Evaluation of *Avena* spp. Accessions for Resistance to Oat Stem Rust

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ABSTRACT

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Oat stem rust, caused by *Puccinia graminis* f. sp. *avenae*, can cause significant yield losses in the eastern prairie region of western Canada. Currently, the predominant race of *P. graminis* f. sp. *avenae* in this region is NA67. Few genes confer resistance to NA67, and none are present in any oat cultivars registered for production in Canada. To detect lines exhibiting resistance to race NA67, we evaluated 9,978 accessions from 22 *Avena* spp. in field nurseries from 2001 to 2004. In all, 35 accessions were highly resistant and 12 were moderately resistant, comprised mostly of the species *A. strigosa*. Seventy-one accessions had an intermediate response, comprised mostly of *A. abyssinica*, *A. barbata*, *A. sterilis*, and *A. vaviloviana*. All other accessions (9,860 = 98.8%) were susceptible to race NA67. Some highly resistant accessions were found to have been incorrectly classified previously as hexaploid species *A. sativa* or *A. sterilis*, and were confirmed by chromosome counts to be diploid or tetraploid. The most promising source of novel stem rust resistance is from the diploid species *A. strigosa*. Transfer of resistance from diploid and tetraploid species to *A. sativa* is very difficult, but the lines identified in this study should prove useful as new sources of resistance to oat stem rust.

Oat (*Avena sativa*) is one of the most important cereal crops grown worldwide. Annual world oat production is about 26 million metric tons (t), and Canada ranks second in production among all countries, at about 3.7 million t (FAO statistics, 2003). Canada is the world's leading oat exporter, shipping nearly 1 million t, primarily to the United States (1). About 90% of the oat production in Canada is in Saskatchewan, Manitoba, and Alberta (1). Production recently has decreased in Alberta and increased in Manitoba, likely from the abandonment of rail transportation subsidy, the proximity of Manitoba to the oat processors in the United States (22), and the higher yield potential in Manitoba. The higher yield potential in Manitoba and eastern Saskatchewan may be attributed, in part, to increased precipitation; however, this factor also increases

the likelihood of plant diseases, which reduce yield and quality of the crop.

One of the most important diseases that can affect oat is stem rust, caused by *Puccinia graminis* f. sp. *avenae*. Severe epidemics of oat stem rust were frequent in North America in the early 1900s and also in western Canada in the 1940s (14). Recent epidemics in Manitoba and eastern Saskatchewan occurred in 1977 (13) and 2002 (5), and caused estimated yield losses of 35 and 5 to 10%, respectively. The 2002 epidemic was attributed to race NA67, which was detected in western Canada for the first time in 1998 (18), and comprised 63% of the population found on cultivated oat in 2003 in Manitoba and Saskatchewan (6). Race NA67 is virulent to resistance genes *Pg1*, *Pg2*, *Pg3*, *Pg4*, *Pg8*, *Pg9*, *Pg13*, *Pg14*, *Pg15*, and *Pg17*, and avirulent to *Pg6*, *Pg10*, *Pg11*, *Pg12*, *Pg16*, and *Pg-a* (10; T. Fetch, *unpublished*). No oat cultivars currently registered for production in Canada possess genes with resistance to NA67 (7).

Breeding efforts to develop oat cultivars with resistance to NA67 are in progress at the Cereal Research Centre (CRC) in Winnipeg, but there are few resistance genes that are desirable to work with. For example, the gene *Pg6* is highly resistant to NA67, but is in a diploid background (14). Transfer of resistance from lower ploidy levels (such as *Pg6*) to the hexaploid cultivated oat *A. sativa* is extremely difficult, due to cross-incompatibility and sterility in

F₁ hybrids (20). *Pg10* is intermediate in expression of resistance, and *Pg12* is expressed only at the seedling stage (14). *Pg11* is expressed only at the adult plant stage, and has been associated with weak straw, reduced yield, and progressive chlorosis as the plant ages (14). *Pg16*, which is derived from *A. barbata*, is linked to undesirable agronomic characteristics that lower yield (2) and is temperature sensitive (4). *Pg-a* is highly resistant to NA67, but is susceptible to race NA28, which sporadically has been detected in the Prairie region of Canada. New sources of stem rust resistance to race NA67 are desirable for the development of resistant cultivars for sustainable oat production in the eastern Prairie region of Canada and worldwide where stem rust is pandemic. The purpose of this investigation was to evaluate collections of *Avena* spp. germ plasm for resistance to race NA67. A preliminary report of this research has been published previously (7).

MATERIALS AND METHODS

Seed of 11,465 unique accessions from 22 *Avena* spp. was obtained from Dr. Harold Bockelman (United States Department of Agriculture—Agricultural Research Service, Aberdeen, ID), Dr. Axel Diedrichsen (Plant Genome Resources Canada, Saskatoon, SK, Canada), and Dr. Eviatar Nevo (University of Haifa, Israel). *Avena* spp. accessions were evaluated for their reaction to stem rust race NA67 in field nurseries established at University of Manitoba field plots in Winnipeg, MB in 2001 (6,860 entries), 2002 (3,361 entries), and 2003 (1,244 entries). Prior to planting of test entries, the oat cv. AC Assiniboia (susceptible to NA67) was sown using a Planet Jr. (Cole Manufacturing Co., Chicago, IL) as spreader rows to provide uniform rust inoculum across the test entries. Test entries were hand planted 10 to 14 days later in 1-m rows, perpendicular to the AC Assiniboia spreader rows. Resistant (*Pg-a*) and susceptible (AC Assiniboia) check lines (1 set per every 100 entries) and full sets (1 set per every 300 entries) of oat stem rust differential lines (10,17) were randomly dispersed among the test entries to provide a measure of inoculum uniformity and to identify potential influence of exogenous inoculum. Nurseries were planted on land that was fallow the previ-

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ous season and hand weeded each year to control weed infestation, which could affect rust development. Spreader rows of AC Assiniboia were inoculated at the flag leaf growth stage (GS37) (23).

The isolate of race NA67 used in studies originally was collected from a cultivated oat grown in Manitoba during 2000 and phenotyped to race using oat stem rust differential lines (10,17). The isolate was increased on the susceptible oat cv. Triple Crown in an isolated greenhouse room in the spring of 2001; urediniospores were collected and stored in glass tubes at -80°C in an ultralow freezer until needed for inoculations. For field inoculations, urediniospores of NA67 were heat shocked at 50°C for 6 min, then mixed with Bayol oil (Esso Canada, Toronto) to a concentration of 1.2 g liter^{-1} and applied to plants using a Microfit Herbaflex sprayer (Micron, Herefordshire, UK) at a rate of 1 to 2 ml m^{-1} of row. A second application was applied at the same rate 10 to 14 days later. Test entries were evaluated for percent severity (percentage of stem infected) and stem rust reaction (R = resistant, MR = moderately resistant, I = intermediate, and S = susceptible) at the heading stage (GS73) using a modified scale of Roelfs et al. (21).

Seed was collected when ripe from all accessions expressing resistance. The

ploidy level of accessions classified as hexaploid or tetraploid was evaluated to confirm their chromosome number. Root tips from germinated seed were pretreated in ice water for 24 h immediately after collection, followed by fixation in 95% ethanol and glacial acetic acid (3:1) for 5 to 6 days. After fixation, root tips were hydrolyzed in 1 N HCl at 60°C for 7 min and then placed in Feulgen stain for a minimum of 20 min. Mitotic metaphase chromosome spreads were prepared by squashing root tips in aceto-carmine dye. The number of chromosomes in three to five nuclei then were determined visually using a light microscope.

Additional studies were conducted in 2004 to evaluate the seedling and field reaction of selected lines that displayed high levels of resistance to race NA67. Seedling tests were conducted using races NA1, NA8, NA16, NA28, NA55, and NA67 (10). These races were selected to provide diversity of virulence for all *Pg* genes. Lines were planted in cones and inoculated using previously described methods (8). Inoculated seedlings were incubated in the dark for 16 h at 20°C and near 100% relative humidity in a dew chamber. Plants then were moved to a greenhouse bench and covered with a plastic sheet for approximately 2 h to provide a period of slow drying and light ($250\text{ }\mu\text{mol}$

$\text{m}^{-2}\text{ s}^{-1}$) to enhance infection. The plastic sheet was subsequently removed and plants maintained in the greenhouse at $20 \pm 4^{\circ}\text{C}$ with a 14-h light period supplemented with high-pressure sodium lighting. The infection type (IT) on seedlings of each line was assessed 12 to 14 days after inoculation using a 0-to-4 scale, where 0 to 2 was considered to indicate resistance and 3 to 4 susceptibility (21). Field tests were conducted at the CRC research station in Glenlea, MB in 2004. The oat cv. Triple Crown, which has no stem rust resistance genes, was used as the susceptible spreader and planted as described previously. The selected resistant lines were hand planted in 1-m rows 14 days later, parallel to the spreader rows. Triple Crown was inoculated with a mixture of races NA8, NA16, NA25, NA27, NA28, NA55, and NA67 (in equal proportions) at the flag leaf stage and 14 days later, and entries were evaluated for rust reaction as described above.

RESULTS

Stem rust infection was uniform across the NA67 nurseries each year, and was severe (70 to 90% severity, susceptible disease reaction) in 2001 and 2003 and moderate (40 to 50% severity, moderately susceptible to susceptible disease reaction) in 2002 on the susceptible check line AC Assiniboia. Stem rust reaction on the resis-

Table 1. Oat stem rust reaction of *Avena* spp. inoculated with *Puccinia graminis* f. sp. *avenae* race NA67 in field nurseries at Winnipeg, MB from 2001 to 2003

Species	Disease reaction ^x				Number of accessions		
	R	MR	I	S	No germination	Winter type	Total accessions
Diploid <i>Avena</i> spp.							
<i>A. atlantica</i> B. R. Baum & Fedak	...	...	...	4	...	4	8
<i>A. brevis</i> Roth	1	...	1	19	...	...	21
<i>A. canariensis</i> B. R. Baum et al.	...	...	1	24	13	2	40
<i>A. clauda</i> Durieu	...	...	...	25	17	17	59
<i>A. damascena</i> Rajh. & B. R. Baum	...	...	...	1	2	...	3
<i>A. eriantha</i> Durieu	...	...	1	28	20	26	75
<i>A. hirtula</i> Lag.	...	...	...	71	17	16	104
<i>A. hispanica</i> Ard.	...	...	...	6	3	1	10
<i>A. longiglumis</i> Durieu	...	...	...	16	2	8	26
<i>A. lusitanica</i> (Tab. Morais) B. R. Baum	...	...	1	12	2	2	17
<i>A. nuda</i> L.	...	...	...	19	...	...	19
<i>A. strigosa</i> Schreb.	28	8	5	72	6	...	119
<i>A. vaviloviana</i> (Malzev) Mordv.	...	...	9	90	2	1	102
<i>A. ventricosa</i> Balansa ex Coss.	...	...	...	...	...	2	2
<i>A. wiestii</i> Steud.	...	...	...	29	3	4	36
Total diploid	29	8	18	416	87	83	641
Tetraploid <i>Avena</i> spp.							
<i>A. abyssinica</i> Hochst.	1 ^y	...	19	228	2	0	250
<i>A. agadiriana</i> B. R. Baum & Fedak	...	...	...	8	...	1	9
<i>A. barbata</i> Pott ex Link	2	1	17	1,275	202	251	1,748
<i>A. maroccana</i> Gand.	...	...	2	31	1	...	34
Total tetraploid	3	1	38	1,542	205	252	2,041
Hexaploid <i>Avena</i> spp.							
<i>A. occidentalis</i> Durieu	...	...	...	47	1	...	48
<i>A. sativa</i> L.	2 ^z	2 ^z	6	933	14	34	991
<i>A. sterilis</i> L.	1 ^z	1 ^z	9	6,922	321	490	7,744
Total hexaploid	3	3	15	7,902	336	524	8,783
Grand total	35	12	71	9,860	628	859	11,465

^x R = resistant, MR = moderately resistant, I = intermediate, and S = susceptible.

^y This highly resistant accession was subsequently determined to be diploid by cytogenetic analysis.

^z These resistant accessions of *A. sativa* and *A. sterilis* were subsequently found to be either diploid or tetraploid by cytogenetic analysis.

tant check line *Pg-a* was low (5 to 10% severity, resistant disease reaction) in all nurseries. The reactions of the oat stem rust differential lines were indicative only of race NA67 (90 to 100% and susceptible on *Pg1*, *Pg2*, *Pg3*, *Pg4*, *Pg8*, *Pg9*, *Pg13*, and *Pg15*; 5 to 10% and intermediate for *Pg16*; 1 to 5% and resistant for *Pg-a*). Stem rust reactions for *Pg6* (1 to 5% and resistant), *Pg10* (25 to 50% and intermediate), *Pg11* (5 to 10% and moderately resistant), *Pg12* (50 to 70% and moderately susceptible), *Pg14* (80 to 95% and susceptible), and *Pg17* (70 to 90% and susceptible) to race NA67 also were noted.

Disease reactions of the *Avena* accessions to race NA67 are presented in Table 1. There were 628 accessions (5.5%) that did not germinate and emerge and 859 (7.5%) that were of winter growth habit and did not produce stem tissue for evaluation. This was more common in the diploid and tetraploid accessions than in the hexaploid accessions. There were high levels of resistance to race NA67 in 35 accessions, predominately found in the diploid species *A. strigosa*. There were 12 accessions rated as moderately resistant, mostly comprised again of *A. strigosa*. There were 71 accessions displaying inter-

mediate resistance, mostly from *A. abyssinica*, *A. barbata*, *A. sterilis*, *A. vaviloviana*, and *A. sativa*. The majority (9,860 = 98.8%) of accessions tested were susceptible to race NA67.

Four accessions classified as hexaploid or tetraploid displayed high levels of resistance to NA67 and, upon cytological analysis, most were found to be incorrectly classified as to species (Table 2). For example, chromosome counts of three highly resistant lines labeled as *A. sterilis* or *A. sativa* landraces verified them as diploid (1) or tetraploid (2); a resistant accession labeled *A. abyssinica* was diploid. Both resistant lines labeled as *A. barbata* were tetraploid. There were no lines identified in this study with high levels of resistance that were hexaploid upon cytological analysis.

Field and seedling reactions of NA67-resistant lines to diverse races of *P. graminis* f. sp. *avenae* are presented in Table 3. Of 35 accessions showing high levels of resistance in previous field tests, 11 could not be evaluated due to insufficient seedstocks or winter growth habit. All other accessions, except CN 65882 and CN 81758, were resistant (range of 5 to 20%, resistant to moderately resistant) at

the adult plant stage when inoculated with a mixture of isolates (NA8, NA16, NA25, NA27, NA28, NA55, and NA67). Stem rust reaction of the susceptible check Triple Crown was 50 to 60% severity and moderately susceptible. The seedling reaction of all lines, except CN 23731 and CN 26171, was susceptible to race NA1. In general, the seedling reaction of most lines was resistant to NA8, NA16, and NA67. NA28 and NA55 had the highest percentage (43 and 34%, respectively) of virulence on the selected accessions. There were several accessions that were segregating for disease reaction and indicate heterogeneity in that accession for rust resistance. Similar patterns of disease response were noted across numerous accessions (e.g., CN 37279, CN 54877, CN 57130, CN 57739, CN 63840, CN 65326, and CN 65327; Saia group), while others, such as CN 58117, CN 65882, and CN 88865, had unique patterns of disease reaction.

DISCUSSION

Our study suggests that stem rust resistance in *Avena* spp. apparently is uncommon. From 9,978 accessions evaluated, only 47 (0.5%) exhibited moderate to high levels of resistance to NA67 and only 71

Table 2. List of *Avena* accessions displaying high levels of resistance to *Puccinia graminis* f. sp. *avenae* race NA67 in field nurseries in Winnipeg, MB from 2001 to 2003

CI/PI number	CN number	Other identifier	<i>Avena</i> sp.	Ploidy level	Origin
Clav 3436	...	4266	<i>A. brevis</i>	Diploid	Brazil
...	CN 21996	CAV 2839	<i>A. strigosa</i>	Diploid	Spain
...	CN 21997	CAV 2840	<i>A. strigosa</i>	Diploid	Spain
...	CN 21998	CAV 2841	<i>A. strigosa</i>	Diploid	Spain
...	CN 22000	CAV 2843	<i>A. strigosa</i>	Diploid	Spain
...	CN 22001	CAV 2844	<i>A. strigosa</i>	Diploid	Spain
...	CN 22002	CAV 2845	<i>A. strigosa</i>	Diploid	Uruguay
Clav 7010	CN 37279	Saia selection	<i>A. strigosa</i>	Diploid	Brazil
Clav 4639	CN 54877	Saia	<i>A. strigosa</i>	Diploid	Brazil
Clav 5057	CN 55115	...	<i>A. strigosa</i>	Diploid	Former Soviet Union
Clav 6858	CN 56730	...	<i>A. strigosa</i>	Diploid	Uruguay
Clav 6956	CN 56818	Pg6	<i>A. strigosa</i>	Diploid	Canada
Clav 7280	CN 57130	...	<i>A. strigosa</i>	Diploid	United States
Clav 8089	CN 57739	...	<i>A. strigosa</i>	Autotetraploid	United States
Clav 9020	CN 58072	CD 3819	<i>A. strigosa</i>	Diploid	Argentina
Clav 9021	CN 58073	CD 3820	<i>A. strigosa</i>	Diploid	Canada
Clav 9066	CN 58117	CD 8088	<i>A. strigosa</i>	Diploid	Canada
Clav 6954	CN 63840	Saia	<i>A. strigosa</i>	Diploid	Brazil
PI 291990	CN 65326	Saia 2	<i>A. strigosa</i>	Diploid	Israel
PI 291991	CN 65327	Saia 4	<i>A. strigosa</i>	Diploid	Israel
PI 304557	CN 65882	4659	<i>A. strigosa</i>	Diploid	United Kingdom
PI 436103	CN 81758	1	<i>A. strigosa</i>	Diploid	Chile
PI 436104	CN 81759	35	<i>A. strigosa</i>	Diploid	Chile
PI 436105	CN 81760	113	<i>A. strigosa</i>	Diploid	Chile
PI 436106	CN 81761	117	<i>A. strigosa</i>	Diploid	Chile
PI 436110	CN 81765	209	<i>A. strigosa</i>	Diploid	Chile
PI 436114	CN 81769	302	<i>A. strigosa</i>	Diploid	Chile
PI 436117	CN 81772	346	<i>A. strigosa</i>	Diploid	Chile
Clav 4747	CN 88865	WIR 5199	<i>A. strigosa</i>	Diploid	Spain
Clav 7233	CN 57087	...	<i>A. abyssinica</i> ^y	Diploid	Ethiopia
...	CN 23731	CAV 4599	<i>A. barbata</i>	Tetraploid	Algeria
...	CN 26171	CAV 7077	<i>A. barbata</i>	Tetraploid	Spain
PI 436031	CN 81687	...	<i>A. sativa</i> ^z	Tetraploid	Chile
PI 436080	CN 81735	...	<i>A. sativa</i> ^z	Diploid	Chile
Nevo 31-4	...	...	<i>A. sterilis</i> ^z	Tetraploid	Israel

^y This species is tetraploid, but this accession was cytogenetically determined to be diploid and thus is misclassified (and unknown) to species.

^z These species are hexaploid, but these accessions were cytogenetically determined to be diploid or tetraploid and thus are misclassified (and unknown) to species.

(0.7%) were intermediate in reaction. This agrees with Martens and Dyck (15), who indicated that stem rust resistance in oat was relatively rare. In previous studies searching for stem rust resistance in wild and cultivated *Avena* spp. from the Middle East, only 6 accessions of 1,538 evaluated (0.4%) displayed resistance to race NA27 (16). It appears that broadly effective stem rust resistance in cereals is uncommon. Fetch et al. (8) evaluated 116 accessions of *Hordeum spontaneum* from Israel for stem rust reaction to races MCCF and QCCJ and found high levels of resistance to be very rare (<1%). Jin et al. (12) evaluated over 18,000 barley (*H. vulgare*) accessions for resistance to the virulent race QCC, and found only 13 that displayed high to intermediate resistance. In the very large gene pool of wheat (*Triticum aestivum*) and related wild species that have been examined extensively for stem rust resistance for over the last 50 years, only 45 numbered stem rust resistance genes have been described (19). However, many of these genes have been found to be ineffec-

tive against predominant races and, thus, are not useful in agriculture (19). Extensive evaluations of hexaploid wheat for new *Sr* genes have been largely unsuccessful; therefore, the most likely sources would lie in related species (15).

In this study, the diploid species *A. strigosa* was clearly the best potential source of new stem rust resistance genes. Thirty-six accessions (30%) of this species had moderate to high levels of resistance to NA67. However, the number of unique genes among the accessions may be low, because many had similar seedling infection type patterns in the seedling tests (Table 3). With the exception of the accessions from Spain, CN 55115, CN 58117, and CN 65882, all other diploid accessions had similar patterns and may contain the same gene or genes. These were mainly from South America and would have been introduced from their Mediterranean origin (20), which would explain their similar pattern of resistance. In contrast, accessions from Spain, the United Kingdom, and the former Soviet Union were diver-

gent in their IT patterns to several races and indicate that several stem rust resistance genes could be present. Genetic studies using intercrosses among the Spanish accessions (CN 21996, CN 21997, CN 21998, CN 22000, and CN 22001) and CN 57130 are in progress to assess the number of different genes that they contain, and preliminary F₂ data indicate that these accessions are allelic to *Pg6* (T. Zegeye and T. Fetch, unpublished).

The potential of *A. strigosa* as a source of rust resistance genes has long been known (3). However, cross-compatibility between *A. strigosa* and *A. sativa* is extremely low (20). One technique that can be used to overcome this cross-incompatibility is to use autotetraploid derivatives of *A. strigosa* in crosses with *A. sativa* (24). Limited success in generating octoploid hybrids from *A. strigosa* × *A. sativa* F₁ interspecific hybrids that were embryo rescued and treated with colchicine to double the chromosome complement also has been made (T. Zegeye and T. Fetch, unpublished). Another alternative would be

Table 3. Field reaction and seedling infection type (IT) of *Avena* accessions displaying high levels of resistance to *Puccinia graminis* f. sp. *avenae* race NA67

Accession	Field reaction ^z	Seedling IT ^y					
		NA1	NA8	NA16	NA28	NA55	NA67
Clav 3436	20 RMR	4	0;	0;	0;1 ⁻	0;	0;
CN 21996	NP	4	34	12 ⁻	34	;2 ⁺ and 24	;2 and 34
CN 21997	7 RMR	34	23 ⁺	34	33 ⁺	34	12 ⁻
CN 21998	NP	34	X ⁻	0, 12 ⁺ c, 4	23 ⁺	0 and 34	; 12 ⁻ , 4
CN 22000	NP	34	14	;1 ⁺	34	23 ⁻ and 4n	11 ⁺
CN 22001	NP	4	2 ⁻ and 34	;2 ⁻	34	23 ⁻ and 34	;1 ⁺
CN 22002	10 RMR	34	0;	0;	0;	0;	0;
CN 37279	NP	4	0;	0;	;1 ⁻	0;	0;
CN 54877	10 RMR	4	0;	0;	;1 ⁻	0;	0;
CN 55115	NP	4	22 ⁺ and 34	22 ⁺	34 and 13 ⁻	23	0;1
CN 56730	10 RMR	4	0;	0;	0;	0;	0;
CN 56818	15 RMR	4	0;	0;	;1 ⁻	0;	0;1 ⁺
CN 57130	10 RMR	4	0;	0;	;1 ⁻	0;	0;
CN 57739	15 RMR	4	0;	0;	;1 ⁻	0;	0;
CN 58072	10 RMR	4	0;	0;	;1 ⁻ and 3 ⁻	0;	0;
CN 58073	5 RMR	4	0;	0;	;1 ⁻ and 3 ⁻	0;	0;
CN 58117	15 RMR	4	0 and 34	12 ⁺ and 24	34	13	;1 and 34
CN 63840	NP	34	0;	0;	0;	0;	0;
CN 65326	10 RMR	34	0;	0;	0;	0;	0;
CN 65327	15 RMR	4	0;	0;	0;1 ⁻	0;	0;
CN 65882	20 I	34	12 ⁻	23 ⁺	22 ⁻	12 ⁻ and 23 ⁺	0;1
CN 81758	30 I	4	0;	0;	0;1 ⁻ and 3 ⁻	0;	0
CN 81759	15 RMR	4	0;	0;	0;1 ⁻	0;	0;
CN 81760	15 RMR	34	0;	0;	0;1 ⁻	0;	0;
CN 81761	20 RMR	4	0;	0;	0;1 ⁻ and 3 ⁻	0;	0;
CN 81765	10 RMR	4	0;	0;	0;1 ⁻	0;	0;
CN 81769	15 RMR	4	0;	0;	0;1 ⁻	0;	0;
CN 81772	15 RMR	4	0;	0;	0;1 ⁻	0;	0;
CN 88865	NP	4	34	4	34	0; and 12 ⁻	;1 and 4
CN 57087	NP	4	0;	0;	0; and 3 ⁻	0;1 ⁻	0;
CN 23731	Winter	0;1 ⁻	;1 ⁻	0;1 ⁻	0;1	4	0;1
CN 26171	10 RMR	0;1 ⁻ and 4	0;	;1 ⁻	11 ⁺	4	0;
CN 81687	5 RMR	4	0;	0;	0;1 ⁻	0;	0;
CN 81735	20 RMR	4	0;	0;	0;1	0;	0;
Nevo 31-4	NP	33 ⁺	0;1 ⁻	4	34	4	4

^y Seedling IT is based on a 0-to-4 scale where 0;, 1, and 2 are indicative of a resistant reaction and 3 or 4 of susceptibility (21). Plus (+) and minus (-) signs are indicative of slightly larger or slightly smaller pustules, respectively, for each type. The letter "c" denotes chlorosis at the pustule margin. Virulence diversity of the NA races was previously described (10,17).

^z Field reaction is the percent severity and the infection response (RMR = resistant to moderately resistant; I = intermediate resistant) to a mixture of isolates (NA8, NA16, NA25, NA27, NA28 NA55, and NA67 in equal proportion) in a 2004 rust nursery at Glenlea, MB, Canada. NP = not planted due to insufficient seed, Winter = winter growth habit.

to use genetic engineering techniques to clone and insert the diploid gene into the desired parent, similar to what has been done with *Rpg1* in barley (11).

The next best sources of stem rust resistance appear to be in the tetraploid species *A. abyssinica* and *A. barbata*. However, in this study, stem rust resistance was predominately at intermediate levels and, even if successfully transferred to *A. sativa*, could reduce yield or introduce undesirable phenotypes (9). The seedling IT patterns in the two *A. barbata* lines (CN 23731 and CN 26171) are identical with the gene *Pg16*; thus, they may be the same gene. *Pg16*, derived from *A. barbata* line D-203, has been introgressed into a hexaploid background (2) and confers resistance to all but one race (NA55) of oat stem rust reported to occur in North America (10). However, this gene appears to lose effectiveness at temperatures exceeding 27°C (4) and has yielded about 10% less in breeding lines where the gene was introgressed (J. Mitchell Fetch, unpublished). The tetraploid line CN 81687 has a seedling IT pattern different than *Pg16* (resistant to NA55) and may be a novel gene. Attempts to generate pentaploid hybrids from crosses of CN 81687 × Sun II *A. sativa* oat and allelism tests to *Pg16* currently are in progress at the CRC in Winnipeg.

In summary, the vast majority (98.8%) of all lines evaluated for reaction to race NA67 were susceptible. There were no hexaploid accessions identified with moderate to high levels of resistance to NA67 from 7,923 accessions tested. Four accessions listed as *A. sativa* and two as *A. sterilis* that displayed high or moderate levels of resistance later were found to be either diploid or tetraploid by cytological examination. Of 642 *A. sterilis* accessions obtained from the University of Haifa, Israel, only one (Nevo [Tel Megiddo] 31-4) displayed a high level of resistance and later was found to be tetraploid. In contrast to Martens (14), it appears that the prospect of finding novel effective oat stem rust

resistance genes from hexaploid sources of germ plasm is unlikely. Nevertheless, the diploid and tetraploid sources of oat stem rust resistance identified in this study should be of value to plant breeding efforts. Successful transfer of resistance from lower ploidy to the hexaploid state is the major obstacle to be overcome.

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