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Leaf rust (*Puccinia triticina*) resistance in winter – facultative wheat (*Triticum aestivum L.*) cultivars from different countries

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Abstract: *Puccinia triticina*, the wheat leaf (brown) rust agent, cause major yield losses in winter-facultative. A feasable approach to control the diesase is the use of slow rusting in cultivars. We evaluated 76 winter-facultative wheat cultivars from different countries, 40 Thatcher leaf rust isolines, and one susceptible check, Sabalan. Since slow rusting acquires the prediction of *Lr* genes in the greenhouse and an effective screening of cultivars against the leaf rust under field epidemy, all cultivars were tested accordingly. Various Lr genes such as *Lr1* (in 7 cultivars), *Lr3* (in 15), *Lr9* (in 5), *Lr10* (in 10), *Lr13* (in 8), *Lr14a* (in 8), *Lr16* (in 7), *Lr17* (in 2), *Lr23* (in 9), *Lr24* (in 3), *Lr26* (in 17), *Lr*27(1), Lr31 (in 1) and a larger slow rusting variation were determined . Genes we determined and those from other genetic pools could most likely increase the resistance in winter – facultative cultivars and decrease yield and quality losses because of leaf rust.

Key words: AUDPC, gene postulation, leaf rust, slow rusting, winter - facultative wheat cultivars

Introduction

Wheat (*Triticum asetivum ssp. aestivum*), grown both in warmer and cooler regions, is one of the primary food crop and an important actor in agricultural systems of developing countries around the world. Several diseases such as *Puccinia* (rusts), *Ustilago* (smuts), *Tilletia* (bunts), and *Erysiphe* (mildew), etc, however, greatly decrease its yield and quality in some years.

Three rusts - including leaf rust - the most destructive wheat pathogens; reduce yield and quality via restricting photosynthesis on wheat leaves (1-5). The genetic resistance, with higher number of genes loaded into wheat genotypes, is the most economical way to control the disease, which was applied in most plant breeding programs (6). A resistance breeding program has to identify resistance genes, first, and then, of course, incorporate them into varieties of economical importance. Many scientists i. e. identified leaf rust (*Lr*) genes: 46 *Lr* genes (7), Lr 13 and Lr12 genes(8), and *Lr1, Lr2, Lr3, Lr13, Lr17,* and *Lr24* genes (9)- and, then, incorporated those into their cultivars. Our main aim was to identify *Lr* resistance genes and determine the level of slow leaf rusting in cultivars from different countries.

Materials and methods

The 76 winter - facultative wheat cultivars and a susceptible check, Sabalan, were tested against *Lr* pathotypes both in the greenhouse and in the field (Table 1). In addition, 40 Thatcher isolines of P. L. Dyck at CIMMYT for leaf rust were also tested (Table 2).

Greenhouse evaluations

Fully grown 9-10 day old seedlings of cultivars (Table 1) were inoculated by urediniospores of MFB/SP, BBG/BN, CCJ/SP, CBJ/QB, CBJ/QQ, MBJ/SP, TBD/TM, MCJ/QM, MCJ/SP, TNM/JM, TCB/TD, LCJ/BN and a light weight mineral oil, Soltrol 70 (Philips 66 Company, Oklohama, USA). Inoculum concentration was 2-3 $mgml^{-1}$ (10-12). Six to eight seedlings, planted in clumps of 5 cm distance from each other, were used for the test in 4 sets of boxes, of each consisted 38 or 39 cultivars, respectively. Inoculated plants were kept in a dark dew chamber for 15 hours at 18-24 ^{0}C, first 5 hours all humid. Then, after 15 minutes humid conditions followed 45 minutes normal conditions, cultivars were moved into a greenhouse at 23-25 ^{0}C (13).

Field evaluations

Previously vernalized cultivars (14-15) were planted in a randomized complete block design with two replications at CIMMYT (Mexico) on May 22nd, 2005. Plots consisted of two 1 – meter rows seeded into clumps of 15 by 70 cm. Susceptible spreaders were planted at every 20 clumps. The average rainfall during the season was 460.9 mm, the minimum temperature 1.49 ^{o}C in December and the maximum 28.27 ^{o}C in April. Two predominant pathotypes, MCJ/SP and MBJ/SP, were first sprayed on spreaders and then, on genotypes. Inoculum applied was 1 gr spores per 1 l of water plus some gliserin (6). Leaf rust severity and response were recorded 5 times on flag leaves at 7-8 day intervals, starting with the appearance of first symptoms during the shooting stage. Severity estimations were according to modified Cobb scale (16) and growth stages to Zadoks Scale (17).

Eight seedlings, planted in clumps of 5 cm distance from each other, were used for the test in 4 sets of boxes, of each consisted 38 or 39 cultivars, respectively. Inoculated plants were kept in a dark dew chamber for 15 hours at 18-24 ^{0}C, first 5 hours all humid. Then, after 15 minutes humid followed 45 minutes normal conditions, cultivars were moved into a greenhouse at 23-25 ^{0}C (13).

Table 1. Cultivars studied from different countries

No	Cross / Cultivar	Origin of country	No	Cross / Cultivar	Origin of country
1	CEYHAN 99	Adana, TURKEY	**40**	SIRENA	Odessa, UKRAINE
2	TUI/PANDA	Adana, TURKEY	**41**	SELYANKA	Odessa, UKRAINE
3	TAHIROVA 2000	Adapazarı, TURKEY	**42**	GALLYA-ARAL1	OZBEKISTAN
4	PAMUKOVA 97	Adapazarı, TURKEY	**43**	BITARAP	TURKMENISTAN
5	BANDIRMA97	Adapazarı, TURKEY	**44**	GUNDJA	TURKMENISTAN
6	AKSEL 2000	Ankara, TURKEY	**45**	5085	ISLAMIC REPUBLIC OF IRAN
7	ZENCIRCI 2002	Ankara, TURKEY	**46**	5233	ISLAMIC REPUBLIC OF IRAN
8	BAYRAKTAR 2000	Ankara, TURKEY	**47**	5274	ISLAMIC REPUBLIC OF IRAN
9	DEMIR 2000	Ankara, TURKEY	**48**	5345	ISLAMIC REPUBLIC OF IRAN
10	TEKIRDAG	Edirne, TURKEY	**49**	5346	ISLAMIC REPUBLIC OF IRAN
11	FATIMA-II	Edirne, TURKEY	**50**	5393	ISLAMIC REPUBLIC OF IRAN
12	TURAN-2000	Edirne, TURKEY	**51**	6918	ISLAMIC REPUBLIC OF IRAN
13	GEREK79	Eskişehir, TURKEY	**52**	4005	ISLAMIC REPUBLIC OF IRAN
14	KIRGIZ 95	Eskişehir, TURKEY	**53**	4007	ISLAMIC REPUBLIC OF IRAN
15	AYTIN 98	Eskişehir, TURKEY	**54**	3006	ISLAMIC REPUBLIC OF IRAN
16	SONMEZ 2001	Eskişehir, TURKEY	**55**	SABALAN	ISLAMIC REPUBLIC OF IRAN
17	KMB0304-32	Eskişehir, TURKEY	**56**	YUMAR	Kansas, USA
18	ALPU 2001	Eskişehir, TURKEY	**57**	CTY*3/TA2460	Kansas, USA
19	META 2002	İzmir, TURKEY	**58**	X88130/X88282	Kansas, USA
20	KASİFBEY 95	İzmir, TURKEY	**59**	X84W063-9-45/T63//KS87807-23	Kansas, USA
21	ZİYABEY 98	İzmir, TURKEY	**60**	KS85W663-7-4-2//KS85W663-7-7-3/APE/3/JGR	Kansas, USA
22	BAGCI 2002	Konya, TURKEY	**61**	KY84C-021-13-1/059E//134/3/JGR	Kansas, USA
23	KONYA 2002	Konya, TURKEY	**62**	TOMAHAWK/KSU94 U331	Kansas, USA
24	DAGDAS 98	Konya, TURKEY	**63**	X85073A-3-1/X86035*-BB-24//KSU94U284	Kansas, USA
25	EKIZ	Konya, TURKEY	**64**	CLK/X86035*-BB-24//TOMAHAWK	Kansas, USA
26	AHMETAGA	Konya, TURKEY	**65**	CLK/X86035*-BB-24//TOMAHAWK	Kansas, USA

27	KINACI 97	Konya, TURKEY	**66**	HBC458G-2/APE//HBF0290	Kansas, USA
28	IVETA NTA-92/89-6	Dobrudja, BULGARIA	**67**	X87581L-1-1/KS84063-9-39-3-27//KS84063-9-39-3-27	Kansas, USA
29	D 795	Sadovo, BULGARIA	**68**	HBK0935W-24/KS84W063-9-34-3-2//KARL 92	Kansas, USA
30	DECAN 4	Fundulea, ROMANIA	**69**	U1275-1-4-2-2/KS85W663-7-4-2//JGR	Kansas, USA
31	BOEMA	Fundulea, ROMANIA	**70**	JCAM/EMU//DOVE/3/JGR/4/THK	Kansas, USA
32	BUCUR	Fundulea, ROMANIA	**71**	JAGGER	Kansas, USA
33	DESTIN	Fundulea, ROMANIA	**72**	HBA142A/HBZ621A//ABILENE	Kansas, USA
34	EXPRES	Fundulea, ROMANIA	**73**	LE 2301	URUGUAY
35	GEORGE	GEORGIA	**74**	CALEDON	SOUTH AFRICA
36	DJAMIN	KIRGIZYSTAN	**75**	ELANDS	SOUTH AFRICA
37	L 4224 K 12	Krasnodar, RUSSIAN FEDERATION	**76**	GANSU-1	PEOPLE REPUBLIC OF CHINA
38	L 3905 K 3-2	Krasnodar, RUSSIAN FEDERATION	**77**	ZHONGMAI 16	PEOPLE REPUBLIC OF CHINA
39	CAPUZ	MOLDOVA			

Field evaluations

Severity estimations were according to modified Cobb scale (16) and growth stages to Zadoks Scale (17). The response to infection was also scored: R = resistant, smaller uredia surrounded by necrotic tissues; MR = moderately resistant, smaller uredia surrounded by necrotic tissues; MS = moderately susceptible, moderate sized uredia without necrotic tissues; S = susceptible, large sized uredia without necrotic tissues. Then, the Area Under the Disease Progress Curve (AUDPC) was calculated over leaf rust scores using Excel computer program. The formula was ∑ (Number of days between 2 consecutive readings)*((First leaf rust reading + Second leaf rust reading)/2).

Results

Greenhouse evaluations

Seedlings of Thatcher near isogenic lines with *Lr3ka*, *Lr16*, *Lr21*, *and Lr29*, *Lr30*, and *Lr32* resistance genes had low or medium infections against to all 12 pathotypes (Table 2). Assumptions based on the comparisions between their and Thatcher lines indicated that these genes were absent in winter-facultative cultivars, because of their higher infections, at least, against to one of the pathotypes. Some other single and multi genic combinations, however, (Table 3) were identified in genotypes: *Lr1* (in 7 cultivars), *Lr3* (15), *Lr9* (5), *Lr10* (10), *Lr13* (8), *Lr14a* (8), *Lr16* (7), *Lr17* (2), *Lr23* (9), *Lr24* (3), *Lr26* (17), *Lr*27 (1), and Lr31 (1).

Cultivars 33, 35, 43, 45, 48, and 49 showed the same low infections type (0; or ;) against BBG/BN, CCJ/SP, CBJ/QB, CBJ/QQ, as RL 6003, had *Lr 1* (Table 2). Cultivars 1, 3, 5, 8, 10, 23, 28, 31, 32, 36, 37, 43, 46, 47, and 54, because of their low **(0;** or **;)** infection types to LCJ/BN, as RL6002, most likely had *Lr3*.

While cultivars 68 and 69 carried *Lr* 9 alone as RL 6007, cultivars 1, 2, 4, 17, 20, 23, 31, and 32 carried *Lr* 10 as RL 6004, in combination with *Lr 3*, *Lr* 13, *Lr* 13, and some unidentified genes. Cultivars 2, 4, 17, and 40 had *Lr* 13 alone or in combination, as Manitou. *Lr* 14a existed alone or in combination with other known or unknown genes in cultivars 7, 23, 24, and 29 as RL 6013. *Lr* 16 occurred alone or in combination in cultivars 33, 38, 48, 59, and 72 as RL 6005. *Lr* 17 gene happened to be in cultivar 72 only, with combination of *Lr* 16 and *Lr* 24, as RL 6008 indicated. *Lr* 23 gene existed alone or in combination in cultivars 1, 24, 36, 40, 44, 52, and 53 as RL 6012.

Table 2. Seedling infection type responses of differentials testers with known *Lr* genes when inoculated with 12 Mexican races of *Puccinia triticina*

		Leaf Rust (Puccinia recondita f.sp. tritici) races											
Lr genes	**Tester lines**	**MFB/ SP**	**BBG/ BN**	**CCJ/ SP**	**CBJ/ QB**	**CBJ/ QQ**	**MBJ/ SP**	**TBD/ TM**	**MCJ/ QM**	**MCJ/ SP**	**TNM/ JM**	**TCB/ TD**	**LCJ/ BN**
Lr1	RL6003	**3+**	**0;**	**;**	**0;**	**0;**	**3**	**3+**	**3+**	**3+**	**3+**	**4**	**3+**
Lr2a	RL6016	**;**	**;1**	**;**	**;**	**;**	**0;**	**3+**	**0;**	**0;**	**3+**	**3+**	**1-**
Lr2b	RL6019	**;**	**1**	**;**	**;1-**	**;**	**;**	**3+**	**0;**	**0;**	**4**	**4**	**1+**
Lr2c	RL 6047	**;1-**	**2+3C**	**;**	**1**	**;1-**	**;**	**3+**	**0;**	**;**	**3+**	**4**	**3C**
Lr3	RL6002	**3+**	**;1-**	**3+**	**3+**	**3**	**3**	**3+**	**3+**	**3**	**3+**	**4**	**;1-**
Lr3ka	RL 6042	**12**	**;1-**	**;1**	**12**	**;1-**	**3C**	**23C**	**12**	**;1**	**3C3+**	**23C**	**12**
Lr3bg	RL6007	**3**	**;1-**	**12**	**12**	**3**	**3**	**3+**	**3**	**12**	**12**	**3+**	**0;**
Lr9	RL6010	**0;**	**0;**	**;**	**0;**	**0;**	**;**	**0;**	**0;**	**0;**	**4**	**0;**	**0;**
Lr10	RL6004	**3+**	**3**	**3+**	**;1**	**3+**	**3**	**3+**	**3+**	**4**	**3+**	**;1**	**3+**
Lr11	RL6053	**3C3**	**X+3**	**3+**	**3+**	**3+**	**3+**	**1+3C**	**3+**	**4**	**1+**	**1+**	**3+**
Lr12	RL6011	**3+**	**3**	**3+**	**3+**	**3**	**3**	**3+**	**3+**	**4**	**3+**	**3+**	**3+**
Lr13	MANITOU	**3+**	**1**	**3+**	**3+**	**3**	**3**	**3+**	**3+**	**3+**	**4**	**3+**	**1+3C**
Lr14a	RL6013	**3+**	**X**	**3+**	**3+**	**3+**	**3**	**3+**	**3+**	**4**	**4**	**3+**	**4**
Lr14b	RL6006	**3+**	**3+**	**3+**	**3+**	**3+**	**3+**	**3+**	**3+**	**4**	**4**	**3+**	**3+**
Lr15	RL6052	**3+**	**;**	**3+**	**;**	**;**	**3+**	**3+**	**;1**	**4**	**4**	**3+**	**1-**
Lr16	RL6005	**1**	**1**	**1**	**1**	**1**	**1+**	**1**	**1**	**1+**	**1+**	**1**	**1**
Lr17	RL6008	**;1**	**;1-**	**3+**	**3+**	**3+**	**3+**	**3+**	**3+**	**4**	**;1**	**;1**	**3+**
Lr18	RL6009	**22+**	**12**	**22+**	**12**	**1**	**12**	**3+**	**2+**	**2+**	**12**	**3+**	**12**
Lr 19	RL6040	**0;**	**0;**	**;**	**0;**	**3+**	**0;**	**0;**	**0;**	**;**	**;**	**0;**	**0;**
Lr20	THEW	**3+**	**3+**	**3+**	**3+**	**3+**	**3+**	**3+**	**3+**	**4**	**3+**	**3+**	**3+**
Lr 21	RL6043	**;1**	**;1-**	**12**	**12**	**12**	**12**	**;1**	**1**	**12**	**;1**	**12**	**1**
Lr22A	RL6044	**3+**	**3+**	**3+**	**3+**	**3+**	**3**	**3+**	**3+**	**4**	**3+**	**4**	**3+**
Lr22B	THATCHER	**3+**	**3+**	**3+**	**3+**	**3+**	**3**	**3+**	**3**	**3+**	**3+**	**4**	**3+**
Lr23	RL 6012	**3+**	**3**	**3+**	**1-**	**1**	**3**	**2+3C**	**1**	**4**	**2+**	**4**	**3+**
Lr24	RL6064	**3+**	**;1-**	**;**	**;1**	**;**	**;1**	**;1**	**;1**	**;1-**	**3+**	**;1**	**0;**
Lr25	TRANSEC	**0;**	**0;**	**0;**	**0;**	**0;**	**;**	**0;**	**0;**	**;**	**4**	**0;**	**0;**
Lr26	RL6078	**3**	**0;**	**3+**	**1**	**0;**	**1+**	**;**	**3+**	**3+**	**X**	**3+**	**3+**
Lr10, Lr27+31	GATCHER	**3**	**;**	**X+**	**;1-**	**X**	**3**	**4**	**3+**	**22+ 3**	**3+**	**;**	**;1**
Lr28	RL6079	**3+**	**;1**	**0;**	**0;**	**0;**	**0;**	**3+**	**0;**	**0;**	**4**	**3+**	**3+**
Lr29	RL6080	**;1-**	**1**	**;1-**	**;**	**;1-**	**;1-**	**;1-**	**;**	**;1-**	**1**	**1**	**1**
Lr30	RL6049	**12**	**1**	**;1**	**12**	**12**	**23C**	**12**	**12**	**;1**	**2+3C**	**12**	**23C**

Lr32	RL5497-1	**;1**	**;1-**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**1**	**1**	**12**
Lr33	RL6057	**2**	**3**	**22C**	**23-**	**3+**	**23C**	**12+**	**12**	**22+**	**2**	**22+**	**23C**
Lr34	RL6058	**3-3**	**3**	**3**	**3-**	**3+**	**3**	**3**	**23C 3+**	**33+**	**3**	**3C3**	**3**
Lr35	RL5711	**3**	**X**	**3C3**	**3C3**	**3C**	**3**	**3**	**3c**	**3+**	**3C**	**3C**	**3**
Lr36	E84018	**;1-**	**1**	**3C3**	**1**	**X**	**12**	**1**	**12**	**33C**	**1**	**1**	**1+**
Lr37	RL6081	**2+3**	**3**	**3+**	**3+**	**3C3**	**3**	**3C3**	**3**	**3+**	**2+3**	**3+**	**3+**
LrB Carina	RL6051	**3**	**3+**	**3+**	**3+**	**3+**	**3**	**3+**	**3+**	**3+**	**12**	**22+**	**3+**
Lr13	WL711	**3**	**X**	**3+**	**3+**	**3+**	**3+**	**3+**	**3+**	**4**	**4**	**4**	**X+**
Lr27+31	BAVIACORA	12	;12	X+	X	X	3+	3+	3+	3+	2+3	X-	X

Lr 24 existed only in cultivars 58 and 72 in combination with other genes as RL 6064. Cultivars 3, 18, 33, 34, 37, 38, 45, 48, 49, 50, 52, 53, 58, 59, 64, 65, and 77 had *Lr* 26 alone or in combination with other genes as RL 6078. *Lr* 27 + 31 existed in cultivar 40 only. While cultivar 39, Capuz of Moldova was the only one, which was resistant to all pathotypes of leaf rust used in the study, cultivar Aytin 98 was the only one without any resistance genes.

Field evaluations

Final disease ratings in the field and AUDPC% (of susceptible check, Sabalan) of genotypes, against to MBJ/SP and MCJ/SP pathotypes were presented in Table 4. The largest AUDPC and field disease rating was for 2240 and 100S infection for Sabalan.

Sixteen cultivars had 0 last field reading and 0% AUDPC, 11 cultivars with 5 last field reading and 1-2% AUDPC and 8 cultivars 10 last field reading and 2 – 8% AUDPC. These were assumed resistant. 14 genotypes, with 20 - 35 last field readings and 10 – 24% AUDPC were moderately resistant. Eight genotypes, with45 - 65 last field readings and 24 – 58% AUDPC, were moderately susceptible. Eight genotypes with 75 and more last field readings and

58 – 95% AUDPC were susceptible.

Slow rusting

Slow rusting or partial resistance (18-19) is a type of long lasting resistance, where wheat plants get infected slowly after rust inoculation, but do not develop any disease, because of longer latent period or fewer - smaller uredinas (12,7). Seventy six genotypes studied had various levels of infection types to both or one of MBJ/SP and MCJ/SP in the greenhouse or field (Table 5).

Three seedlings with low infection had 0 field reaction, one seedling 10, and one had 100. Four seedlings with; 1, 1+ infection had 0 in the field and 3 had 5. One cultivar with 2, 2+ seedling infection had 5, 10, and 15 field reactions. All cultivars in these three groups were race-specific resistant ones. Two cultivars with 5, two with 15, two with 20 in the field had X+, 2+3c, 3c, and 3c3 in the seedling and were race-specific, too. These 6 cultivars had the last reactions of 5- 20MSMR and were grouped as slow rusting ones since slow rusting occur in the seedling stage (12,20). Cultivars, with 3, 3+, 4 susceptible reactions against both or one of MBJ/SP and MCJ/SP pathotypes, had 0 - 100 reaction in the field. Those had race-specific adult plant resistance.

Cultivar 34 (Expres) with 5 MS, cultivar 47 (5274) with 30 MS and variety 20 (Kaşifbey) with 50 MS had smaller AUDPCs than those of susceptible cultivar SABALAN and they were postulated to have 1-2 minor adul plant resistance genes (21).

AUDPCs of the cultivars ranged between 0-2240 (the susceptible cultivar SABALAN = 2240). Six cultivars had high susceptibility to leaf rust in the field. They had 83-100% AUDPC and 70-100S for the last leaf rust

Table 3. Genes postulated against 12 different leaf rust (*Puccinia triticina*) pathotypes

NO	MFB/SP	BBG/BN	CCJ/SP	CBJ/QB	CBJ/QQ	MBJ/SP	TBD/TM	MCJ/QM	MCJ/SP	TNM/JM	TCB/TD	LCJ/BN	Postulated Lr genes
1	3C3	;	X	;	1	3+	3C3	1	3C3	3	;	;	3,10,23,+
2	3C	;1	3	0;	12	3+	3+	4	4	23	0;	X	10,13,+
3	12	0;	X	;1-	0;	12	;	3C3	3	;1-	2+3C	0;	3,26,+
4	23C	X	3+	;	X	3	3	3+	4	3+	;	X	10,13,+
5	23C	;	3	3+	X+	3+	3	4	3+	X	3+	;1-	3,+
6	2+3	X	3	23C	X	3+	3+	3	3	3+	22+	23C	+
7	2+3	X	3	23C	3+	3	3+	3+	3+	4	3C3	3	14a,+
8	12	;	0;	12	3C3	3+	4	3C3	;1	4	4	;	3,+
9	12	;1-	;	1	23C	3	3C3	3	;1-	3+	2+3	;1	+
10	12	0;	23C	23C	;12	3	3+	3+	23C	3C3	3C3	;	3,+
11	;1	0;	;	;1	0;	12	;	12	;	;1-	22+	0;	+
12	3	X	3	3+	3	3	3+	4	4	3+	4	3+C	14a
13	3	X	3+	3+	3+	3+	3+	4	4	3+	2+ 4 1L2L	4	14a
14	3+	X+	3+	3+	3+	3+	3+	4	4	3+	2+3 4 1L2L	4	14a
15	3	3	3+	3	3+	3+	3+	3+	3+	3+	3+	4	None
16	3C	;	3C3	3	3	3+	3+	3+	23C	3+	3+	3+	+
17	3	1+	X	;	3	3+	3+	3	12	4	;	;1-	10,13,+
18	12	0;	3	;1	0;	12	0;	3+	4	;1	3	2+3C	26,+
19	23C	X	3+	3+	3+	3+	22+	4	4	2+3C	3	X+	13,+
20	23C	1	3	;	3	3+	3	3+	4	3C	0;	1	10,13,+
21	3	X	3+	3+	3+	3+	23C	4	4	3+	X+	X+	13,+
22	12	X	3	12	12	3	23C	23C	23C	3+	X-	X+	+
23	12	0;	;	;	12	3+	3C3	23C	;	4	;	;	3,10,+
24	3	X+	3+	3	3	3+	3+	3+	4	4	3+	3+	14a
25	3	X	3C3	23C	;	12	3+	;1	23C	4	4	3+	14a,23,+
26	3+	X	3+	3+	3+	3+	3+	4	4	4	4	X+	13
27	3C3	X	3+	12	X+	2	3	3+	4	3+	3C3	3+	14a,+
28	;	0;	33C	3	3	3	22+	3C3	X-	X	3+	0;	3,+

29	3	X	X+	;1	;1	3+	2+3	1	4	2+	4	3+	14a,23,+
30	;	0;	;	0;	;1	3	;	;1-	1	;1-	;	;1-	+
31	12-	0;	0;	0;	;	3-3	;23C	;12	;	;12	;	0;	3,10,+
32	23C	0;	23C	;	3	3	3C3	3+	23C	23C	0;	0;	3,10,+
33	1	0;	0;	0;	0;	1	;	;1	1	1	1	1	1,16,26
34	2	0;	3C3	12	0;	;1	;	23C	3+	X	23C	3+	26, +
35	3	0; ;1 3 4p 1p 1p	3	0; 3 3p 4p	0; 3+ 2p 4p	3	3+	3+	3+	4	3+	22+	1 (hetero)
36	3	;1	X	;1-	;1	3+	2+	1	4	1+3C	4	0;	3,23,+
37	;1-	0;	3	12	0;	3C	;1-	3+	3+	;1	3+	;1-	3,26
38	;1-	0;	;	;1	0;	2	;	;1-	;	1	1	;	16,26
39	;1-	0;	0;	0;	0;	;1	;	;1	;	;	;	0;	Res to all
40	12	1	3+	12	;12	3+	12	X	4	12	12	1+	17,23,27+31
41	;	0;	0;	0;	0;	3-3	23C	;1	;	;1	;	0;	+
42	23C	3	3+	3	3+	3	3	3+	4	4	3	4	+ (MFB)
43	;1-	0;	;	;	;	1+	1	;	;1	1	;1	0;	1,3,16
44	3C3	0;	1+	;1-	1	3	23C	1	23C	23C	23C	3+	23,+
45	12	0;	0;	0;	0;	1+2	;	1+	2+3C	X	22+	3C	1,26,+
46	2+3C	;1-	X+	; 12 4p2p	;1	3+	23C 3+ 5p4p	X 3+ 1L 2L	3+	;12	0; X 5p2p	;	3,10,+
47	2+3C	0;	X-	;1-	0;	12	;	2+3	4	;	1	;	3,26,+
48	;1-	0;	0;	0;	0;	12	;	1+	2+3C	;1	0;	1	1,16,26
49	;1-	0;	12 0; 3p2p	;	0;	12	;	1+	1+2	;1	0;	;1	1,16,26
50	;1-	0;	;1	;1	0;	12	0;	12	;1	;	23C	12	16,26
51	3+	X	3+	3+	3+	3+	3+	3+	4	4	4	2+3C	13
52	23	;	3C3	;1-	0;	1+3C	;	1	3+	X	3C3	3+	23,26,+
53	23	0;	3C3	;	0;	1+3C	;	1	3	;12	3C3	3+	23,26,+
54	3+	;	3	;1-	;1	3+	3+	;1	4	X	3+	0;	3,23
55	3+	3+	3+	3+	3+	3+	3	4	4	1+3C	3+	4	+
56	;1-	2	23	12	12	3+	3C3	3+	3+	X	22+	3+C	+
57	0;	;	;	;	0;	0;	0;	0;	;	22+	0;	0;	9,+
58	23C	0;	0;	0;	0;	;	0;	;	;1-	;1-	;	;1-	24,26,+
59	12	1	3	12	1	3	1	12	4	22+	22+	1	+

60	23C	0;	0;	0;	0;	;	0;	;	;1-	22+	0;	;	24,+
61	12	12	3+	1	1	3+	1	12	3+	22+	12	2	+
62	0;	;1	;1	;	;	0;	0;	0;	;1-	2+3C	0;	;1-	9,+
63	0;	0;	;1-	0;	0;	0;	0;	0;	;1-	3+	0;	0;	9
64	;1	0;	12	;	0;	;1	;	3C3	12	;1-	;1-	;	26,+
65	;1	0;	12	0;	0;	;1	0;	3	12	;1-	;	0;	26,+
66	;	0;	;	0;	;12	;	0;	0;	;	;1	0;	0;	+
67	12	X-	3	12	;1	3+	12	22+	4	2+	22+	2	+
68	0;	0;	0;	0;	0;	;1	0;	0;	;1-	23C	;0	;1-	9,+
69	0;	1	;	;	;	0;	0;	0;	;1-	3C3	;0	0;	9,+
70	12	0;	0;	0;	0;	3+	12	22+	3+	23C	22+	2	1,+
71	12	1	3+	12	;12	3+	12	12	4	2	2	1+	+
72	1+	0;	0;	0;	0;	;1-	;	;	;1-	1+	;	;1-	16,17,24
73	1	1	X+	12	;1	3+	12	12	4	12	12	12	+
74	3	;1	3	3	3	3	3C3	12	1 4 3p 3p	3+	22+	3	+
75	12	;	;1-	12	;	12	123C	12	;1-	3+	1	23-	+
76	12	3	3+	3	3C3	3	23C	3	4	23C	3	3	+
77	3C3	0;	3	12	0;	23C	;	3+	4	X	4	4	26

reading in the field. They were postulated to have no adult plant resistance genes.

Discussion

Prevalence of thirteen leaf rust resistance genes - *Lr1* (in 7 cultivars), *Lr3* (15), *Lr9* (5), *Lr10* (10), *Lr13* (8), *Lr14a* (8), *Lr16* (7), *Lr17* (2), *Lr23* (9), *Lr24* (3), *Lr26* (17), *Lr*27 (1), and Lr31 (1) - and a larger variation for slow leaf rusting as well as incorporation of genes from other resources, when

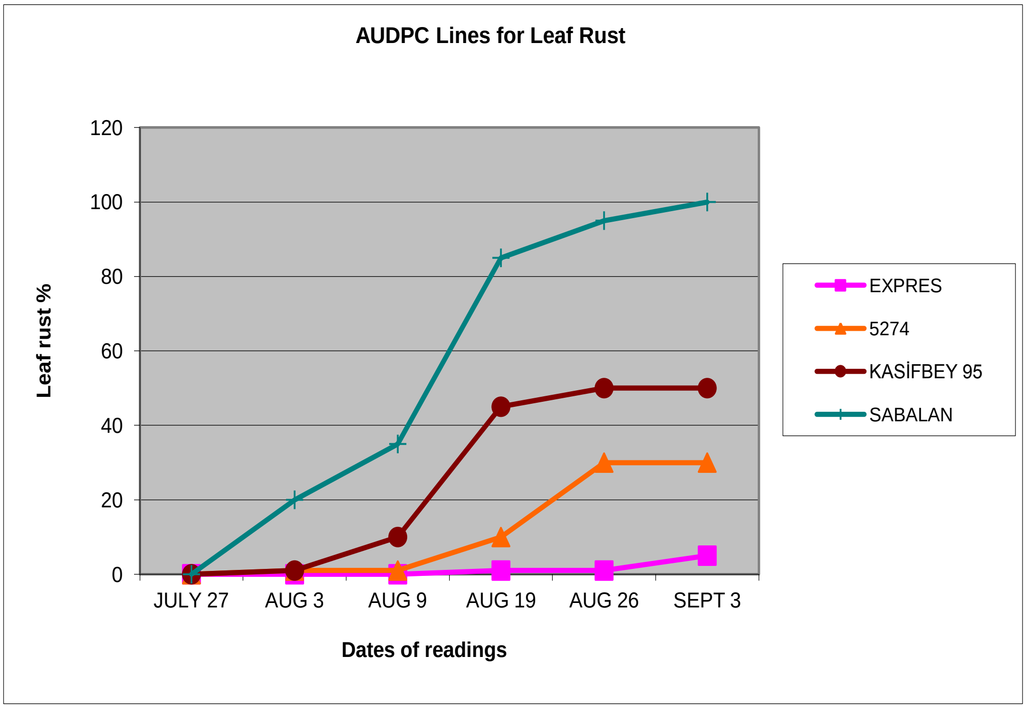
Table 4. Infection severity, infection type, and AUDPC% of 77 cultivars against to MBJ/SP, MCJ/SP pathotypes

No	Infection severity	Infection type	AUDPC%	No	Infection severity	Infection type	AUDPC%
10	0		0	50	10	MSMR	8
12	0		0	48	10	MS	8
31	0		0	23	15	MS	9
32	0		0	77	25	MS	10
57	0		0	18	25	MSS	12
58	0		0	17	30	MS	13
60	0		0	71	25	MS	14
61	0		0	53	20	MSS	15
62	0		0	40	30	MS	15
63	0		0	21	20	MS	16
64	0		0	2	20	MS	16
66	0		0	1	20	MS	17
68	0		0	76	20	MSS	17
70	0		0	52	20	MS	20
72	0		0	19	30	MS	21
73	0		0	47	30	MS	21
28	5	MSMR	1	4	20	MS	21
27	5	MR	1	75	35	MS	24
51	5	MSS	1	11	45	MS	29
39	5	MSMR	1	43	45	MS	31
42	5	MS	1	45	45	MS	32
34	5	MS	2	25	60	S	41
33	5	MSMR	2	35	55	MS	42
41	5	MS	2	74	65	MSS	45
30	5	MS	2	20	50	MS	48
37	5	MS	2	24	80	S	52
49	5	MR	2	26	65	MS	58
56	10	MS	2	8	80	S	60
65	10	MSS	2	15	80	S	69
6	10	MR	4	36	95	S	73
5	10	MS	4	54	75	S	74
3	10	MSMR	4	29	85	S	83
22	10	MR	5	13	90	S	95
7	10	MSMR	5	44	90	S	96
67	20	MSS	5	14	100	S	97
38	10	MS	6	9	100	S	98
46	10	MR	7	55	100	S	100
59	15	MR	7	16	20/70	MS/S	
69	15	MS	8			$LSD_{0.05}$	**7.49**

Table 5. Grouping wheat genotypes by greenhouse infection type and field reaction severity against to leaf rust (*Puccinia triticina*) MBJ/SP and MCJ/SP pathotypes

	Field reaction severity												
Infection type in the greenhouse	**0**	**5**	**10**	**15**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
0;, ;	**3**	0	-	-	1	-	-	-	-	-	-	-	1
;1, 1+	**4**	**3**	-	-	-	-	-	-	-	-	-	-	-
2, 2+	**0**	**1**	**1**	1		-	-	-	-	-	-	-	-
X+, 2+3c, 3c, 3c3	**0**	**2**	-	**2**	**2**	-	-	-	-	-	-	-	-
3, 3+, 4	**6**	**14**	**8**	**5**	**5**	**3**	**1**	**3**	**2**	**3**	-	**2**	**3**

* One cultivar, which was mixture, not included.



Graph 1. AUDPC lines of some selected varieties

needed, might secure winter wheat production in the world against any possible leaf rust damages. Some genes we identified here were similar to those in the USA, Mexico, China, and Japan, while some not (7, 13, 22,23). We failed to identify *Lr3ka*, *Lr21*, *Lr29, Lr30*, *Lr32*, and *Lr34* resistance genes, determined with low or medium infections against all 12 pathotypes in the cultivars, as appeared in the seedlings of Thatcher near isogenic lines.

These missing resistance genes need to be incorporated into future winter cultivars (13, 22, 23,7). Some other single and multi-genic combinations i.e. *Lr1*, *Lr3*, *Lr9*, *Lr10*, *Lr13*, *Lr14a*, *Lr16*, *Lr17*, *Lr23*, *Lr24*, *Lr26*, *Lr*27, and *Lr*31, however, existed in the cultivars as did in Mexican, Japanese, Chinese, and American ones (13, 22, 23,7). The genes *Lr9*, *Lr10*, *Lr14a*, *Lr24*, and *Lr31* in the cultivars we tested were not prevalent in Mexican ones. On the contrary, *Lr34*, resistance genes available in Mexican cultivars were absent in our cultivars (13). Similarly, some genes were common (*Lr1*, *Lr3*, *Lr9*, *Lr10*) with the USA but some not. Resistance genes in cultivars from the USA seemed to be more diverse than ours (7). The cultivars in the study, in addition to *Lr13*, *Lr14a*, *Lr16*, *Lr17*, and *Lr*24 resistance genes, had all other ones as Japanese cultivars (23). Similarly, the cultivars in the study, in addition to *Lr9*, *Lr13*, *Lr14a*, *Lr17*, *Lr23*, *Lr24*, *Lr26*, *Lr27*, and *Lr31* resistance genes, had all other ones in common as Chinese cultivars (22). One might generalize here that resistance genes in the cultivars tested were more diverse than those of other countries except for those from the USA.

Leaf rust resistance genes must have originated from some old cultivars: Chinese Spring, Frondoso, Frontiera for *Lr*13, Knox for *Lr*12 and *Lr*34, which were later most likely utilized as resistant parents to improve Atlas 66, Atlas 50, Coastal, and Coker 47 – 27 (after 18). Later, assumedly other sources were probed for the resistance, some of which we most likely had in our cultivars as well as in cultivars of other regions. Incorporation of various genes with different genetic backgrounds assured, of course, different types of resistance, of which the most preferred one was durable slow rusting type. Thirty six resistant cultivars with 0 – 8 AUDPC% and 10 final disease rating indicated a very high level of resistance in our study. That slow infection of wheat plants in slow rusting or partial resistance (18,19), while it permits disease develop, but by limiting the loss due to leaf rust, assures a better crop, because of longer latent period or fewer - smaller uredinas (10,7).

The results in the study clearly showed that 1) some resistance genes were still effective but some others not anymore, 2) number of resistance genes effective in cultivars tested were higher compare to those in Mexico, China, and Japan but not in the USA, 3) both seedling and / or field resistance existed in the cultivars, 4) slow rusting, determined by AUDPC% over the most susceptible cultivar, was clear, 5) slow rusting cultivars was higher in the cultivars tested, indicating a good genetic background in winter wheat cultivars for the trait, 6) some leaf rust resistance genes, though, were absent, 7) searching and / or incorporating new sources of leaf rust resistance genes into newer cultivars would, therefore, be needed.

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