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HERITABILITY, VARIATION AND RELATIONSHIP BETWEEN FROST RESISTANCE OF WINTER BARLEY AND SOME OF ITS CHARACTERS

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ABSTRACT

The aim of the present paper has been to define heritability and mutual relations between frost resistance and the other traits of two- and six-rowed winter barley: yield, 1000 grain weight and grain filling as well as earliness, plant height and resistance to lodging. The research material was made up of winter barley breeding strains of F_6-F_7 generation researched over 1999-2002 over three two-year cycles. All the characters analysed were marked with coefficient of variability (CV) coefficients of heritability (H) and coefficients of phenotypic and genotypic correlation. The greatest variation over years was observed for frost resistance of both two- and six-rowed barley. Such a great variation of the strains researched makes it possible to select forms resistant in both cultivar groups. The coefficient of heritability of frost resistance was in two-rowed barley quite stable, however in six-rowed barley – it was changing considerably (from zero to 0.83). Two-rowed barley showed low values of heritability coefficient (H) for yield and resistance to lodging. In two-rowed and six-rowed barley the mutual relations between the characters studied changed depending on the set of strains researched, while in six-rowed barley the values of genotypic correlation was significant for most of the characters researched.

Key words: winter barley, frost resistance, heritability, yield, correlation

INTRODUCTION

Spring forms are considered to constitute the species most resistant to abiotic stresses [4], while winter forms show a low capacity for frost hardening [12], and so they usually winter badly, which reduces their wide cultivation despite a recently growing interest of brewing industry in winter barley. Despite the breeding works being carried out, farmers still do not have cultivars suitable for cultivation on the areas where winters are slightly more severe. The reason of little progress in developing winter-hard barley forms is, on the one hand, complicated heritability of the character and, on the other hand, a scarcity of papers on that species [6,7]. Similarly there are not many reports on the relationship between frost resistance and other characters. Such reports, despite providing applicable knowledge, could show handy while making selection and accelerate progress in that field. Six-rowed barley, although it comes in straight line from two-rowed barley, represents a separate group of forms now which differs from its predecessor not only in the structure of the ear, but also a great deal of other characters, and so in scientific research these forms are generally treated separately or compared [14,16,20]. In winter barley breeding there also exist two directions, while in Poland two-rowed barley is treated as malting barley, while six-rowed barley as the fodder one.

Despite numerous research into frost resistance of cereals, the papers on this character in barley are much less numerous than in wheat [6,7,30]. No reports on the relationship between frost resistance and other characters makes breeding this species very difficult and undoubtedly is one of the most essential reasons of little progress in launching the breeding of barley forms combining resistance to unfavourable wintering conditions with satisfactory yield and favourable technological parameters.

The aim of this paper was to define genetic conditions and mutual relations between frost resistance and the characters in barley: yield, 1000 grain weight and grain filling, as well as earliness, plant height and resistance to lodging. The assumption was to answer the question whether there exists a character which would be of high heritability and highly correlated with frost resistance making intermediary selection possible. The research was carried out parallel, for two- and six-rowed barley, due to the above differences between those two cultivar groups.

MATERIAL AND METHODS

The research material consisted of three sets of two- and six-rowed winter barley strains of F_6-F_7 generation investigated in three two-year cycles. Set I researched over 1999-2000 included 16 strains of two-rowed and 18 six-rowed barley, set II (2000-2001), respectively 16 and 13 strains of each form group and set III including 17 strains of two- and six-rowed barley each researched over 2001-2002. The research covered strains of the last stages of breeding experiments (experiments pre-preliminary and preliminary) which differed in the characters analysed. Strains of six-rowed and two-rowed barley grew in separate experiments, but each two-year cycle included the same strains. Yield, 1000 kernel weight, grain filling, earliness (determined as the number of days since May 1^{st} to heading), plant height and resistance to lodging were defined throughout breeding experiments carried out in four locations; Bąków, Oleśnica, Łagiewniki and Modzurów. The strains researched were growing on plots of 10 m^2, with the standard level of fertilisation. Four-replication experiments were set up with randomised blocks design method. The field experiments results reported from different locations were averaged (weighted mean) in order to eliminate the environmental variation.

Frost resistance was evaluated with the field-laboratory method [10,15] at the Institute of Plant Breeding and Acclimatisation in Cracow. The autumn growth and hardening took place under natural, while freezing under artificial conditions. Temperature of freezing ranged from -12°C to -15°C, while this value was determined based on trial freezing. The frost resistance was measured with a percentage of living plants following freezing against the initial number of seedlings. The results of two-year experiments were averaged, which allowed, to some extent, for eliminating the changeability of frost hardening conditions, and the data obtained that way were used for further calculations.

For each set and for each character variance analysis was carried out following the two-directional classification, separating the total variation into the component related with the environment, component resulting from genetic differences between genotypes and the other one as the interaction between the genotype and the environment which served as denominator for F test when verifying hypotheses about the main components. The mean squares for genotypes and genotypic and environmental interaction were used to evaluate coefficients of heritability of characters (H) as equivalents of coefficients of heritability (h^2), following the formula by Baker et al. [2], namely:

$$H=(m_1-m_2)/m_1$$

where:
H – coefficient of heritability,
m_1 and m_2 – mean squares respectively for genotypes and genotype x environment interaction.

Standard error of H coefficient was calculated following Hallauer and Miranda [11]. Then for each character there were calculated weighted heritability coefficient and standard error of all the experiment sets. The same components of variance analysis were used to calculate the genotypic and phenotypic correlation between the characters studied. To calculate correlation coefficients the formulas by Baker et al. were used [2]. For the seven characters researched variability coefficients (CV) were calculated and then used to evaluate the genotypic and environmental interaction; CV value ranging from 0 to 5% informs that the calculated mean square for the interaction discussed depends exclusively on randomness, while higher values are due to this interaction [25,30].

RESULTS AND DISCUSSION

Two-rowed barley

Means, ranges and variability coefficients of the characters researched differed considerably over years (Table 1), which seems obvious as each of them is exposed to a considerable modification by environmental factors. Table 1 shows that frost resistance of the strains researched not only differed much more than the other characters but also showed the greatest variation. Variation coefficients ranging from 13.8% in 2000-01 (set II) to 22.5% in 1999-2000 (set I) suggest a powerful interaction between the genotypes investigated and the environment. Similarly high values of CV were observed researching wheat frost resistance [9]. A powerful genotypic and environmental interaction was also reported for the number of days to heading; CV ranged from 10.5 to 17.5%, although mean values of that feature did not show that high differences and fell within 11.5-13.7%. Slightly lower CV values yet also exceeding 5% were noted for 1000 grain weight and grain filling. One can assume, therefore, that similarly for those characters the variation resulted mainly from genotypic and environmental interaction. The variability coefficient lower than 5% was observed only for plant height, and so the variation across the objects researched as far as this feature is concerned was exclusively due to randomness [25,30].

Table 1. Means, ranges and coefficients of variability of the characters researched of two-rowed winter barley over 1999-2002

Character		Years			Total
		1999-2000 set I	2000-2001 set II	2001-2002 set III	
Frost resistance, %	Mean	36.3	42.2	25.6	34.7
	CV, %	22.5	13.8	20.2	18.4
	H ± SE	0.437 ± 0.197	0.449 ± 0.216	0.557 ± 0.308	
Yield, $t \cdot ha^{-1}$	Mean	7.05	7.48	7.61	7.38
	CV, %	5.01	6.62	4.09	5.24
	H ± SE	0.192 ± 0.220	0.409 ± 0.219	0.249 ± 0.208	
Grain filling, %	Mean	–	–	72.6	72.6
	CV, %	–	–	10.2	10.2
	H ± SE	–	–	0.350 ± 0.199	
1000 grain weight, g	Mean	44.1	43.9	42.7	43.6
	CV, %	12.2	10.8	8.8	10.6
	H ± SE	0.903 ± 0.172	0.741 ± 0.195	0.657 ± 0.176	
Number of days since May 1 to heading	Mean	11.5	11.6	13.7	12.3
	CV, %	15.3	17.5	10.5	14.4
	H ± SE	0.892 ± 0.172	0.834 ± 0.191	0.745 ± 0.172	
Height, cm	Mean	98.1	93.6	92.7	66.1
	CV, %	4.74	4.87	4.31	4.64
	H ± SE	0.756 ± 0.176	0.738 ± 0.195	0.645 ± 0.177	
Resistance to lodging (9-1 scale*)	Mean	8.06	7.76	7.85	7.89
	CV, %	6.61	9.30	6.46	7.46
	H ± SE	0.271 ± 0.212	0.548 ± 0.207	0.110 ± 0.2491*	

* 9 – resitantresistant, 1 – susceptible

Table 1 shows that also that the degree of heritability of frost resistance remained average and was similar across all the line sets estimated. It was, therefore, considerably lower than heritability much observed by Clivieri and Danuso [5] which amounted to 0.98. Surely, similarly as in other cereals, the character is controlled by numerous genes induced by low temperature [6,26,24]; their expression depends on hardening and freezing conditions. One can assume that the degree of heritability will change depending on what genes (under specific conditions) will decide about frost resistance development, which means that enhancing barley frost resistance will be extremely difficult.

"H" coefficient for grain yield was changing depending on the set evaluated and was low or average and considerably lower than the values recorded by Nadziak et al. [17], according to which winter barley yield heritability was H = 0.618 and 0.634. Similarly low values were observed when researching spring barley [8] where the degree of heritability H was only 0.312. Genetic plant height control was high and similar to that noted for spring barley, yet almost twofold higher than that reported by Nadziak et al. [18] for other genotypes. H value for the number of days to heading was high (0.625 and 0.795), similarly as reported by Nadziak et al. [18]. A comparison of the results obtained with the reports by other authors suggests that the degree of heritability of the characters studied depended considerably on the genotypes applied.

Table 2 includes coefficients of phenotypic and genotypic correlation (above and below the diagonal, respectively) as the mutual relationships between characters constitute an element which must be factored in by every breeder [28]. Correlation of the genetic type can be used in breeding limiting the selection to these characters which result in a desired level of other properties [1]. The table gives only the values of significant and highly significant coefficients to make the table more clear and the comparisons – easier. Table 2 also shows that the mutual relations between the characters studied were changing depending on the set of strains researched. Significant negative relationships between frost resistance and yield and plant height were reported for set II; the correlations were both phenotypic and genotypic. For that set of strains, it will be possible to obtain winter-hard forms of a shortened culm, however combining frost resistance with high yield can be difficult. The other sets of strains did not show any relationship between frost resistance and any other of the characters studied, and so similarly as for wheat [9] the selection towards that character should be made independently.

Table 2. Means, coefficients of variability (CV) and coefficients of heritability (H) of the characters researched of the six-rowed winter barley over 1999-2002

Character		Years			Total
		1999-2000 set I	2000-2001 set II	2001-2002 set III	
Frost resistance, %	Mean	36.8	39.9	20.2	32.3
	CV, %	17.9	26.0	13.4	19.1
	H ± SE	0.00 ± 0.05	0.83 ± 0.08	0.00 ± 0.046	
Yield, $t \cdot ha^{-1}$	Mean	7.37	7.68	7.89	7.65
	CV, %	3.27	3.21	5.06	3.85
	H ± SE	0.46 ± 0.19	0.05 ± 0.25	0.88 ± 0.056	
Grain filling, %	Mean	68.8	59.4	64.2	64.2
	CV, %	10.3	14.0	15.8	13.4
	H ± SE	0.80 ± 0.08	0.65 ± 0.14	0.62 ± 0.15	
1000 grain weight, g	Mean	39.3	38.0	38.9	38.7
	CV, %	4.77	5.80	5.95	5.51
	H ± SE	0.85 ± 0.06	0.79 ± 0.09	0.69 ± 0.13	
Number of days since May 1 to heading	Mean	11.2	12.0	14.6	12.6
	CV, %	11.7	7.44	7.02	8.72
	H ± SE	0.89 ± 0.05	0.56 ± 0.17	0.73 ± 0.11	
Height, cm	Mean	101.4	101.3	100.2	101.0
	CV, %	2.88	2.12	3.43	2.81
	H ± SE	0.30 ± 0.21	0.33 ± 0.23	0.81 ± 0.08	
Resistance to lodging (9-1 scale*)	Mean	7.91	7.43	6.91	7.42
	CV, %	5.01	5.38	8.34	6.24
	H ± SE	0.46 ± 0.19	0.12 ± 0.25	0.79 ± 0.09	

* 9 – resitantresistant, 1 – susceptible

Calculating coefficients of correlation between frost resistance determined with the field-laboratory method and the other characters researched seems justifiable. Rajka [20] and Sutka et al. [23] show that it is a good indicator of frost resistance and practice reveals that very frequently it is the only indicator of resistance to unfavourable conditions of wintering available to the breeder under moderate climate conditions where severe winters are quite frequent, however they are not a rule. An additional advantage of the method applied is that autumn growth and acclimatisation take place under natural conditions, which makes it closer to field conditions than other laboratory tests [21].

Six-rowed barley

Data presented in Table 3 show that out of all the seven characters researched, the greatest variation over years was recorded for frost resistance. Mean level of that character ranged from 39.9% winter survival for set I to 20.2% for set III. High CV values suggest a considerable share of the genotypic and environmental interaction in the variation observed [30]. A similar variation and variability over years were observed for grain filling. Coefficients of variability calculated for that character were slightly lower than for frost resistance, yet they also showed a considerable interaction between the genotype and the environment.

Table 3. Coefficients of phenotypic correlation (rP) above the diagonal and genotypic correlation (rG) below the diagonal between the characters researched (two-rowed barley)

Characters	Set	1	2	3	4	5	6	7
Frost resistance, % (1)	Set I							
	Set II		-0.67**				-0.68**	
	Set III							
Yield, t·ha^{-1} (2)	Set I							
	Set II	-0.98**			-0.53*			
	Set III			-0.51*	-0.67**		0.51*	
Grain filling, % (3)	Set I							
	Set II							
	Set III		-0.96**		0.88**		-0.49*	
1000 grain weight, g (4)	Set I		-0.75**			-0.46*		
	Set II		-0.98**					
	Set III		-0.98**	0.98**			-0.44*	
Number of days since May 1 to heading (5)	Set I				-0.48*			
	Set II							
	Set III							
Height, cm (6)	Set I							
	Set II	-0.77**			-0.62**			
	Set III		0.99**	-0.86**	-0.70**			-0.44*
Resistance to lodging (9-1 scale) (7)	Set I						-0.68**	
	Set II							
	Set III							

* significant at α = 0.05; ** significant at α = 0.01

Slight differences between mean yield, 1000 grain weight and plant height observed in two-year periods were due to randomness (CV < 5%) and must have been related with the fact that in each cycle a different set of genotypes was researched. Similar inconsiderably high variation was noted for lodging and the number of days since May 1 to heading; the share of the genotypic and environmental interaction was inconsiderable here, which is seen from low variability coefficients [30].

Coefficients of heritability (H) of the characters analysed differed depending on the set of the genotypes researched. As for frost resistance, a high H value was observed only in the second set of strains, in the other ones it equalled zero. The reasons of such discrepancies can be traced to the above mentioned high genotypic and environmental interaction due to the fact that although plant freezing from each set was the same, yet hardening took place under natural conditions. Different weather conditions over years made the acclimatisation in each period discussed was slightly different, which resulted in a different level of frost resistance [13]. Variable hardening conditions could have also caused differences in the expression of genes induced by low temperature [7,27,24].

Variable degree of heritability of yield, plant height and resistance to lodging makes it difficult to relate the results obtained to similar research carried out by Nadziak et al. [17,18], Bichoński [3] and Węgrzyn and Bichoński [29]. One can assume that these characters will be transferred to progeny depending on the components selection for crossing which, therefore, should be done extremely carefully, if possible based on earlier research. Quite stable and high H values were, however, observed for grain filling, 1000 grain weight and the number of days since May 1 to heading. It is interesting that at a low (mean for all the forms researched: 64.1%) grain filling, the coefficient of heritability of this character was quite high (H = 0.80, 0.65 and 0.62, respectively for I, II and III line sets), unlike it was observed for two-rowed barley [8] where the average grain filling was 79.2% and the degree of heritability was almost zero (H = 0.000486). To explain this phenomenon, however, further research is needed which would go beyond the coverage of the present paper.

Similarly as for two-rowed barley, also for six-rowed strains coefficients of phenotypic and genotypic correlation have been calculated (Table 4). Some coefficients of genotypic correlation assumed values higher than one. A similar phenomenon was observed by Śmiałowski and Węgrzyn [28] researching rye. According to these authors, it occurs when the coefficient of correlation includes also environmental correlation at an extremely high effect of the environment on one or both characters. Table 4 shows that almost all the characters researched were significantly phenotypic-correlated; the value and significance of correlation coefficients in respective sets of genotypes differed. Significant genotypic correlation also occurred depending on the set of genotypes researched, however they were less frequent than the phenotypic ones and phenotypic correlation was not always a result of genetic conditions. Frost resistance was phenotypic- and genotypic-correlated with the kernel weight and size (grain filling) only in the third set of the forms researched. This relationship must be considered favourable. The main obstacle in increasing the winter barley cultivation area is an excessively low frost resistance, and as for six-rowed barley – excessively low 1000 grain weight and grain filling make it impossible to use this group of cultivars for malting. The existence of genotypes combining these three characters (such as set III) shows a potential for malting forms of six-rowed winter barley. What is also favourable is the negative correlation between frost resistance and plant height, in two sets (II and III) which results from genetic conditions. The relationship between frost resistance and the other characters researched was only due to the effects of the environment; all the coefficients of genotypic correlation showed non-significant. The comprehensive mutual relationship of the characters evaluated frequently also the genotypic one can create some difficulties for breeders as the correlations are not always breeding-friendly. The correlation which is favourable is the correlation between 1000 grain weight and yield, which is phenotypic in all the sets researched as well as the phenotypic and genotypic ones in sets I and III. A negative correlation between 1000 grain weight and grain filling is unfavourable yet limited only to the phenotype, during selection it must therefore be factored in, however non-significant coefficients of genotypic correlation suggest obtaining forms in which the mutual relationship between these characters will be positive, just like it was observed in the earlier reports [3,29].

Table 4. Coefficients of phenotypic correlation (rP) above the diagonal and genotypic correlation (rG) below the diagonal between the characters researched (six-rowed barley)

Characters	Set	1	2	3	4	5	6	7
Frost resistance, % (1)	Set I		-0.12**	0.23**		-0.18**	-0.11**	-0.30**
	Set II		0.19**	0.40**	0.37**		-0.20**	
	Set III		-0.30**	0.46**	0.49**	-0.18**	-0.18**	
Yield, $t \cdot ha^{-1}$ (2)	Set I			0.44**	0.34**	-0.21**	-0.33**	0.39**
	Set II			0.42**	0.39**	-0.21**	-0.20**	0.46**
	Set III			0.56**	0.63**		0.48**	0.66**
Grain filling, % (3)	Set I		0.57**		-0.36**	0.59**		-0.17**
	Set II				-0.15**	0.88**	0.30**	0.20**
	Set III	0.57**	0.66**		-0.30**	0.77**		0.31**
1000 grain weight, g (4)	Set I		0.31**				0.19**	
	Set II					0.35**	0.35**	0.50**
	Set III	0.69**	0.86**					0.25**
Number of days since May 1 to heading (5)	Set I			0.65**				-0.18**
	Set II			1.05**	0.45**		-0.25**	
	Set III			0.79**			0.38**	-0.18**
Height, cm (6)	Set I							-0.20**
	Set II	-0.54**		0.57**	0.45**	-0.29**		-0.18**
	Set III	-0.26*	0.52**			0.42**		0.43**
Resistance to lodging (9-1 scale) (7)	Set I		1.15**		0.24**		-0.30*	
	Set II				0.75**			
	Set III		0.78**	0.33**			0.49**	

* significant at α = 0.05; ** significant at α = 0.01

More clear differences between the two groups of barley strains occurred for the other characters analysed. Two-rowed barley yielded slightly lower (7.31 t·ha^{-1} on average) than the six-rowed barley (7.65 t·ha^{-1}), but it showed a higher 1000 grain weight and their better grain filling, which was signalled also by Spunar et al. [22] and Ortiz et al. [19]. The reasons of that phenomenon can be traced to the fact that locus vrs 1 on chromosome 2H, which determines the row type was convergent with QTL of a wide effect determining the yield, plant height and grain weigh and size. Marquez-Cedillo et al. [16] report on a frequent occurrence in the population of six-rowed barley of positive transgressive segregants for all the characters, which suggests that it is possible to obtain six-rowed forms of favourable yield structure parameters.

CONCLUSIONS

1. Higher coefficients of variability of the same characters observed in two-rowed barley suggest that while transgression from two- to six-rowed forms the variation of some characters narrowed.
2. Under identical conditions the degree of heritability of frost resistance was in different sets of two-rowed barley similar, however in six-rowed barley it was changing considerably. In both cultivar groups the level of frost resistance could have been defined by expression of different genes. It also seems that this character is more stable in two-rowed barley.
3. Two-rowed barley showed low values of the heritability coefficient (H) of the yield and resistance to lodging; enhancing these characters can turn out to be difficult and selection effectiveness can change depending on the initial plant material.
4. Coefficients of heritability different over years for frost resistance, yield, plant height and resistance to lodging observed for six-rowed barley stress the importance of adequate selection of parental components in crossing schedules.

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