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Genetic control for resistance to leaf rust in wheat-*Agropyron* lines: Agro 139 and Agro 58

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Abstract Leaf rust resistance lines of *Triticum aestivum* carry highly effective *Lr* genes from *Agropyron intermedium* (Host) Beauv. This Agro 58 and Agro 139 resistance segregated independently of *Agropyron* leaf-rust resistance genes *Lr-19*, *Lr-24* and *Lr-9* from *Ae. umbellulata*. Monosomic analysis showed that the *Lr* gene in Agro 139 was incorporated into wheat chromosome 6D. C-banding analysis could not determine the C-banding pattern of *A. intermedium* in wheat-*Agropyron* lines Agro 58 and Agro 139. It is assumed that the transfers occurred from the euchromatin regions of the *Agropyron* chromosomes to the euchromatin regions of the wheat chromosomes. It is suggested that the *Lr* gene from Agro 139 be designated $LrAg^i$-*1* and the *Lr* gene from Agro 58 designated $LrAg^i$-*2*.

Key words Wheat-*Agropyron* lines
Resistance to leaf rust · Monosomic analysis
C-banding · $LrAg^i$-*1*, $LrAg^i$-*2*

Introduction

Although wide hybridization between *Triticum aestivum* and *Agropyron* intermedium has been carried out for 60 years only one gene for resistance to leaf rust has been localized, *Lr-38*. In this paper the chromosome location and identification of leaf-rust resistance in wheat-*Agropyron* lines Agro 58 and Agro 139 is reported.

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Materials and methods

Genotypes

Lines S29+Agro1/S52/AS13/2/AS12 (abbreviated Agro 58) and line S46/S29-1-139-M-2-2/AS12 (abbreviated Agro 139) were produced by crossing the substitution wheat-*Agropyron intermedium* lines with local cultivars. The substitution lines were acquired from M. Sinigovec, All-Russian Research Institute of Phytopathology, Moscow, Russia. Line Agro 139 was crossed with the 'Saratovskaya 46' series of monosomics obtained from the Laboratory of Genetics and Cytology, South-East Agriculture Research Institute, Russia (Voronina et al. 1984). Leaf-rust resistance of segregations F_2, F_1BC_1 and testcross populations was tested by inoculating plants with local populations collected in the field at Saratov.

C-banding

Root-tip chromosomes of wheat-*Agropyron* lines Agro 58, Agro 139 and bread wheat 'Saratovskaya 29' (S29) were C-banded according to a procedure described by Badaev et al. (1985).

Results

Segregation F_2, F_1BC_1

Wheat-*Agropyron* lines Agro 58 and Agro 139 were crossed with the susceptible cultivar 'Saratovskaya 46' (S46). The F_1 hybrids were highly resistant to leaf rust: type 0; 1. One part of the F_1 hybrids were self-pollinated, while the other part was backcrossed once to 'S46', with the F_1 plants as males. Of the 94 plants of the F_2 population 'S46'/Agro 58, 70 were resistant and 24 susceptible, which closely fits the 3:1 ratio (χ^2=0.01) expected for monogenic control of resistance to leaf rust. These results agree with segregation data in F_1BC_1 'S46'/Agro 58, although of the 132 plants of the F_1BC_1 population 81 were resistant and 51 susceptible, which does not fit the 1:1 ratio (χ^2=6.82); χ^2 heterogenity was 0.36, which closely fits the 1:1 (Table 1). Similar results were obtained in segregation F_2 and F_1BC_1 'S46'/Agro 139. The χ^2 for segrega-

Table 1 Segregation of leaf-rust resistance in the F_2 and F_1BC_1 generations of the crosses 'S46'/Agro 58, 'S46'/Agro 139 (*R* resistant, *S* susceptible)

Hybrids	Number of plants		Expected ratio	χ^2 (3:1)[a] (1:1)
	R	S		
F_2 'S46'/Agro 58	70	24	3:1	0.01
F_2 'S46'/Agro 139	66	26	3:1	0.52
F_1BC_1 'S46'/Agro 58	21	12	1:1	2.45
	19	11	1:1	2.13
	23	17	1:1	0.90
	18	11	1:1	1,69
Total	81	51	1:1	6.82
		heterogeneity		0.36
F_1BC_1 'S46'/Agro 139	25	15	1:1	2.50
	18	10	1:1	2.29
	15	9	1:1	1.50
	16	9	1:1	1,96
Total	74	43	1:1	8.21
		heterogeneity		0.03

[a] The χ^2 value for significance at the 5% probability level is 3.84

tion F_2 was 0.52, and χ^2 F_1BC_1 was 8.21, but χ^2 heterogenity was 0.03. Segregations in F_1BC_1 'S46'/Agro 58 and F_1BC_1 'S46'/Agro139 showed that the *Lr* genes of Agro 58 and Agro 139 were transferred with pollen without disturbance.

Allelism test

Wheat-*Agropyron* lines were crossed with nearly-isogenic lines 'Thatcher', carrying *Lr-9*, *Lr-19*, *Lr-24*, and with each other to determine whether they carried different genes. In the Volga region only three *Lr* genes, *Lr-9*, *Lr-19* and *Lr-24*, are highly effective. Of the 49 plants of the F_2 population Agro 58/Tc*Lr-9*, 46 were resistant and 3 susceptible, which closely fits the 15:1 ratio (χ^2=0.001) expected for independent segregation of two loci. The χ^2 for segregation F_2 Agro 58/Tc*Lr-19* was 0,12, χ^2 for segregation F_2 Agro 58/Tc*Lr-24* was 0,01, χ^2 for segregation F_2 Agro 58/Agro 139 was 0,15. Similar results were obtained for segregations F_2 Agro 139/Tc*Lr-9* and Agro 139/Tc*Lr-19*: χ^2=0.02 and χ^2=0.01 (Table 2). Thus, the resistance of Agro 58 and Agro 139 segregated independently of leaf resistance genes *Lr-9*, *Lr-19* and *Lr-24*. However, it is well known that leaf-rust resistance genes from wild relatives may be located on differents chromosomes of wheat.

For example, *Lr-19* is located on 7AL and 7DL; *Lr-38*, on 2AS, 1DL, 3DS, 5AS, 6DL; and *Hp* from rye is located on 4AL, 5BS and 6D. Furthermore, different species carry alleles of the same gene; for example, *Lr-19* from Ag. elongatum (2n=70) and *Lr-19*d from *Ag. distichum* (2n=28) (McIntosch et al. 1993). Therefore, in the case of intergeneric translocation F_2 segregation analysis alone is not enough to locate and identify the genes for leaf-rust resistance and additional tests with molecular markers are needed. We explain our F_2 segregation data as differences in the chromosomal location of the genes and as intermediate stages of unidentifiable allelic relationships between alleles.

Table 2 Segregation of leaf-rust resistance in the the F_2 generation of crosses Agro 58 and Agro 139 × *Lr* gene testers (*R* resistant, *S* susceptible)

Hybrids	Number of plants		χ^2 (15:1)[a]
	R	S	
Agro 58/Tc*Lr-9*	46	3	0.01
Agro 58/Tc*Lr-19*	55	3	0.12
Agro 58/Tc*Lr-24*	48	3	0.01
Agro 58/Agro 139	49	4	0.15
Agro 139/Tc*Lr-9*	56	4	0.02
Agro 139/Tc*Lr-19*	79	5	0.01

[a] The χ^2 value for significance at the 5% probability level is 3.84

Table 3 Segregation of leaf-rust resistance in the F_2 generation from monosomic F_1s of crosses 'Saratovskaya 46' monosomics × Agro 139 (*R* resistant, *S* susceptible)

Monosomic	Number of plants		χ^2 (3:1)[a]
	R	S	
1A	65	26	0.62
2A	45	31	10.11
3A	55	34	1.11
4A	47	26	4.71
5A	88	30	1.03
6A	140	31	4.46
7A	51	28	4.60
1B	37	41	31.61
2B	24	19	10.55
3B	46	23	2.56
4B	58	27	2.08
5B	35	19	2.99
6B	98	24	0.85
7B	102	44	2.06
1D	24	13	1.23
2D	30	6	1.33
3D	65	37	5.03
4D	35	13	0.11
5D	95	24	1.45
6D[b]	181	4	52.73
7D	69	19	0.55

[a] The χ^2 value for significance at the 5% probability level is 3.84
[b] The critical chromosome

F_2 monosomic analysis

The line Agro 139 was crossed with the 'Saratovskaya 46' monosomics, and the F_1 monosomic plants were self-pollinated. The F_2 populations derived from the F_1 monosomics in which the gene was not on the monosome were expected to segregate in a ratio of 3 resistant:1 susceptible. The F_2 populations from 21 crosses were tested for leaf-rust resistance. The 13 segregations fitted a 3:1 ratio. The segregations of the F_2 populations with monosomics 2A, 4A, 6A, 7A, 1B, 2B, 3D and 6D did not fit a 3:1 ratio, although only the cross with monosomic 6D appeared to have an excess of resistant plants (Table 3). All 4 susceptible plants were checked and found to be nullisomics. Thus, the data suggested that the *Lr* gene of Agro 139 is on chromosome 6D.

C-banding analysis

The chromosomes of *Ag. intermedium* have a C-banding pattern that is typical of outcrossing plants and which is situated in the distal and terminal parts of the chromosomes (Endo and Gill 1984; Aizatulina et al. 1989). Easily identified C-banding patterns of wheat-*Agropyron* lines Agro 139 and Agro 58 were not found of the *Ag. intermedium* chromosomes, and large segments of *Ag. intermedium* chromosomes including into wheat chromosomes. There were no differences between the C-banding patterns of leaf-rust resistance wheat-*Agropyron* lines Agro 139 and Agro 58 and susceptible bread wheat 'S29'. We assume that the transfers occurred in the euchromatinous regions of the *Ag. intermedium* and bread wheat chromosomes.

Discussion

In common wheat, *Triticum aestivum* L. em Thell., four *Lr* genes (*Lr-19*, *Lr-24*, Lr-29, Lr-38) from *Ag. elongatum* and *Ag. intermedium* have been used to give resistance to leaf rust (McIntosh 1993). In this paper the resistance of wheat-*Ag. intermedium* lines Agro 58 and Agro 139 has been shown to differ from that conferred by *Lr-9*, *Lr-19*, *Lr-24* and to be incorporated into other chromosomes. Lines Agro 58 and Agro 139 represent new sources of leaf-rust resistance, from *Ag. intermedium*. Although Agro 58 and Agro 139 have the undesirable trait yellow flour linked with the *Lr* genes, they are employed in breeding programs. The gene for resistance to leaf rust from Agro 139 was concluded to be in the 6D chromosome. C-banding analysis in Agro 58 and Agro 139 did not show the C-banding pattern of large segments or whole chromosomes of *Ag. intermedium*. We believe that the *Agropyron* segments are small and incorporated into the euchromatin regions of the wheat chromosomes. Agro 58 and Agro 139 are two of the more promising lines, being derived from the crossing of wheat-*Agropyron* substitution lines with local cultivars of bread wheat. This presumably reflects the fact that only small *Ag. intermedium* chromosomal segments are incorporated into the wheat chromosome complement in these lines, as indicated by the present results. We suggest designating the *Lr* gene from Agro 139 as $LrAg^{i}$-1, and the *Lr* gene from Agro 58 as $LrAg^{i}$-2.

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