Screening *Capsicum annuum* Accessions for Resistance to Six Isolates of *Phytophthora capsici*

Byron L. Candole and Patrick J. Conner

University of Georgia–Tifton Campus, Horticulture Department, 4604 Research Way, Tifton, GA 31793

Pingsheng Ji

University of Georgia, College of Agricultural and Environmental Sciences, Coastal Plain Experiment Station, Plant Pathology Department, P.O. Box 748, Tifton, GA 31793

**Abstract.** *Phytophthora* blight caused by *Phytophthora capsici* Leon. is one of the most important diseases of bell peppers (*Capsicum annuum* L.) in Georgia. The level of resistance in commercial bell pepper cultivars is not effective in managing this disease in moist and humid conditions, and new sources of resistance are needed. A mixture of six *Georgia* isolates of *P. capsici* was used for greenhouse mass screening of 2301 accessions of *Capsicum annuum*. From the initial screening, 77 accessions were identified as resistant to *P. capsici*-induced root rot. From those 77 accessions, 28 accessions were selected for seed increase and further replicated root inoculation tests. Replicated tests confirmed the resistance of 14 of the 28 accessions, although genetic variability within the accessions hampered the analysis of resistance in some accessions. Two accessions, PI 201237 and PI 640532, demonstrated consistently high levels of resistance to root rot. These two accessions are potential sources of resistance genes that can be incorporated into commercial bell pepper cultivars.

Bell pepper (*Capsicum annuum*) is one of the economically important crops in the state of Georgia where the total farm-gate value of bell pepper was $\approx$810 million in 2007 (Boatright and McKissick, 2008). *Phytophthora* blight, caused by the oomycete pathogen *Phytophthora capsici* (Leonian, 1922), is a serious threat to production of peppers worldwide (Babadoost, 2004). This disease has become a major disease constraint to bell pepper production, affecting the plants at all growth stages (from seedling to adult plant) and all plant parts, including roots, leaves, stems, and fruits. *P. capsici* attacks the roots at all developmental stages, causing sudden wilt and collapse of the infected plant (Lefebvre and Palloix, 1996). *Phytophthora* infection is enhanced by warm temperatures and frequent rainfall (Weber, 1932), conditions that are common in the southeastern United States during the summer months. In Georgia, the most common symptoms caused by *P. capsici* infection are root rot, crown rot, and leaf blight.

Recommended management strategies for *P. capsici* include cultural practices that ensure well-drained soils in the field, crop rotation, soil solarization, use of mulches to prevent splash/soil dispersal, and chemical control (Ristaino and Johnston, 1999). The host range of *P. capsici* includes multiple crops and weed species (Erwin and Rebeiro, 1996; French-Monar et al., 2006). Oospores can persist in the soil for long periods (Hausbeck and Lamour, 2004). For these reasons, crop rotation with other major crops is often not an effective management option. The fungicide mefenoxam has been heavily relied on to control *P. capsici*. However, because this chemical has a single mode of action, resistance has developed in *P. capsici* and many field isolates are now unresponsive to mefenoxam application (Café-Filho and Ristaino, 2008; French-Monar et al., 2005; Hausbeck and Lamour, 2004).

The use of *P. capsici*-resistant bell pepper cultivars is an important aspect in the management of this disease. *P. capsici*-resistant bell pepper cultivars such as Paladin, Aristotle, Revolution, and Alliance are available commercially, but their resistance is not consistently effective against *Phytophthora* blight in all locations or production systems (Oelke et al., 2003). Additionally, most resistant cultivars lack the horticultural characteristics necessary to compete with susceptible cultivars (Ristaino and Johnston, 1999). ‘Aristotle’ is the most widely grown bell pepper cultivar in southern Georgia where its level of resistance is often not effective against root rot, foliar, and stem blights under warm temperatures and high moisture conditions.

The development of new resistant pepper cultivars is dependent on the identification of resistance in the pepper germplasm. Several partial screenings have been made for resistance to *P. capsici* in the *Capsicum* germplasm. Kimble and Grogan (1960) examined 613 pepper lines and cultivars and found three (PI 188476, PI 201232, PI 201234) with high levels of resistance to *Phytophthora* root rot. Barkdale (1984) examined 24 PI lines and several cultivars for foliar resistance. PI 201232 and PI 201234, which were previously shown to be resistant to crown and root rot, were shown to also have high levels of foliar resistance. Reischneider et al. (1986) examined seven genotypes derived from resistant cultivars or breeding lines and found one line, CNPH 286, to be reliably resistant to root rot. PI 201232 and PI 201234, or lines obtained from them, have been the main sources of resistance used in early breeding work in the United States and Europe (Ortega et al., 1991). Two lines from Mexico, Line 29 and Criollo de Morelos-334 (CM-334), were also found to exhibit high levels of resistance (Ortega et al., 1991). Most recent work has focused on resistance from the landrace CM-334, which has demonstrated the highest level of resistance to date when screened for root rot resistance and leaf resistance (Ortega et al., 1991; Walker and Bosland, 1999). CM-334 is resistant to *Phytophthora capsici* in roots, stems, and leaves (Alcantara and Bosland, 1994; Bosland and Lindsey, 1991; Walker and Bosland, 1990). However, Walker (1991) found that in progenies derived from CM-334, foliar blight resistance and root rot resistance were controlled by independently segregating genes. Further work by Sy et al. (2005) demonstrated that stem blight resistance from CM-334 was controlled by a single gene, *Psr*, when ‘Early Jalapeno’ was the susceptible parent and that this gene was inherited independently from those controlling foliar blight and root rot resistance. Thus, it appears that foliar blight, stem blight, and root rot are separate disease syndromes that need to be analyzed independently.

Reliance on a small number of resistance sources may lead to undesirable levels of genetic vulnerability. No systematic searches have been conducted in recent years using the pepper germplasm available at the USDA National Plant Germplasm System (R. Jarrett, personal communication). The objective of this study was to conduct a more thorough screening of this germplasm to find sources of resistance to *P. capsici* that could be incorporated into a new commercial bell pepper cultivar for the Georgia production region.

**Materials and Methods**

Test plants. *Capsicum annuum* accessions were obtained from the USDA, ARS Plant Genetic Resources Conservation Unit in Griffin, GA. The total of 3118 accessions used in this study represented all the *C. annuum* accessions available from this location. The term accession is used in this article to refer to the original seed lot that was
obtained from the USDA under a particular accession number. Because some accessions represent landraces or were derived from mixed fruit collections, accessions are not necessarily genetically homogenous. The term “line” is used to refer to the selfed seed collected from individual plants grown out from accession seed. Multiple lines from the same accession may or may not be genetically homogenous, depending on the genetic variation present in the original accession. The test plants were watered twice daily and fertilized twice a week with water-soluble fertilizer (24N–6P–16K) diluted to provide 315 ppm nitrogen. All tests were performed in the greenhouse where the air temperature before and during the disease incubation process had a diurnal range of 13 to 30 °C. ‘Camelot’ and Criollo de Morelos 334 (CM-334) were used as the susceptible and resistant controls, respectively, in all tests. CM-334 was kindly provided by P. Bosland (New Mexico State University) and ‘Camelot’ was obtained from Rupp Seeds (Wauseon, OH).

**P. capsici isolates and inoculum preparation.** Three virulent isolates from the USA: PC-F681, PC-1145, and three from the A2 (PC-F1R3, PC-F1R6, PC-F1S12) mating types of *P. capsici* were used in the mass screening and subsequent inoculation tests. These isolates were all obtained from grower fields in Tift County, GA. Isolate PC-1A1 was isolated from surrounding large numbers of *Cucurbita pepo* L. *Cucurbita* was inoculated to and reisolated from bell pepper before use. All other isolates were obtained directly from bell pepper before use. A mixture of zoospores from these six isolates was used in inoculating the test plants. The zoospores were produced aseptically by transferring 10 agar plugs from the advancing portion of 5-d-old cultures (25 °C, under dark condition) of *P. capsici* in 5% (v/v) clarified V8 juice agar (Kuhajek et al., 2003) to 100 × 15-mm petri dishes (≈12 plates/isolate) and 10 mL of clarified V8 juice was added thereafter. After 24 h of incubation at 25 °C under dark conditions, the V8 juice in each plate was replaced with 10 mL of sterilized 1x phosphate buffered saline solution (MSS) (Kuhajek et al., 2003) and the plates were incubated at 20 °C for 30 cm under two fluorescent lights (cool white, 20 W, 25 °C, 35 μmol·m⁻²·s⁻¹) for 24 h. The MSS from each plate was then replaced with the same volume of fresh MSS and the plates were allowed to incubate for 3 more days.

Zoospores from each isolate were harvested separately. To harvest the zoospores, the MSS was removed from each plate and then washed twice with 10 mL of sterile distilled water. After the second washing, 10 mL of sterile distilled water was added to each plate and placed in the refrigerator (1.3 °C) for 45 min. The plates were then incubated at room temperature and monitored for zoospore release. The zoospore suspension from each petri dish was then transferred very slowly to a 250-mL graduated cylinder and left undisturbed for 5 min. The upper 50 mL of the zoospore suspension was pipetted out and added to a 50-mL tube with water-soluble centrifuge tube. The tube was then inverted gently two to three times to evenly distribute the zoospores in the suspension. One milliliter of the suspension was transferred to a 2-mL microcentrifuge tube with flat cap and vortexed for 10 s to encyst the zoospores. The zoospore concentration was determined using a hemacytometer and adjusted to 2000 zoospores/mL (Bosland and Lindsey, 1991). Equal volumes of zoospore suspensions were then combined for inoculation.

**Primary screening of accessions for root rot resistance.** A total of six to 12 plants was tested for each accession. Seeds from each accession were sown in plastic cells of a multitop bedding plant container (Com-Pack D806; Hummert International, St. Louis, MO). Each cell measured 6 cm × 4 cm × 5.5 cm and contained Redi Earth plug and seeding mix (Sun Gro, Bellevue, WA). The cells containing the seeds were then placed in 25.2 × 25.9 cm × 6.1-cm plastic trays with drainage holes (F1020 flats; Hummert International).

Root inoculation was made according to a previously described procedure (Bosland and Lindsey, 1991). Before inoculation, the trays containing 14-d-old pepper seedlings were placed in water-filled trays to saturate the soil around the roots. A 5-mL zoospore suspension was then delivered onto each cell using an automatic dispenser (Finpipette, Vantaa, Finland) resulting in a final concentration of 10,000 zoospores per cell. The saturated condition was maintained for another 48 h and disease evaluation was performed 14 d after inoculation. The plants were evaluated based on a 10-point scale (Bosland and Lindsey, 1991): 0 = no response, vigorous, healthy; 1 = slight stunting and small lesions on stems; 2 = stunted or small lesions on stems, lower leaves wilted, stunted; 7 = brown roots, slight stunting, very small lesions on stems; 8 = brown roots, small lesions on stems, lower leaves wilted, stunted plants; 9 = brown roots, large lesions on stems, girdling, whole plant wilted, and stunted; 9 = death. Even numbers corresponded to intermediate response. A disease index value of 2 or less was considered resistant, and a value greater than 2 was considered susceptible. Seeds from individual plants from each accession that were identified as resistant and survived to fruit set were harvested separately. To produce seed, plants were kept in a screened greenhouse with an absence of pollinators. Seed was collected from ripe fruit, hand-separated, dried on a laboratory benchtop, and kept refrigerated until used.

**Retest of primary selections.** A total of 28 accessions in which three or more inoculated plants survived the primary screen to seed set were chosen for seed increase and replicated inoculation tests to confirm the results of the mass screening. Individual surviving plants from each of the 28 accessions were selfed to produce 109 seed lines for testing. The seeds from each surviving plant of each accession were sown separately in plastic cells of a multipot bedding plant container (Com-Pack D812; Hummert International) containing the same growing medium as described previously.
Results

Only 2301 (74%) of the 3118 accessions germinated to yield at least three plants for root inoculation. As a result of the large number of accessions tested, accessions that germinated poorly were not retested. Mean root rot ratings of accessions ranged from 1 to 9 with the majority of accessions rated as very susceptible (Fig. 1). Results of the original screening have been placed on the U.S. Dept. Agr. Germplasm Resources Information Network web site (http://www.ars-grin.gov/cgi-bin/npgs/html/desc.pl?116072). Of the 2301 tested accessions, 77 (3.3%) had a mean root rot severity of 2 or less and were considered resistant. Thirty-seven of those 77 (48%) accessions had at least one plant that survived to fruit set (Table 1). Plants did not survive to fruit set primarily as a result of latent infections with *P. capsici*, transplant shock resulting from repotting after scoring roots, poor adaptation to greenhouse culture, and the long times needed for some genotypes to produce seed. Unfortunately, some accessions were also very poor producers of seed, at least under these growing conditions, and did not provide enough seed for further replication and/or field testing. As a result of the large number of lines sampled in this project, no attempt was made to further test accessions that did not survive to fruit maturity. However, these accessions are available on the web site listed previously and should be considered in future studies looking for potential new sources of resistance to *P. capsici*.

Five accessions (PI 201231, PI 201239, PI 593485, PI 593493, PI 593573) were consistently resistant (root rot severity rating = 1) with a cv = 0 and plant survival ranging from 30% to 100% (Table 1). A further 20 accessions responded with all plants scored within the resistant range of 1 to 2 root rot severity rating. Fifteen of these 20 accessions had a most commonly observed rating of 1 and five had a most commonly observed rating of 2. Although the other 12 accessions were resistant based on their mean root rot severity rating, and most plants within an accession were within the resistant range (0 to 2), individual plant responses within the accession ranged from resistant (1) to susceptible (3 to 6). The resistant control CM-334 had an average rating of 1 with 100% survival and the susceptible control, ‘Camelot’, had an average rating of 9 with no surviving plants (Table 1).

Of the 37 accessions that survived to seed set, 28 accessions produced enough seed for further replicated testing. Selfed seed from each surviving plant of the original accession was tested separately so that most accessions were represented by multiple seed lines. Based on the average root rot severity over all lines tested per accession, results from the replicated inoculation tests (with greater sample sizes) showed that of the 28 accessions tested, 14 confirmed their resistant reactions from the previous mass screening tests (root rot severity rating 2.0 or less) and

\[ \text{Survival} \times 100 \]

\[ = \frac{\text{number of plants surviving to fruit set}}{\text{number of plants tested per accession}} \times 100. \]

![Fig. 1. Frequency distribution of mean root rot severity derived from a mass screening of Capsicum annuum accessions with Phytophthora capsici. Only the 2301 accessions with three or more scored plants are included in the distribution.](Image 280x617 to 555x783)

Table 1. Accessions of Capsicum annuum that were identified as resistant and survived to seed set from mass screening against six Georgia isolates of Phytophthora capsici.

| Accession | Name | Country of origin | Root rot severity | Survival (%) |
|-----------|------|-------------------|-------------------|--------------|
| PI 201231 | Chilcaucle Amarillo | Mexico | 1 | 1.0 | 0.0 | 100 |
| PI 201239 | Chile Ancho San Luis | Mexico | 1 | 1.0 | 0.0 | 100 |
| PI 593485 | 10210 | Mexico | 1 | 1.0 | 0.0 | 30 |
| PI 593493 | 10258 | Mexico | 1 | 1.0 | 0.0 | 33 |
| PI 593573 | 10688 | Brazil | 1 | 1.0 | 0.0 | 33 |
| PI 439273 | | Mexico | 1 | 1.1 | 0.1 | 57 |
| PI 593495 | 10263 | Mexico | 1 | 1.1 | 0.1 | 33 |
| PI 183922 | Murch | India | 1 | 1.2 | 0.2 | 33 |
| PI 511882 | Chile negro | Mexico | 1 | 1.2 | 0.2 | 60 |
| PI 593572 | 10678 | Brazil | 1 | 1.2 | 0.1 | 60 |
| PI 631147 | Perennial | | 1 | 1.2 | 0.2 | 33 |
| PI 640833 | Cascabella | United States | 1 | 1.2 | 0.2 | 50 |
| PI 201237 | Chilpotle Mico | Mexico | 1 | 1.3 | 0.3 | 83 |
| PI 439302 | | Mexico | 1 | 1.3 | 0.2 | 17 |
| PI 511884 | Chil de Chapa | Mexico | 1 | 1.3 | 0.2 | 33 |
| PI 566811 | Chile criollo | Mexico | 1 | 1.3 | 0.2 | 100 |
| PI 593564 | 10641 | Mexico | 1 | 1.3 | 0.2 | 40 |
| PI 640448 | Szechwan 3 | Taiwan | 1 | 1.4 | 0.2 | 33 |
| PI 640532 | 871076 | Mexico | 1 | 1.4 | 0.2 | 33 |
| PI 511883 | Chile criollo | Mexico | 1 | 1.5 | 0.3 | 50 |
| PI 640461 | 83-168 | China | 1 | 1.5 | 0.2 | 73 |
| PI 640641 | IR | Indonesia | 1 | 1.5 | 0.5 | 40 |
| PI 640659 | | Thailand | 1 | 1.5 | 0.2 | 13 |
| Grif 9109 | BG-912 | Mexico | 1 | 1.6 | 0.2 | 100 |
| PI 640663 | PBC 602 | Taiwan | 1 | 1.6 | 0.2 | 11 |
| PI 640670 | Singh 4 | India | 1 | 1.6 | 0.2 | 9 |
| PI 224438 | No. 1713 | Mexico | 1 | 1.7 | 0.2 | 100 |
| PI 593511 | 10325 | Mexico | 1 | 1.7 | 0.3 | 33 |
| PI 640480 | HDA 336 | France | 1 | 1.7 | 0.7 | 43 |
| PI 640560 | Phyo 636 | Netherlands | 1 | 1.7 | 0.5 | 43 |
| PI 640588 | Ycb 76105 | United States | 1 | 1.7 | 0.3 | 33 |
| PI 640671 | CA 8 | Sri Lanka | 1 | 1.7 | 0.2 | 17 |
| PI 640581 | U-Kimba | Nigeria | 1 | 1.8 | 0.3 | 27 |
| PI 640516 | Chicken Heart | Taiwan | 1 | 1.9 | 0.3 | 25 |
| PI 640582 | UL-2190 | Nigeria | 1 | 2.0 | 0.3 | 30 |
| PI 640682 | PBC 661 | Tanzania | 1 | 2.0 | 0.5 | 11 |
| PI 640803 | Red Hot | Philippines | 1 | 2.0 | 0.4 | 10 |
| Ciriollo de Morelos 334 | | Mexico | 0 | 1.0 | 0.0 | 100 |

Based on a 0 to 9 scale (Bosland and Lindsey, 1991): 0 = no response; 3 = brown roots, slight stunting, very small lesions on stems; 7 = brown roots, large lesions on stems, girdling, whole plant wilted, and stunted; 9 = dead plants. A resistant (R) reaction is a severity rating of less or equal to 2 and a susceptible (S) reaction is a severity rating of greater than 2.
the other 14 accessions had susceptible reactions (root rot severity rating greater than 2.0) (Table 2). However, there was moderate variation among lines within an accession as well as among plants within a line. For example, accession PI 201231 had an overall score of 2.5 but had three lines with an average score in the resistant range (1.3, 1.8, 2.0) and two lines in the susceptible range (2.4, 3.3). Only in accessions PI 201237 and PI 640532 did all plants from all lines respond within the resistant range.

Under field conditions, root discoloration ranged from 11.5% (PI 593573) to 100% (PI 640527), whereas the plant survival at maturity ranged from 95.3% (PI 511883) to 100% (PI 593573, PI 640516) (Table 3). However, there was moderate variation among lines within an accession as well as among plants within a line. For example, accession PI 566811 had an overall root discoloration (PI 566811, PI 593573, PI 640516) (Table 3) but was observed to be susceptible in the subsequent replicated inoculation test (Table 1) and was observed to be susceptible in the subsequent replicated inoculation test (Table 2). Of the three accessions reported as resistant by Kimble and Grogan (1960), two (PI 188476 and PI 201234) were resistant but only a single plant germinated for testing. Differences in susceptibility ratings between the previous and current studies may be the result of differences in the isolates used for testing or in the inoculation methods used.

Discussion

To our knowledge, this is the first reported wide-scale testing of Capsicum germplasm for resistance to P. capsici since the original work of Kimble and Grogan (1960), although doubtless much screening work has been done in breeding programs throughout the world. These tests demonstrated the availability of accessions that are potential sources of resistance to Georgia isolates of P. capsici and potentially can be incorporated into commercial bell pepper cultivars.

The majority of the 28 accessions included in the replicated root inoculation tests came from Mexico (15 accessions), whereas two accessions each came from Brazil, Taiwan, Nigeria, and United States and one accession each from China, France, The Netherlands, and Indonesia with one accession (PI 631147) of unknown origin (Table 1). These accessions express a wide range of fruit and plant morphological characteristics, including many that had small very pungent fruits.

However, some accessions, including PI 640480 and PI 640532, had relatively large pod size and good levels of resistance. None of these accessions were previously identified or reported as resistant except PI 640560 (cv. PHYO 636), an accession that was previously reported resistant to root rot (Palloix et al., 1988), was resistant in the mass screening test (Table 1) but was observed to be susceptible in the subsequent replicated inoculation test (Table 2). Of the three accessions reported as resistant by Kimble and Grogan (1960), two (PI 188476 and PI 201234) were found to be susceptible in this screening and one (PI 201232) was resistant but only a single plant germinated for testing. Differences in susceptibility ratings between the previous and current studies may be the result of differences in the isolates used for testing or in the inoculation methods used.

Table 2. The reaction of selected Capsicum annuum accessions in replicated inoculation tests against a mixture of six Georgia isolates of Phytophthora capsici.

| Accession Name/Variety | Line number | Line Mean | Root rot severity | Line Mode | Line SD |
|------------------------|-------------|----------|-------------------|-----------|---------|
| PI 511882 Chile negro | 1           | 2.9      | 1–4               | 1         | 1.0     |
| PI 511882 Chile negro | 2           | 7.5      | 2–9               | 1         | 1.8     |
| PI 511882 Chile negro | 3           | 4.5      | 1–9               | 2         | 2.2     |
| PI 511883 Chile criollo | 1        | 0.7      | 1–5               | 1         | 1.6     |
| PI 511883 Chile criollo | 2         | 2.0      | 2                  | 2         | 0.0     |
| PI 511883 Chile criollo | 3         | 2.3      | 0–5               | 2         | 1.6     |
| PI 566811 Chile criollo | 1         | 1.3      | 1–3               | 1         | 1.4     |
| PI 566811 Chile criollo | 2         | 1.4      | 0–2               | 2         | 0.6     |
| PI 566811 Chile criollo | 3         | 1.4      | 1–2               | 1         | 0.5     |
| PI 566811 Chile criollo | 4         | 1.1      | 0–1               | 2         | 0.7     |
| PI 566811 Chile criollo | 5         | 1.4      | 1–2               | 1         | 0.5     |
| PI 566811 Chile criollo | 6         | 1.9      | 1–3               | 2         | 0.5     |
| PI 566811 Chile criollo | 7         | 1.3      | 0–3               | 2         | 0.9     |
| PI 566811 Chile criollo | 8         | 1.2      | 0–2               | 2         | 0.8     |
| PI 566811 Chile criollo | 9         | 1.5      | 1–2               | 1         | 0.5     |

(Continued on next page)
| Accession | Name/Variety  | Line number | Reaction 1 | Reaction 2 | Reaction 3 | Reaction 4 | Reaction 5 | Reaction 6 | Reaction 7 | Reaction 8 | Reaction 9 |
|-----------|---------------|-------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| PI 631147 | Perennial     | 1           | 2.9        | 1–9        | 3          | 1.5        |            |            |            |            |            |
|           |               | 2           | 1.9        | 0–9        | 1          | 1.4        |            |            |            |            |            |
|           |               | 3           | 2.3        | 0–4        | 2          | 0.5        |            |            |            |            |            |
| PI 640488 | Szechwan 3    | 1           | 3.5        | 1–9        | 3          | 1.3        |            |            |            |            |            |
|           |               | 2           | 3.1        | 1–9        | 3          | 1.3        |            |            |            |            |            |
|           |               | 3           | 3.3        | 1–9        | 2          | 1.4        |            |            |            |            |            |
| PI 640461 | 83–168        | 1           | 1.8        | 1–4        | 2          | 0.8        |            |            |            |            |            |
|           |               | 2           | 2.2        | 1–5        | 2          | 1.1        |            |            |            |            |            |
|           |               | 3           | 2.4        | 0–9        | 2          | 1.1        |            |            |            |            |            |
|           |               | 4           | 2.6        | 1–9        | 2          | 1.1        |            |            |            |            |            |
|           |               | 5           | 2.4        | 1–9        | 2          | 1.5        |            |            |            |            |            |
|           |               | 6           | 1.9        | 1–7        | 1          | 1.0        |            |            |            |            |            |
|           |               | 7           | 2.3        | 1–8        | 2          | 1.2        |            |            |            |            |            |
|           |               | 8           | 2.1        | 0–9        | 1          | 0.7        |            |            |            |            |            |
| PI 640516 | Chicken Heart | 1           | 1.8        | 0–5        | 3          | 0.7        |            |            |            |            |            |
|           |               | 2           | 3.0        | 1–9        | 2          | 1.7        |            |            |            |            |            |
|           |               | 3           | 2.3        | 1–9        | 2          | 1.1        |            |            |            |            |            |
| PI 640312 | 871076        | 1           | 0.9        | 0–1        | 1          | 0.2        |            |            |            |            |            |
|           |               | 2           | 1.2        | 1–2        | 1          | 0.2        |            |            |            |            |            |
|           |               | 3           | 0.6        | 0–1        | 0          | 0.5        |            |            |            |            |            |
| PI 640560 | Phyto 636     | 1           | 4.3        | 1–9        | 3          | 3.0        |            |            |            |            |            |
|           |               | 2           | 2.7        | 0–3        | 3          | 0.3        |            |            |            |            |            |
|           |               | 3           | 2.8        | 1–5        | 3          | 1.1        |            |            |            |            |            |
| PI 640581 | U-Kimba       | 1           | 2.2        | 0–4        | 2          | 0.3        |            |            |            |            |            |
|           |               | 2           | 3.3        | 1–9        | 2          | 1.8        |            |            |            |            |            |
|           |               | 3           | 3.1        | 1–9        | 2          | 1.4        |            |            |            |            |            |
| PI 640582 | UL-2190       | 1           | 2.4        | 1–7        | 3          | 1.0        |            |            |            |            |            |
|           |               | 2           | 2.2        | 1–4        | 1          | 1.2        |            |            |            |            |            |
|           |               | 3           | 3.1        | 1–5        | 3          | 1.3        |            |            |            |            |            |
| PI 640588 | YCb 76105     | 1           | 1.3        | 0–3        | 1          | 1.1        |            |            |            |            |            |
|           |               | 2           | 3.0        | 1–9        | 1          | 1.6        |            |            |            |            |            |
|           |               | 3           | 3.0        | 0–9        | 2          | 3.4        |            |            |            |            |            |
| PI 640641 | IR            | 1           | 2.0        | 1–3        | 2          | 0.7        |            |            |            |            |            |
|           |               | 3           | 2.0        | 1–3        | 1          | 0.8        |            |            |            |            |            |
|           |               | 4           | 2.8        | 1–9        | 3          | 1.0        |            |            |            |            |            |
|           |               | 5           | 2.7        | 1–6        | 2          | 1.1        |            |            |            |            |            |
| PI 640333 | Cascabella    | 1           | 0.7        | 0–1        | 1          | 0.4        |            |            |            |            |            |
|           |               | 2           | 0.6        | 0–1        | 1          | 0.4        |            |            |            |            |            |
|           |               | 3           | 0.7        | 0–3        | 0          | 1.2        |            |            |            |            |            |
|           |               |             |            |            |            |            |            |            |            |            |            |

*Lines are selfed seed from individual plants which survived to seed set from the mass screening.

Based on a 0 to 9 scale (Bosland and Lindsey, 1991): 0 = no response; 3 = brown roots, slight stunting; very small lesions on stems; 7 = brown roots, large lesions on stems, girdling, whole plant wilted, and stunted; 9 = dead plants. Means are average of four replicates with six plants per replicate. Numbers in parentheses are overall means and SDs, respectively, for the accession.
Table 3. The response of *Capsicum annuum* accessions to Phytophthora root rot under field conditions.

| Accession/variety | Line number | Root discoloration (%) | Plant survival (%) |
|-------------------|-------------|------------------------|--------------------|
| Camelot (susceptible control) | 1 | 100.0 a | 73.0 c |
| PI 640527 | 2 | 99.3 a |
| PI 611147 | 2 + 3 | 95.3 b |
| PI 439321 | 2 | 99.3 a |
| PI 640588 | 2 + 2 | 99.3 a |
| PI 39273 | 1 | 99.3 a |
| PI 640560 | 1 + 1 | 99.3 a |
| PI 640532 | 1 + 1 | 99.3 a |
| PI 640581 | 2 + 2 | 99.3 a |
| PI 593573 | 2 | 99.3 a |
| PI 640516 | 2 | 99.3 a |
| PI 631147 | 2 | 99.3 a |
| PI 640527 | 1 | 99.3 a |
| PI 439321 | 1 | 99.3 a |
| PI 439273 | 1 | 99.3 a |
| PI 640560 | 1 | 99.3 a |
| PI 640532 | 1 | 99.3 a |
| PI 640581 | 2 | 99.3 a |
| PI 593573 | 2 | 99.3 a |
| PI 640516 | 2 | 99.3 a |
| PI 631147 | 2 | 99.3 a |
| PI 640527 | 1 | 99.3 a |

Lines are selfed seed from individual plants which survived to seed set from the mass screening. Seeds from two lines within an accession were combined in cases in which seeds from one plant were insufficient for further testing.

Percentage of the root system with brown discoloration or rotted. Numbers are averages of five replicates with 20 plants per replicate.

Survival = (number of surviving plants/total number of plants) × 100. Numbers are averages of five replicates with 32 plants per replicate.

can be used in a pepper breeding program. Lastly, the genetic aspects of these resistance sources need to be verified, and the variability among isolates that are responsible for causing each syndrome need to be clarified so that the resistance genes can be effectively used to manage Phytophthora blight in a sustainable way.

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