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DIALLEL ANALYSIS OF CHARACTERS DETERMINING LODGING RESISTANCE OF BARLEY (*HORDEUM VULGARE* L.) I. AN ESTIMATE OF PARENTAL FORMS AND F_1 HYBRIDS REGARDING MORPHOLOGICAL AND PHYSICAL CHARACTERS OF THE STEM [1]

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Summary. The paper presents the development of morphological and physical characters of the stem in parental forms and F_1 hybrids, obtained from diallel crossing of two lodging-resistant cultivars of spring barley (Diva, Aramir) and three low lodging-resistant strains (CJ 3614, EP 79, R 567).

On the basis of the obtained results it was found that forms with a higher lodging resistance had simultaneously shorter and thicker lower internodes and were characterized by a much better stem elasticity and tolerance to breakage. Physical characters of the stem (Young's modulus and bending stress) more differentiated the studied genotypes regarding their lodging resistance than did morphological characters.

Studies of many authors concerning variation of stem morphological and physical characters determining lodging resistance of barley showed that these characters are determined genetically (Bauer 1964, Zenisceva 1972, Jeżowski 1978, 1981). However, no more extensive studies with the aim to determine the inheritance mode of these characters, particularly physical properties of the stem, have been undertaken so far.

The purpose of the performed studies was genetic analysis of morphological characters and physical properties of F_1 hybrids from diallel crossing of cultivars and strains with different lodging grade. This paper presents variation of morphological and physical characters of the stem in parental forms and F_1 hybrids.

MATERIAL AND METHODS

The studying material consisted of two cultivars (Aramir, Diva) and three strains of spring barley (CJ 3614, EP 79 and R 567). These forms were crossed in a half-diallel fashion. The F_1 hybrids and their parental forms were studied in a field experiment laid out in a randomized complete block design with three replications. Two hundred seeds were sown on each plot at the space of 20×5 cm.

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The lodging grade was estimated at the full maturity stage using 5-point survey scale, where 1 means no lodging and 5 — the largest lodging.

The following characters were analysed: stem length, length of the first and second internodes (counted from the stem base), their outside diameter and wall thickness. Besides that, on the basis of measurements made in the median part of all the internodes the average outside diameter and the thickness of stem walls were calculated. The stem elasticity and its resistance to breaking were also studied. The stem elasticity was determined by Young's modulus, while the stem resistance to breakage was estimated by the bending stress at the moment of the stem breakage (Skubisz 1978, Jeżowski 1981).

The obtained results concerning morphological characters and physical indices were statistically treated using various, but closely related methods of multivariate analysis. First of all, a multivariate analysis of variance (Caliński, Kaczmarek 1973, Ceranka et al. 1977) constituting a basis for testing hypotheses about comparisons between forms, especially between hybrids and their parental forms, was performed. All the hypotheses were verified by simultaneous test procedures. In order to present graphically the position of the studied forms with respect to all the analysed characters simultaneously, an analysis of canonical variables was made (Rao 1964, Caliński, Kaczmarek 1973, Caliński et al. 1975).

RESULTS AND DISCUSSION

The mean values of the studied morphological characters are given in Table 1. A comparison of F_1 hybrids with the mean of the parental forms and with the cv. Aramir resistant to lodging (control) is presented in Table 2. From the data presented in these tables it follows that the strains EP 79, CJ 3614 and R 567 were

Table 1. Morphological stem characters of parental forms and F_1 barley hybrids

Hybrids and parental forms	Stem length (cm)	Internode length (cm)		Outside diameter of internodes (mm)		Mean diameter of stem (mm)	Thickness of internode walls (mm)		Mean thickness of stem walls (mm)
		Ist	IInd	Ist	IInd		Ist	IInd	
EP 79	86.20	5.03	10.43	2.18	2.72	2.66	0.30	0.21	0.16
EP 79 × CJ 3614	83.16	7.20	11.63	2.08	2.40	2.30	0.20	0.17	0.17
EP 79 × R 567	95.70	7.33	11.70	2.20	2.52	2.36	0.25	0.27	0.20
Aramir × EP 79	91.10	6.06	10.40	2.28	2.74	2.83	0.29	0.20	0.20
EP 79 × Diva	91.60	6.53	10.10	2.09	2.73	2.80	0.26	0.19	0.19
CJ 3614	54.33	6.20	9.40	1.70	1.96	2.08	0.18	0.14	0.15
CJ 3614 × R 567	68.60	7.03	10.56	1.93	2.26	2.38	0.23	0.13	0.12
Aramir × CJ 3614	69.06	6.76	9.93	2.08	2.36	2.52	0.21	0.16	0.18
Diva × CJ 3614	70.83	5.76	9.33	1.00	2.29	2.59	0.23	0.17	0.17
R 567	70.86	5.90	10.03	2.09	2.34	2.44	0.20	0.14	0.16
Aramir × R 567	77.36	7.13	10.66	2.23	3.56	2.66	0.24	0.18	0.19
R 567 × Diva	80.00	6.36	10.60	2.33	2.73	2.76	0.24	0.19	0.18
Aramir	73.16	5.33	8.73	2.15	2.47	2.63	0.20	0.15	0.19
Aramir × Diva	77.00	6.03	9.33	2.38	2.63	2.80	0.25	0.18	0.18
Diva	77.00	6.00	9.53	2.34	2.70	2.88	0.25	0.25	0.20

Table 2. A comparison of F_1 barley hybrids with the mid-parent (MP) and control cv. Aramir regarding the morphological stem characters

Contrast	Contrast estimate								
	Stem length	Internode length		Outside diameter of internodes		Mean stem diameter	Wall thickness of internodes		Mean thickness of stem walls
		Ist	IInd	Ist	IInd		Ist	IInd	
(EP 79 × CJ 3614) – MP	12.90*	1.30*	1.22	0.14	0.06	0.02	−0.04	0.00	0.02
(EP 79 × CJ 3614) – Aramir	10.00*	1.87*	2.90*	−0.07	−0.08	−0.25	0.00	0.02	−0.02
(EP 79 × R 567) – MP	17.16*	1.56*	1.46	0.15	−0.01	−0.19	0.00	0.10*	0.04*
(EP 79 × R 567) – Aramir	22.21*	2.00*	2.96*	0.14	0.05	−0.27	0.05	0.12*	0.01
(Aramir × EP 79) – MP	11.42*	0.60	0.80	0.11	0.14	0.18	0.05	0.02	0.02
(Aramir × EP 79) – Aramir	17.93*	0.73	1 67*	0.12	0.26	0.20	0.09*	0.04	0.01
(EP 79 × Diva) – MP	10.00*	0.72	0.12	0.02	0.02	0.04	−0.02	−0.01	0.00
(EP 79 × Diva) – Aramir	18.43*	1.20	1.37	0.14	0.26	0.17	0.06	0.04	0.00
(CJ 3614 × R 567) – MP	6.00	0.98	0.85	0.03	0.10	0.12	0.04	−0.01	0.00
(CJ 3614 × R 567) – Aramir	−4.57	1.70*	1.83*	−0.22	−0.21	−0.13	0.03	−0.02	−0.04*
(Aramir × CJ 3614) – MP	5.32	1.00	0.90	0.15	0.15	0.17	0.03	0.02	0.02
(Aramir × CJ 3614) – Aramir	−4.10	1.43	1.20	−0.07	−0.11	−0.10	0.01	0.01	−0.01
(Diva × CJ 3614) – MP	5.15	−0.34	−0.14	−0.12	−0.04	0.12	0.02	0.00	0.00
(Diva × CJ 3614) – Aramir	−2.33	0.43	0.60	−0.25	−0.18	−0.04	0.03	0.02	−0.02
(Aramir × R 567) – MP	5.35	1.50	1.30	0.10	0.16	0.12	0.05	0.03	0.01
(Aramir × R 567) – Aramir	4.20	1.80*	1.93*	0.07	0.09	0.03	0.04	0.02	0.00
(R 567 × Diva) – MP	6.65	0.42	0.82	0.11	0.21	0.10	0.02	0.02	0.00
(R 567 × Diva) – Aramir	6.83	1.03	1.87*	0.17	0.26	0.13	0.04	0.04	−0.01
(Aramir × Diva) – MP	1.92	0.37	0.20	0.14	0.05	0.04	0.02	0.01	−0.01
(Aramir × Diva) – Aramir	3.83	0.70	0.60	0.23	0.16	0.16	0.05	0.03	−0.01
EP 79 – Aramir	13.03*	−0.30	1.70	0.03	0.24	0.03	0.09*	0.05	−0.03*
CJ 3614 – Aramir	−18.83*	−0.87	0.66	−0.45*	−0.51*	−0.53*	−0.02	−0.01	−0.04*
R 567 – Aramir	−2.30	−0.57	1.30	−0.06	−0.13	−0.19	0.00	−0.01	−0.03*
Diva – Aramir	3.80	0.67	0.80	0.19	0.22	0.25	0.05	0.10*	0.01

* significance at $\alpha = 0.05$

characterized by significantly larger lodging grade than the cv. Aramir, whereas difference between the cv. Aramir and Diva was nonsignificant.

F_1 hybrids obtained from crossings of the studied strains and cultivars were characterized by a significantly higher lodging grade than the cv. Aramir, whereas differences between the hybrids and the mean of their parental forms were nonsignificant.

The analysed F_1 hybrids distinguished by a somewhat longer length of the stem and first internode in comparison with the mean of the parental forms, but only for hybrids of EP 79 strain with the remaining forms the differences were statistically significant. These hybrids as compared to the control also distinguished significantly by a larger length of the stem and studied internodes.

Table 3. Lodging grade and physical stem indices of parental forms and F_1 barley hybrids

Hybrids and parental forms	Stem bending stress $\left(\frac{N}{mm}\right)$	Young's modulus $\left(\frac{N}{mm}\right)$	Lodging grade
EP 79	21.07	1139	4.33
EP 79 × CJ 3614	25.71	1360	4.33
EP 79 × R 567	30.07	1071	4.33
EP 79 × Aramir	26.32	1516	3.33
EP 79 × Diva	27.95	1488	3.33
CJ 3614	20.95	926	3.66
CJ 3614 × R 567	14.58	1085	4.33
CJ 3614 × Aramir	27.16	1277	3.00
CJ 3614 × Diva	23.96	1207	4.00
R 567	22.07	1187	4.33
R 567 × Aramir	27.89	1337	3.00
R 567 × Diva	28.87	1235	3.00
Aramir	49.30	2033	1.66
Aramir × Diva	42.07	1690	1.66
Diva	42.27	1829	2.66

The outside diameter and the thickness of F_1 stem walls were on the level of the parental mean. An exception were EP 79 × R 567 hybrids, which were characterized by significantly thicker walls of the second internode. A comparison of hybrids with the control showed that only hybrids of Aramir × EP 79 significantly differed from the control by the wall thickness of the 1st internode and hybrids of EP 79 × R 567 by the wall thickness of the 2nd internode.

Besides morphological characters of the stem, its physical characters, i.e. the stem bending stress and the stem elasticity index (Young's modulus), were also analysed. The means of these characters are presented in Table 3, whereas the comparison of F_1 hybrids with the mean of their parental forms and with the control cv. Aramir is given in Table 4. From these tables it follows that lodging forms were characterized by low values of the both physical indices. For the cultivars with a large lodging resistance (Aramir, Diva) these indices were almost two-fold higher. When comparing the hybrids with the mean of their parental forms and with the control cv. Aramir (Table 4), it may be noticed that in the case of a significant diffe-

rence in lodging grade, significant were also differences in the studied physical indices.

On the basis of the results of Tables 1–4 it may be found that there are interrelationships between the lodging grade and the morphological and physical characters. The forms characterized by a high lodging resistance simultaneously had shorter and thicker lower internodes and distinguished by a much better stem elasticity and resistance to breaking than lodging forms. Zenisceva and Stankova (1962), Otto (1973) and Jeżowski (1981) also found a similar relationship.

Table 4. A comparison of F_1 barley hybrids with the mid-parent (MP) and control cv. Aramir regarding the lodging grade and physical stem indices

Contrast	Contrast estimate		
	Stem bending stress	Young's modulus	Lodging grade
(EP 79 × CJ 3614) – MP	4.71	327.00	0.33
(EP 79 × CJ 3614) – Aramir	−23.58*	−673.00*	1.33
(EP 79 × R 567) – MP	8.50	−92.17	0.00
(EP 79 × R 567) – Aramir	−19.23*	−962.00*	2.66*
(EP 79 × Aramir) – MP	−8.86	−69.83	0.33
(EP 79 × Aramir) – Aramir	−22.97*	−516.66*	1.67
(EP 79 × Diva) – MP	−3.72	3.67	−0.33
(EP 79 × Diva) – Aramir	−21.35*	−545.00*	1.67*
(CJ 3614 × R 567) – MP	−6.93	28.17	0.33
(CJ 3614 × R 567) – Aramir	−34.72*	−948.00*	2.67*
(CJ 3614 × Aramir) – MP	−7.97	−202.50	0.67
(CJ 3614 × Aramir) – Aramir	−22.14*	−755.66*	1.33
(CJ 3614 × Diva) – MP	−7.85	−171.00	0.67
(CJ 3614 × Diva) – Aramir	−25.53*	−826.00*	2.33*
(R 567 × Aramir) – MP	−7.79	−272.33	0.00
(R 567 × Aramir) – Aramir	−21.40*	−695.33*	1.33*
(R 567 × Diva) – MP	−3.30	−273.17	−0.67
(R 567 × Diva) – Aramir	−20.43*	−798.00*	1.33
(Aramir × Diva) – MP	−3.72	−240.50	−1.00
(Aramir × Diva) – Aramir	−7.23	−342.33*	0.00
EP 79 – Aramir	−28.23*	−803.66*	2.66*
CJ 3614 – Aramir	−28.35*	−1106.33*	2.00
R 567 – Aramir	−27.23*	−846.00*	2.66*
Diva – Aramir	−7.03	−203.66	1.00

* significant at $\alpha = 0.05$

The position of F_1 hybrids and their parental forms in relation to each other is presented in Fig. 1 by the first two canonical variables, taking into account totally the lodging grade and morphological characters. From Fig. 1 it can be seen that the analysed genotypes have basically formed a single, rather closely concentrated group, the parental forms with a high lodging resistance and their hybrids being arranged very closely to each other (Aramir (13), Diva (15), Aramir × Diva 14). Hybrids from crossing of lodging-resistant and less resistant forms were in a close neighbourhood to a resistant form. The genotypes characterized by the lowest lodging resistance appeared to be more distant from the remaining forms.

Fig. 2 presents the position of F_1 hybrids and their parental forms in relation

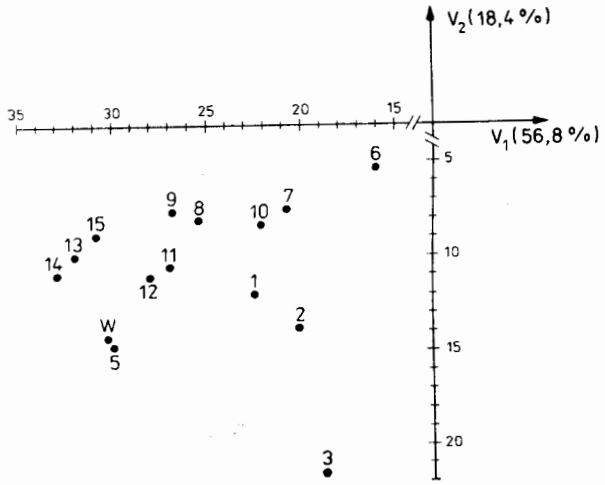

Fig. 1. Position of parental forms and F_1 hybrids of barley expressed by the first two canonical variables V_1 and V_2 considering the lodging grade and morphological stem characters

1 — EP 79, *2* — EP 79 × CJ 3614, *3* — EP × R 567, *4* — Aramir × EP 79, *5* — EP 79 × Diva, *6* — CJ 3614, *7* — CJ 3614 × R 567, *8* — Aramir × CJ 3614, *9* — Diva × R 567, *10* — R 567, *11* — Aramir × R 567, *12* — R 567 × Diva, *13* — Aramir, *14* — Aramir × Diva, *15* — Diva.

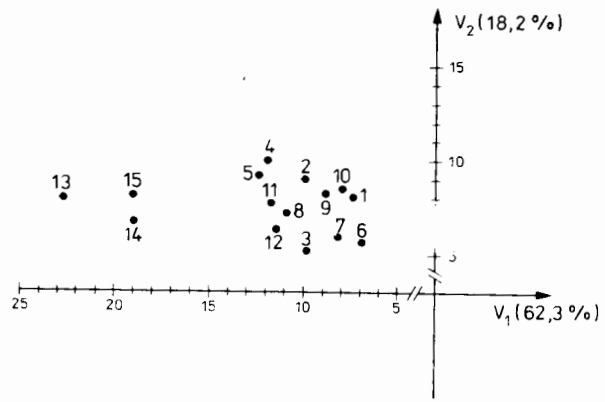

Fig. 2. Position of parental forms and F_1 hybrids of barley in the space of the first two canonical variables V_1 and V_2 for the lodging grade and physical stem indices simultaneously

1 — EP 79, *2* — EP 79 × CJ 3614, *3* — EP 79 × R 567, *4* — Aramir × EP 79, *5* — EP 79 × Diva, *6* — CJ 3614, *7* — CJ 3614 × R 567, *8* — Aramir × CJ 3614, *9* — Diva × R 567, *10* — R 567, *11* — Aramir × R 567, *12* — R 567 × Diva, *13* — Aramir, *14* — Aramir × Diva, *15* — Diva

to each other, taking into account totally the lodging grade and physical stem characters. In Fig. 2 it is seen that the parental forms resistant to lodging as well as their hybrids (Aramir, Diva, Aramir × Diva) form a completely distinct group, markedly separated from the remaining forms. When comparing the both figures it may be noticed that physical characters of the stem more differentiated the studied genotypes with regard to their lodging resistance than did morphological characters. These results are in agreement with the results of similar studies carried out by Jeżowski earlier (1981).

The presented results of the studies concern variation of morphological and physical characters of the stem in parental forms and their F_1 hybrids. A statistico-genetical analysis of these characters will be presented in the next part of this work.

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ANALIZA DIALLELICZNA CECH DETERMINUJĄCYCH ODPORNOŚĆ JĘCZMIENIA JAREGO (*HORDEUM VULGARE* L.) NA WYLEGAŃIE I. OCENA FORM RODZICIELSKICH I MIESZAŃCÓW F_1 POD WZGLĘDEM CECH MORFOLOGICZNYCH I FIZYCZNYCH ŹDŹBŁA

Streszczenie

Badano kształtowanie się cech morfologicznych i fizycznych źdźbła u form rodzicielskich i mieszańców F_1, uzyskanych ze skrzyżowania w układzie diallelicznym pięciu form jęczmienia o zróżnicowanej odporności na wyleganie: Aramir, Diva, CJ 3614, EP 79, R 567. Stwierdzono, że formy charakteryzujące się dużą odpornością na wyleganie miały krótsze i grubsze dolne międzywęźla oraz źdźbła bardziej elastyczne i wytrzymałe na złamanie aniżeli formy wylegające. Cechy fizyczne źdźbła (moduł Younga i naprężenie zginające) różnicowały badane genotypy z punktu widzenia odporności na wyleganie w większym stopniu niż cechy morfologiczne.

ДИАЛЛЕЛЬНЫЙ АНАЛИЗ ПРИЗНАКОВ, ОБУСЛАВЛИВАЮЩИХ УСТОЙЧИВОСТЬ ЯРОВОГО ЯЧМЕНЯ (*HORDEUM VULGARE* L.) К ПОЛЕГАНИЮ I. ОЦЕНКА РОДИТЕЛЬСКИХ ФОРМ И ГИБРИДОВ F_1 ОТНОСИТЕЛЬНО МОРФОЛОГИЧЕСКИХ И ФИЗИЧЕСКИХ ПРИЗНАКОВ СТЕБЛЯ

Резюме

В настоящей работе представлено формирование морфологических и физических признаков стебля у родительских форм и гибридов F_1. Гибриды поколения F_1 были получены от диаллельного скрещивания двух устойчивых к полеганию сортов ярового ячменя (Diva, Aramir) и трёх мало устойчивых к полеганию линий (CJ 3614, EP 79, R 567).

На основании полученных результатов установлено, что формы, характеризующиеся большой устойчивостью к полеганию, имели одновременно более короткие и более крупные нижние междоузлия, а также обладали намного лучшей эластичностью и намного большей выносливостью стебля к сломанию, чем полегающие формы. Физические признаки стебля (модуль Янга и сгибающее напряжение) больше дифференцировали исследуемые генотипы согласно с их устойчивостью к полеганию, чем морфологические признаки.