Spring Wheats Immune or Highly Resistant to Ustilago tritici

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ABSTRACT

Nielsen, J. 1983. Spring wheats immune or highly resistant to *Ustilago tritici*. Plant Disease 67:860-863.

A total of 2,644 lines or cultivars of spring wheat of diverse origin were tested for their reaction to 31 races of *Ustilago tritici* that originated from 12 countries. Two hundred four immune or highly resistant entries were identified by an improved partial-vacuum technique of inoculation. Because new races of loose smut of wheat appear to arise infrequently, the resistance of these entries may be long-lasting.

Loose smut of wheat, caused by Ustilago tritici (Pers.) Rostrup, occurs wherever wheat, Triticum aestivum L. and T. turgidum (L.) Thell., is grown. It is more common in climates with cool moist weather at flowering of the host (49). Yet, even in the dry and warm summer of the Canadian prairies, economic losses occur. In 1981, the cultivar Sinton occupied 20.6% (308,610 ha) of the acreage seeded to wheat in the province of Manitoba, Canada. Loose smut was

Contribution No. 1062, Agriculture Canada, Research Station, Winnipeg, Manitoba.

Accepted for publication 5 January 1983.

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Plant Disease/Vol. 67 No. 8

found in 95% of the fields of Sinton, with an average infection of 1.5%, causing an estimated loss of \$1.67 million. This loss could have been prevented if all farmers had followed the recommendation to treat the seed of this cultivar with an appropriate fungicide every second year. The annual cost of the fungicide would have been about \$390,000.

The desirability of resistance has been realized in many countries, and lines and cultivars were identified that could be used as sources for resistance in Argentina (2,8,16), Australia (41,42), Belgium (36), Bulgaria (13,31), Canada (1), China (54), Czechoslovakia (45), Germany (12,40,46,50), Great Britain (5,14), India (6,7,18,21-23,27-30, 33,39,52), Iraq (48), Netherlands (38), Pakistan (43), Poland (44), Rumania (15,51), South Africa (20), Sweden (24,37), United States (3,4,11,17,47,53), and USSR, (19,25,26).

Unfortunately, the inocula used to

detect resistance were composed of undefined field collections or races from the area for which the future resistant cultivars were intended. This approach, based on limited selection pressure, resulted in the release of cultivars with resistance that was short-lived because of the appearance of new races. These were probably either already present in the area in low frequency or were introduced. Increasing trade and exchange of seed within and between countries increases the possibility of introducing a race that is virulent on a hitherto resistant local cultivar.

When searching for enduring resistance to loose smut, it is therefore imperative that the lines or cultivars be tested to as wide a spectrum of races as possible. An entry that passes such a screening has a good chance of being resistant to most races that may be introduced from abroad. When used in another country, it is likely to be resistant to most or all races found there. From this, it is obvious that the search for sources of resistance to U. tritici has to go hand in hand with a survey of the races of the pathogen as they occur worldwide (34). This approach has been taken in the screening of lines and cultivars to be described in this paper.

The purpose of this study was to build up a stock of diverse sources of resistance to all races of *U. tritici* so far identified for use in Canada and other countries.

MATERIALS AND METHODS

The seed of part of the entries originated from the tests of Anderson (1) and from his later and similar but unpublished experiments. Other entries were selected from the USDA World Wheat Collection, from the International Spring Wheat Rust Nurseries, and from other introductions by plant breeders and pathologists at the Winnipeg Research Station. Single-plant lines of most of the entries were established in 1974 and those of later entries as soon as they had shown resistance to the first inoculum. Thereafter, seed from these lines was used.

Ten to 12 seeds of each entry were sown in one hill. Ten hills were arranged 30 cm apart in each row. The spacing between the rows alternated between 90 and 30 cm; the wider spacing allowed movement between two rows of hills during inoculation. Blocks of several hundred hills were surrounded by a border row of a resistant cultivar sown 30 cm from the hills.

At midanthesis, three to six spikes of each hill were selected for inoculation. About 1 cm was cut off the tips of these spikes with scissors to mark the inoculated spikes, making identification by tags redundant.

An improved partial-vacuum method was used for inoculation. The principles of this method were first developed by Moore (32) and improved by Cherewick and Popp (10) and Cherewick and Cunningham (9). I further modified it so that one person could efficiently inoculate large numbers of entries. These modifications will be described in detail and Figure 1 gives a schematic outline of them

The inoculum was contained in a 1-L glass jar placed in a wire basket. The basket was permanently fixed to the lower end of the inoculating stand (32) made of thin-walled steel pipe. The jar was closed with a screw cap into which a short piece of copper pipe had been soldered. Rubber tubing on one end of

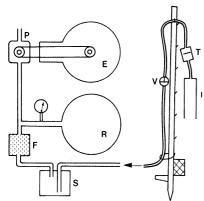


Fig. 1. Schematic outline of changes in equipment used for partial-vacuum inoculation of wheat with *Ustilago tritici*. E = gasoline engine, P = vacuum pump, R = reservoir with gauge, F = filter, S = trap, V = threeway valve, T = trap, and I = inoculation cylinder; further details in text.

Table 1. Cultivars of spring wheat immune or highly resistant to 31 races of Ustilago tritici

CI or PI no.	CN no.	Name or designation	CI or PI no.	CN no.	Name or designation
Triticum aestivum, immune			243666	5259	A STATE OF THE STA
124998			245452	5260	
133296	2721	Chinese/ Ae. umbellulata	250044	5261	
165696	2722		250047	5262	
180633	5257	Heines Kolben/38MA	250900	5264	
		4768-33	268294	2731	
180639	2725	Hein. Kolb./38MA2//	272522	2675	
		Garnet/Juljuli	283887	5253	Persian
82410	2726		283890	5254	Persian
189783	2771	49-4789.H511	289815	2732	
189791	2772	49-4845.H553	303676	2672	I. BO. 2753/459
189792	2773	49-4847.H553		5230	Barbela Grosso
189801	5280	49-4824		2655	DC 825-4, R.L. 380
212456	2748	S 24		2684	K.B. 286 C 6042
212465	5271	S 41		2689	Kenya 4262
220124	2747	Surkh		2697	Line 1290-2258
20133	5258			2680	Marquillo/Waratah,
27057	2745	Sterling			1-40-62
50757	5263	S.C.I.II.g			Navajoa
250793	5244	K 728		2707	NS 4021/K 338AC
322009	5229	B-987		2713	Olaeta Gral Guenes
322232	5250	New Pusa 201		5251	Olaeta Gral Mitre
347025	3230	Safidak		2715	Original Rubin
347139		White Kalk		2717	
347139 347195		FAO 26.495		2717	Pembina, CT 229 Percy
771173	2634	Aragon 03		5252	Percy Pergamino Gaboto
	5231			3232 2719	Pergamino Gaboto Peru/Supremo
		Chinese/Emmer C.T. 224		2719	
	2653				Pilot 2/Thatcher, N 21
	2658	Dominator		2734	Red Egyptian/Thatche
	5239	Era/Pembina		2735	Redondo Negro
	2663	Glenlea		2749	S 5746, C.T. 324
	5241	Glenlea/Neepawa		2738	Saunders
	2665	H-44-24		2740	Selkirk
	2668	Hope		2741	Selkirk*8/Exchange
		Kavkaz/ Pakistan 20		2750	Tartan
	2685	Kenya 117.A		2751	TC/ K33833// Triumph
	2686	Kenya 294.B.2.A.3			3/Trit/4/Agrop.
	2687	Kenya 338.Z.2.G.2		2752	Thatcher*2/Frontana-
	2688	Kenya 340.Y.4.A.1			Thatcher
	2690	Kenya 4271		2767	T. vulgare var. pseudo
	2705	M70-3524	le le		.2115
	2702	Massaux No. 5		2757	Warigo
	2703	Mercury		2761	Wis. 245/Tc
	5248	Mida-Kenya 117.A//		2762	Wis. 245/II-50-17
		Frontana		2764	WT-Nor 10-B/Selk*6/
	2711	Olaeta Aquila			MY54-Nor 10-B/
	2712	Olaeta Calandria			Andes*3
	2736	Russell		2768	4232-10
	2739	Saunders/C.T. 609		2769	4232-20
	2744	Sinvalocho M.A.		2770	4233-44
	2746	Supremo*2/Kenya			
	2753	TimstKenya 58/	T. turgidun	n var. durun	r. immune
		Gabo//Lee	135574	2709	Obispado
	5282	T. persicum var. stram.	136575	5273	Semental de Sevilla,
	2755	T. tim./ Ae.squ.//			Linea 70
		1111-Chin/3/NS*3-144/	185729	5227	Alentejo
		4/ NT	227945	2774	
	2678	T. vulgare, 1-36-62	254161	5265	
	2760	Wheat-Rye Transloc.	272530	2699	Majus
	2,00	238-5/ Pemb.*5	290518	5267	
	2763	Wis. 250	306557	5234	Collection No. 2954
	5277	Wis. 261/Manitou	326312	2694	K-43843
	2765	Zlatka	320312	2631	Akmolinka 5
	2103	LIAIKA		2632	Amarelejo
T april	highly =cc	stant		5228	Argelia
T. aestivum, 7090	2650	Stant		2635	Argena Arnautka 00614
11456	5242	Hood			Baharia
		Hood		2640	
11704	2756	Union		2641	Bald Medeah
11869	5269	Regent		2642	Bayody
15326	5270	Rolette		2644	Branco
17353	2/	Partizanka		2645	Czakinskaja 226
70715	2651			2647	Candeal, Sel.
83402	5243	I 12			La Prevision
94559	5274	Shatilov Exp. Stn. 11388		2656	Deves #892
50604	2700	Maria Escobar		2664	Golden Ball
67740	5255			2666	Hercules
67758	2723			2669	Hordeiforme 10
71000	2724			2670	Hordeiforme 189,
73464	5256				1-36-83
82424	2727			2671	Hordeiforme 496
	2728			2673	ICAR 50/1668
X74 45		Gandum I Surkh			Juljuli
			1	2681	Juljuli
220690	5240 2667			2602	Kahla
220690 227056	2667	Hoopvol		2682	Kahla
182435 220690 227056 232799 238391				2682 2683	Kahla Karakilcik No. 1133

Table 1. (continued from preceding page)

CI or PI no.	CN no.	Name or designation	CI or PI no.	CN no.	Name or designation
	2692	Khali		2659	D.T. 137
	2693	Krasnodarskaja 362		5237	Echinodesinflatus,
	2695	Ld. 340-Khapli/PI 94701			I-1-2440
	5249	Mourisco		2662	FO SD 32.24
	2710	Obispado de Medina		2674	Indur Compactum
	2714	Orgaz		5246	Lakota
	2733	Preto Amarelo		2696	Ld.357*4//Stew.//
	2737	Russo			PI 192179-Ld.357
	2743	Sentry/Ld. 379-Ld. 357		2698	Lobeiro
	5275	Towner, Ld. 370		2701	Marrocos No. 24
	5281	T. durum var. leucomelan		2704	Milturum 0274, 1-28-25
	2766	1973 IRN Entry 356		2706	N.D. 4/Lee, N.D. 905
		-		2716	P.D. 13
T. turgidum var. durum, highly resistant			2754	Tripolitico	
220426	2654	Dakar 49		2676	T. durum, 1-36-39
232815	5272	San Giorgio R 539		2677	T. turgidum, 1-36-45
297852	2660	ELS-6304-8-D			
298586	5268		Other Triticum spp., immune		
306535	2652	Collection No. 2889	7786	5232	(T. dicoccum)
	2636	A 178	10123	5233	(T. dicoccum)
	2637	A 192	11651	5236	T. timopheevi, D 357-1
	2638	A 194	254217		Timococcum
	2639	A 200	266850	5266	T. timopheevi
	2633	Anafil Escuro		5238	Emmer
	2643	Beloturka		2661	Flavescens Dicoccum,
	2646	Camadi			I-38-36
	2648	Capeiti 8		5245	Khapli (Emmer)
		CRIC 26301-68		2679	T. dicoccoides, 1-38-55
		CRIC 26314-68		5276	T. spelta, WG 58-464
	5235	D 63-5-C, Duroussia,		2758	T. spelta, WG 58-466
		BD 1419		2759	T. spelta, WG 59-334
	2657	Dimini Lesvon, YF 2560		5278	Yaroslav Emmer

this pipe lead to the bottom of the jar and from the other end, to the copper pipe in the split rubber stopper described by Cherewick and Popp (10). This pipe was sealed at the top and two holes were drilled in its side to prevent the inoculum from squirting to the top of the inoculation cyclinder (Fig. 1) at evacuation. A small trap in the form of a Plexiglas cylinder $(3 \times 8 \text{ cm})$ was inserted in the vacuum line about 10 cm above the inoculation cylinder to keep inoculum from reaching the valve. The inoculation cylinder (5 \times 25 cm) was made of Plexiglas, with a rubber stopper and copper pipe at its top.

The vacuum pump was mounted on a small sled or cart that was moved in the 1.5-m wide pathway between blocks of hills during inoculation. A rubber vacuum tube 6 m long connected the pump with the valve on the inoculating stand. The stand could then be moved freely between the rows of hills. Two inoculating stands could be connected to one unit so that two operators inoculated opposite blocks of hills at the same time. A gasoline engine of 1/2-1 hp was used to drive a rotary vacuum pump (we used an Eberbach Air-Cooled Rotary Air Blast and Suction Pump). The pump maintained a vacuum of about 80 torr in the reservoir of about 6 L. Fine dirt was screened off by a filter (ceramic, automotive type) and droplets of inoculum were settled in a sturdy flask.

A vacuum gauge was mounted on the reservoir. A three-way valve (push-button type, hydraulic, MAXAM 703-131-810 A) was fastened to the inoculating stand at a height convenient for the operator. In

normal position of the valve, the inoculating cylinder was open to the atmosphere and the vacuum line closed, maintaining a vacuum in the reservoir. After spikes were selected and enclosed with the split stopper in the inoculation cylinder, the valve was pressed. This connected the vacuum reservoir with the cylinder, resulting in an immediate and high vacuum in the cylinder. At the same time, inoculum was drawn into the cylinder and the vacuum maintained for 2-3 sec. The valve was then released to the normal position, which closed the vacuum line and opened the cylinder to the atmosphere. The evacuation was repeated, after which the inoculum was drained back into the storage vessel. The operator sat on a one-legged stool tied to his waist during the inoculation of individual hills.

The inoculum was a suspension of a mixture of spores of two to five races or field collections of *U. tritici*, and each component of such a mixture was present at a concentration of about 500 mg/L of water. The screening started in 1965 with races T 1, 2, 3, and 4 collected in Canada. In successive years, new entries of the host were added to the tests and all entries were successively tested to an increasing number of races that had been isolated from field collections of loose smut from Canada and other countries. A few of the entries that were susceptible to newly identified races were added to the set of cultivars used to differentiate races of U. tritici. Before 1981, the screening process used 31 races from Canada (races T 1-5, T 10, T 15-20, and T 32), Argentina (T 12), Brazil (T 21-25), Czechoslovakia (T

9), Denmark (T 7), Germany (T 8), India (T 11), Poland (T 29 and 31), Sweden (T 6), Tunisia (T 14), Turkey (T 26 and 27), and the USSR (T 13 and 28). A detailed description of these races and techniques for their study and a description of differential cultivars will be published separately.

Seed from inoculated spikes was either sown in a bed in a greenhouse (max. 60 seeds per entry) or all the available seed was sown in 2-m rows in the field the following year. At heading, the percentage infection was established by counting the infected and healthy plants in the greenhouse or by estimating the percentage of infected spikes in the field. Any entry with more than 15% infection in any one year was classed as susceptible and not tested again. Entries with up to 15% infection were classed as highly resistant; those with no infection in all tests were classed as immune. Both classes will be referred to as resistant.

RESULTS AND DISCUSSION

By 1981, a total of 2,644 lines or cultivars had been screened with the 31 races of loose smut and 204 resistant entries were found (Table 1). They originated from 34 countries of all continents and include common and durum wheats and a few entries of other *Triticum* spp. Most of these resistant entries are in the Canadian Plant Gene Resources Inventory, Agriculture Canada, Ottawa (CN numbers in Table 1), and seed can be obtained from Ottawa or the author. A list of the 2,440 susceptible entries is available on request from the author.

The origin of the resistant entries, and in many cases their genetic background, is diverse. It is thus probable that an entry adapted for any local condition can be found among them and that different genes for resistance are present in this material.

Most of the cultivars identified as resistant in earlier tests by other workers were now susceptible, indicating that the inocula used in my investigation had a wider virulence. It is not possible to discuss the present reaction of all entries in those tests; however, an example of differences between an earlier and the present screening may suffice. In 1961, Anderson (1) listed 159 resistant cultivars, but when these were retested with the inocula described here, only 31 were resistant. Many of the others are susceptible to Canadian races with virulence on cultivar Thatcher and its derivatives. One such formerly resistant entry (WG 57-982, Thatcher × Regent) (1) has been chosen as a differential cultivar to identify races carrying gene Utv₄, which is responsible for virulence on Thatcher and its derivatives (35). Other entries from Anderson's tests were susceptible to races from abroad.

Several entries resistant in tests in other

countries were also resistant in my tests in Canada. The cultivars Preto Amarelo and Sinvalocho were resistant in Argentina (2) and Mercury was resistant in Bulgaria (31). There were also a few cases where a cultivar was susceptible abroad but resistant to the inocula used in this study. They are cultivar Capeiti 8 in the USSR (25) and Czakinskaya 226, Hordeiforme 496, and Regent in Czechoslovakia (45). The first three cultivars are durum wheats. Because most races of loose smut are specialized on either common or durum wheats, it is probable that a race with virulence on these three and possibly other durum cultivars exists.

The common wheat cultivar Regent was resistant when released in 1941, but field collections with virulence on it were found later (W. Popp, unpublished). The race with this virulence was not maintained and has not been found since in collections from Canada or elsewhere. Such a race will possibly also be virulent on its resistant parent H44 and on cultivars such as Selkirk with resistance derived from H44 or cultivar Hope.

To detect races that may be virulent on these or other entries, I would welcome either tests of this collection of resistant cultivars with local inocula in other countries or the receipt of field collections of loose smut for an analysis of the races they represent. This continuing survey will assist in incorporating resistance to all known races into new cultivars. The spring wheats listed here are, at present, the best sources for such resistance.

ACKNOWLEDGMENTS

I am indebted to the late R. G. Anderson for permission to further test his material. I thank J. C. Craddock, USDA, Beltsville, and breeders and pathologists at this station and elsewhere for supplying seed of many of the entries; the Danish State Seed Testing Station, Sorgenfri, Denmark, for hosting the test in 1969; and the many individuals and institutions who sent me field collections of spores of *U. tritici* from various countries.

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