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Resistance to Belly Rot in Cucumber Identified through Field and Detached-fruit Evaluations

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Abstract. **Belly rot, caused by the fungal pathogen *Rhizoctonia solani* Kühn., is a severe disease in many regions that produce cucumber (*Cucumis sativus* L.). Annual crop loss to belly rot is commonly 5% to 10%, but losses as high as 80% can occur in individual fields. There are no resistant cultivars, so fungicides are used to provide partial control. Genetic resistance in an acceptable cultivar would be more desirable and economical. Studies were conducted in Summers 1991 and 1992 to screen promising germplasm for belly rot resistance using field and detached-fruit screening methods. In 1991, 105 cultigens (cultivars, breeding lines, and plant introduction accessions) were evaluated for belly rot resistance. The tests were repeated in 1992 with 63 cultigens, including the most resistant cultigens identified in 1991 and appropriate controls. Several cultigens were identified as potential sources of resistance genes. Pickling cucumbers showing resistance included PI 197085, PI 271328, and an F_4 selection of PI 197087 x PI 280096. Slicing cucumbers with resistance included 'Marketmore 76' and the F_1 of Gy 14 x PI 197087. Belly rot resistance was not correlated with other horticultural traits measured, including fruit type, skin type, spine color, and firmness. The resistant cultigens identified should be useful for developing cucumber cultivars with enhanced resistance to *Rhizoctonia solani*.**

Cucumbers are an important vegetable crop in many regions of the world. In the United States, a concentrated area of cucumber production is located in the southeastern United States, where North Carolina is the second leading state in pickling cucumber production and fourth leading state in slicing cucumber production [U.S. Dept. of Agriculture (USDA), 1990]. The warm and humid climate of this region is favorable to many fungal pathogens, including *Rhizoctonia solani* (AG-4), which is the causal agent of belly rot. Yield losses to belly rot typically range from 5% to 10% (Jenkins and Averre, 1981), but may be as high as 80% in individual fields (Lewis and Papavizas, 1980). In North Carolina, belly rot is estimated to be present in 72% of all cucumber fields (St. Amand and Wehner, 1991). Symptoms appear as sunken, brown, necrotic lesions, which often develop a hard, corky layer (Jenkins and Averre, 1981) and which can appear on apparently healthy fruit in as little as 24 h. Blemishes on the fruit result in an unmarketable product.

Fungicides have been used to control belly rot, but those methods often provide inadequate control and are not economical (Halterlein et al., 1981; Jones, 1961). Similarly, solarization has been shown to reduce the level of *R. solani* in the soil, although this technique may not be possible for all growers (Keinath, 1995). Biological control may soon become an option for controlling *Rhizoctonia*-caused diseases. Bacteria such as *Pseudomonas* spp. (De Freitas and Germida, 1991; Fridlender et al., 1993), *Laetisaria* spp. (Lewis and Papavizas, 1992), and several other species have been shown to be antagonistic toward *R. solani*. Unfortunately, biological control alone is often inconsistent under production conditions and may not provide sufficient protection where product appearance is a measure of quality.

An unavailable means of control is genetic resistance in acceptable cultivars. Resistant cultivars used alone or combined with other control methods could be an economic means of controlling belly rot. Tests for identifying resistant cucumbers have been developed using field and detached-fruit screening methods (Wehner and Jenkins, 1986) to identify resistant cultigens (breeding lines, cultivars, and plant introduction accessions) for use in a breeding program.

Studies were designed to 1) increase the understanding of belly rot resistance and 2) evaluate cucumber cultigens using modifications of previously described field and detached-fruit tests to identify belly rot-resistant cultigens for use in breeding. Additionally, we compared disease incidence and disease severity measurements for evaluating belly rot resistance and attempted to correlate resistance with several horticultural traits.

Materials and Methods

Field tests were conducted in Summers 1991 and 1992 at the Horticultural Crops Research Station at Clinton, N.C. All cucumbers were grown using recommended horticultural practices (Schultheis, 1990). Fertilizer was incorporated before planting at a rate of 90N–39P–74K ($kg \cdot ha^{-1}$), and a side dressing of N at 34 $kg \cdot ha^{-1}$ was applied at the vine tip-over stage. Plots 1.5 m long (separated by 1.5-m alleys) were planted on raised, shaped beds. Plots were overplanted and thinned to 10 plants in 1991 and 15 plants in 1992. Irrigation was applied as needed up to three times a week for a minimum of 25 mm (including rainfall) per week. Weed control was provided by ethalfluralin (Curbit) 3 EC at 4.8 $L \cdot ha^{-1}$.

Inoculum preparation. Inoculum was prepared by mixing 5 kg of crimped oats (the substrate for the fungus) with 3 L of tap water in Nalgene autoclavable trays (540 × 435 × 130 mm). The mixture was allowed to sit overnight. The trays were then autoclaved the following 2 consecutive days for 90 min at 121 °C. A suspension was made that consisted of one 100-mm-diameter potato dextrose agar (PDA) plate (20 mL agar) of 7-d-old *R. solani* per 300 mL of sterile water blended for 30 s. The resulting suspension was then poured over the sterile oats and allowed to grow for 4 to 6 weeks at room temperature. Trays were sampled periodically to confirm growth of *R. solani*. Contaminated trays were discarded.

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Inoculum preparation was changed slightly in 1992. Instead of inoculating the oats with a suspension, twenty 7-mm-diameter disks were punched directly from PDA plates and spread over each tray. After the fungus had completely colonized the oats (6 weeks), the trays were stored at 13 °C until needed.

Field test, 1991. The 1991 field test was a randomized complete-block design, with 105 cultigens and six replications. Seeds were planted on 13 May, and included all cultigens identified as resistant in previous experiments and check cultivars. Pickling and slicing cucumber germplasm was tested together. The field was infested at the vine tip-over stage (18 June) using oat grains infested with *R. solani* at a rate of 6400 grains/m^2. Three fungal isolates of *R. solani* were used in 1991: Rs-H-58, isolated in Mississippi from cucumber during 1984; Rs-H-16, isolated in Clayton, N.C., from cucumber during 1983; and Rs-H-06, isolated in Clinton from cucumber during 1983. Isolates were blended together in equal amounts before infesting the field. Three isolates were used in the first year to mimic the variation of natural populations that might be found in an infested field. In subsequent experiments, the number and identity of isolates used varied based on isolate availability.

One week before the anticipated harvest, all fruit were picked off and discarded to ensure proper size of developing fruit (50 mm in diameter) for rating the following week on 8 July. Only fruit that had reached the proper size and that were resting on the soil were rated. A mean was determined for each plot by evaluating all available fruit. Disease severity was estimated by visually estimating the percentage of the fruit surface damaged on all fruit in each plot. Disease severity was rated on a scale of 1 to 9, where 1 = no disease, 2 = 1% of fruit surface with lesions, 3 = 2% to 3% of fruit surface with lesions, 4 = 4% to 6% of fruit surface with lesions, 5 = 7% to 10% of fruit surface with lesions, 6 = 11% to 15% of fruit surface with lesions, 7 = 15% to 20% of fruit surface with lesions, 8 = 21% to 30% of fruit surface with lesions, and 9 = more than 30% of fruit surface with lesions.

Other traits measured included fruit type (pickle, slicer, Beit alpha = Middle Eastern origin with smooth skin and few spines, or wild = horticulturally unacceptable), skin type (smooth, warty, or netted), spine color (white, brown, or black), and fruit firmness. Firmness was measured by punching three fruit per plot on the top carpel, one-third of the way from the peduncle end, using a USDA fruit tester with an 8-mm-diameter tip (Blanpied et al., 1978).

Detached-fruit test, 1991. The detached-fruit test was a randomized complete-block design with 105 cultigens, three replicates, and three harvest dates. The same 105 cultigens that were tested in the 1991 field test were used but were grown in a separate plot. The test was conducted in a greenhouse on flats infested at a rate of 6400 grains/m^2, with *R. solani* isolate Rs-H-58.

One 50-mm-diameter fruit was harvested on each of three dates (17 June, 24 June, and 5 July) from each plot, dipped in a 10% Clorox solution (2.6% sodium hypochlorite), allowed to air dry, and placed on the inoculated flats containing moist, steam-sterilized field soil. Flats were placed in a dark humidity chamber for the duration of the test (25 to 30 °C and ≈100% relative humidity). Fruit were rated on 25 June, 4 July, and 16 July in the same manner as the 1991 field test.

Field test, 1992. The 1992 field test, planted 11 May, was a randomized complete-block design with four replications. The evaluation was conducted separately for the pickling and slicing cucumber germplasm. In the pickling cucumber evaluation 39 cultigens were tested, and in the slicing cucumber evaluation 24 cultigens were evaluated. Cultigens evaluated included the most resistant cultigens identified the previous year, untested cultigens, and susceptible control cultivars (Gy 14 x PI 419108 and Coolgreen).

The field was infested on 24 June using colonized oat grains as described above. Two isolates were used in 1992 (Rs-H-143N isolated in Clayton from cucumber during 1986 and Rs-H-16). All fruit were picked off and discarded 1 week before harvest as in previous experiments. Disease severity was estimated as previously described, and disease incidence was measured by counting the number of infected fruit and dividing by the total number of fruit in each plot. Pickling cucumbers were rated on 6 July and slicing cucumbers on 9 July. Because plants were still healthy, all fruit except grade no. 1 were removed from the vines so a second rating could be made. All plots (pickling and slicing) were rated again on 16 July. Other data collected included stand count, plant type [determinate (*de*)] vs. indeterminate (*De*)], fruit type, number of staminate nodes in the first five nodes on five plants per plot, number of oversized (early) fruit, number of cull (nubbin and crooked) fruit, and ratings for shape, color, seed cell size, and overall impression of fruit quality. Horticultural traits were evaluated on a visual 1 to 9 scale, where lower ratings indicated greater quality.

Statistical analysis. Data were analyzed as plot means using the GLM procedure of SAS (SAS Institute, Cary, N.C.). Cultigen means were compared using Fisher's protected LSD at $P = 0.05$. Pearson correlation coefficients were calculated to make comparisons among measured traits and belly rot resistance.

Results

In general, severe disease development was observed in all three screening tests based on comparison of means to the susceptible control cultigens PI 432855 (Table 1), Gy 14 x PI 419108 (Table 2), and Coolgreen (Table 3). However, there were many individual fruit in each test with no symptoms, some of which are likely escapes from disease.

Field test, 1991. Disease severity ranged from a mean rating of 1 (no disease) for PI 197085 and an F_4 selection of PI 197087 x PI 280096 to a mean rating of 6.2 for PI 419108 and PI 109063 (Table 1). The mean of the experiment was a rating of 4.5, indicating that an average of 4% to 6% of the fruit surface was damaged by disease. The horticulturally acceptable breeding line NCBR1-C1(1) also exhibited belly rot resistance, with a mean severity rating of 1.4%. Cultivars among the most resistant included Addis, Ashley, Pacer, Pixie, and Sprint 440. Important correlations between belly rot resistance and other horticultural traits were not identified, although significant ($p = 0.05$) Pearson correlation coefficients were found among belly rot resistance and three traits including fruit type ($r = 0.12$), skin type ($r = 0.11$), and spine color ($r = -0.11$). The correlation coefficient between firmness and belly rot resistance was not significant ($p = 0.82$).

Detached-fruit test, 1991. There were significant differences among harvests for the detached-fruit test. There was also a significant cultigen × harvest interaction, although this was expected because of the large number of cultigens. Cultigens ranged in resistance from a mean low rating of 2 to a mean high rating of 7.8, with an experiment mean of 5.2 (Table 1). The most resistant cultigens included 'Marketmore 76', 'Wautoma', M 30, and PI 163216. Significant ($p = 0.05$) correlation coefficients among belly rot resistance and horticultural traits ranged from $r = 0.08$ for fruit type to $r = 0.22$ for spine color (data not shown), indicating that disease resistance was independent of important horticultural traits.

Field test, 1992. Mean severity ratings ranged from 2.1 to 8.6 for pickling cucumbers (Table 2). The mean for the first harvest was slightly higher at 5.6 compared to 4.8 for the second harvest. Disease incidence among cultigens ranged from 6.3% to 61.7%

Table 1. Belly rot resistance in the 1991 field and detached fruit studies, with cultigens listed in order of decreasing resistance based on the mean of the two experiments. Disease severity is based on a 1 to 9 visual rating scale.[z]

Rank	Cultigen	Seed origin	Seed source	Disease severity		
				Mean	Field	Detached-fruit
1	Marketmore 76	Cornell Univ.	Asgrow Seed	2.7	3.4	2.0
2	NCBR1-C1(1)	N.C. State Univ.	88-GH-301⊗	2.9	1.4	4.4
3	Addis	N. C. State Univ.	N.C. State Univ.	3.0	2.8	3.3
4	M 30	N.C. State Univ.	88-GH-254-1⊗	3.0	---	3.0
5	PI 163216	India	88-GH-186⊗	3.0	---	3.0
6	PI 197085	India	88-GH-256⊗	3.2	1.0	5.5
7	PI 197087 x PI 163216	N.C. State Univ.	90-GH-955⊗	3.3	---	3.3
8	PI 197087 x PI 280096	N.C. State Univ.	90-GH-953⊗	3.5	1.0	6.0
9	PI 271328	India	90-GH-949⊗	3.5	3.5	---
10	Sprint 440	Asgrow Seed	Asgrow Seed	3.6	3.5	3.6
11	Clinton	N.C. State Univ.	Petoseed	3.7	3.8	3.6
12	Calypso	N.C. State Univ.	Petoseed	3.8	4.3	3.2
13	NCBR1-C1(2)	N.C. State Univ.	88-GH-800-1⊗	3.8	3.7	3.9
14	Wautoma	Wis.–USDA	N.C. State Univ.	3.8	4.7	2.9
15	Regal	N.C. State Univ.	Harris-Moran	3.8	3.5	4.2
16	M 21	N.C. State Univ.	N.C. State Univ.	3.9	4.7	3.1
17	Poinsett 76	Cornell Univ.	N.C. State Univ.	3.9	3.7	4.1
18	M 16	N.C. State Univ.	90-GH-942⊗	4.0	4.3	3.8
19	PI 280096 x PI 197088	N.C. State Univ.	88-GH-263-1⊗	4.0	2.3	5.8
20	Pacer	Harris-Moran	Harris-Moran	4.2	3.0	5.3
21	Pixie	Clemson Univ.	N.C. State Univ.	4.2	3.5	4.9
22	Gy 14 x PI 197085	N.C. State Univ.	86-GH-709 x 763	4.2	2.5	6.0
23	Gy 14 x PI 197087	N.C. State Univ.	86-GH-709 x 765	4.2	3.2	5.3
24	PI 414159	United States	90-GH-939⊗	4.2	4.5	4.0
25	PI 105340	P.R. China	90-GH-938⊗	4.2	4.7	3.8
26	Chipper	Clemson Univ.	N.C. State Univ.	4.4	4.5	4.2
27	NCBR1-A2(2)	N.C. State Univ.	90-GH-965⊗	4.4	5.0	3.9
28	Dasher II	Petoseed	Petoseed	4.4	5.5	3.4
29	Gy 14 x PI 109483(1)	N.C. State Univ.	90-GH-926⊗	4.4	4.0	4.9
30	Gy 14 x PI 109483(2)	N.C. State Univ.	90-GH-925#	4.4	3.6	5.3
31	M 21 x PI 197088	N.C. State Univ.	86-GH-450⊗	4.4	4.6	4.3
32	PI 165509	India	88-GH-713⊗	4.4	4.7	4.1
33	Pacer x PI 197087(1)	N.C. State Univ.	90-GH-957⊗	4.4	4.7	4.2
34	NCBR1-C3	N.C. State Univ.	88-GH-804-1⊗	4.4	3.0	5.9
35	Gy 14 x PI 179676	N.C. State Univ.	86-GH-709 x 735	4.5	4.7	4.3
36	NCBR1-B2(2)	N. C. State Univ.	88-GH-793-1⊗	4.5	5.0	4.0
37	NCBR1-B2(1)	N.C. State Univ.	88-GH-298-1⊗	4.5	4.8	4.2
38	PI 197088	India	90-GH-945⊗	4.5	4.5	---
39	Gy 14 x PI 165509	N.C. State Univ.	90-GH-928⊗	4.6	3.4	5.7
40	NCBR1-B4(2)	N.C. State Univ.	88-GH-300⊗	4.6	4.5	4.6
41	NCBR1-B1(1)	N.C. State Univ.	88-GH-1207-1⊗	4.6	4.5	4.6
42	NCBR1-C2	N.C. State Univ.	88-GH-302⊗	4.6	4.2	5.0
43	Wis. SMR 18	Univ. Wis.	N.C. State Univ.	4.6	4.2	5.0
44	NCBR1-D3(3)	N.C. State Univ.	88-GH-812⊗	4.6	5.7	3.6
45	Ashley	Clemson Univ.	N.C. State Univ.	4.7	3.4	6.0
46	M 21 x M 30	N.C. State Univ.	86-GH-453⊗	4.7	4.5	4.9
47	NCBR1-A1(2)	N.C. State Univ.	90-GH-963⊗	4.7	4.0	5.4
48	Straight 8	Ferry-Morse	Rogers NK	4.7	4.7	4.7
49	Gy 14 x PI 357852	N.C. State Univ.	86-GH-709 x 1061	4.8	4.2	5.3
50	NCBR1-A2(1)	N.C. State Univ.	90-GH-964⊗	4.8	4.5	5.0
51	Sumter	Clemson Univ.	N.C. State Univ.	4.8	5.3	4.2
52	Gy 14 x PI 109275	N.C. State Univ.	87-GH-1 x 245	4.8	4.2	5.4
53	M 15 x PI 280096(1)	N.C. State Univ.	90-GH-959⊗	4.8	5.0	4.6
54	M 21 x PI 280096	N.C. State Univ.	88-GH-264-1⊗	4.8	5.0	4.6

Table 1. Continued.

Rank	Cultigen	Seed origin	Seed source	Disease severity		
				Mean	Field	Detached-fruit
55	NCBR1-A1(1)	N.C. State Univ.	90-GH-962⊗	4.8	3.6	6.0
56	NCBR1-B3	N.C. State Univ.	88-GH-299⊗	4.8	4.2	5.4
57	PI 357852	Yugoslavia	90-GH-947⊗	4.8	4.8	4.9
58	PI 379282	Yugoslavia	87-GH-41⊗	4.8	4.7	5.0
59	M 15	N. C. State Univ.	N. C. State Univ.	4.9	5.2	4.6
60	NCBR1-B1(2)	N.C. State Univ.	88-GH-792-1⊗	4.9	5.7	4.1
61	NCBR1-B4(1)	N.C. State Univ.	90-GH-967⊗	4.9	5.0	4.8
62	NCBR1-A1(3)	N.C. State Univ.	88-GH-285-1⊗	4.9	3.8	6.0
63	SR 551	Cornell Univ.	N.C. State Univ.	4.9	3.8	6.0
64	Gy 14 x PI 137839	N.C. State Univ.	86-GH-543 x 562	5.0	4.3	5.6
65	Gy 14 x PI 283901	N.C. State Univ.	86-GH-709 x 940	5.0	4.7	5.2
66	Gy 14 x PI 271328	N.C. State Univ.	86-GH-709 x 919	5.0	4.7	5.3
67	Gy 14 x PI 280096	N.C. State Univ.	86-GH-709 x 936	5.0	3.8	6.2
68	NCBR1-D4	N.C. State Univ.	88-GH-308⊗	5.0	5.2	4.8
69	NCBR1-D3(2)	N.C. State Univ.	88-GH-811-1⊗	5.0	5.8	4.3
70	Gy 14 x PI 414159	N.C. State Univ.	88-GH-708-1⊗	5.1	5.0	5.2
71	NCBR1-A3	N.C. State Univ.	88-GH-287-1⊗	5.1	4.8	5.4
72	NCBR1-A4	N.C. State Univ.	88-GH-288-1⊗	5.1	5.0	5.2
73	NCBR1-C4	N.C. State Univ.	88-GH-304⊗	5.2	5.2	5.2
74	NCBR1-D2	N.C. State Univ.	88-GH-306⊗	5.2	6.0	4.4
75	NCBR1-D3(1)	N.C. State Univ.	88-GH-307⊗	5.2	4.6	5.8
76	Carolina	Clemson Univ.	N.C. State Univ.	5.2	4.3	6.0
77	Gy 14 x PI 109063	N.C. State Univ.	90-GH-923⊗	5.2	4.8	5.7
78	Little John (AR 79-75)	Univ. Ark.	N.C. State Univ.	5.2	3.8	6.7
79	Gy 14 x PI 181756	N.C. State Univ.	86-GH-709 x 741	5.3	4.2	6.4
80	Gy 14 x PI 379282	N.C. State Univ.	87-GH-1 x 41	5.3	4.3	6.3
81	(M 15 x M 30) x M 30	N.C. State Univ.	90-GH-960⊗	5.3	5.7	4.9
82	PI 179676	India	86-GH-735⊗	5.4	5.0	5.8
83	Gy 14	N. C. State Univ.	N.C. State Univ.	5.4	5.7	5.2
84	H-19	Univ. Ark.	N.C. State Univ.	5.5	4.5	6.5
85	Gy 14 x PI 105263	N.C. State Univ.	88-GH-1174-1⊗	5.6	4.8	6.3
86	PI 283901	Czechoslovakia	86-GH-940⊗	5.6	5.5	5.6
87	PI 280096 x PI 163216	N.C. State Univ.	88-GH-1192⊗	5.7	4.6	6.8
88	Gy 14 x PI 178886	N.C. State Univ.	86-GH-709 x 729	5.8	5.8	5.7
89	GY 14 x PI 105340	N.C. State Univ.	90-GH-930⊗	5.8	4.7	6.9
90	Gy 14 x PI 419108	N.C. State Univ.	87-GH-1 x 109	5.8	4.8	6.8
91	PI 137839	Iran	86-GH-562#	5.8	5.0	6.6
92	PI 197087	India	90-GH-946⊗	5.8	---	5.8
93	PI 109483	Turkey	88-GH-249⊗	5.9	4.5	7.3
94	PI 178886	Turkey	90-GH-726⊗	5.9	6.0	5.8
95	M 15 x PI 280096(2)	N.C. State Univ.	88-GH-277-1⊗	6.1	5.0	7.2
96	PI 105263	Turkey	88-GH-253-1⊗	6.1	5.0	7.2
97	Supergreen	Harris-Moran	Harris-Moran	6.1	4.8	7.4
98	Coolgreen	Asgrow Seed	Asgrow Seed	6.2	5.5	7.0
99	Pacer x PI 197087(2)	N.C. State Univ.	88-GH-275-1⊗	6.3	---	6.3
100	PI 109063	Turkey	88-GH-1176-1⊗	6.4	6.2	6.7
101	PI 181756	Lebanon	90-GH-395⊗	6.4	5.8	7.1
102	PI 181942	Syria	90-GH-212⊗	6.6	5.8	7.5
103	PI 419108	P.R. China	90-GH-961⊗	6.8	6.0	7.7
104	PI 432855	P.R. China	90-GH-934⊗	6.9	6.0	7.8
105	PI 280096	Russia	90-GH-409#	---	---	---
Mean					4.5	5.2
LSD (5%)					1.7	1.3
CV (%)					32.7	26.6

[z]Ranking based on mean disease severity of six replications for field tests and nine replications for the detached-fruit test.
⊗Self-pollination; #sib-pollination. A seed source in the format 88-GH-306⊗ indicates the seed was increased in greenhouse plot 306 in 1988.

(mean of two harvests), and mean incidence was 20% for the first harvest and 39% for the second harvest. Resistant pickling cucumber accessions (disease severity rating ≤4.0) included PI 197085, PI 197086, and PI 109483. The most resistant cultivars were Regal and National Pickling, with mean ratings of 4.0 and 4.1, respectively. In the pickling cucumber trial, significant correlations ($p \leq 0.05$) with belly rot severity ranged from $r = 0.25$ for oversized fruit to $r = 0.27$ for seed cell size. Traits without significant correlation coefficients to this trait included plant type, fruit type, number of staminate nodes, color, seed cell size, and overall potential. Although some correlations were significant, in no case was the relationship between disease resistance and these traits considered important.

Mean severity ratings ranged from 2.6 to 8.9 for the slicing cucumber types (Table 3). The means for both harvests were similar at 4.7 and 4.8 for harvests one and two, respectively. Incidence among cultigens ranged from 24.7% to 61.5% (mean of two ratings). Mean incidence was 31% for the first rating and 53% for the second. In the slicing cucumber trial, significant correlations ($p \leq 0.05$) with belly rot resistance ranged from $r = -0.32$ for color and seed cell size to $r = 0.40$ for fruit type. Correlation coefficients were not significant for number of staminate nodes, culls, oversized fruit, shape, overall impression, or plant type. Again, none of the correlations was considered to be important. 'Pacer', 'Marketmore 76', and the F_1 of Gy 14 x PI 197087 were the most resistant slicing cucumbers.

General observations. Severity and incidence were correlated, as were the two harvests in 1992 (Tables 2 and 3). For pickling cucumbers, the Pearson product-moment correlation for incidence and severity was significant for rating period one ($r = 0.75$) and two ($r = 0.83$). Both were significant at $p = 0.01$. For slicing cucumbers, the Pearson product-moment correlation coefficient between incidence and severity was $r = 0.83$ for rating period one and $r = 0.74$ for rating period two. Again, both were significant at $p = 0.01$.

Correlations between the 1992 field test and the 1991 detached-fruit tests were different for pickling and slicing fruit types, at $r =$

Table 2. Belly rot resistance of pickling cucumbers as determined in the 1992 field test, with cultigens in order by decreasing belly rot resistance based on mean disease severity determined on a 1 to 9 rating scale.

	Disease severity[z]			Disease incidence[y]		
Cultigen	Mean	Rating 1	Rating 2	Mean	Rating 1	Rating 2
PI 197088	2.2	2.2	---	6.3	6.3	---
PI 197085	2.2	2.5	2.0	12.8	18.3	5.3
PI 197086	2.3	2.8	1.8	11.6	16.6	6.6
PI 109483	3.0	---	3.0	38.9	---	38.9
PI 271328	3.2	3.2	3.3	31.2	28.7	33.8
UW 92G	3.4	3.5	3.2	35.4	32.0	38.8
PI 280096 x PI 197088	3.4	2.5	4.2	41.8	25.5	58.5
NCBR1-A2(b)	3.5	3.8	3.2	22.4	19.5	25.2
NCBR1-A2(a)	3.5	3.2	3.8	25.5	22.0	29.0
UW 92H	3.5	4.2	2.8	28.2	36.3	20.0
RNK-PC4	3.5	4.0	3.0	29.5	26.7	32.4
Regal	3.5	3.5	3.5	40.9	34.0	47.8
Gy 14 x PI 197085	3.6	3.8	3.5	22.1	22.6	21.7
PI 197087 x PI 280096	3.6	3.8	3.5	32.6	36.3	28.8
National Pickling	3.8	3.8	3.8	31.6	25.4	37.7
Wis.SMR 18	3.8	4.2	3.5	33.1	29.6	36.5
M 21	3.8	3.5	4.0	37.8	29.6	46.0
UW 92F	3.8	4.0	3.5	38.0	42.2	33.8
PI 357852	3.8	3.5	4.0	45.2	39.5	50.8
NCBR1-C3	3.9	3.8	4.0	46.3	33.9	58.8
M 30	4.0	4.0	4.0	11.3	8.3	14.3
Gy 14 x PI 271328	4.0	4.2	3.8	39.8	39.2	40.5
NCBR1-C1(2a)	4.0	3.8	4.2	42.7	38.8	46.5
Gy 14 x PI 165509	4.1	4.2	4.0	48.9	44.8	53.1
PI 280096	4.2	4.5	3.8	40.0	34.9	45.0
Addis	4.2	4.5	4.0	40.6	36.5	44.8
Gy 14 x PI 109483	4.2	4.2	4.3	46.1	36.3	55.9
PI 197087	4.3	4.3	4.3	46.8	48.8	44.8
Calypso	4.4	4.2	4.5	46.7	41.3	52.0
NCBR1-C1(2b)	4.5	4.8	4.2	41.5	37.6	45.5
Gy 14	4.6	5.2	4.0	51.5	51.1	51.9
UW 92E	4.6	5.0	4.2	61.5	67.8	55.3
Sumter	4.8	5.2	4.5	61.7	58.7	64.7
Gy 14 x PI 419108	4.9	4.8	5.0	57.5	41.1	73.9
Mean	3.8	3.9	3.7	31.9	28.6	34.7
LSD (5%)	1.3	1.5	1.1	21.0	24.3	25.5
CV (%)	24	27	22	49	61	53

[z]Severity was determined by visually estimating the percentage of the fruit surface damaged on all fruit in each of four replications.
[y]Incidence was calculated as number of damaged fruit/total number of fruit.

–0.24 and $r = 0.73$, respectively (Table 4). The correlation between the 1991 detached-fruit test and the 1991 field test was $r = -0.22$ for pickling cucumbers. For slicing cucumbers the correlation between the 1991 detached-fruit test and the 1991 field test was $r = 0.48$ and was significant at $p = 0.05$. The 1991 and 1992 field tests with pickling cucumbers did not show strong correlations, with the Pearson product-moment correlation ranging from $r = 0.32$ to 0.45. For pickling cucumbers, there was no correlation between the 1992 field tests and the 1991 detached-fruit test ($r = -0.24$ to 0.14). Similar correlations were much higher for the slicing cucumbers. The 1991 and 1992 field tests resulted in correlations of 0.54 and 0.77, and all were significant at $p = 0.05$. The 1992 field test also showed higher correlations to the 1991 detached-fruit test with $r = 0.38$ to 0.80. These correlations are important since they indicate strong trends and clearly show differences between pickling and slicing cucumbers.

Discussion

Among the pickling cucumber cultigens that exhibited belly rot resistance (defined as a severity rating ≤4.0) in both of the field tests (1991 and 1992) were PI 197085, PI 197087 x PI 280096 F_4, and PI 271328. PI 197085 and PI 197087 have netted skin and, when mature, are covered with corky sutures resembling a muskmelon (*Cucumis melo* L.). Those cultigens were reported to be resistant in another study (Clark and Block, 1984). PI 197086, PI 197088, and PI 165509, which also have netted skin, also have been reported as belly rot resistant (Clark and Block, 1984; Wehner et al., 1992). PI 197086 was not included in the 1991 test due to lack of seeds, but was among the most resistant cultigens evaluated in the 1992 field test. In 1992, PI 165509 failed to set fruit, and PI 197088 set only one fruit, therefore accurate ratings were not obtained for those cultigens. In 1991, PI 165509 was among the most resistant in the detached-fruit test, but was near the mean in the 1991 field test. PI 197088 set no fruit in the 1991 detached-fruit test and was near the mean in the 1991 field test. In no case was a netted-fruited cultigen more susceptible than the mean value of an experiment. Through repeated testing, it appeared that there was an advantage for netted skin types in resisting infection by *Rhizoctonia solani*. However, even though netted skin may serve as a physical barrier to infection, it is horticulturally unacceptable, so resistant cultigens with netted skin would have little value in a commercial cultivar.

'Calypso' was one of the more widely grown pickling cucumbers in the United States (Schultheis, 1990). In both of the field tests, 'Calypso' was found to have resistance near the mean of all cultigens tested. Therefore, the development of pickling cucumbers with greater belly rot resistance could have a significant impact within the pickling cucumber industry.

Among the slicing cucumbers, 'Marketmore 76' was highly resistant in both of the field tests and was previously reported to be resistant (Wehner et al., 1992). Gy 14 x PI 197087 F_1 was also highly resistant in both field tests. In 1991, 'Marketmore 76' was among the most resistant in the 1991 detached-fruit test, but Gy 14 x PI 197087 F_1 was near the mean. Other slicing cultigens that were moderately resistant in the 1991 field and detached-fruit tests were 'Sprint 440', 'Poinsett 76', and 'Regal'. 'Dasher II' is a widely

Table 3. Belly rot resistance of slicing cucumbers as determined in the 1992 field test, with cultigens in order by decreasing belly rot resistance based on mean disease severity determined on a 1 to 9 rating scale.

	Disease severity[z]			Disease incidence[y]		
Cultigen	Mean	Rating 1	Rating 2	Mean	Rating 1	Rating 2
Pacer	3.0	2.8	3.2	29.2	19.8	38.5
Marketmore 76	3.2	3.5	3.0	24.7	25.9	23.4
M 21 x PI 197088	3.2	2.8	3.5	31.1	22.0	40.1
Gy 14 x PI 197087	3.2	3.0	3.3	36.2	22.2	56.7
NCBR1-D3	3.4	3.0	3.8	33.9	26.2	41.5
Dasher II	3.4	3.5	3.2	36.9	29.4	44.4
PI 105340	3.5	3.5	3.5	34.9	24.3	45.5
NCBR1-A1(a)	3.5	3.0	4.0	35.4	17.7	53.1
NCBR1-A1(c)	3.5	3.5	3.5	37.0	18.0	56.0
Ashley	3.5	3.2	3.8	37.5	23.6	51.4
NCBR1-B3	3.5	2.8	4.2	37.6	25.0	50.1
NCBR1-C1	3.6	3.8	3.5	39.1	30.7	47.4
Sunex 3724	3.6	3.5	3.8	40.9	23.2	58.7
RNK-SC5	3.8	4.2	3.5	37.3	33.9	40.7
NCBR1-A1(b)	3.8	3.5	4.0	41.7	17.4	66.0
Sprint 440	3.9	4.0	3.8	37.2	26.2	48.2
PI 432855	4.2	3.8	4.5	55.5	45.7	65.3
Coolgreen	4.3	4.8	3.8	49.3	43.5	55.4
Gy 14 x PI 181756	4.4	4.8	4.0	52.8	39.6	66.0
PI 419108	4.4	4.8	4.0	54.5	39.2	70.0
PI 181756	4.4	4.0	4.8	60.1	41.2	79.0
Gy 14 x PI 419108	4.5	4.5	4.5	43.8	36.7	50.9
Supergreen	4.6	5.2	4.0	54.7	55.3	54.2
Gy 14 x PI 105340	5.0	4.5	5.5	61.5	50.6	72.4
Mean	3.8	3.7	3.9	41.8	30.7	53.1
LSD (5%)	0.8	1.4	0.9	12.4	23.6	26.1
CV (%)	15	26	16	30	55	35

[z]Severity was determined by visually estimating the percentage of the fruit surface damaged on all fruit in each of four replications.
[y]Incidence was calculated as number of damaged fruit/total number of fruit.

Table 4. Correlations (r) among 1991 and 1992 field and detached-fruit tests for pickling and slicing cucumbers.[z]

		1992			1991	
		Rating 1	Rating 2		Test means	
		Incidence	Severity	Incidence	Detached-fruit	field
Pickling cucumbers						
1992 Rating 1	Severity	0.75**	0.58**	0.51**	–0.19	0.43*
	Incidence		0.53**	0.69**	0.11	0.32*
1992 Rating 2	Severity			0.83**	–0.21	0.44*
	Incidence				0.12	0.45*
Mean	Severity				–0.24	0.41*
	Incidence				0.14	0.36
1991 Detached-fruit	Severity					–0.22
Slicing cucumbers						
1992 Rating 1	Severity	0.83**	0.41*	0.43*	0.47*	0.55**
	Incidence		0.59**	0.44*	0.55**	0.60**
1992 Rating 2	Severity			0.74**	0.38	0.69**
	Incidence				0.41	0.77**
1992 Mean	Severity				0.73**	0.54*
	Incidence				0.80**	0.56**
1991 Detached-fruit	Severity					0.48*

[z]Incidence calculated as infected fruit per plot/total fruit per plot. Severity was rated visually on a 1 to 9 scale. Data are means of four replications.
**,*Significant at $P = 0.01$ or 0.05, respectively.

grown slicing cucumber, but has only intermediate resistance. It was in the top one-third in the 1991 detached-fruit test and the 1992 field test and was among the bottom one-third in the 1991 field test.

An additional cultigen of interest is the horticulturally acceptable breeding line M 30. That cultigen had a reduced level of disease incidence compared with other cultigens showing similar disease severity (Table 2). This could indicate a mechanism of resistance different from those observed in fruit with a reduced percentage of surface damage.

In 1992, disease incidence was higher for pickling and slicing cucumbers during the second rating period. That was likely due to a higher pathogen population arising from the previous infection of cucumber fruit, which may have served as an additional inoculum source. The percentage of the fruit surface damaged did not change over the two harvests.

Pickling and slicing cucumbers responded differently in the detached-fruit test. Correlation coefficients for field vs. detached-fruit tests of pickling cucumbers were ≈0 (Table 4). On the other hand, high significant correlation coefficients were obtained among field and detached-fruit tests involving slicing cucumbers. Those correlations may be underestimated because some of the cultigens included in the slicer group (about which little was known) turned out to be pickling type. The different results between pickling and slicing cucumbers may be due to differences in skin toughness, since slicing cucumbers are often bred with a thicker skin to resist damage during shipping.

Based on our results, when evaluating pickling cucumbers, field tests can be used to provide reliable ratings. Field and detached-fruit tests worked reasonably well for slicing cucumbers, since those tests were somewhat correlated. We feel that more weight may be given to the field tests since they more closely resemble natural conditions. Significant and high correlation coefficients were obtained for incidence vs. severity measurements, especially within year. This suggests that the two traits were measuring the same type of resistance. Incidence data is much easier to collect and also eliminates some of the subjective biases associated with visual severity measurements, therefore incidence data should be collected in future experiments of this type.

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