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Resistance and partial resistance to *Phytophthora sojae* in early maturity group soybean plant introductions

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Abstract *Phytophthora sojae*, an important yield limiting pathogen of soybean, causes seed, seedling, root, and stem rots. Losses caused by *P. sojae* can be controlled by both major gene and partial resistance. Early maturity group (MG) soybeans are an increasingly important crop in northwestern Minnesota and eastern North Dakota. Early MG plant introductions (PIs) from the USDA Soybean Germplasm Collection and early MG public and private cultivars were evaluated for resistance and partial resistance to *P. sojae*. Of the 113 PIs, PI438445, and PI438454 exhibited resistance to *P. sojae* races 4, 7, 17, and 28 indicating they may possess either *Rps1c*, *Rps1k*, previously unidentified or multiple resistance gene to *Phytophthora sojae* (*Rps*) genes. Because they exhibited partial resistance equal to or greater than the standard check cultivar Conrad, three early MG soybean cultivars (MN0902, MN0302, and 91B53) were selected as standard checks to evaluate early MG PIs for partial resistance. Sixty-nine PIs were evaluated for partial resistance to *P. sojae* races 7 and 25 using the inoculum layer method. Of this group of PIs, 22 had the same level of partial resistance as Conrad to *P. sojae* race 7 while 19 had the same degree of partial resistance to race 25. Twelve PIs had same level of partial resistance as Conrad to both *P. sojae* races 7 and 25. The PIs and cultivars identified in this study will be of great value in developing early MG soybean cultivars suitable for planting in Canada and the northern United States.

Keywords Resistance · Partial resistance · *Phytophthora sojae* · Soybean (*Glycine max* L.) · Plant introduction

Abbreviations

MG	Maturity group
PIs	Plant introductions
Rps	Resistance gene to Phytophthora sojae

Introduction

Phytophthora sojae (Kaufmann and Gerdemann), the causal agent of Phytophthora root and stem rot, is a major pathogen of soybean [*Glycine max* (L.) Merr.] throughout soybean growing areas of the world (Erwin and Ribeiro 1996). Considered the second most significant yield-suppressing disease in the United States, Phytophthora root and stem rot is

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especially important as a disease of soybeans in the north central United States (Wrather et al. 2001).

Planting resistant cultivars has been the best measure to control Phytophthora root and stem rot (Burnham et al. 2003a). Fourteen dominant host resistance genes (*Rps1a*, *Rps1b*, *Rps1c*, *Rps1d*, *Rps1k*, *Rps2*, *Rps3a*, *Rps3b*, *Rps3c*, *Rps4*, *Rps5*, *Rps6*, *Rps7*, and *Rps8*) have been identified at eight different loci. Nine (*Rps1a*, *Rps1b*, *Rps1c*, *Rps1k*, *Rps2*, *Rps3a*, *Rps4*, *Rps6*, and *Rps7*) of these genes have been deployed into public and private cultivars (Burnham et al. 2003b). However, as resistance gene to *Phytophthora sojae* (*Rps*) genes have been deployed, new virulence pathotypes of *P. sojae* which can defeat known *Rps* genes have been reported making the task of breeding resistant cultivars difficult (Kaitany et al. 2001; Kurle and El Araby 2001; Leitz et al. 2000; Miller et al. 1997; Tooley et al. 1982).

Partial resistance, a highly heritable, quantitative trait, is a valuable complement to major gene resistance. Because it exerts no selection pressure on the pathogen population, it should be more durable than race specific resistance (Dorrance et al. 2003) and, in addition, genetic traits associated with partial resistance do not have a negative effect on yield in the absence of *P. sojae* infection (Dorrance et al. 2003). Combining partial resistance with single gene resistance has also been proposed to maintain the effectiveness of resistance genes (Burnham et al. 2003a) since it reduces the severity of root rot and slows the rate of disease development.

Soybean production in Minnesota has recently expanded from traditional soybean growing areas (MG I and II) in the southern half of the state into northwestern counties where early maturing soybean cultivars (MG 00, 0, and I) are grown. Numerous *P. sojae* races, including races 4, 25, 27, 28, and 45, are present in southern Minnesota (Kurle and El Araby 2001) as a consequence of planting resistant soybean cultivars. Use of partial resistance may become necessary as the prevalence of more complex races increases. However, in most situations the *Rps1c*, *Rps1k*, or *Rps6* resistance genes are still effective. In northern Minnesota, where extensive planting of soybean is more recent, only a limited number of simple pathotypes of *P. sojae*, including races 3 and 4 are present. Here the *Rps1c*, *Rps1k*, or *Rps6* resistance genes offer effective protection against *P. sojae* when incorporated into adapted varieties either alone or as combinations of resistance genes. Little information is available about the resistance reactions of early MG soybean plant introductions (PIs) being used to develop early maturing soybean cultivars (MG 00, 0, and I). Screening of these PIs for resistance to either *P. sojae* race 3 or 4, and for partial resistance to *P. sojae* can provide much-needed germplasm resources for use in breeding early MG cultivars. The objectives of this study were to identify early MG PIs in the USDA Soybean Germplasm Collection that possess: (1) the *Rps1c* or *Rps1k* resistance gene, and (2) partial resistance to *P. sojae*.

Materials and methods

Early maturity group soybean plant introductions

The 113 early MG (MG 000, 00, 0, and I) soybean PIs examined in this study were obtained from the USDA Soybean Germplasm Collection in Urbana, Illinois. These were selected from ~400 early MG soybean PIs previously evaluated for their agronomic qualities under field conditions by the soybean breeding program at the University of Minnesota. Of these PIs, 113 were selected because they exhibited acceptable agronomic traits including yield, plant growth characteristics, and plant architecture. The PIs evaluated originated from a wide variety of countries. The majority were collected from China or the Russian Federation.

Phytophthora sojae isolates

Isolates of *P. sojae* races 4, 7, 17, 25, and 28 were used as inoculum for this study (Table 1). *P. sojae* races 4, 7, and 25 were isolated from soybean fields in Minnesota. *P. sojae* races 17 and 28 were obtained from Dr. Anne E. Dorrance (Ohio State University). All isolates were created from a single oospore and tested for virulence pathotype against 13 differential lines each containing a single resistance gene [PI548571 (*Rps1a*), PI547842 (*Rps1b*), PI547791 (*Rps1c*), PI103091 (*Rps1d*), PI547890 (*Rps1k*), PI547788 (*Rps2*), PI547862 (*Rps3a*), PI591509 (*Rps3b*), PI591510 (*Rps3c*), PI547874 (*Rps4*), PI547764 (*Rps5*), PI591511 (*Rps6*), and PI591512

Table 1 Virulence pathotype of *P. sojae* race 3 and races used to detect resistance in selected early maturity group soybean plant introductions

Race	Virulence pathotype[a]
3	*Rps1a*, *Rps7*
4	*Rps1a*, *Rps1c*, *Rps7*
7	*Rps1a*, *Rps2*, *Rps3a*, *Rps3c*, *Rps4*, *Rps5*, *Rps6*, *Rps7*
17	*Rps1b*, *Rps1d*, *Rps3a*, *Rps3b*, *Rps3c*, *Rps4*, *Rps5*, *Rps6*, *Rps7*
25	*Rps1a*, *Rps1b*, *Rps1c*, *Rps1k*, *Rps7*
28	*Rps1a*, *Rps1b*, *Rps1k, Rps5*, *Rps7*

[a] Virulence pathotype indicates which *Rps* genes in the host are compatible with the *P. sojae* isolate

(*Rps7*)] before being used as inoculum. Isolates were stored on V8 juice agar plates at 25°C.

The 113 soybean PIs were evaluated as sources of resistance genes especially for *Rps1c* and *Rps1k*. *P. sojae* races 7, 17, and 28 collectively have compatible interactions with *Rps* genes *1a*, *1b*, *1d*, *1k*, *2*, *3a*, *3b*, *3c*, *4*, *5*, *6*, and *7* but not *Rps1c* and were used to identify soybean PIs with *Rps1c*. If a soybean PI is resistant to these three races, it indicates that the PI may possess *Rps1c* alone or *Rps* gene combinations. Similarly, *P. sojae* races 4, 7, and 17 collectively have compatible interactions with *Rps* genes *1a*, *1b*, *1c*, *1d*, *2*, *3a*, *3b*, *3c*, *4*, *5*, *6*, and *7* but not *Rps1k* and were used to identify soybean PIs with *Rps1k*. To detect *Rps8*, a novel *Rps* gene or *Rps* gene combinations in the PIs, *P. sojae* races 7, 17, and 25 were used.

Evaluation of plant introductions for resistance by hypocotyl injection method

The hypocotyl injection method (Dorrance and Schmitthenner 2000) was used to evaluate the PIs for resistance to *P. sojae*. All PIs were inoculated with *P. sojae* races 4, 7, 17, 25, and 28. Inoculum was prepared by growing each isolate of *P. sojae* at 25°C for ~7 days on V8 juice agar in polystyrene Petri dish. Media containing *P. sojae* was cut into 1-cm wide strips and placed in a hypodermic syringe (Monoject Luer Lock syringe, 12 cc, 20 gauge needle). It was then macerated by being forced through the syringe three times. In each test, six soybean seeds of each PI were planted in one 4-in. polystyrene pot with vermiculite as the growth medium. After 6–7 days, when cotyledons were fully opened, an incision was made in the hypocotyl 1 cm below the cotyledonary node and ~0.2–0.4 ml of inoculum slurry was placed in and around the wound. The pots were arranged in a randomized complete block design in the growth chamber. Following inoculation, the seedlings were kept in a dark misting chamber (90% relative humidity) at 25°C for 24 h. After 24 h, the growth chamber conditions were changed to 50% relative humidity, 25°C with a day-night cycle of 14 h light and 10 h darkness. The seedlings were watered thoroughly once daily. The seedlings were evaluated for resistant or susceptible reactions 4–6 days after inoculation. A resistant reaction was defined as a normally growing plant (a hypersensitive reaction occurred and no lesion developed from the injection wound). A susceptible reaction was defined as a dead plant (dark brown lesion extended from the injection wound and caused collapse of the plant). The reaction of each PI was determined by the proportion of inoculated plants responding with a susceptible reaction. The categories and proportion of susceptible plants (P) determining each category were: resistant (R): $P \leq 0.25$; intermediate (I): $0.25 < P < 0.75$; susceptible (S): $P \geq 0.75$. Susceptible Minnesota cultivar McCall (*rps*, no *Rps* gene) was used as control in each test. The test was repeated three times.

Identification of check cultivars possessing high-partial resistance by inoculum layer method

In order to find check cultivars that can be utilized in evaluating early MG PIs for partial resistance, 24 early MG cultivars (MG 00, 0, and I) (Minnesota Varietal Trials Results 2001, 2002, 2003) (Table 2) were examined for partial resistance using the inoculum layer method. Four standard check soybean lines (Conrad, Sloan, OX20-8, and PI399073) with known partial resistance characteristics were included as standards for comparison. Conrad is considered to have a high level of partial resistance to *P. sojae* and Sloan (*rps*) is a susceptible cultivar (low level of partial resistance). OX20-8 (*Rps1a*) has been characterized as having a low level of partial resistance. PI399073 was thought to have high level of partial resistance but was later found to possess *Rps8* (Burnham et al. 2003b).

Table 2 Root rot rating of 28 soybean cultivars evaluated for partial resistance to *P. sojae* races 7 and 25

Cultivar/PI	Resistance gene	Maturity group	Seed source	Root rot rating
MN0302	*Rps*1k*	0.3	Minnesota	3.00a
MN0902	*rps***	0.9	Minnesota	3.00a
PI399073	*Rps8*	4.0	Ohio	3.50a
91B53	*rps*	1.6	Minnesota	4.00a
Sturdy	*Rps1a*	2.0	Minnesota	4.75b
Kato	*Rps1a*	1.3	Minnesota	5.50b
Conrad	*rps*	2.6	Ohio	6.00b
MN1401	*Rps1a*	1.4	Minnesota	6.50b
MN0301	*Rps1a*	0.3	Minnesota	6.50b
Walsh	*Rps6*	0.2	Minnesota	6.75b
Parker	*Rps1a*	1.5	Minnesota	7.00b
MN1301	*Rps1c*	1.3	Minnesota	7.00b
MN0201	*Rps1k*	0.2	Minnesota	7.25b
90A07	*rps*	0.7	Minnesota	7.50b
Glacier	*Rps6*	0.8	Minnesota	8.00c
Council	*Rps1a*	0.5	Minnesota	8.00c
Sloan	*rps*	2.7	Ohio	8.25c
Danatto	*rps*	0.4	Minnesota	8.25c
Surge	*Rps1a*	0.9	Minnesota	8.25c
Minnatto	*Rps1a*	0.9	Minnesota	8.50c
MN0901	*Rps1a*	0.9	Minnesota	8.75c
Traill	*Rps1a*	0.0	Minnesota	8.75c
OX20-8	*Rps1a*	2.0	Ohio	8.75c
Jim	*rps*	0.8	Minnesota	8.75c
Lambert	*Rps1a*	0.7	Minnesota	9.00c
Barnes	*Rps6*	0.2	Minnesota	9.00c
Agassiz	*Rps1a*	0.0	Minnesota	9.50c
McCall	*rps*	0.7	Minnesota	9.75c

The root rot rating was compared to check cultivar Conrad considered to have high-partial resistance to *P. sojae* (scale: one resistant to ten susceptible). Cultivars with the same letters were not significantly different at $P \leq 0.05$

*Rps** = resistance gene; *rps*** = no resistance gene

The 24 early MG cultivars either have no *Rps* gene or have *Rps1a*, *Rps1c*, *Rps1k*, or *Rps6*. All were susceptible to *P. sojae* races 7 and 25 based on the result of hypocotyl injection test. The modified inoculum layer method was used Dorrance and Schmitthenner 2000. Inoculum consisted of 2-week-old *P. sojae* culture grown on V8 juice agar plate at 25°C. A 0.25-cm layer of *P. sojae*-covered agar was removed from the Petri dish and placed 5 cm below seeds planted in vermiculite in a 6-in. polystyrene pot. Ten seeds were planted in each pot. The soybean roots were inoculated with *P. sojae* as they grew through the inoculum layer. The test was arranged in a randomized complete block design with four replications in the greenhouse. Pots were watered thoroughly once daily. Three weeks after planting, the plants were removed from the pot, roots were washed free of vermiculite and agar, and roots were rated for root rot severity based on the scale modified from Dorrance and Schmitthenner 2000. The scale ranged from 1 to 10: 1–2: healthy, no symptoms; 3–4: slight discoloration of secondary roots to first sign of pruning of secondary roots; 5–6: pruning of secondary roots to first appearance of lesions on primary roots; 7–8: secondary roots essentially absent, lesions present; 9–10: damping off of seedling, dead seedling, rotted seed.

Evaluation of plant introductions for partial resistance

Once a PI was identified as susceptible to a *P. sojae* race in the hypocotyl injection test, the PI was evaluated for partial resistance to the isolate using the

inoculum layer method as described above. *P. sojae* races 7 and 25 were used as inoculum to evaluate the 69 PIs that had shown susceptibility to races 7, 17, and 25 in hypocotyl injection tests.

Three early MG cultivars (McCall, 91B53, and MN0902) and three MG II cultivars (Sloan, OX20-8, and Conrad) were included in each test as standard checks. The check cultivars were used so that comparisons could be made among all of the PIs evaluated with the two different *P. sojae* races. In order to easily compare our results with other researchers we used the following scale for evaluation of partial resistance: 1 = no root rot; 2 = up to 10% root mass rotted; 3 = up to 25% root mass rotted; 4 = up to 50% root mass rotted; 5 = all roots rotted, up to 20% of plants killed; 6 = up to 50% of plants killed; 7 = up to 75% of plants killed; 8 = up to 90% of plants killed; 9 = all plants killed (Dorrance and Schmitthenner 2000).

Statistical analysis

All pots were arranged in a randomized complete block design with three replications. The test was repeated twice. Root rot ratings were subjected to analysis of variance using general linear models procedure (PROC GLM) of SAS (SAS Institute Inc., Cary, NC). When selecting check cultivars, means were separated using Duncan's new multiple range test ($P \leq 0.05$). When evaluating partial resistance, means were separated using Fisher's protected least significant differences (LSD) at $P = 0.05$.

Results

Sources of resistance

Of the 113 soybean PIs evaluated for resistance (*Rps* genes) using the hypocotyl injection method in the growth chamber, 69, or ~61%, were susceptible ($P \geq 0.75$ where P is the proportion of susceptible plants out of all inoculated plants from three replications) to all three *P. sojae* races indicating that they did not have any of the 13 *Rps* genes known when this experiment was conducted and could be evaluated for partial resistance with *P. sojae* races 7 and 25. No PI showed a resistant reaction ($P \leq 0.25$) to all *P. sojae* three races (7, 17, and 25).

Soybean PI438445 and PI438454 showed a resistant reaction ($P \leq 0.25$) to *P. sojae* races 7, 17, and 28 and an intermediate reaction ($0.25 < P < 0.75$) to *P. sojae* races 4, 7, and 17, indicating that they may have either *Rps1c*, *Rps1k*, a novel *Rps* gene, or multiple *Rps* genes. PI603299 had an intermediate reaction to *P. sojae* races 4, 7, and 17, indicating that it may have *Rps1k*, a novel *Rps* gene, or multiple *Rps* genes.

Identification of check cultivars with high-partial resistance

The inoculum layer test provided an objective, easily determined measure of partial resistance to *P. sojae*. Of the 24 early MG cultivars evaluated for partial resistance, four, 91B53, PI399073, MN0302, and MN0902, had a mean root rot severity significantly less than that of Conrad ($P \leq 0.05$) (Table 2) and were considered to have high levels of partial resistance. Three early MG cultivars, 91B53, MN0302, and MN0902, were then used as checks to evaluate early MG soybean PIs for partial resistance to *P. sojae*. At the time when this investigation was conducted, it was not known that PI399073 possessed a single gene for resistance to *P. sojae* and it was included as a check cultivar with high level of partial resistance.

Sources of partial resistance

Using the check cultivars identified among the early MG cultivars, the inoculum layer test enabled us to determine the degree of partial resistance present in the early MG PIs. Root rot severity ratings of the PIs evaluated for partial resistance ranged from 2.00 to 8.17 when tested with *P. sojae* race 7 and ranged from 2.33 to 8.33 when *P. sojae* race 25 was used. In this evaluation, the check cultivar Conrad had root rot ratings of 3.50 and 2.83 when inoculated with *P. sojae* races 7 and 25, respectively. The interaction of *P. sojae* race with soybean genotype was highly significant ($P < 0.001$). Root rot severity among soybean PIs evaluated for partial resistance was significantly different ($P < 0.001$) when tested with either *P. sojae* race 7 or 25. The six replications were not significantly different ($P > 0.01$) for either *P. sojae* race 7 or 25.

Forty-three soybean PIs and two check cultivars, McCall and Sloan, had partial resistance significantly

less than Conrad when inoculated with *P. sojae* race 7 (LSD = 1.43 and $P = 0.05$). Twenty-two soybean PIs and check cultivars OX20-8 and 91B53 had a level of partial resistance that was not significantly different from Conrad when inoculated with *P. sojae* race 7 (LSD = 1.43 and $P = 0.05$). Minnesota check cultivar MN0902 had partial resistance significantly greater than Conrad (LSD = 1.43 and $P = 0.05$), which was consistent with the result from the earlier inoculum layer test identifying check cultivars (Table 3).

Forty-five soybean PIs and two check cultivars Sloan and McCall had partial resistance significantly less than Conrad when inoculated with *P. sojae* race 25 (LSD = 1.25 and $P = 0.05$). Nineteen soybean PIs and the check cultivars 91B53 and MN0902 had a level of partial resistance that was not significantly different from Conrad (LSD = 1.25 and $P = 0.05$) (Table 3).

Twelve soybean PIs (PI437161, PI437700, PI438148, PI445831, PI449459, PI468377, PI504484, PI549051B, PI561308, PI561389B, PI592919, and PI593975) had the same level of partial resistance as Conrad when inoculated with either *P. sojae* race 7 or 25 (Table 3).

Table 3 Root rot rating of plant introductions and check cultivars inoculated with *P. sojae* races 7 and 25

PI number/cultivar	Root rot rating to race 7	Root rot rating to race 25
PI437161	2.50a	2.83a
PI437700	3.50a	3.33a
PI438148	3.50a	3.83a
PI445831	4.50a	4.00a
PI449459	4.83a	2.83a
PI468377	3.75a	3.83a
PI504484	3.50a	3.50a
PI549051B	4.50a	2.50a
PI561308	4.17a	3.67a
PI561389B	2.67a	4.00a
PI592919	4.67a	2.17a
PI593975	2.33a	3.00a
PI437228	4.17a	NA
PI437296	NA	3.83a
PI438158B	4.83a	NA
PI445798	NA	3.83a
PI445815	NA	3.00a
PI458824	NA	2.83a
PI475821	4.67a	NA
PI479716	NA	3.00a
PI495831	4.30a	NA
PI507373	4.00a	NA
PI548380	4.33a	NA
PI561285B	4.17a	NA
PI561367	3.33a	NA
PI578425	NA	4.00a
PI592922	3.17a	NA
PI597397B	NA	3.00a
PI603294	3.17a	NA
MN0902	2.00b	2.67a
91B53	2.40a	4.00a
Conrad	3.50a	2.83a

The root rot rating was compared to check cultivar, Conrad with high-partial resistance to *P. sojae* (scale: one resistant to nine susceptible). Cultivars with the same letters were not significantly different at $P = 0.05$

Discussion

Soybean production in Minnesota has expanded into areas of the state where very early MG soybean cultivars are grown. One goal of this study was to find early MG PIs with *Rps1c* or *Rps1k*, which can be used in breeding cultivars for this area. In order to find new sources of resistance to *P. sojae*, soybean PIs from early MG's were inoculated with specific *P. sojae* races that would collectively cause a susceptible reaction in plants containing 13 of the known *Rps* genes (except for *Rps8*). If a PI was susceptible to *P. sojae* races 7, 17, and 25, we assumed it did not have any of the 13 *Rps* genes. It was then evaluated for partial resistance. However, it is possible that in one PI there is combination of two or more *Rps* genes, which could have either a susceptible or resistant reaction with these isolates. Because of the limited number of *P. sojae* races tested, the full range of resistance genes in the PIs selected could not be determined. To identify the nature of resistance found in this study, molecular markers (Burnham et al. 2002; Demirbas et al. 2001; Gordon et al. 2007; Sandhu et al. 2005) should be used to determine the resistance genes that are present in the PIs. In addition, QTL for partial resistance sources present in the PIs and cultivars should be identified since they exhibited levels of partial resistance equal to that of the standard check cultivar Conrad.

We encountered numerous intermediate reactions in the hypocotyl inoculation test. There are several possible causes for this response including genetically non-uniform seeds, temperature induced susceptibility, unequal amounts of inoculum, or virulence differences among the *P. sojae* races. All the seeds of the PIs used in this study were provided by the USDA Soybean Germplasm Collection. Although steps had been taken to assure that seed produced for this purpose was harvested from visually uniform plants, it is still possible that the plants of a particular PI were not genetically uniform. To correct this problem, it would be necessary to use seeds produced from a single plant. However, it is also worthwhile to further examine the PIs, which showed intermediate reactions in order to avoid disposal of valuable resistance sources. Although all the hypocotyl inoculations were performed in growth chambers with controlled temperature (25°C), humidity, and light, the temperature (29°C) was higher than the setting during the 24-h dark humid incubation right after inoculation. This may have induced susceptibility of soybean to *P. sojae*. Temperature induced susceptibility of soybean to *P. sojae* was found to be induced by transferring plants to 33°C immediately after inoculation (Gijzen et al. 1996). Temperature induced susceptibility is generally consistent for specific *Rps* genes, regardless of genetic background (Gijzen et al. 1996). However, temperature induced changes in host–pathogen interaction may not be readily predictable if the soybean plants carry more than one *Rps* gene.

The amount of inoculum applied should be quantified more accurately. About 0.2–0.4 ml of inoculum slurry was applied to each plant. We checked for the presence of oospores but we did not control the number of oospores inoculated into each plant. In a study (H. Jia, unpublished data) conducted to see if the age of inoculum in the hypocotyl injection method would affect the inoculation efficiency we used 3-, 5-, 7-, and 10-day-old *P. sojae* grown on V8 juice agar medium to inoculate soybean plants of the same growth stage. No significant difference was found in plant reaction when equal amounts of the inoculum slurry were used. Usually *P. sojae* starts to produce oospores after 5 days. However, different isolates produce oospores at different rates and the size of oospores is different. Since the 113 PIs were inoculated with each *P. sojae* race and a large amount of inoculum was used, there could be virulence differences within each isolate from different Petri dishes. These differences may be attributed to the instability of virulence in mass cultures and the variability within pathogen populations (Schmitthenner and Van Doren 1985).

No single strategy can control Phytophthora root and stem rot completely. *Rps* genes alone are not durable because of the selection pressure that they exert on diverse virulence pathotypes of *P. sojae*. Partial resistance probably cannot provide a level of control adequate to maintain profitable levels of yield. However, even with our limited understanding of partial resistance to *P. sojae* it appears that there are different responses to infection that could be exploited to delay or limit the damage *P. sojae* caused to the soybean plant (Dorrance et al. 2003; Tooley et al. 1982). Thus, long-term management for Phytophthora root and stem rot requires integration of multiple disease management strategies such as planting cultivars possessing both appropriate *Rps* genes and types of partial resistance combined with tillage, rotation, soil drainage, and seed treatments (Dorrance et al. 2003).

Soybean germplasm has been established as a valuable reservoir of new sources of disease resistance (Athow et al. 1986; Dorrance and Schmitthenner 2000; Kyle et al. 1998), which may be used for improving soybean crop. The two resistant PIs (PI438445 and PI438454) found in this study can provide new sources of the *Rps1c* or *Rps1k* resistance genes that can be quickly incorporated into early MG soybean cultivars. The high level of partial resistance identified in MN0902, MN0302, and 91B53 could become promising resources for future breeding efforts that rely on partial resistance. The close relationship of MN0902 and MN0302 suggests that it might be useful to evaluate the parents of the two cultivars for additional sources of partial resistance.

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