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Screening of *Cucurbita moschata* Duchesne Germplasm for Crown Rot Resistance to Floridian Isolates of *Phytophthora capsici* Leonian

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***Abstract. Phytophthora capsici* causes seedling death, crown and root rot, fruit rot, and foliar blight on squash and pumpkins (*Cucurbita* spp. L.). A total of 119 *C. moschata* accessions, from 39 geographic locations throughout the world, and a highly susceptible butternut squash cultivar, Butterbush, were inoculated with a suspension of three highly virulent *P. capsici* isolates from Florida to identify resistance to crown rot. Mean disease rating (DR) of the *C. moschata* collection ranged from 1.4 to 5 (0 to 5 scale with 0 resistant and 5 susceptible). Potential resistant and tolerant individuals were identified in the *C. moschata* collection. A set of 18 PIs from the original screen were rescreened for crown rot resistance. This rescreen produced similar results as the original screen ($r = 0.55$, $P = 0.01$). The accessions PI 176531, PI 458740, PI 442266, PI 442262, and PI 634693 were identified with lowest rates of crown infection with a mean DR less than 1.0 and/or individuals with DR = 0. Further selections from these accessions could be made to develop *Cucurbita* breeding lines and cultivars with resistance to crown rot caused by *P. capsici*.**

Cucurbitaceae L. includes ≈120 genera and over 800 species. The family is predominantly of tropical origin with a few members that have been able to adapt to temperate climates. The genus *Cucurbita* consists of five cultivated species and 10 wild species, with perennials or annuals plants (Teppner, 2004).

The most important cultivated species in the genus *Cucurbita* are *C. pepo* L. 'summer squash', *C. maxima* Duchesne 'winter squash', and *C. moschata* 'winter and crookneck squash', and of minor importance, *C. argyrosperma* Huber 'silver-seed gourd' and *C. ficifolia* Bouché 'fig-leaf cucurbit'.

Cucurbita value is based on the use of immature and mature fruit of summer and winter squashes, respectively (Ferriol and Picó, 2008). The Statistic Division of the Food and Agriculture Organization of the United Nations (FAOSTAT data, 2007) ranked world cucurbit production (including watermelons, cucumbers, squash, pumpkins, and gourds) among the 10 leading vegetable crops worldwide. Pumpkin, squash, and gourd production was ≈20 million tons with China as the major producer followed by India, Russia, and the United States.

Cucurbita moschata is a highly diverse winter squash species adapted to hot and humid weather and low altitudes. Fruit size and color are highly variable. Flesh colors range from light yellow to dark orange. *Cucurbita moschata*'s largest genetic variability occurs in the American Tropics with variation increased by hybridization with wild species (Ferriol and Picó, 2008). The Butternut type of *C. moschata* is one of the most widely known in Europe and the United States.

Exotic germplasm and wild species from the USDA germplasm collection are used as genetic resources for breeding. Two wild squash species, *C. lundelliana* Bailey and *C. okeechobeensis* ssp. *okeechobeensis* Bailey, have been recently studied as useful sources for disease resistance such as powdery mildew and *P. capsici* crown rot resistance (Cohen et al., 2003; Contin and Munger, 1977; Metwally et al., 1996; Padley, 2008). *Cucurbita lundelliana* is native to the Yucatan peninsula and can be hybridized with *C. moschata*, *C. maxima*, *C. ficifolia*, *C. pepo*, and *C. argyrosperma* (Ferriol and Picó, 2008; Sitterly, 1972; Whitaker, 1959). *Cucurbita okeechobeensis* is formed by subspecies *okeechobeensis* and *martinezii* Walters & Decker. Subspecies *martinezzi* is endemic to Mexico, growing in the same region as *C. moschata* ssp. *sororia* Merrick & Bates (Ferriol and Picó, 2008). *Cucurbita okeechobeensis* ssp. *okeechobeensis* is endemic to Florida. This subspecies is currently categorized as rare or endangered in the National Germplasm Repository (GRIN, 2009), and it can be hybridized with *C. ecuadorensis* Cutler & Whitaker, *C. moschata*, *C. argyrosperma*, and *C. pepo*. *Cucurbita lundelliana* and *C. okeechobeensis* are also cross-compatible (Ferriol and Picó, 2008).

Interest in breeding for resistance to *P. capsici* is of importance because of the economic impact *P. capsici* syndromes can have on cucurbit production. This oomycete pathogen affects a wide range of solanaceous and cucurbitaceous plants worldwide (Erwin and Ribeiro, 1996; Tian and Babadoost, 2004). Infection can occur at any plant stage, producing damping-off, root rot, crown rot, foliar blight, and fruit rot symptoms (Hausbeck and Lamour, 2004). Losses resulting from *P. capsici* in commercial production can reach 100%. Chemical, cultural, and mechanical practices have been reported to reduce *P. capsici* infection, but multiple cycles of infection and spore production have made its control difficult (Babadoost et al., 2008; Hausbeck and Lamour, 2004). Furthermore, resistance to the fungicides mefenoxam and metalaxyl has been reported in *P. capsici* (Parra and Ristaino, 2001; Ristaino and Johnston, 1999). Genetic resistance to *P. capsici* would constitute an important component of *P. capsici* management.

Recently, resistance to the crown rot syndrome in squash has been introgressed into University of Florida breeding lines, Fla. 27-12 and Fla. 27-17, from *C. lundelliana* and *C. okeechobeensis* ssp. *okeechobeensis* through a series of hybridizations and single plant selections (Padley et al., 2008). The genetic composition of each line is 62.5% *C. moschata*, 25% *C. lundelliana*, and 12.5% *C. okeechobeensis*. Preliminary data also indicated that each line was segregating for resistance to foliar blight (Kabelka, personal communication). Unfortunately, transfer of these sources of resistance into a *C. moschata* background has proven to be challenging as a result of unmarketable fruit quality and hybridization barriers between species. The purpose of this research was to identify sources of resistance to *P. capsici* within the USDA *C. moschata* germplasm collection. This study included the evaluation of the crown rot screen's consistency, identification of resistant individuals, and the response of S_1 progeny from resistant selections to *P. capsici*.

Materials and Methods

Plant material. One hundred nineteen germplasm accessions of *C. moschata*, representing diverse geographic locations (39 countries), were randomly chosen and used for these studies. These accessions were available in the Plant Genetic Resources Conservation and Utilization S-9 collection in Griffin, GA. *C. moschata* 'Butterbush' (W. Atlee Burpee & Co.), a known highly susceptible cultivar, was used as a control for all these studies (Table 1).

Inoculum preparation. Three highly virulent Floridian *P. capsici* mating-type A1 isolates (01-1983A, RJM98-739, and RJM98-805) recovered from squash obtained from Dr. P. Roberts (SWREC, Immokalee, FL) were used. Inoculum was prepared as described by Padley et al. (2008) as follows. One 5-mm mycelial plug from cornmeal agar for each *P. capsici* isolate was transferred to a 20% clarified V8 agar plate to grow at room temperature. After 7 d, 10 5-mm V8 agar mycelial plugs for each isolate were placed into a 20% clarified V8 broth plate

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to grow for an additional 7 d in a 28 °C incubator. Broth was then drained and mycelium was washed two times with sterilized distilled water. Sterilized distilled water was added to cover mycelial growth. Plates were placed under incandescent lights at 28 to 30 °C to induce sporangial development. After 24 h, sporangia were chilled at 4 °C for 45 min to induce zoospore release. Mycelium was strained through cheesecloth. A 1-mL encysted zoospore sample was counted using a hemacytometer. Each isolate was adjusted to 2×10^4 zoospores/mL concentration. A combined suspension of motile zoospores containing equal amounts of the three isolates was used in our study for inoculation.

Screening. Protocols to evaluate the crown response to *P. capsici* in squash were previously described by Tian and Babadoost (2004). Padley et al. (2008) tested and modified these protocols for screening crown rot resistance in *C. pepo* germplasm. Padley's et al. (2008) protocol was used to evaluate the *C. moschata* germplasm collection as follows.

Cucurbita moschata accessions were evaluated using a completely randomized design. Eight seeds per accession and the susceptible control were individually sown in 15.2-cm azalea plastic pots containing Fafard #3S potting mix (Fafard Inc., Agawam, MA). Greenhouse temperatures were maintained between 19 to 34 °C. Seedlings were watered daily and each received 1 g of slow-release fertilizer at the cotyledon stage (Osmocote 14-14-14 NPK; The Scotts Company LLC, Marysville, OH). At the third to fourth true-leaf-stage, each seedling was inoculated at its crown with 5 mL of the 2×10^4 zoospores/mL suspension of the three Floridian *P. capsici* isolates using a pipette. The infection conditions were optimized by saturating the soil 24 to 36 h before inoculation.

Twenty-one d after inoculation, the plants were visually rated based on a scale ranging from 0 to 5, in which 0 = no symptoms, 1 = small brown lesion at base of stem, 2 = lesion has progressed up to the cotyledons causing constriction at the base, 3 = plant has partially collapsed with apparent wilting of leaves, 4 = plant has completely collapsed with severe wilting present, and 5 = plant death (Fig. 1). A mean DR, calculated as a weighted average, SD, and a percentage of plants with a DR 1 or less, was calculated for each accession and the susceptible control. Plants with a DR less than 2 were considered resistant/tolerant and with a DR of 2 to 5 were considered susceptible to crown rot produced by *P. capsici*.

Rescreen. Eighteen accessions were chosen from the original screening results for crown rot resistance to *P. capsici* as follows: 14 accessions with a DR of 0 to 2.8, two accessions with a DR of 3.4, and two accessions with a DR of 5.0 (Table 1). These accessions were selected to represent low, medium, and high DR from the original screen. Selected accessions were rescreened for crown rot resistance to *P. capsici* using the protocol described previously. The susceptible cultivar 'Butterbush' was also included as a control in these studies.

Table 1. Mean disease ratings of *Cucurbita moschata* accessions screened with a suspension of three *Phytophthora capsici* isolates from Florida.[z]

Accession[y]		Mean DR[x] (0 to 5 scale)		SD		Plants DR1 or less (%)		Origin
PI	634693	1.4	(0.9)[w]	0.7	(0.4)	75.0	(100.0)	India
PI	483347	1.6	(1.6)	1.4	(1.4)	75.0	(75.0)	Korea
PI	458740	2.0	(0.7)	1.4	(0.5)	42.9	(100.0)	Paraguay
PI	483346	2.1	(5.0)	1.8	(0.0)	62.5	(0.0)	Korea
PI	500537	2.1	(2.1)	1.2	(1.8)	25.0	(62.5)	Zambia
PI	211996	2.3	(4.6)	2.0	(1.1)	12.5	(0.0)	Iran
PI	442262	2.3	(0.9)	1.5	(0.4)	37.5	(100.0)	Mexico
PI	442266	2.3	(0.9)	1.8	(0.4)	50.0	(100.0)	Mexico
PI	543228	2.3	(2.6)	1.8	(2.0)	50.0	(50.0)	Bolivia
PI	511952	2.5	(3.8)	1.9	(1.8)	50.0	(12.5)	Mexico
PI	458728	2.6	(2.4)	1.8	(1.9)	37.5	(62.5)	Argentina
PI	418965	2.7	(1.6)	1.9	(1.6)	33.3	(75.0)	China
PI	176531	2.8	(2.5)	2.3	(1.9)	37.5	(50.0)	Turkey
PI	500558	2.8	(3.5)	1.5	(2.1)	12.5	(37.5)	Zambia
PI	182197	2.9		1.5		12.5		Turkey
PI	500559	2.9		1.8		25.0		Zambia
PI	512169	2.9		1.9		37.5		Mexico
PI	475750	3.0		1.5		12.5		Paraguay
PI	222760	3.4		1.8		12.5		Iran
PI	442273	3.4	(2.3)	1.8	(1.8)	12.5	(37.5)	Mexico
PI	449349	3.4	(5.0)	1.8	(0.0)	12.5	(0.0)	Guatemala
PI	247674	3.4		1.5		0.0		Zaire
PI	169441	3.5		1.6		0.0		Turkey
PI	201474	3.5		1.6		0.0		Mexico
PI	634706	3.5		1.6		0.0		Sri Lanka
PI	211999	3.6		1.9		25.0		Iran
PI	634705	3.6		1.9		25.0		Nepal
Grif	5603	3.8		1.8		12.5		India
PI	381813	3.8		1.8		12.5		India
PI	381816	3.8		1.8		12.5		India
PI	442283	3.8		1.5		0.0		Mexico
PI	451835	3.8		1.8		12.5		Guatemala
PI	482573	3.8		1.8		12.5		Zimbabwe
PI	490020	3.8		1.8		12.5		Malaysia
PI	500506	3.8		1.8		25.0		Zambia
PI	432453	3.8		1.8		16.6		Ecuador
PI	358507	3.9		1.6		12.5		United States
PI	634692	3.9		1.6		12.5		Yemen
PI	379296	4.0		1.9		25.0		Former Serbia and Montenegro
PI	165033	4.1		1.6		12.5		Turkey
PI	200822	4.1		1.6		12.5		Myanmar
PI	257532	4.1		1.6		12.5		Spain
PI	357918	4.1		1.6		12.5		Former Serbia and Montenegro
PI	442250	4.1		1.6		12.5		Mexico
PI	458743	4.1		1.6		12.5		Paraguay
PI	500562	4.1		1.6		12.5		Zambia
PI	524427	4.1		1.4		0.0		Zambia
PI	312125	4.3		1.4		0.0		Guatemala
PI	419202	4.3		1.4		0.0		China
PI	438549	4.3		1.4		0.0		Belize
PI	438796	4.3		1.4		0.0		Mexico
PI	500536	4.3		1.2		0.0		Zambia
PI	512675	4.3		1.5		0.0		Spain
PI	634695	4.3		1.3		0.0		China
PI	163229	4.4		1.2		0.0		India
PI	653840	4.4		1.3		0.0		China
Grif	935	4.5		1.4		12.5		Nepal
Grif	1738	4.5		1.4		12.5		Nepal
PI	200823	4.5		1.4		12.5		Myanmar
PI	357919	4.5		1.4		12.5		Former Serbia and Montenegro
PI	419083	4.5		1.1		0.0		China
PI	419137	4.5		0.9		0.0		China
PI	482548	4.5		1.1		0.0		Zimbabwe
PI	482549	4.5		1.4		12.5		Zimbabwe
PI	550690	4.5		1.4		12.5		United States
PI	135371	4.6		1.1		0.0		Afghanistan
PI	482536	4.6		1.1		0.0		Zimbabwe
PI	200737	4.6		1.1		0.0		Guatemala
PI	255345	4.6		1.1		0.0		Iran

(*Continued on next page*)

Table 1. (*Continued*) Mean disease ratings of *Cucurbita moschata* accessions screened with a suspension of three *Phytophthora capsici* isolates from Florida.[z]

Accession[y]		Mean DR[x] (0 to 5 scale)		SD		Plants DR1 or less (%)		Origin
PI	368585	4.6		1.1		0.0		Former Serbia and Montenegro
PI	442272	4.6		1.1		0.0		Mexico
PI	482513	4.6		1.1		0.0		Zimbabwe
PI	482538	4.6		1.1		0.0		Zimbabwe
PI	483345	4.6		1.1		0.0		Korea
PI	163230	4.8		0.7		0.0		India
PI	211998	4.8		0.7		0.0		Iran
PI	498429	4.8		0.7		0.0		Colombia
PI	442252	4.9		0.4		0.0		Mexico
Grif	1583	5.0		0.0		0.0		China
Grif	9457	5.0		0.0		0.0		United States
PI	135375	5.0		0.0		0.0		Afghanistan
PI	165575	5.0		0.0		0.0		India
PI	169410	5.0		0.0		0.0		Turkey
PI	169415	5.0		0.0		0.0		Turkey
PI	174194	5.0		0.0		0.0		Turkey
PI	183258	5.0		0.0		0.0		Saudi Arabia
PI	199014	5.0		0.0		0.0		Africa
PI	200736	5.0		0.0		0.0		El Salvador
PI	201772	5.0		0.0		0.0		United States
PI	201858	5.0		0.0		0.0		Iran
PI	209116	5.0		0.0		0.0		Puerto Rico
PI	209117	5.0		0.0		0.0		Puerto Rico
PI	222785	5.0		0.0		0.0		Iran
PI	244707	5.0		0.0		0.0		Brazil
PI	249565	5.0		0.0		0.0		Thailand
PI	264551	5.0		0.0		0.0		Guatemala
PI	287532	5.0		—		0.0		Italy
PI	288239	5.0		0.0		0.0		Egypt
PI	369346	5.0		0.0		0.0		Costa Rica
PI	406848	5.0		0.0		0.0		Honduras
PI	438548	5.0		0.0		0.0		Belize
PI	438551	5.0		0.0		0.0		Belize
PI	438553	5.0		0.0		0.0		Belize
PI	438741	5.0		0.0		0.0		Mexico
PI	441723	5.0		0.0		0.0		Brazil
PI	441725	5.0		0.0		0.0		Brazil
PI	441726	5.0		0.0		0.0		Brazil
PI	451841	5.0		0.0		0.0		Guatemala
PI	451846	5.0		0.0		0.0		Guatemala
PI	458650	5.0		0.0		0.0		Suriname
PI	482492	5.0		0.0		0.0		Zimbabwe
PI	482500	5.0		0.0		0.0		Zimbabwe
PI	490351	5.0		0.0		0.0		Burkina Faso
PI	490354	5.0		0.0		0.0		Burkina Faso
PI	536494	5.0		0.0		0.0		Maldives
PI	560946	5.0		0.0		0.0		Bolivia
PI	560952	5.0	(4.5)	0.0	(1.4)	0.0	(12.5)	Bolivia
PI	595436	5.0	(5.0)	0.0	(0.0)	0.0	(0.0)	Puerto Rico
PI	438810	—		—				Mexico
Butterbush[v]		5.0	(4.3)	0.0	(1.5)	0.0	(0.0)	United States

[z]Accessions are ranked according to their mean disease rating (DR). Data in parentheses are rescreened genotype results.
[y]Accession prefix and number.
[x]DR = 0 to 5, in which 0 = no symptoms, 1 = small brown lesion at base of stem, 2 = lesion has progressed up to the cotyledons causing constriction at the base, 3 = plant has partially collapsed with apparent wilting of leaves, 4 = plant has completely collapsed with severe wilting present, and 5 = plant death.
[w]Rescreen accessions were chosen with low (mean DR of 0 to 2.8), medium (mean DR = 3.4), and high values (mean DR = 5.0) from the original screen.
[v]Butterbush, highly susceptible cultivar to crown rot.

A mean DR, SD, and percentage of plants with a DR 1 or less were calculated for each accession and the susceptible control. Consistency between the original and the rescreen DRs were compared using Spearman's rank correlation coefficient.

Screening of S_1 progeny from resistant individuals. Two plants of PI 211996 and PI 176531, identified in the original screening results were grown and self-pollinated to obtain S_1 seed (Table 2). Eight S_1 seeds per resistant selection and a susceptible cultivar, Butterbush, were planted and grown. Plants were screened for crown rot resistance to *P. capsici* as described previously. A mean DR, SD, and a percentage of plants with a DR 1 or less were calculated.

Disease ratings were compared by using a Wilcoxon analysis ($P < 0.05$). Data analysis was performed using the NPAR1WAY procedure of SAS (Statistical Analysis System Version 9.1; SAS Institute, Cary, NC).

Results and Discussion

Potential sources of resistance to crown rot produced by *P. capsici* were identified in the *C. moschata* collection. Mean DR for the screened *C. moschata* germplasm ranged from 1.4 to 5.0 (Table 1). PI 634693 (from India) and PI 483347 (from Korea) with a mean DR of 1.4 and 1.6, respectively, had the lowest mean DR values and were considered possible sources of resistance and/or tolerance to *P. capsici*. Additional PIs from these results were considered susceptible with higher DR values. The number of accessions with a mean DR of 2.0 to 2.9, 3.0 to 3.9, 4.0 to 4.9, and 5.0 were 15, 21, 40, and 41, respectively. Among these screened PIs, only two plants of PI 211996 (Iran) and two plants of PI 176531 (Turkey) were resistant (DR = 0) to *P. capsici*. However, ≈39.5% of the 119 screened PIs had at least one individual with a resistant phenotype with a DR = 1.

Fourteen accessions representing a low mean DR of 0 to 2.8, two accessions with a medium mean DR = 3.4, and two accessions with a high mean DR = 5.0 were chosen from the original screen and were rescreened for *P. capsici* resistance. Mean DR for the rescreened accessions ranged from 0.7 to 5.0 (Table 1). PI 458740 (from Paraguay), PI 442266 (from Mexico), PI 442262 (from Mexico), and PI 634693 (from India) had a mean DR less than 1.0 and were selected as sources of resistance to crown rot. The number of accessions for the remaining PIs with a mean DR of 1.0 to 1.9, 2.0 to 2.9, 3.0 to 3.9, 4.0 to 4.9, and 5.0 were 2, 6, 1, 2, and 3, respectively. The rescreen identified a total of seven seedlings from accessions PI 458740 (two), PI 442266 (one), PI 442262 (one), PI 634693 (one), PI 418965 (one), and PI 442273 (one) resistant to *P. capsici* (DR = 0). Fourteen accessions had at least one genotype with a DR = 1.

Cucurbita moschata cv. Butterbush was highly susceptible with a mean DR of 5.0 and 4.3 and SD of 0 and 1.5 in the screen and rescreen experiments, respectively. The susceptible control 'Butterbush' was highly susceptible in all the experiments when inoculated with *P. capsici*, confirming the efficiency of the screening method because of the absence of escapes.

The presence of a large number of seedlings with DR = 1 was attributed to the genetic variation within each accession. However, genotypes with DR = 1 were not used for further breeding and selection because of their unknown genetic make-up. One or several genes could be associated with resistance to *P. capsici* in the *C. moschata* germplasm. Padley et al. (2009) reported that resistance to crown rot caused by *P. capsici* was conferred by three dominant genes in a F_7 breeding line derived of *C. lundelliana*, *C. okeechobeensis*, and *C. moschata* species in its pedigree.

Previous research investigating resistance to *P. capsici* reported that environmental variation can affect the screening results as a result of uncontrolled conditions. Walker

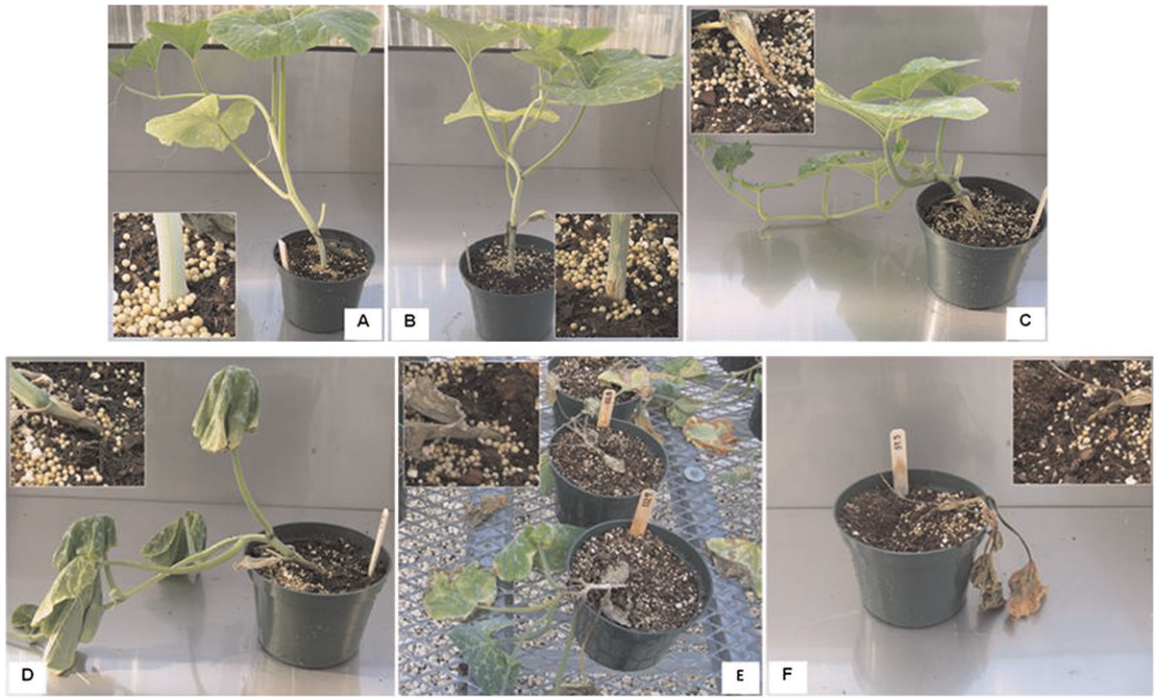

Fig. 1. Disease rating (DR), 0 to 5 scale, for response of *Cucurbita moschata* germplasm to crown rot caused by *Phytophthora capsici*. Symptoms rated 21 d after inoculation: (**A**) score 0 = no symptoms; (**B**) score 1 = small brown lesion at base of stem; (**C**) score 2 = lesion has progressed up to the cotyledons causing constriction at the base; (**D**) score 3 = plant has partially collapsed with apparent wilting of leaves; (**E**) score 4 = plant has completely collapsed with severe wilting present; and (**F**) score 5 = plant death.

Table 2. Segregation for resistance to *Phytophthora* crown rot in S_1 progeny generated by selfing resistant seedlings (DR = 0) of PI 211996 and PI 176531 from the original screen results.[z]

Accession[y]		Plants per DR[x] (no.)						Mean DR[x] (0 to 5 scale)	SD	Plants DR 1 or less (%)
		0	1	2	3	4	5			
PI_A[w]	211996	2	1	2	1	0	2	2.3	2.0	37.5
$S_1(PI_A)$	S_1(211996)	2	2	2	0	0	2	2.0	2.0	50.0
PI_B	176531	2	1	1	0	1	3	2.8	2.3	37.5
$S_1(PI_B)$	S_1(176531)	0	6	0	0	0	2	2.0	1.9	75.0
$S_1(PI_B)$	S_1(176531)	0	4	1	0	1	2	2.5	1.9	50.0
BB	Butterbush	0	0	0	0	0	8	5.0	0.0	0.0

[z]Accessions and their S_1 progeny screen results based on the number of plants per DR (0 to 5 scale) and their mean DR. Accessions are ranked by generation.
[y]Accession prefix and number.
[x]DR = disease rating (0 to 5), in which 0 = no symptoms, 1 = small brown lesion at base of stem, 2 = lesion has progressed up to the cotyledons causing constriction at the base, 3 = plant has partially collapsed with apparent wilting of leaves, 4 = plant has completely collapsed with severe wilting present, and 5 = plant death.
[w]S_1 = first generation obtained from self-pollination of resistant plants (DR = 0). Subscript A and B represent the two different accessions used in selection.

and Bosland (1999) reported that efforts in breeding and selection for resistant cultivars to *P. capsici* could be ineffective in pepper if screening methods do not allow for the separation of resistant and susceptible genotypes for root rot and foliar blight disease syndromes. Similarly, Reifschneider et al. (1986) described the importance of controlling several factors affecting the expression of resistance to blight caused by *P. capsici* in pepper. Plant age, isolate virulence, zoospore concentration, and inoculation method affected their screening results. They suggested the use of standardized screening methods to identify resistant plants.

Padley et al. (2008, 2009) developed and reported an effective method for screening genotypes with crown rot resistance to *P. capsici* in squash, which consistently differentiated resistant and susceptible genotypes. Controlled environmental conditions were maintained that excluded sources of variation between the original screen and the rescreen results for all our experiments.

Comparisons between the original screen and the rescreen gave a Spearman's rank correlation coefficient of $r = 0.55$ ($P = 0.01$). Variation in these experiments as noted by the Spearman's rank correlation coefficient and their DR was believed to be largely attributed to the presence of heterogeneity for resistance to crown rot in the *C. moschata* germplasm accessions. Small sample size, unknown number of resistance genes for *P. capsici*, and bias toward low mean DR accessions during rescreening could be partially responsible for the reduced correlation coefficient between experiments. Furthermore, if the resistant phenotype is conditioned by dominant alleles at three loci as reported by Padley et al. (2009), then the resistant phenotype could represent as few as ≈43% in S_1 progeny from heterozygous resistant genotypes. If the trait being selected is polygenic, then a large number of segregating plants will be required to obtain the desired genotype. These factors did not appear to affect the results and selection for resistant genotypes. It was noticed that the screened accessions shifted positions between experiments (ranks) but always had a lower mean DR when compared with susceptible accessions (Table 1).

Heterogeneity for resistance to crown rot in *Cucurbita* was previously reported by Padley et al. (2008). They found that resistance to crown rot caused by Florida *P. capsici* isolates was segregating within some of the *C. pepo* PIs and that additional breeding and selection were necessary to fix the resistance into a breeding line. Donahoo et al. (2009) described the existence of variable levels of host resistance in *Cucumis melo* L. PIs. Likewise, Kousik and Thies (2010) reported heterogeneity for resistance to *P. capsici* in bottle gourd, *Lagenaria siceraria* Standl.

The existence of heterogeneity in our selected germplasm for resistance to *P. capsici* was analyzed in the S_1 progeny of four resistant plants with DR = 0, PI 211996 (two plants) and PI 176531 (two plants). One of the resistant plants (from PI 211996) did not produce seed when self-pollinated. Padley (2008) reported similar fertility problems in advanced breeding lines of *C. pepo*. The screening of eight seedlings each from the three remaining *P. capsici* crown rot-resistant selections

revealed that the mean DR of selected resistant PIs and their S_1 progeny were not significantly different (Table 2). However, an increase of at least one to three plants with a DR 1 or less was observed between PIs and S_1 progeny. These results indicated that the PIs were heterozygous for the resistance genes and that the frequency of resistant genotypes could be increased in advanced generations.

Similar findings were reported in tomato, pepper, and pumpkin in which different levels of resistance to *P. capsici* were attributed to a partial (quantitative) resistance (Hwang and Hwang, 1993; Kim and Hwang, 1992; Lee et al., 2001). Inheritance of *P. capsici* resistance in pepper and squash was reported to be governed by three genes, inherited in a Mendelian fashion, which formed part of the whole root rot, crown rot, and foliar blight resistance (Padley et al., 2009; Walker and Bosland, 1999).

Resistant and tolerant genotypes to foliar blight and fruit rot caused by *P. capsici* have been found in breeding lines derived from *C. okeechobeensis* and *C. lundelliana* at the University of Florida. These resistant genotypes varied among experiments depending on the syndrome being evaluated. A tissue-specific genetic control for resistance to *P. capsici* in squash is believed to be present (Chavez and Kabelka, unpublished results). In pepper, tissue specificity for the genes controlling resistance to *P. capsici* has been reported (Barksdale et al., 1984; Sy et al., 2005; Walker and Bosland, 1999). Further studies to differentiate the effect of each syndrome produced by *P. capsici* in resistant lines are necessary.

In conclusion, resistance to *P. capsici* was found in representatives of the USDA *C. moschata* germplasm collection. Accessions PI 176531, PI 458740, PI 442266, PI 442262, and PI 634693 were the most resistant with a mean DR less than 1.0 and/or individuals with DR = 0. These differences among screen and rescreen results in the *C. moschata* germplasm were attributed to segregation for resistance to crown rot caused by *P. capsici*. Similar results were obtained when different accessions progeny showed some differences in mean DR when compared with their parents. Selection of resistant and/or tolerant genotypes for crown rot caused by *P. capsici* can be done through screening and selection. Future projects will require studying resistance of selected individuals for crown rot, foliar blight, fruit rot, and their interaction.

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