Measurement of Quantitative Resistance to *Septoria nodorum* in Wheat

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ABSTRACT

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Four sets of wheat lines (representing early selections for Septoria resistance, cultivars used as parents in crosses, modern cultivars, wild relatives, and a nursery containing cultivars that had been screened extensively for resistance to *Septoria tritici*) were inoculated quantitatively with *S. nodorum*. Lines of *Triticum fungicidum, T. timopheevi,* and *T. dicoccoides* were most resistant. Among the few good modern lines of *T. aestivum* were EP-VOC-214 and CVL 2204/Y2375/BGL/TB/TB. Certain wheat lines appeared promising for use in accumulating additive resistance to Septoria.

Septoria glume blotch of wheat, caused by *Septoria nodorum* (Berk.) Berk. (*Leptosphaeria nodorum* Müller) lowers the yield and quality of the crop in many parts of the world (1–3,6,9,12). Wheat lines with genetic resistance continue to be sought (7,8), and more sensitive methods to detect resistance are being used (4,5,11). As data have accumulated, it has become more evident that resistance to *S. nodorum* is not likely to be found in the form of single major genes (10,11). Therefore, many sources of resistance and sources that give the best levels of resistance when combined are needed to expedite the development of resistant cultivars.

This study of resistance to *Septoria nodorum* is the first in which we have used the quantitative inoculation technique described in 1977 (5) and in which we tested lines that were developed by use of the methods for accumulating small increments of resistance (11).

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MATERIALS AND METHODS

The isolates of *S. nodorum* were collected in Montana wheat fields. The most virulent isolates were selected and grown on yeast-malt agar for 7 days at 20 C under constant light from 20 W cool-white fluorescent lights (6.6×10^3 ergs/cm^2/sec) (8,10). The plates were flooded with 3–5 ml of sterile water and the cirrhi that contained pycnidiospores were removed by gently rubbing the agar surface with a glass rod. A spore suspension from several agar plates was used to inoculate seedlings.

Seeds of all cultivars and lines were sown and seedlings were grown in the manner and environment we described previously (4). Fifteen milliliters of spore suspension were sprayed onto plants as they revolved at 45 rpm (5). Initial spore concentrations and numbers of spores deposited on glass slides placed among the seedlings during inoculation (5) are given for each experiment in Tables 1–4. Inoculated seedlings were moved into a moisture chamber where they were misted with two cold-water humidifiers

Table 1. Response of winter wheat seedlings to infection by *Septoria nodorum*[x]

Wheat cultivar[y]	CI or PI	Lesions (no./cm^2)	% Necrosis
Fortuna (susceptible SW[z] check)	13596	14.94 a	48.25 a
Flint	6307	4.57 b	45.33 a
Gasta	11398	1.89 c	10.99 b
Redchief	12109	1.91 c	9.19 bc
Hope/Hussar//Trumbull/3/Fulhio/Purkof	12373	2.34 c	9.54 bc
Redchief/3/Nebraska No. 60//Mediterranean/Hope	13550	1.86 c	3.73 c
Moro	13740	2.75 c	4.83 bc
Fortuna (susceptible SW check)	13596	13.05 a	41.85 a
Manitou (SW check)	13775	8.97 b	31.46 ab
Candeal de Arevalo	191037	4.02 c	15.33 d
PS-5	186399	2.82 cd	21.80 cd
Brevor/Norin10//Anderson/Coker 55-9	14032	2.44 d	26.78 bc
T. fungicidum	282931	1.03 e	8.33 e
T. timopheevi	326318	0.66 e	6.52 e
Fortuna (susceptible SW check)	13596	11.70 a	48.93 a
Winoka	14000	5.63 b	18.28 bc
Arthur	14425	4.04 b	25.00 b
Winalta	13670	5.55 b	19.68 bc
Riley	13702	4.73 b	10.78 d
Blueboy II	15281	4.11 b	11.42 d
Holly	14579	1.51 c	12.11 cd
Fortuna (susceptible SW check)	13596	13.09 a	31.23 a
Dekalb SB-8 (SW check)		9.21 a	22.78 ab
World Seeds 1812 (SW check)		12.89 a	29.11 ab
Oasis	15929	3.97 b	23.31 bc
McNair 1913	15289	5.05 b	11.77 cd
Arthur 71	15282	5.65 b	20.56 abc
McNair 701	15288	3.32 b	9.53 d

[x]Original concentration of pycnidiospores/ml = 2.45×10^7. Pycnidiospores deposited on glass slides = 20,300 spores/cm^2.
[y]Horizontal space separates groups that were inoculated at the same time and subjected to statistical analysis separately. Values followed by the same letter are not significantly different at $P = 0.05$, by Duncan's multiple range test.
[z]SW = spring wheat.

Table 2. Response of winter wheat seedlings to infection by *Septoria nodorum*[x]

Wheat cultivar[y]	CI or PI	Lesions (no./cm^2)	% Necrosis
Fortuna (susceptible SW[z] check)	13596	29.77 a	37.63 a
Hadden	13488	8.58 b	9.72 c
Fultz	1923	5.71 b	15.60 b
Standerton winter	4178	7.35 b	15.62 b
Hybrid 143	4160	4.73 bc	7.82 c
Harvest Queen	5314	2.78 cd	4.06 c
Red May	5336	1.98 d	3.01 c
Fortuna (susceptible SW check)	13596	36.21 a	57.37 a
Manitou (SW check)	13775	20.51 b	24.18 c
Michigan Amber 144R3	11379	16.56 bc	21.83 c
Imbler	10066	12.21 c	36.82 b
E-32	10672	8.92 d	23.64 c
Turkey Sel.	11506	6.66 d	21.78 c
Redhart	8898	2.43 e	10.60 d
Fortuna (susceptible SW check)	13596	32.95 a	40.41 a
Anderson	12536	10.87 b	20.73 b
Turkey Sel.	11965	4.74 c	6.67 cd
Turkey Sel.	11984	5.24 c	4.09 de
Moking	12556	5.50 c	3.08 e
	12752	4.51 c	10.78 c
Redchief	12109	1.91 d	2.65 e
Fortuna (susceptible SW check)	13596	30.31 a	39.86 a
WO 1812 (SW check)		16.98 b	27.23 b
Redcoat	13170	3.63 c	8.15 c
	13554	4.51 c	6.04 cd
Knox 62	13701	3.28 c	4.94 cd
Blueboy	14031	4.99 c	5.41 cd

(*continued on next page*)

Table 2. (*continued from preceding page*)

Wheat cultivar[y]	CI or PI	Lesions (no./cm^2)	% Necrosis
Fortuna (susceptible SW check)	13596	38.24 a	45.05 a
Centurk	15075	18.45 b	42.78 b
SL4/64-78 (DB-1)		17.97 b	30.17 c
MT 7015		9.13 c	33.74 bc
SL32/64-14 (DB-2)		9.13 c	16.74 d
Coker 68-8		2.34 d	2.60 f
72-18-4 (Seg. F_4)		4.23 d	9.48 e
Fortuna (susceptible SW check)	13596	39.10 a	48.56 a
Dekalb SB-8 (SW check)		19.03 b	32.62 b
Maris Widgeon		14.56 bc	32.70 b
MT 7439A		12.14 c	18.93 c
MT 7406		4.45 d	9.97 d
Maris Huntsman		7.26 d	16.26 c

[x]Original pycnidiospore concentration = 2.425×10^7 spores/ml. Pycnidiospores deposited on glass slides = 32,200 spores/cm^2.
[y]Horizontal space separates groups that were inoculated at the same time and subjected to statistical analysis separately. Values followed by the same letter are not significantly different at $P = 0.05$, by Duncan's multiple range test.
[z]SW = spring wheat.

Table 3. Response of spring and winter wheat seedlings to infection by *Septoria nodorum*[x]

Wheat cultivar[y]	Type[z]	CI or PI	Lesions (no./cm^2)	% Necrosis
Fortuna (susceptible check)	S	13596	29.72 a	25.78 a
Bonanza	S	14077	15.21 b	15.83 b
Bulgaria 88	W	94407	15.16 b	19.45 b
Nainari 60	S	13747	18.65 b	34.74 a
Wisc. Sel.	S	12632	11.61 c	16.05 b
Knox 62	W	13701	3.26 d	8.04 c
Redhart (resistant check)	W	8898	1.33 e	2.25 d
Fortuna (susceptible check)	S	13596	26.10 a	36.27 a
Centana	S	12974	19.17 b	36.09 a
Tioga	S	17286	18.10 b	23.49 b
Manitou	S	13775	14.15 bc	23.83 b
Blueboy	W	14031	12.04 c	4.62 c
ND 6579	S		11.51 c	25.38 b
Hadden	W	13488	3.13 d	1.82 c
Fortuna (susceptible check)	S	13596	21.08 a	25.24 a
Thatcher	S	10003	13.51 b	13.29 bc
Pitic 62	S	13927	10.76 bc	13.14 bc
Sheridan	S	13586	8.41 cd	17.51 b
Polk	S	13773	9.21 cd	12.33 bc
Wared	S	15926	9.64 cd	9.23 c
Olaf	S	15930	7.29 d	10.99 bc
Fortuna (susceptible check)	S	13596	19.46 a	21.09 a
WO 1812	S		16.19 b	21.04 a
MT 711	S		10.23 c	14.76 b
91-712	S		9.61 d	21.28 a
91-707	S		7.79 e	16.88 c
Twin	S	14588	7.35 e	10.37 d
91-728	S		4.87 f	10.36 d
Fortuna (susceptible check)	S	13596	23.59 a	20.78 ab
MT 7156	S		18.13 b	26.55 a
Norana	S	15927	14.55 bc	13.95 bc
Era	S	13986	11.61 cd	9.45 c
Shortana	S	15233	9.49 de	15.08 bc
MT 7149	S		7.12 ef	11.82 c
MT 7150	S		6.11 f	18.89 b
Fortuna (susceptible check)	S	13596	17.38 a	31.36 a
Dekalb SB-8	S		12.97 ab	10.74 c
MT 7310	S		10.69 bc	18.35 b
MT 7312	S		7.87 cd	11.21 c
Oasis	W	15929	8.31 cd	8.60 cd
Arthur 71	W	15282	6.47 d	13.92 bc
Redcoat	W	13170	3.15 e	5.06 d

[x]Original pycnidiospore concentration = 1.882×10^7 spores/ml. Pycnidiospores deposited on glass slides = 24,700 spores/cm^2.
[y]Horizontal space separates groups that were inoculated at the same time and subjected to statistical analysis separately. Values followed by the same letter are not significantly different at $P = 0.05$, by Duncan's multiple range test.
[z]S = spring wheat; W = winter wheat.

Table 4. Response of spring and winter wheat seedlings to infection by *Septoria nodorum* (Tel-Aviv University Nursery, Israel)[x]

Wheat cultivar[y]	Type[z]	CI or PI	Lesions (no./cm^2)	% Necrosis
Fortuna (susceptible check)	S	13596	16.51 a	25.47 a
Triticale 217	S		14.53 a	12.49 b
Nabob	W	8869	16.31 a	11.55 b
Bet-Dagan 233	S		10.90 b	17.51 ab
Magnif 142	S	337156	9.45 b	16.24 b
Mivhor 1177	S		10.03 b	25.33 a
Colotana	S	13556	4.74 c	6.22 c
Fortuna (susceptible check)	S	13596	16.47 a	35.89 a
Hazera 337	S		13.72 b	37.56 a
Fortulaga-1	S		6.66 c	18.87 b
Fiume	W-S	274000	6.20 c	7.52 c
Giorgi 331 (*T. durum*)	S	15108	4.70 cd	7.04 c
Frondoso	S	12078-1	2.51 de	5.62 cd
Zenati-Boutielle (*T. durum*)	S		0.86 e	2.51 d
ND 12-11	S		24.82 a	39.04 a
Fortuna (susceptible check)	S	13596	20.35 ab	35.57 a
WO 1812	S		16.32 bc	37.20 a
Tobari 66	S	14194	12.78 cd	29.80 ab
H574-1-2-6	S		8.38 de	26.06 b
Russian	W	94478-1	6.27 e	12.66 c
Etit 38 (*T. durum*)	S		6.11 e	22.29 b
Fortuna (susceptible check)	S	13596	21.26 a	43.84 a
Bulgaria 88	W	94407-2	13.04 b	28.23 b
Penjamo 62	S	13924	13.46 b	40.37 a
N. 163 (*T. durum*)	S		6.22 c	13.97 c
Florence-Aurore 8193	S		4.76 cd	14.07 c
CVL 2204/Y 2375/BGL/TB/TB	W	13554	2.45 de	5.72 d
T. dicoccoides G-25	S		1.14 e	1.70 e
Fortuna (susceptible check)	S	13596	23.84 a	45.84 a
EP-VOC-686	S		17.88 b	22.63 bc
EP-VOC-216	S		9.73 c	50.62 a
EP-VOC-676	S		9.74 c	42.45 a
Cee'on	S		11.72 c	27.74 b
Toropi	S		7.48 cd	17.08 c
EP-VOC-214	S		4.93 d	5.79 d
Fortuna (susceptible check)	S	13596	29.20 a	49.85 a
Bet-Dagan 131	S		21.21 b	37.85 bc
Hazera 881/299	S		16.28 bc	35.11 bc
Hazera 18	S		16.95 bc	37.47 abc
Miriam	S		16.27 bc	35.45 bc
Lakhish	S		15.31 c	44.86 ab
Yafit	S		9.86 d	27.75 c
Fortuna (susceptible check)	S	13596	17.55 a	39.29 a
Dekalb's SB-8	S		18.12 a	27.95 b
EP-VOC-512/12	S		13.07 b	26.69 b
Manitou	S	13775	8.34 c	26.36 b
Racine	W	13172	6.57 cd	28.44 b
H574/Pan 5187[2]	S		3.93 d	13.58 c
Redchief	W	12109	0.84 e	2.65 d

[x]Original pycnidiospore concentration = 4.91×10^7 spores/ml. Pycnidiospores deposited on glass slides = 15.02×10^4 spores/cm^2.
[y]Horizontal space separates groups that were inoculated at the same time and subjected to statistical analysis separately. Values followed by the same letter are not significantly different at $P = 0.05$, by Duncan's multiple range test.
[z]S = spring wheat; W = winter wheat.

for 48 hr at 22 ± 2 C, after which they were returned to the growth chamber.

Eight days after inoculation, the number of lesions on each leaf was counted and the length and width of each leaf were recorded. The amount of necrotic tissue on infected leaves was estimated 15 days after inoculation. Necrotic tissue was usually discontinuous and interspersed with chlorotic or green tissue, thus necessitating an estimation of area.

RESULTS

Many of the wheats examined in these experiments were selected on the basis of earlier qualitative inoculations. Tables 1 and 2 show data on a group of winter wheats that were used as parents in our breeding program at Bozeman, MT, and that have been included in the USDA Septoria nurseries. *Triticum fungicidum* (PI 282931) and *T. timopheevi* (PI 326318) were the most resistant (Table 1) based on number of lesions and percentage of necrosis. Among the common wheats, *T. aestivum*, CI 14032 from North Carolina, and PI 186399 from China had the fewest lesions, and seven entries were equally resistant to necrosis, according to the statistical analysis. Redhart (CI 8898) and a derivative of it, Coker 68-8, were highly resistant soft red wheats, and Redchief (CI 12109) was the most resistant hard red wheat (Table 2).

A group of winter and spring wheat

varieties and lines that had potential for use as parents are listed in Table 3. They may be compared with Fortuna, the susceptible check, and with Redhart, the resistant check.

The nursery from Tel Aviv University that had been selected for resistance to *Septoria tritici* Rob. ex Desm. in Israel, was tested for reaction to *S. nodorum* (Table 4). These lines are of particular interest in areas where *S. nodorum* and *S. tritici* both occur. Again, the entries in Table 4 may be compared with those in the other tables by the use of the susceptible check cultivar, Fortuna. The most resistant entry in the Tel Aviv nursery was *T. dicoccoides* G-25, a wild relative of cultivated wheat from Israel. Most of the more resistant entries are older bread wheat cultivars from Brazil and Argentina or durum wheat cultivars from Italy. Modern semidwarf cultivars such as Hazera 337 (Israel) and Tobari 66 (CIMMYT) are highly susceptible.

DISCUSSION

At least three principal points become clear from these data: 1) Resistance to *S. nodorum* and *S. tritici* does not often reside in the same line or cultivar. 2) The highest levels of resistance among lines tested are in wild species of the genus *Triticum*. 3) Resistance is invariably less in progeny of crosses than in parents when resistance to Septoria was not a major selection criterion. Fortunately, a few wheats of good agronomic type have considerable resistance to both *S. nodorum* and *S. tritici*. Examples are EP-VOC-214 and CVL 2204/Y2375/BGL/TB/TB (Table 4). Others with potential for hybridization and selection are MT 7149 (Table 3) and H574/Pan 5187[2] (Table 4).

Another aspect of these data is the relationship between the number of small, restricted lesions and area of spreading necrosis in individual lines. We tend to believe that necrosis involving large areas of plant tissue is more important and damaging generally than are lesions per se. The two seem to be unrelated, though, only when lesions are very small and restricted and do not expand or coalesce. But examination of the data in tables will reveal numerous cases of few lesions, combined with a large area of necrosis. So, both parameters are necessary to obtain a balanced perspective of resistance and susceptibility.

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