since a drastic reduction in stem height can induce a considerable decrease in total biomass and hence in grain yield (ORE 1991, MADIĆ *et al*. 2000 and 2005).

SEARS *et al.* (1981), THOMAS *et al.* (1984) reported that four recessive alleles cause shorter stems. The short stem trait of barley is determined by one, two or three recessive genes, the most widespread of them being the *sdw* gene, whereas the other two are found in few genotypes and have not been defined (MICKELSON and RASMUSSON 1994). HELLEWELL *et al*. (2000) pointed to the fact that the short stem and spike length traits of barley are affected by the *sdw* and *denso* alleles mapped to the same region of the long arm of chromosome 3H and that the *sdw* alleles induce a 10-20 cm reduction in stem height. As reported by PRŽULJ *et al*. (2000), barley stem-reducing genes and wheat *Rht* genes affect differently the phenotype, in a way that *dwarf* genotypes have a fragile stem and show higher disease susceptibility and poorer malt quality.

Stem height is highly dependent on internode length, particularly on that of the lower internodes which should be short in order to be sufficiently strong to resist lodging. Stem height reduction can include length reduction of all internodes or of the first and third ones. Lodging resistance is largely affected by the second basal internode which is being inherited through additive and dominant gene effects in the F_1 and F_2 generations, the non-additive effect being the most influential (VAZQUEZ and SANCHEZ 1989, PAVLOVIĆ 1993). Increased lodging resistance results from the vertical distribution of internodes making up a single axis, as opposed to non-resistant stems where angles occur at the junction points between internodes (KRIVOGORNICYN *et al*. 1984).

Given the importance of stem height and second-internode length in barley breeding, this paper examines different modes of inheritance, gene effects and genetic variance components in an attempt to justify more clearly the potential inclusion of the tested parental cultivars in further breeding programmes.

MATERIALS AND METHODS

Modes of inheritance and genetic variance components were evaluated using five parental cultivars and lines and their F_1 and F_2 hybrids developed through incomplete diallel crossing. The parents (KG-1/90, NS-293, Jagodinac, KG-15 and KG-10/90) were selected on the basis of the trait concept, with the parents being divergent for stem height and second-internode length.

The trial was established at an experimental field of the Small Grains Research Centre in Kragujevac as a randomized block design in three replicates. The parents, F_1 and F_2 generations were sown in the same year at low plant density in 1 m rows at a row spacing of 20 cm and within-row plant spacing of 10 cm.

A random sample was taken at full maturity of the plants:
- a total of 30 plants for all parents and F_1 combinations (3x10),
- a total of 150 plants for all F_2 combinations (3x50).

Modes of inheritance were determined by a significance test of the generation means relative to the corresponding parental mean (KRALJEVIĆ-BALALIĆ *et al.* 1991). Genetic variance components and regression analysis in the diallel crossings were calculated using the method of MATHERA and JINKSA (1971).

RESULTS AND DISCUSSION

The analysis of variance showed that the means of the parents indicated significant differences between cultivars and that the parent choice was adequate. Stem height was smallest in the KG-10/90 line and greatest in KG-1/90.

Stem height in the F_1 generation displayed different modes of inheritance. The crosses implying significant differences in stem height among the parents were partially dominated by parents having higher stems, whereas the prevailing modes of inheritance in the other combinations included dominance or super dominance. Partial dominance or dominance also prevailed in the inheritance of stem height in the F_2 generation (Tab. 1).

The genetic analysis of the inheritance of stem height was variable, ranging from partial dominance to superdominance. Partial dominance in the inheritance of stem height was reported by PAVLOVIĆ (1993), KNEŽEVIĆ *et al.* (1993), MADIĆ *et al.* (2003), dominance by LALIĆ *et al.* (1984), and superdominance by VAZQUEZ and SANCHEZ (1989), ORE (1991).

Table 1. Means of the parents, F_1 and F_2 generations for stem height and second-internode length

Parents and their hybrids	Stem height		Second-internode length	
	F_1	F_2	F_1	F_2
KG-1/90	87.07		12.10	
KG-1/90x KG-15	85.8^{d}	82.1^{pd}	10.80^{pd}	10.95^{pd}
KG-1/90x KG-10/90	76.2^{pd}	72.9^{i}	10.50^{pd}	10.28^{pd}
KG-1/90x Jagodinac	81.3^{pd}	78.5^{pd}	10.25^{pd}	10.08^{pd}
KG-1/90x NS-293	88.5^{d}	86.4^{d}	11.13^{pd}	10.46^{pd}
KG-15	60.02		7.45	
KG-15x KG-10/90	64.0^{sd}	63.4^{d}	8.20^{sd}	8.35^{sd}
KG-15x Jagodinac	70.5^{sd}	66.8^{d}	8.76^{pd}	8.55^{pd}
KG-15x NS-293	72.3^{d}	70.2^{d}	9.20^{pd}	8.95^{pd}
KG-10/90	55.30		6.80	
KG-10/90 x Jagodinac	65.2^{pd}	63.3^{pd}	9.25^{d}	9.15^{d}
KG-10/90 x NS-293	67.6^{pd}	66.5^{pd}	9.40^{pd}	9.48^{d}
Jagodinac	66.9		9.15	
Jagodinac x NS-293	72.8^{pd}	72.0^{pd}	10.89^{d}	10.69^{d}
NS-293	70.16		10.12	
LSD 0.05	3.39	2.28	1.38	0.93
0.01	4.57	3.08	1.90	1.33

Pd – partial dominance, ***d*** - dominance, ***i*** – intermediate inheritance and ***sd*** – superdominance

The parent mean for the second-internode length differed between the lines, being highest in KG-1/90 (12.1 cm) and lowest in KG-15 (6.8 cm). The mean in the F_1 generation was intermediary or approaching that of the parent having a longer second internode, except in the KG-15xKG-10/90 combination where the mean was higher than that of the parent having a higher mean in both generations. The same relations were obtained in the F_2 generation. In addition, the means for the second-internode length were almost identical in F_1 and F_2 generations. The mode of inheritance of the second-internode length in the F_1 and F_2 generations was partial dominance of the longer-internode parent (Tab.1).

The analysis of the genetic variance components in the F_1 and F_2 generations detected a higher value of the dominant component (H1 and H2 higher than D) and, therefore, the genetic variance in stem height inheritance was predominated by the dominant component. The F value of both generations was positive and showed a larger effect of dominant genes in the trait inheritance. The average degree of dominance was higher than unity in both generations and indicated superdominance in stem height inheritance given all the cross combinations. The ratio of dominant to recessive genes was higher than unity in both generations, implying that dominant alleles prevailed over recessive alleles in all parents.

The obtained heritability value (0.43) suggested that, apart from being genetically determined, stem height was considerably affected by environmental factors (Tab. 2). Similar results were reported by KNEŽEVIĆ *et al.* (1996) as well as by LU *et al.* (1997) who showed significant additive genetic effects and additive x dominant gene interactions in F_1 and F_2 generations.

Table 2. The genetic variance components for stem height and second (basal) internode length

Variance Components	Stem height values		Second-internode length values	
	F_1	F_2	F_1	F_2
D	8.46	7.80	5.20	5.35
H_1	158.26	102.14	1.08	5.20
H_2	156.90	73.92	1.06	4.91
F	8.60	6.90	1.30	3.20
E	1.23	1.88	0.25	0.12
$H_2/4H_1$	0.247	0.18	0.245	0.240
u	0.597	0.765	0.568	0.60
v	0.403	0.235	0.432	0.40
$\sqrt{H_1/D}$	4.32	3.62	0.42	0.97
K_D/K_R	1.26	1.02	1.72	1.79
Heritability (%)		0.43		0.46

The analysis of the genetic variance components for the second-internode length revealed a higher value of the additive component vs. that of the dominant one in the F_1 generation and a reverse proportion in the F_2 generation, where the dominant component was considerably increased and almost identical to the additive one (Tab. 2). This conforms to the results on individual crossings being predominated by partial dominance in F_1 and determined by both partial dominance and dominance in F_2. Similar results were obtained by PAVLOVIĆ (1993) in his analysis of 4x4 diallel crosses in wheat, whereas VASQUEZ and SANCHEZ (1989) showed that non-additive effects played a more important role in the inheritance of internode length in barley.

The average degree of dominance in both generations was lower than unity, indicating partial dominance, given all of the combinations, although it approached unity in F2 (0.97). The ratio of dominant alleles to recessive alleles in both generations was higher than unity, implying that dominant alleles prevailed over the recessive ones in all parents.

CONCLUSION

A diallel crossing of five divergent genotypes of two-rowed winter barley was carried out in order to examine the modes of inheritance, gene effect and genetic variance components for stem height and second-internode length in F_1 and F_2 generations.

There were highly significant differences in the examined traits between the tested barley genotypes and their offspring. Stem height and internode length were greatest in the KG-1/90 genotype (line) and smallest in KG-10/90.
The dominance of parents having higher stems was the prevailing mode of stem height inheritance in most of the combinations in F_1 and F_2 generations, the degree of dominance ranging from partial to superdominance. Intermediary dominance or dominance mostly occurred in the inheritance of second-internode length in most combinations.

The analysis of genetic variance components showed that the dominant gene effect was the most contributing factor to the inheritance of stem height. Additive effect genes prevailed in the inheritance of second-internode length in the F_1 generation. Both additive and dominant gene effects played an important role in the F_2 generation.

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NASLEĐIVANJE VISINE STABLA I DUŽINE DRUGE INTERNODIJE KOD HIBRIDA JEČMA

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Visina stabla i dužina druge (bazalne) internodije su veoma značajne komponente otpornosti ječma prema poleganju. U cilju proučavanja načina nasleđivanja visine stabla i dužine druge internodije izvršeno je dialelno ukrštenje pet divergentnih genotipova ječma (KG-1/90, NS-293, Jagodinac, KG-15, KG-10/90). U nasleđivanju visine stabla kod većine kombinacija u F_1 i F_2 generaciji je preovladavala dominacija roditelja veće visine stabla, gde je stepen dominacije varirao od parcijalne do superdominacije. U nasleđivanju dužine druge internodije kod najvećeg broja kombinacija je uglavnom bio ispoljen parcijalno dominantni način nasleđivanja.

Komponente genetičke varijanse i prosečan stepen dominacije u F_1 i F_2 generaciji su ukazali da je nasleđivanju visine stabla preovladavao dominantni efekat gena. U nasleđivanju dužine druge internodije u F_1 generaciji su preovladavali geni sa aditivnim efektom, dok su u F_2 pored njih značajni i dominantni efekati gena.

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