Sources of Resistance to Soybean Rust in Perennial *Glycine* Species

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ABSTRACT

Hartman, G. L., Wang, T. C., and Hymowitz, T. 1992. Sources of resistance to soybean rust in perennial *Glycine* species. Plant Dis. 76:396-399.

Accessions of 12 perennial *Glycine* species were evaluated for resistance to *Phakopsora pachyrhizi*, the causal agent of soybean rust. A total of 23% of the accessions were resistant, 18% were moderately resistant, and 58% were susceptible. In two experiments, 59 and 40% of the accessions of *G. tabacina* (2n=80) were resistant. Resistance to *P. pachyrhizi* was identified in accessions of *G. argyrea*, *G. canescens*, *G. clandestina*, *G. latifolia*, *G. microphylla*, and *G. tomentella*, but not in accessions of *G. arenaria*, *G. cyrtoloba*, *G. curvata*, and *G. falcata*.

Phakopsora pachyrhizi Sydow has a wide host range, which includes soybeans (*Glycine max* (L.) Merr.), other *Glycine* spp., and a number of genera in the legume family (1,6,36,38). Yield losses caused by rust on commercial soybeans are economically important in many countries in the Eastern Hemisphere, ranging from 13 to 70% in field plots (26,39).

Single genes for resistance to rust in soybeans have been described (2,14, 15,22). Races of the fungus were reported (8), and based on our knowledge, all commercially available cultivars are susceptible to at least some genotypes of the pathogen. Lines with partial resistance were identified (40), and the quantitative relationship of rust on tolerant lines and partially resistant lines to yield has been reported (13). The difficulties associated with identifying and quantifying rate-reducing resistance and the ineffectiveness of race-specific resistance have led to the search for sources other than *G. max* for resistance (4,6).

The genus *Glycine* consists of two subgenera, *G.* subg. *Glycine* and *G.* subg. *Soja* (Moench) F. J. Herm. *G.* subg. *Glycine* has 15 perennial species (30,34). A number of useful traits have been identified from these species (3,19). Thus far, incorporating the useful traits from the perennial species into cultivated soybeans through wide hybridization has been ineffective, because the hybrids are sterile.

In Australia, both race-specific and race-nonspecific resistance have been reported in some perennial *Glycine* spp. (4,5,7,18). Single resistance genes of at least four distinct loci were detected in lines of *G. canescens* F. J. Herm. (5). A single major gene for resistance to *P. pachyrhizi* was found in *G. argyrea* Tind. (18). Hybrids derived from intersubgeneric crosses with *G. max* may have high levels of resistance, but the exploitation of these in a soybean breeding program has been nonexistent. Recently, Singh et al (35) obtained sterile backcross progeny by crossing soybean and *G. tomentella* Hayata, and subsequently they have obtained BC_2, BC_3, and BC_4 progeny. The BC_4 populations are expected to be fertile (Hymowitz, *unpublished*). The potential usefulness of these derivatives and their hybrids has not yet been utilized in developing rust-resistant soybean lines.

Because there has been only one report (6) in which authors have systematically screened a portion of the wild perennial *Glycine* spp. for resistance to *P. pachyrhizi*, our objective was to screen many accessions, so that future intersubgeneric crosses with soybean will focus on those species that have a high frequency of accessions with rust resistance.

MATERIALS AND METHODS

Over a 3-yr period, 294 accessions representing 12 perennial *Glycine* spp. were screened for resistance to *P. pachyrhizi* at the Asian Vegetable Research and Development Center in Taiwan. Five seeds of each accession were scarified and planted into a sterilized potting mix of soil, compost, rice hulls, and sand (5:3:1:1) in 15-cm diameter clay pots. Seedlings were thinned to three per pot, and potted plants were placed outside the greenhouse surrounded by a susceptible soybean cultivar, Tainan Kaohsiung No. 5 (TK 5), which was planted in pots at the same time.

Plants were inoculated with a urediniospore solution of approximately 1×10^5 uredinia per milliliter using a hand-pumped sprayer. The inoculum was prepared from field-infected leaves of cultivar TK 5 (which has no characterized genes for resistance). Leaves were kept in polyethylene bags for 24 hr and

Accepted for publication 26 October 1991 (submitted for electronic processing).

soaked in water, and the solution was sieved through two layers of cheesecloth. Plants were inoculated twice between 50 and 65 days after planting.

In the first experiment, 191 accessions of perennial *Glycine* spp. from the University of Illinois at Urbana-Champaign were screened in four trials. The first trial consisted of 100 accessions planted on 10 March 1986. Disease was assessed on 27 May and 10 June. The second trial was planted on 11 September 1986 and consisted of 100 new accessions plus 34 of those that had been rated as moderately resistant or resistant in trial 1. Four assessments were made at 9- to 11-day intervals starting on 22 December 1986. The third trial was planted on 9 March 1987 with 58 accessions (25 resistant accessions from trials 1 and 2, and 33 resistant accessions tested only in trial 2). Two assessments were made, on 21 May and 2 June. The fourth trial was planted on 27 August 1987 with 61 accessions selected as resistant from at least two of the previous three trials. These were assessed on 11 and 20 November.

In experiment 2, 98 accessions representing 11 *Glycine* spp. from J. J. Burdon (CSIRO, G.P.O. Box 1600, Canberra, A.C.T. 2601, Australia), were planted on 4 March 1988 and assessed on 2, 15, and 24 June. Fourteen accessions were screened again on 2 September 1988 to confirm their initial resistant reaction.

In all experiments, three cultivated soybeans (AGS 181, AGS 129, and TK 5) were used as control. Rust was assessed on the following scale: resistant (R) = no or few necrotic lesions; moderately resistant (MR) = lesions occurring on less than 20% of the foliage, with sporulation reduced compared to a susceptible reaction; and susceptible (S) = greater than 20% of foliage covered with lesions, with well-developed pustules and normal to heavy sporulation. In experiment 1, trials 1 and 2, there were no replications; all other trials had four replications. The last assessment time in each trial was used to categorize the disease reaction.

RESULTS AND DISCUSSION

In all trials, the cultivated soybeans used as controls were judged to be susceptible, with abundant pustules containing uredinia and urediniospores. Of the 294 wild *Glycine* accessions, 23% were resistant, 18% were moderately resistant, and 58% were susceptible.

In experiment 1, 51% of the accessions tested were susceptible, 21% were moderately resistant, and 28% were resistant (Table 1). At least one accession in each of the *Glycine* spp. tested was resistant, except in *G. cyrtoloba* Tind. and *G. falcata* Benth., where all accessions were susceptible. There was a higher percentage of accessions with resistance in *G. tabacina* (Labill.) Benth. ($2n$=80) than in *G. tabacina* ($2n$=40). This trend was not similar for *G. tomentella* amphiploids, which were as susceptible as diploids.

In experiment 2, 14 of 98 accessions were resistant in the first trial, but when retested, two of the accessions were moderately resistant, and the other 12 were again rated as resistant (Table 2). *G. argyrea* (G 1626, G 2003/9, G 2003/13, and 2004/1), *G. clandestina* Wendl. (G 1664, G 1225, and G 1558), *G. tabacina* (G 1226, G 1254, G 1258, and G 1262), and *G. tomentella* (G 1316, G 1366, and G 1359) had resistant accessions, whereas seven other *Glycine* spp. had no accessions that were resistant. Of these 98 accessions tested from Australia, 20 of them have PI numbers that were also tested from the accessions obtained from Illinois. Three of the accessions, PI 446988 (G 1359), PI 446995 (G 1366), and PI 446974 (G 1226), were rated as resistant from both the Australian and Illinois seed sources. Except for two accessions, the other 17 had the same reaction type regardless of the source of seed.

We found that the majority of resistant accessions occurred in *G. tabacina* ($2n$=80). Burdon and Marshall (6) reported

Table 1. Reactions of accessions of *Glycine* spp. after inoculation with *Phakopsora pachyrhizi* in a series of four trials conducted outside the greenhouse

Glycine species[a]	Plant introduction	Rating
G. argyrea ($2n$=40)	505151	Resistant
G. canescens ($2n$=40)	399478, 440928, 440929, 440933, 440935–440942, 446936–446938, 483192	Susceptible
	440943, 446935	Moderately resistant
	483193	Resistant
G. clandestina ($2n$=40)	233138, 246590, 248252, 255745, 339660, 378870, 400967, 440945, 440947, 440948, 440951, 440954, 440958–440961, 440973, 446943, 483194	Susceptible
	440955, 440957	Moderately resistant
	339656, 429809, 440949, 440952, 440966, 440969	Resistant
G. cyrtoloba ($2n$=40)	440962, 440964	Susceptible
	373993, 446944	Moderately resistant
G. falcata ($2n$=40)	246591	Susceptible
G. latifolia ($2n$=40)	253238, 319696, 321394, 440978–440980, 446964	Susceptible
	342433, 378709	Moderately resistant
	321393	Resistant
G. microphylla ($2n$=40)	339659, 339665, 440972, 446940	Susceptible
	440974, 446941, 446942	Moderately resistant
	339664, 440956, 440971	Resistant
G. tabacina ($2n$=40)	373984, 373990, 378703, 378705, 440989, 440993, 446965, 446966[b], 446967, 446968[b]	Susceptible
	339661, 373986	Moderately resistant
	320546[c], 373983, 433361[a]	Resistant
G. tabacina ($2n$=80)	248253, 373983, 440991, 440992, 440997	Susceptible
	193232, 321392, 339658, 342432, 373981, 373982, 373985, 373992, 378706, 378707, 393534, 440982, 440984, 440986, 440994, 440996, 446999, 483200	Moderately resistant
	272099, 319697, 320545, 320546, 320549, 321391, 378704, 393533, 440981, 440983, 440985, 440987, 440988, 440990, 440995, 446945, 446969–446979, 447000, 483198, 483199	Resistant
G. tomentella ($2n$=40)	441000, 446930[a], 446954[a], 446956[a], 446957[a], 446981[a], 483223	Susceptible
	446980	Moderately resistant
	446991[a], 446993, 446995, 446998[a]	Resistant
G. tomentella ($2n$=78)	339657, 339663, 373980, 373988, 440999, 441006, 441007, 441009, 441010[d], 441011, 446985, 483224	Susceptible
	373991, 378708, 441001, 483218	Moderately resistant
	441008	Resistant
G. tomentella ($2n$=80)	320548[e], 393556, 441002–441004, 441012, 446946, 446948, 446949, 446952, 446953, 446960–446962	Susceptible
	441005, 446951, 446959, 505201	Moderately resistant
	330961, 446988	Resistant

[a] Seed obtained from University of Illinois at Urbana-Champaign.
[b] Chromosome number not known.
[c] $2n$=120.
[d] $2n$=78, 79, 80.
[e] $2n$=79, 80.

Table 2. Reactions of accessions of *Glycine* spp. after inoculation with *Phakopsora pachyrhizi* in a repeated experiment outside the greenhouse

Glycine species[a]	Chromosome number	Reaction[b]			Total assayed
		S	MR	R	
G. arenaria	40	2	0	0	2
G. argyrea	40	0	2	4	6
G. canescens	40	13	1	0	14
G. clandestina	40	13	0	3	16
G. cyrtoloba	40	4	0	0	4
G. curvata	40	4	0	0	4
G. latifolia	40	6	2	0	8
G. latrobeana	40	3	0	0	3
G. microphylla	40	5	2	0	7
G. tabacina	40	1	2	0	3
	80	5	1	4	10
G. tomentella	40	4	1	2	7
	80	11	2	1	14
Total		71	13	14	98

[a] Seeds obtained from J. J. Burdon, CSIRO (perennial *Glycine* core collection), Division of Plant Industry, P.O. Box 1600, Canberra City, A.C.T. 2601, Australia.
[b] S = susceptible, MR = moderately resistant, R = resistant.

that *G. tabacina* had the second highest percentage of resistant accessions after *G. tomentella*. However, the *G. tomentella* accessions tested in our study did not have such a high percentage of resistance. In our experiments, we used an inoculum source from the field, presumably consisting of different races, and our experiments were conducted outside, under environmental conditions that exist when rust is normally epidemic in the field. Testing these accessions for resistance in other geographic locations may produce somewhat different results, since races of the pathogen have been reported (8).

The wild perennial *Glycine* spp. are known to possess economically valuable characteristics that are lacking in the cultivated germ plasm. For example, investigations have shown that several wild perennial *Glycine* accessions carry resistance to brown spot, caused by *Septoria glycines* Hemmi (20). In addition, the wild perennial *Glycine* spp. have been reported to carry resistance to soybean rust, Phytophthora root rot, yellow mosaic virus, and powdery mildew (7,11,23,29). Accessions have been identified that are salt-tolerant (17,27,28), are tolerant to certain herbicides (12,21,37), and can be regenerated from protoplast, leaf, cotyledonary, petiole, and hypocotyl tissues (9,10,16,25).

The useful genes in perennial *Glycine* spp. have not been transferred to *G. max*, because of the low frequency of successful crosses and because of early pod abortion (32). A few intersubgeneric hybrids have been reported (24,31,32,33), but all F_1 plants were sterile. However, recent advances in producing successful crosses between synthesized amphiploids of *G. max* × *G. tomentella* and its backcross-derived progeny may make the transfer of useful genes to commercial soybeans more feasible (35). The relationship of the dominant resistant genes that have been reported to occur in *G. argyrea* (18) and in *G. canescens* (5) to those described in *G. max* (2,14,15,22) has not been compared and needs further investigation. The usefulness of these resistant genes will depend on their ease of transfer to soybean and whether or not they are stable over time and over the races of *P. pachyrhizi* that may occur in different environments.

ACKNOWLEDGMENTS

This research in part was funded by USAID/USDA Grant No. SG-86-GRSR-2-2865. We thank A. T. Tschanz for his involvement in the initiation of this project and J. J. Burdon of CSIRO for seed.

LITERATURE CITED

1. Bromfield, K. R. 1980. Soybean rust: Some considerations relevant to threat analysis. Prot. Ecol. 2:251-257.
2. Bromfield, K. R., and Hartwig, E. E. 1980. Resistance to soybean rust and mode of inheritance. Crop Sci. 20:254-255.
3. Brown, A. H. D., Grant, J. E., Burdon, J. J., and Grace, J. P., and Pullen, R. C. 1985. Collection and utilization of wild perennial *Glycine*. Pages 345-352 in: Proc. World Soybean Res. Conf., 3rd. R. Shibles, ed. Westview Press, Boulder, CO.
4. Burdon, J. J. 1986. The potential of Australian native *Glycine* species as sources of resistance to soybean leaf rust (*Phakopsora pachyrhizi*). Pages 823-832 in: New Frontiers in Breeding Researches. B. Nampompeth and S. Subhadrabandu, eds. Faculty of Agriculture, Kasetsart University, Bangkok.
5. Burdon, J. J. 1988. Major gene resistance to *Phakopsora pachyrhizi* in *Glycine canescens*, a wild relative of soybean. Theor. Appl. Genet. 75:923-928.
6. Burdon, J. J., and Marshall, D. R. 1981. Evaluation of Australian native species of *Glycine* for resistance to soybean rust. Plant Dis. 65:44-45.
7. Burdon, J. J., and Marshall, D. R. 1981. Inter- and intra-specific diversity in the disease response of *Glycine* species to the leaf rust fungus *Phakopsora pachyrhizi*. J. Ecol. 69:381-390.
8. Burdon, J. J., and Speer, S. S. 1984. A set of differential hosts for the identification of pathotypes of *Phakopsora pachyrhizi* Syd. Euphytica 33:891-896.
9. Grant, J. E. 1984. Plant regeneration from cotyledonary tissue of *Glycine canescens*, a perennial wild relative of soybean. Plant Cell Tissue Organ Cult. 3:169-173.
10. Hammatt, N., Davey, M. R., and Nelson, R. S. 1986. Plant regeneration from seedling cotyledons, leaves and petioles of *Glycine clandestina*. Physiol. Plant. 68:125-128.
11. Harrison, W. J., Kenworthy, C. A., Thomas, C. A., and Thomison, P. R. 1989. Infection of *Glycine* species with *Phytophthora*. Agron. Abstr. 1989:84.
12. Hart, S. E., Kenworthy, W. J., and Glenn, D. S. 1988. Mechanism of 2,4-D resistance in perennial *Glycine* species. Agron. Abstr. 1988:82-83.
13. Hartman, G. L., Wang, T. C., and Tschanz, A. T. 1991. Soybean rust development and the quantitative relationship between rust severity and soybean yield. Plant Dis. 75:596-600.
14. Hartwig, E. E. 1986. Identification of a fourth major gene conferring resistance to soybean rust. Crop Sci. 26:1135-1136.
15. Hartwig, E. E., and Bromfield, K. R. 1983. Relationships among three genes conferring specific resistance to rust in soybeans. Crop Sci. 23:237-239.
16. Hymowitz, T., Chalmers, N. L., Costanza, S. H., and Saam, M. M. 1986. Plant regeneration from leaf explants of *Glycine clandestina* Wendl. Plant Cell Rep. 3:192-194.
17. Hymowitz, T., Woolley, J. T., and Peters, D. B. 1987. Screening of the wild perennial *Glycine* species for salt tolerance. Soybean Genet. Newsl. 14:271-272.
18. Jarosz, A. M., and Burdon, J. J. 1990. Predominance of a single major gene for resistance to *Phakopsora pachyrhizi* in a population of *Glycine argyrea*. Heredity 64:347-353.
19. Kenworthy, W. J. 1989. Potential genetic contributions of wild relatives to soybean improvement. Pages 883-888 in: Proc. World Soybean Res. Conf., 4th. A. J. Pascale, ed. Asociacion Argentina de la Soja, Buenos Aires.
20. Lim, S. M., and Hymowitz, T. 1987. Reactions of perennial wild species of the genus *Glycine* subgenus *Glycine* to *Septoria glycines*. Plant Dis. 71:891-893.
21. Loux, M. M., Liebl, R. A., and Hymowitz, T. 1987. Examination of the wild perennial *Glycine* collection for tolerance to glyphosate. Soybean Genet. Newsl. 14:268-271.
22. McLean, R. J., and Byth, D. E. 1980. Inheritance of resistance to rust (*Phakopsora pachyrhizi*) in soybeans. Aust. J. Agric. Res. 31:951-956.
23. Mignucci, J. S. 1975. Powdery mildew of soybeans. M.S. thesis. University of Illinois, Urbana.
24. Newell, C. A., and Hymowitz, T. 1982. Successful wide hybridization between the soybean and a wild perennial relative, *G. tomentella* Hayata. Crop Sci. 22:1062-1065.
25. Newell, C. A., and Luu, H. T. 1985. Protoplast culture and plant regeneration in *Glycine canescens* F. J. Herm. Plant Cell Tissue Organ Cult. 4:145-149.
26. Ogle, H. J., Byth, D. E., and McLean, R. J. 1979. Effect of rust (*Phakopsora pachyrhizi*) on soybean yield and quality in south-eastern Queensland. Aust. J. Agric. Res. 30:883-893.
27. Pantalone, V. R. III, and W. J. Kenworthy. 1989. Salt tolerance in *Glycine max* and perennial *Glycine*. Soybean Genet. Newsl. 16:145-146.
28. Shannon, M. C., Shouse, P. J., Zidan, A. T., and Hymowitz, T. 1989. Variability in salt tolerance among wild relatives of soybean. Agron. Abstr. 1989:99.
29. Singh, B. B., Gupta, S. C., and Singh, B. D. 1974. Sources of field resistance to rust and yellow mosaic diseases of soybean. Indian J. Genet. Plant Breed. 34:400-404.
30. Singh, R. J., and Hymowitz, T. 1985a. The genomic relationships among six wild perennial species of the genus *Glycine* subgenus *Glycine* Willd. Theor. Appl. Genet. 71:221-230.
31. Singh, R. J., and Hymowitz, T. 1985b. An intersubgeneric hybrid between *Glycine tomentella* Hayata and the soybean, *G. max* (L.) Merr. Euphytica 34:187-192.
32. Singh, R. J., and Hymowitz, T. 1987. Intersubgeneric crossability in the genus *Glycine* Willd. Plant Breed. 98:171-173.

33. Singh, R. J., Kollipara, K. P., and Hymowitz, T. 1987. Intersubgeneric hybridization of soybeans with a wild perennial species, *Glycine clandestina* Wendl. Theor. Appl. Genet. 74:391-396.
34. Singh, R. J., Kollipara, K. P., and Hymowitz, T. 1988. Further data on the genomic relationships among wild perennial species (2n=40) of the genus *Glycine* Willd. Genome 30:166-176.
35. Singh, R. J., Kollipara, K. P., and Hymowitz, T. 1990. Backcross-derived progeny from soybean and *Glycine tomentella* Hayata intersubgeneric hybrids. Crop Sci. 30:871-874.
36. Vakili, N. G. 1978. Field observations and host range of soybean rust, *Phakopsora pachyrhizi* in Puerto Rico. Pages 4-15 in: Proc. Workshop Soybean Rust West. Hemisphere. N. C. Vakili, ed. USDA-ARS, U.S. Government Printing Office, 1977-771-106/12. 81 pp.
37. White, R. H., Liebl, R. A., and Hymowitz, T. 1990. Examination of 2,4-D tolerance in perennial *Glycine* species. Pesticide Biochem. Physiol. 38:153-161.
38. Yeh, C. C. 1981. Rust and purple seed stain of soybeans. Ph. D. thesis. University of Illinois at Urbana-Champaign. 103 pp.
39. Yeh, C. C., and Yang, C. Y. 1975. Yield loss caused by soybean rust, *Phakopsora pachyrhizi*. Plant Prot. Bull. (R.O.C.) 17:7-8.
40. Zambolim, L., do Vale, F. X. R., and Chaves, G. M. 1983. Partial resistance of soybean cultivars to *Phakopsora pachyrhizi*. Fitopatol. Bras. 3:117-12.