Evaluation of Radish Cultivars for Resistance to Clubroot (*Plasmodiophora brassicae*) Race 6 for Midwestern United States

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ABSTRACT

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Sixty-eight radish cultivars and breeding lines were tested in the greenhouse for resistance to clubroot caused by *Plasmodiophora brassicae* , race 6. Although most of the American radishes tested were moderately to highly susceptible, all of the Japanese and many of the Dutch cultivars were completely resistant. Further field tests of 16 Dutch radishes indicated that the cultivars Novitas, Roem van Zwijndrecht, Flevo, Robijn, Saxafire, Scharo, and Verano were resistant and horticulturally suitable for commercial production in the midwestern United States.

Clubroot, caused by *Plasmodiophora brassicae* Wor., is a disease of worldwide importance in crucifer production (2,5,9,11,17). The fungus infects root hairs of susceptible hosts and causes developing roots to form large distorted swellings and knobs (5,9). Severely infected plants are stunted and often wilt due to reduced root function. The fungus forms resting spores within infected tissue that are released into the soil when the tissue decays. Spores can remain viable in soil for at least 7 yr (5,9), and heavily infested fields may have to be abandoned for crucifer production.

In recent years, clubroot has become a limiting factor in the production of radishes (*Raphanus sativus* L.) on organic "muck" soil in Ohio and other midwestern states (13). The disease affects the base of the bulb and the taproot (Fig. 1) and necessitates extensive grading after harvest to remove infected radishes. In severe cases, entire plantings have been destroyed.

Chemical control of clubroot has been only partially successful. Root dipping of transplants in fungicides containing pentachloronitrobenzene (PCNB) or benzimidazole derivatives has provided control in some cases (1,3,10,12,17) but has been completely ineffective in muck soils (6,8). A preliminary study we conducted confirmed that these compounds were ineffective in controlling radish clubroot when incorporated into muck soil (14).

The main thrust of clubroot control has been based on developing resistant cultivars (9,11,17). Differences in susceptibility among radish cultivars were observed quite early (7), but only a few studies have been made since then (9). Breeding efforts with all crucifers have been frustrated by the development of physiological races of the pathogen (2,4,12,15–17). This report summarizes greenhouse and field screening tests of radish germ plasm for resistance to *P. brassicae,* race 6.

MATERIALS AND METHODS

Radish bulbs infected with *P. brassicae* were collected from a commercial muck farm in north central Ohio. These were sent to Paul Williams, Department of Plant Pathology, University of Wisconsin-Madison, for determination of the virulence spectrum of this population using the concepts and standard set of 15 European clubroot differentials (ECD) developed by Buczacki et al (4). Infected bulbs collected at the same location were kept frozen at −18 C for use as inoculum throughout this study.

Sixty-eight radish cultivars and breeding lines from the United States, Europe, and Japan were evaluated in the greenhouse for clubroot resistance during January and February 1979. Muck soil was placed in 30 × 60 × 7 cm wooden flats, and radish lines were seeded in single rows 30 cm long and 10 cm apart. Two replicates of one row each were used for each line. Resting spores of *P. brassicae* were extracted from frozen radish bulbs by comminuting the "clubbed" roots with a small volume of sterile distilled water in a blender for 1 min, filtering through cheesecloth, and

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adjusting the final spore concentration to approximately 1.7×10^6/ml. About 30 ml of this suspension was poured uniformly over each row of seeds before covering with soil. After 1 wk, seedlings were thinned to 10 per row. Plants were grown in the greenhouse at 20–25 C under fluorescent lights with a 12-hr photoperiod at 100–200 hlx. Soil was kept at or near field capacity by frequent watering. Six weeks after seeding, mature radishes were uprooted and examined for clubroot symptoms and horticultural characteristics.

Cultivars resistant in greenhouse tests were further evaluated in field tests in August 1979 at two commercial muck farms in northeast and north central Ohio. Identical plots were planted at each location on naturally infested soil and a third was seeded on uninfested soil at the north central location. Seeds of each variety were put into separate hopper boxes of a commercial radish drill, and single rows about 100 m long were planted. Four weeks later, 100 mature radishes were harvested by hand from each row and evaluated for clubroot development and horticultural characteristics.

RESULTS AND DISCUSSION

The infection pattern of the population of *P. brassicae* obtained from Ohio radishes on the 15 European clubroot differential hosts was ECD 16/6/30 (4). This response indicates that this population varies only slightly from those normally found in the midwestern United States in fields planted to *Brassica oleracea* crops such as cabbage, broccoli, cauliflower, and brussel sprouts. This population, commonly referred to as race 6, gives an infection pattern of ECD 16/2/30. The difference between these two designations is that approximately half of the ECD No. 8 differential plants (*Brassica napus*) were susceptible while the others were resistant, indicating a buildup of virulence in the population capable of infecting this normally resistant differential.

Greenhouse tests of radish cultivars indicated that most of the American radishes were moderately to highly susceptible to this population of *P. brassicae*, whereas all of the Japanese and many of the European radishes were resistant (Table 1). Sixteen resistant European cultivars that were horticulturally similar to the red bulb-type radishes grown in the United States were further evaluated in the field along with standard American cultivars. In these tests, serious clubroot developed only on the infested plot at the north central farm where 14 Dutch cultivars remained completely resistant while the susceptible standards, Scarlet Knight and Red Prince, were 100 and 68% infected, respectively. At the other two locations, all cultivars were evaluated for desirable horticultural characteristics as well as marketable yield, which is reported in detail in a separate paper (13).

From these data the following resistant Dutch cultivars (listed in approximate order of preference) appear to be those most suited to commercial radish production in the midwestern United States: Novitas, Roem van Zwijndrecht, Flevo, Robijn, Saxafire, Scharo, and Verano (Table 1).

Table 1. Response of 68 radish cultivars and breeding lines to *Plasmodiophora brassicae* race 6 in greenhouse and field evaluations

Entry	Radish type[a]	Origin	Susceptibility[b]	
			Greenhouse[c]	Field[d]
Novitas[e]	1	Holland	0	0
Roem van Zwijndrecht[e]	1	Holland	0	0
Flevo[e]	1	Holland	0	0
Robijn[e]	1	Holland	0	0
Saxafire[e]	1	Holland	0	0
Scharo[e]	1	Holland	0	0
Verano[e]	1	Holland	0	0
Kokarde	1	Holland	0	0
Korda	1	Holland	0	0
Middle East Giants	1	Holland	0	0
Americano	1	Holland	0	0
Sarxkatra	1	Holland	0	0
Qumkader	1	Holland	0	0
Real	1	Holland	0	0
Scarabelle	1	Holland	0	1
Piggelmee	1	Holland	0	1
Kader	1	Holland	0	
Minitas	1	Holland	0	
Robino	1	Holland	0	
Katra	1	Holland	0	
Rota	1	Holland	0	
Radar	1	Holland	0	
RS1004	1	Holland	1	
Risenbutter	1	Holland	1	
Prinz Roten	1	Holland	2	
Bolide	1	Holland	3	
Saxerre	1	France	0	1
Crimson Giant	1	United States	1	
Novired	1	United States	1	
Cavalrondo	1	United States	1	
Crimson Knight	1	United States	1	
Champion	1	United States	2	1
Cherry Bell	1	United States	2	1
NK3	1	United States	2	
NK8	1	United States	2	
Red Boy	1	United States	2	
Scarlet Knight	1	United States	3	3
Red Prince	1	United States	3	3
Scarlet Globe	1	United States	3	
Early Scarlet Globe	1	United States	3	
Scarlet Globe Short Top	1	United States	3	
Stoplite	1	United States	3	
Comet	1	United States	3	
Cavalier	1	United States	3	
NK7	1	United States	3	
NK10	1	United States	3	
NK13	1	United States	3	
NK15	1	United States	3	
Fuego	1	United States	3	
Far Red	1	United States	3	
Round Scarlet Giant	2	Japan	0	
Lange Scharlaken Rode	2	Holland	3	
Long Scarlet Globe	2	United States	3	
French Breakfast	2	United States	3	
18 daagse Halflange Rode Witpunt	3	Holland	2	
Halfrood/Half wit	3	Holland	3	
Ronde Rode Kleinwitpunt	3	Holland	3	
Sparkler	3	United States	3	
Ronde Witte	4	Holland	0	
Ijskegel	5	Holland	2	
Icicle Short top	5	United States	2	
Ookura	6	Japan	0	
Shogoin	6	Japan	0	
Wakayama	6	Japan	0	
Shikou	6	Japan	0	
Nezumi	6	Japan	0	
Hooryo	6	Japan	0	
Shirokubi-Myashige-Maruziri	6	Japan	0	

[a] 1 = red bulb type, 2 = elongated red bulbs, 3 = red bulbs with white tips, 4 = white bulb type, 5 = white icicle type, 6 = large, elongated, white Japanese type.

[b] 0 = resistant (no sign of infection), 1 = slightly susceptible (< 10% of bulbs with clubbed roots), 2 = moderately susceptible (10–30% of bulbs with clubbed roots), 3 = highly susceptible (> 30% of bulbs with clubbed roots).

[c] Test consisted of two replicates of 10 plants each.

[d] Evaluation consisted of 100 plants pulled at random from about a 100-m row.

[e] Resistant and horticulturally suitable for commercial production in the midwestern United States.

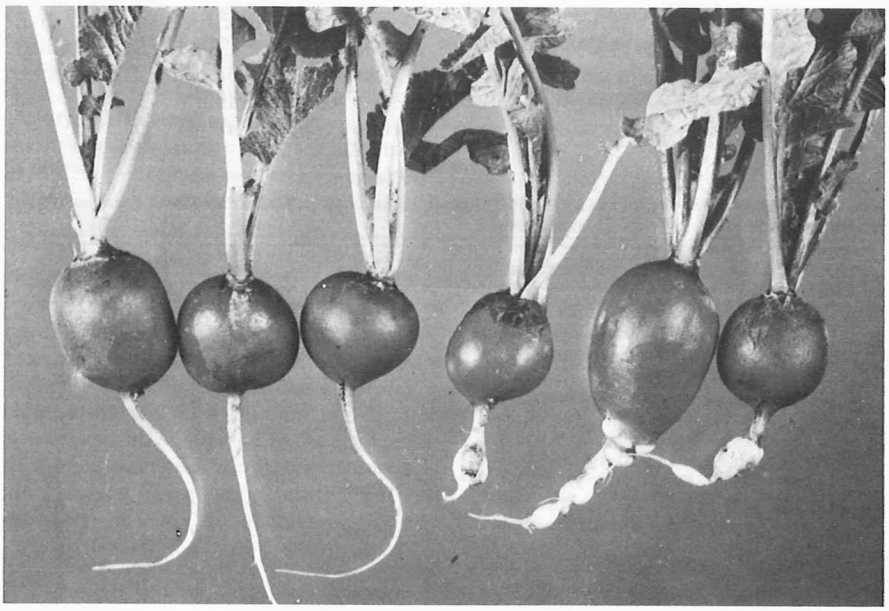

Fig. 1. Clubroot-resistant radish cultivar Saxarite (left) compared with susceptible cultivar Scarlet Knight (right) harvested from a commercial "muck" field naturally infested with *Plasmodiophora brassicae*.

Although these cultivars could be used directly by commercial radish growers, they do not carry resistance to Fusarium yellows (*F. oxysporum* f. sp. *conglutinans*, race 2), an important problem in the United States that does not occur in Europe. Fortunately, preliminary studies on the inheritance of clubroot resistance in radish indicate that combining this trait with Fusarium yellows resistance in a horticulturally acceptable cultivar will not be difficult (H. S. Humaydan and R. C. Rowe, *unpublished*). Development of new radish cultivars utilizing this source of resistance is now under way and should provide a solution to the radish clubroot problem here unless the virulence spectrum of this *P. brassicae* population shifts markedly in the future.

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