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New Sources of Resistance to Gummy Stem Blight in Watermelon

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ABSTRACT

Gummy stem blight, caused by *Didymella bryoniae* (Auersw.) Rehm, is a major disease of watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai]. Plant breeders need sources of resistance that can be incorporated into adapted breeding lines to help control the disease. We tested all the available accessions from the USDA-ARS watermelon germplasm collection, including *C. lanatus* var. *citroides* (L.H. Bailey) Mansf., for resistance to gummy stem blight. The experiment was a randomized complete block with 1332 cultigens, two sites (field and greenhouse), two or four replications, and two to six plants per plot. The resistant check was PI 189225 and the susceptible check was 'Charleston Gray'. PI 279461, PI 482379, PI 254744, PI 526233, PI 482276, PI 271771, PI 164248, PI 244019, PI 296332, and PI 490383 were selected as the most resistant cultigens to be used in future breeding efforts. The most susceptible cultigens were PI 183398, PI 169286, PI 223764, PI 226445, PI 525084, PI 534597, and PI 278041.

Watermelon is a major vegetable crop in the USA, with a total production in 2001 of about two million megagrams of marketable fruit (USDA-ARS, 2001). Gummy stem blight caused by *Didymella bryoniae* (Auersw.) Rehm [= *Mycosphaerella citrullina* (C.O. Sm.) Gross. and *Mycosphaerella melonis* (Pass) Chiu & Walker] and its anamorph *Phoma cucurbitacearum* (Fr.:Fr.) Sacc. [= *Ascochyta cucumis* Fautrey & Roum] (Keinath et al., 1995) is one of the most destructive diseases of this crop. Resistance to gummy stem blight was ranked for several years by watermelon researchers in the USA as the third most important trait for germplasm evaluation [after bacterial fruit blotch, caused by *Acidovorax avena* subsp. *citrulli* (Schaad et al.) Willems et al. = *Pseudomonas pseudoalcaligenes* subsp. *citrulli*, and Fusarium wilt, caused by *Fusarium oxysporum* Schlechtend.:Fr. f. sp. *niveum* (E.F. Sm.) W.C. Snyder & H.N. Hans].

Gummy stem blight was first described by Fautrey and Roumeguere in France as the disease caused on cucumber (*Cucumis sativus* L.) by *Ascochyta cucumis* in 1891 (Chiu and Walker, 1949; Sherf and MacNab, 1986). In 1917, gummy stem blight was reported for the first time in the USA, affecting watermelon fruit from Florida (Sherbakoff, 1917), where it is still an important limiting factor for the watermelon industry (Keinath, 1995; Schenck, 1962). One severe gummy stem blight epidemic on watermelon was reported in the southeastern USA, with over 15% of the watermelon crop in South Carolina abandoned before harvest (Power, 1992). In addition, severe economic losses have been reported during transportation and in storage because of the disease commonly known on fruit as black rot, caused by *D bryoniae* as well (Leupschen, 1961; Norton, 1978; Sowell and Pointer, 1962).

Gummy stem blight on watermelon plants is evident as crown blight, stem cankers, and extensive defoliation, with symptoms observed on the cotyledons, hypocotyls, leaves, and fruit (Maynard and Hopkins, 1999). *Didymella bryoniae* is a fungus that is seed-borne (Lee et al., 1984), air-borne (van Steekelenburg, 1983), or soil-borne (Bruton, 1998; Keinath, 1996). Important factors favoring either artificial or natural inoculations are the presence of wounds, particularly on old leaves (Blakeman, 1971; Pharis et al., 1982; Svedelius, 1990; van Steekelenburg, 1985a), and the presence of free water on the foliage (van Steekelenburg, 1981, 1984, 1985a).

Adequate control of gummy stem blight through fungicide applications (Keinath, 1995, 2000) and good cultural practices (Keinath, 1996; Rankin, 1954) is difficult, particularly during periods of frequent rainfall when relative humidity remains high for a long period. There have been reports of acquired resistance of *D. bryoniae* to fungicides (Kato et al., 1984; Keinath and Zitter, 1998; Malathrakis and Vakalounakis, 1983; Miller et al., 1997; van Steekelenburg, 1987). Genetic resistance to gummy stem blight has received attention (Norton et al., 1993, 1995, 1986) and would be preferable to other methods if resistant germplasm can be identified and used to develop adapted cultivars.

Methods of seedling evaluation for resistance to gummy stem blight have been reported in watermelon (Boyhan et al., 1994; Dias et al., 1996), melon (*Cucumis melo* L.) (Zhang et al., 1997), squash (*Cucurbita pepo* L.) (Zhang et al., 1995), and cucumber (St. Amand and Wehner, 1995b; Wehner and Shetty, 2000; Wehner and St. Amand, 1993). These studies shared a similar inoculation technique, based on spraying the seedlings with a water suspension of spores collected from in vitro cultures of the pathogen. Spore concentration used to evaluate cucurbits for resistance to gummy stem blight differed among experiments and species ranging between 10^5 and 10^7 spores/mL (Boyhan et al., 1994; St. Amand and Wehner, 1995a, 1995b; van Deer Meer et al., 1978; van Steekelenburg, 1981; Wehner and St. Amand, 1993; Zhang et al., 1995, 1997). Inoculation of cotyledons was tested and shown to be unreliable for resistance to gummy stem blight (Chiu and Walker, 1949; van Deer Meer et al., 1978; Wyszogrodzka et al., 1986).

In previous studies, there were genetic differences for gummy stem blight resistance among commercial cultivars of watermelon. 'Congo' was the least susceptible, 'Fairfax' was intermediate, and Charleston Gray was the most susceptible (Schenck, 1962). PI 189225 was the most resistant of 439 accessions evaluated from the USDA-ARS watermelon germplasm collection (Sowell

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and Pointer, 1962). Several years later, PI 271778 (intermediate in gummy stem blight resistance between PI 189225 and Charleston Gray) was identified as an additional source of resistance (Sowell, 1975). A later evaluation effort of 138 watermelon accessions showed that PI 500335, PI 505590, PI 512373, PI 164247, and PI 500334 were resistant to gummy stem blight (Boyhan et al., 1994). In crosses with susceptible Charleston Gray, resistance in PI 189225 was controlled by a single recessive gene (Norton, 1979).

Resistant watermelon cultivars were developed from two crosses ('Jubilee' × PI 271778, 'Crimson Sweet' × PI 189225) by selecting disease-resistant seedlings from backcrossed families that produced high yield of excellent quality fruit (Norton et al., 1986). 'AU-Jubilant' and 'AU-Producer' (Norton et al., 1986), 'AU-Golden Producer' (Norton et al., 1993), and 'AU-Sweet Scarlet' (Norton et al., 1995) were released with moderate to high resistance to anthracnose [caused by *Colletotrichum orbiculare* (Berk. & Mont.) Arx = *C. lagenarium* (Pass.) Ellis & Halst], Fusarium wilt, and gummy stem blight. However, they were much less resistant to gummy stem blight than the resistant parents PI 189225 and PI 271778. To date, no cultivars of watermelon (Sumner and Hall, 1993), melon (McGrath et al., 1993), or cucumber (Wehner and Shetty, 2000; Wehner and St. Amand, 1993) have been released that have high resistance to natural epidemics of gummy stem blight in the field.

The objective of this study was to evaluate the available USDA-ARS watermelon germplasm collection for resistance to gummy stem blight using commercial cultivars as reference points.

MATERIALS AND METHODS

We conducted all our experiments at the North Carolina State University Plant Pathology Greenhouses in Raleigh, NC, and at the Horticultural Crops Research Station in Clinton, NC. All *Citrullus* PI accessions were obtained from the Southern Regional Plant Introduction Station at Griffin, GA. The checks were 51 watermelon cultivars, along with a set of seven cucumber cultivars, to provide reference points for gummy stem blight resistance. Countries with the most accessions in the collection (of the 1274 evaluated) were Turkey (294), Yugoslavia (164), Zimbabwe (122), India (120), Spain (70), Zambia (55), South Africa (34), Syria (28), Iran (27), and China (26).

We isolated the strains of *D. bryoniae* from diseased cucumber tissues harvested from naturally infected plants in Charleston, SC, in 1998. In 2001, we reisolated the strains of *D. bryoniae* from watermelon plants that were artificially inoculated with the isolates in isolation in our greenhouses by the following technique. Pycnidia were identified with a dissecting microscope (20×) and transferred to Petri plates containing potato dextrose agar (PDA) (25 mL/Petri plate). Isolates were selected from the first subculture on artificial medium on the basis of macroscopic observations: colonies dark in color and showing concentric circles of growth were kept and transferred to fresh PDA. Cultures that did not appear contaminated by other fungi or bacteria, were transferred to a medium containing 25% PDA to stimulate abundant sporulation. Finally, we observed pycnidia/pseudothecia and spores to verify that their shape and size matched those of *D. bryoniae* as published (Zitter et al., 1996).

For long-term storage (Dhingra and Sinclair, 1995), we transferred the fungus onto a disk of sterile filter paper (Whatman #2, 70-mm diam) sitting over a layer of PDA in a Petri plate, subcultured the fungus for 2 to 4 wk, dehydrated the filter paper disk and the mycelium for 12 to 16 h at room temperatures (24 ± 3°C) under a sterile laminar-flow hood, cut the filter paper into squares (5 × 5 mm), and stored them in sterile test tubes in a refrigerator (3 ± 1°C) in the dark.

For all sites, *D. bryoniae* was grown on Petri plates containing 25 mL PDA. We incubated infested Petri plates for 2 to 4 wk at 24 ± 2°C under alternating periods of 12 h of fluorescent light (40 to 90 μmol $m^{-2}s^{-1}$ PPFD) and 12 h of darkness until pycnidia formed. For all inoculations, we prepared a spore suspension by flooding the culture plates with 5 to 10 mL of sterile, distilled water, and scraping the surface of the agar to remove the spores from the mycelia. We filtered the liquid from each plate through 4 layers of sterile cheesecloth to remove dislodged agar and some mycelia. The final pH of the inoculum was not adjusted. We measured spore concentration with a hemacytometer and adjusted to a concentration of 5×10^5 spores/ml by adding deionized water. Tween 20 (0.06 g/L) was added to the inoculum to keep the spores well dispersed in the inoculum solution.

We performed our field and greenhouse studies in 1998, 1999, 2000, and 2001. We retested the most resistant and most susceptible cultigens from the previous years of evaluation in 2000 (35 cultigens selected in 1998–1999) and 2001 (70 cultigens selected in 1998–2000).

In the greenhouse, we inoculated plants at the second true leaf stage, after damaging the trichomes on the leaf surface by brushing the plants with a wooden stake (20 cm long and 2 cm wide). The sprayer was a hand-pumped spray bottle. Immediately before inoculation, we moved the plants into a humidity chamber made of clear polyethylene on the sides and top. The top was kept open during the summer and closed during the fall to keep the internal temperature close to 24°C, the optimum for *D. bryoniae*. We used humidifiers in the chamber running continuously for the treatment time (1 d before inoculation through 3 d after inoculation) to keep the relative humidity close to 100% day and night. Plants were watered daily using overhead sprinklers, except when humidifiers were running.

Greenhouse temperatures averaged 23 to 43°C (0800–2000 h) and 12 to 24°C (2000–0800 h) for the seasons when the experiments were performed. We seeded directly in plastic pots (100 × 100-mm size, 600-mL volume) filled with a soilless mix of peat, vermiculite, and perlite. We used more than one seed per pot to ensure a good plant stand, and then thinned the seedlings to reach the desired number of plants per pot (Table 1), and assembled pots to form the plots.

In the field, we inoculated plants when they reached the fourth true-leaf stage, after irrigating with about 12 mm of water during the two previous days to promote guttation on the day of inoculation, and damaging the trichomes on the leaf surface by brushing the plants with a wooden stake (20 cm long and 2 cm wide) mounted at the end of an aluminum handle (60 cm long). Plants were inoculated two to three times at 2-wk intervals by spraying the inoculum onto all upper leaf surfaces. We delivered the inoculum as a fine mist using a backpack sprayer operated at the pressure of 200 to 275 kPa (30–40 psi). After inoculation, at 1600 h the same day, we irrigated with approximately 12 mm of water, to promote fungal growth and disease outbreak with high relative humidity at night.

Field plots were 1.5 m long with multiple plants each

Table 1. Number of cultigens, replications, and plants/replication for each year and site of testing for resistance to gummy stem blight.

		Evaluation‡			Retest§		
Year	Site†	Cultigens¶	Replication#	Plant††	Cultigens¶	Replications#	Plants††
1998	greenhouse	1283	4	3	–	–	–
	field	1283	2	6	–	–	–
1999	greenhouse	1283	8	3	–	–	–
	field	1283	6	3	–	–	–
2000	greenhouse	321	16	2	35	6	3
	field	321	12	2	35	6	3
2001	greenhouse	321	4	2	70	4	2
	field	321	4	6	70	4	3

† Plants were inoculated with a suspension of spores in the greenhouse at the second true-leaf stage and in the field at the fourth true-leaf stage.
‡ Evaluation of all the PI accessions and checks.
§ Retest of only the most resistant and most susceptible PI accessions and checks from previous years of evaluation.
¶ Number of cultigens (PI accessions and checks) tested for each year.
# Number of replications in a RCBD for each year.
†† Number of plants per plot tested for each year.

(Table 1). Seeds were planted on shaped beds 1.5 m apart (center to center), or 3.0 m apart in the retest (2000, 2001). Plots were separated at each end by 1.5-m alleys. Guard rows of the watermelon susceptible cultivars Charleston Gray and Calhoun Gray planted on continuous plot surrounded each test.

We used a randomized complete block design for both sites (field and greenhouse) and for all years.

In the greenhouse, plants were rated for disease severity 3 wk after inoculation. In the field, plants were rated for disease severity when symptoms appeared on the leaves and stems of the susceptible checks. Instead of the interval Horsfall-Barratt scale, we adopted an ordinal disease assessment scale (Gusmini et al., 2002), being 0 = immune; 1 = yellowing on leaves (suspect of disease only); 2 to 4 = symptoms on leaves only; 5 = some leaves dead, no symptoms on stem; 6 to 8 = symptoms on leaves and stems; 9 = plant dead (Table 2). Plants with a disease rating greater than 5 had lesions on the stem, thus being prone to death in the following development of the disease. Plants with a disease rating ≤ 5, instead, had lesions only on the leaves and never developed stem lesions. This threshold for the absence/presence of stem lesions qualifies this rating scale in the discontinuous ordinal class, where one unit increase in rating does not necessarily correspond to a fixed quantity of increased susceptibility to the disease. We preferred this disease assessment scale because it allowed us to record lesions either on leaves or on stems. Leaf ratings are important, because plant yield and survival is affected by leaf area, which is reduced by severe disease outbreaks. Stem ratings are important, because large, localized lesions can kill the plant, especially if located near the crown (base) of the plant.

PI accessions can be variable, especially when they are collected as samples from wild populations. It is possible that resistant plants exist within an accession that is mostly susceptible. Therefore, we checked variability within cultigen to determine whether PI accessions were more variable than inbred cultivars.

Table 2. Disease assessment scale for testing resistance to gummy stem blight in watermelon.

Rating	Description of symptoms
0	no symptoms
1	yellowing on leaves (suspect of disease only)
2	moderate symptoms (<20% necrosis) on leaves only
3	slight symptoms (21–45% necrosis) on leaves only
4	severe symptoms (>45% necrosis) on leaves only
5	some leaves dead, no symptoms on stem
6	moderate symptoms (<20% necrosis) on leaves, with necrosis also on petioles and stem (<3 mm long)
7	slight symptoms (21–45% necrosis) on leaves, with necrosis also on petioles and stem (3-5 mm long)
8	severe symptoms (>45% necrosis) on leaves, with necrosis also on petioles and stem (>5 mm long)
9	plant dead

Data were analyzed by the MEANS, GLM, and CORRELATION procedures of SAS-STAT Statistical Software Package. Data were summarized as mean, number of replications (each replication was a combination of year, season, and site), and standard deviation over replications. Data were standardized (mean = 4.5, standard deviation = 1.5) by the STANDARD procedure of SAS-STAT to reduce variability over years, locations, replications, and rater. The most resistant cultigens were chosen as having a low mean disease severity rating (mean < 4.0), a similar reaction in field and greenhouse, and a low standard deviation. The most susceptible cultigens were chosen as having a high mean disease severity rating (mean > 6.0), a similar reaction in field and greenhouse, and a low standard deviation.

RESULTS AND DISCUSSION

The complete dataset for all the 1332 cultigens tested for resistance to gummy stem blight was submitted to the Germplasm Resources Information Network (http://www.ars-grin.gov/; verified 12 November 2004) for those interested in particular cultigens. The most resistant and most susceptible cultigens are presented here, along with the adapted cultivars used as checks.

Plant-to-plant variation within cultigen was similar for PI accessions and inbred cultivars (Table 3). The standard deviation for most cultigens was 0.8 to 2.0, and was not higher for PI accessions than for cultivars (Table 4).

The analysis of variance (Table 4) showed a significant cultigen effect for overall rating in the evaluation, and in the greenhouse and field separately. The F ratio in the field was lower than in the greenhouse. Therefore, the greenhouse was slightly more accurate in detecting differences in levels of resistance to gummy stem blight between cultigens. The LSD ($\alpha = 0.05$) was 0.4 overall, 0.2 in the field, and 0.3 in the greenhouse. The range/LSD ratio also can be used to determine the strength of a test in separating the means and it attributed high efficacy to our evaluation experiments (12.2 overall, 20.3 in the greenhouse, and 33.0 in the field).

Table 3. Plant-to-plant variation for two PI accessions and one inbred cultivar differing in resistance to gummy stem blight in the greenhouse in 2001†.

	Replication 1		Replication 2		Replication 3		Replication 4	
Cultigen name	Plant 1	Plant 2	Plant 1	Plant 2	Plant 1	Plant 2	Plant 1	Plant 2
PI 482276‡	3	2	2	2	2	4	–	4
PI 169286§	9	7	8	4	8	6	9	9
Charleston Gray¶	5	4	6	8	5	5	–	8

† Disease assessment scale adopted for evaluating watermelon for resistance to gummy stem blight: 0 = immune; 1 = yellowing on leaves (suspect of disease only); 2 to 4 = symptoms on leaves only; 5 = some leaves dead, no symptoms on stem; 6 to 8 = symptoms on leaves and stems; 9 = plant dead.
‡ PI accession randomly chosen among the most resistant.
§ PI accession randomly chosen among the most susceptible.
¶ Inbred cultivar used as susceptible check.

Two different measures of repeatability were estimated: repeatability over years and over replications within year and site. Gummy stem blight had significant (genetic or environmental) variability in previous evaluations for resistance in cucumber (Wehner and Shetty, 2000; Wyszogrodzka et al., 1986), melon (Zhang et al., 1997), squash (Zhang et al., 1995), and watermelon (Boyhan et al., 1994). In our evaluation experiments, repeatability over years was low but significant, (r = 0.10–0.36). Therefore, several years of testing will be needed to correctly rank watermelon cultigens for resistance to this disease. Gummy stem blight outbreaks are highly influenced by environmental conditions such as relative humidity, ventilation, and temperature (van Steekelenburg, 1984, 1985a, 1985b; van Steekelenburg and Vooren, 1980). Therefore, low correlation between years may be the result of differences in environmental conditions in our evaluation experiments.

We obtained better estimates of cultigen performance by repeating the test over years, and by using many replications per test. In the greenhouse, the use of a humidity chamber reduced the influence of relative humidity and ventilation of the greenhouse on pathogen development, which has been a major cause of variation in greenhouse experiments for van Steekelenburg (1984, 1985a). The evaluation of such a high number of cultigens in each test required the use of large areas (typically 1–2 ha per test), increasing the variation within a field. This is supported by the high and significant correlations between adjacent replications in the field and the low and nonsignificant correlations between replications further apart, particularly evident in field tests with many replications in the field (data not shown). Therefore, repeatability over replications was significantly higher in the greenhouse than in the field tests, since greenhouse conditions within year were more uniform.

Between 1986 and 1995, Norton released four watermelon cultivars resistant to gummy stem blight: AU-Jubilant and AU-Producer (Norton et al., 1986), AU-Golden Producer (Norton et al., 1993), and AU-Sweet Scarlet (Norton et al., 1995). All these cultivars were developed with either PI 189225 or PI 271778 as resistant parent, but their level of field resistance was low to moderate. Specifically, the level of resistance was lower than in the resistant parent PI 189225 (Mean = 3.8) in AU–Producer (Mean = 5.0), AU-Golden Producer (Mean = 4.1), and AU-Sweet Scarlet (Mean = 5.1). AU-Jubilant had the same level of resistance (Mean = 4.2) of its resistant parent PI 271778.

The loss of resistance during selection from the wild parent to the adapted progenies might have been caused by Norton's selection technique which was based solely on greenhouse data (Norton, 1979) or transplanting to the field survivors from greenhouse seedling testing (Norton et al., 1986, 1993, 1995; Sowell and Pointer, 1962). The use of greenhouse data only is not sufficient to evaluate watermelon germplasm for resistance to gummy stem blight. In our evaluation of the genetically widest available set of cultigens, the correlation between field and greenhouse was low (overall, r = 0.30), in contrast to similar evaluation experiments with melon and cucumber, where correlations between field and greenhouse were consistently high (St. Amand and Wehner, 1995b; Zhang et al., 1997). Our evaluation method, instead, combined data from greenhouse and field to help find higher levels of disease resistance with consistent reaction under both testing conditions. We can assume that cultigens more resistant than PI 189225 and PI 271778 both in the field and greenhouse tests under heavy artificial inoculation will be largely more adapted to survive natural epidemics of gummy stem blight. Therefore, we presented data for mean disease resistance (Table 4) for all accessions that were more resistant than PI 189225, the most resistant accession previously known. Including PI 189225, there were 60 accessions that had some level of resistance. We present the data for them in Table 4 to make it easy to compare means, standard deviations, number of replications, and seed sources of the most resistant accessions, and to compare their advantage over susceptible accessions and checks (including PI 189225).

We identified seven consistently susceptible cultigens for use as checks, along with adapted susceptible cultivars, and for breeding and inheritance studies: PI 183398, PI 169286, PI 223764, PI 226445, PI 525084, PI 534597, and PI 278041. We identified 10 cultigens with low disease severity rating and low variability for reaction to gummy stem blight both in the field and the greenhouse: PI 279461, PI 482379, PI 254744, PI 526233, PI 482276, PI 271771, PI 164248, PI 244019, PI 296332, and PI 490383 (Table 4). Other resistant cultigens were tested in fewer replications, so will need more data to verify whether they are useful. The best cultigens should be useful for inheritance studies, evaluating different

Table 4. Overall, greenhouse, and field average disease rating for the most resistant and the most susceptible PI accessions, and checks (cultivars and PI accessions) evaluated for resistance to gummy stem blight in the greenhouse at North Carolina State University, Raleigh, NC, and in the field at the Horticultural Crops Research Station at Clinton, NC. Tests were conducted each year from 1998 to 2001†.

		Overall		Greenhouse			Field		
Cultigen name	Seed source	Mean	SD	Replications	Mean	SD	Replications	Mean	SD
				Most resistant PI accessions					
PI 279461‡	Japan	2.3	1.3	8	2.8	1.5	6	1.7	0.6
PI 482379‡	Zimbabwe	2.6	0.9	8	2.6	0.5	7	2.6	1.2
PI 254744‡	Senegal	2.6	1.8	11	3.0	2.0	10	2.1	1.5
PI 526233‡	Zimbabwe	2.7	1.1	10	2.4	0.8	2	4.2	1.1
PI 482276‡	Zimbabwe	2.7	1.0	11	2.5	1.1	6	3.1	0.6
PI 271771‡	South Africa	2.8	2.1	20	2.7	2.1	3	4.0	1.2
PI 164248‡	Liberia	2.8	2.0	8	3.0	1.1	7	2.4	2.7
PI 244019‡	South Africa	2.8	2.0	23	3.2	2.2	14	2.3	1.5
PI 296332‡	South Africa	2.9	1.2	7	2.7	1.4	6	3.1	0.9
PI 296339	South Africa	2.9	1.1	1	2.9	0.0	6	2.9	1.2
PI 490383‡	Mali	2.9	1.5	13	3.4	1.0	5	1.6	2.0
PI 379243	Yugoslavia	2.9	1.8	10	3.5	0.9	6	2.1	2.7
PI 296337	South Africa	3.0	0.8	9	2.7	0.8	5	3.6	0.6
PI 271770	South Africa	3.0	1.1	27	2.7	1.1	16	3.7	0.8
PI 490375	Mali	3.0	1.6	7	2.8	1.9	5	3.2	1.1
PI 512398	Spain	3.0	0.8	9	3.1	0.8	3	2.8	0.7
PI 482315	Zimbabwe	3.0	1.3	11	3.2	0.9	8	2.8	1.7
PI 482283	Zimbabwe	3.0	1.5	18	3.2	1.1	16	2.8	1.9
PI 482284	Zimbabwe	3.0	1.6	17	3.5	1.6	9	2.2	1.5
PI 532666	Swaziland	3.0	1.3	2	3.7	0.2	5	2.7	1.5
PI 249009	Nigeria	3.0	1.6	7	3.8	1.6	5	2.0	0.8
PI 296343	South Africa	3.1	1.5	8	2.7	1.0	6	3.5	2.1
PI 490384	Mali	3.1	1.4	8	2.7	1.0	4	3.9	1.8
PI 512388	Spain	3.1	0.9	9	2.8	0.8	6	3.7	0.8
PI 482257	Zimbabwe	3.1	1.5	11	2.9	1.1	7	3.5	2.0
PI 211915	Iran	3.1	1.7	23	3.0	1.7	8	3.4	1.8
PI 508443	Korea	3.1	1.6	7	3.2	1.5	4	3.0	1.8
PI 542114	Botswana	3.1	1.3	11	3.2	1.3	3	3.1	1.6
PI 241689	Chile	3.1	1.1	11	3.3	1.1	3	2.0	0.2
PI 500312	Zambia	3.1	1.1	11	3.6	1.0	7	2.3	0.7
PI 271982	Somalia	3.2	1.4	2	0.9	0.3	7	3.8	0.7
PI 247398	Greece	3.2	2.0	2	1.5	4.1	7	3.6	1.1
PI 195771	Guatemala	3.2	1.7	6	2.3	1.2	4	4.7	1.4
PI 227203	Japan	3.2	1.8	6	2.4	1.1	4	4.4	2.0
PI 435990	China	3.2	1.9	8	2.5	1.7	3	5.2	0.2
PI 319237	Japan	3.2	2.5	11	2.8	2.3	6	4.0	2.9
PI 512361	Spain	3.2	1.1	9	2.8	0.8	4	4.1	1.4
PI 542123	Botswana	3.2	1.4	17	2.9	1.4	5	4.1	0.9
PI 482267	Zimbabwe	3.2	1.5	10	3.0	1.8	6	3.3	1.0
PI 482342	Zimbabwe	3.2	1.1	21	3.2	0.9	12	3.2	1.4
PI 470248	Indonesia	3.2	1.3	16	3.2	1.2	9	3.2	1.6
PI 271773	South Africa	3.2	1.1	10	3.4	0.8	7	2.8	1.5
PI 482294	Zimbabwe	3.2	1.6	10	3.7	1.1	6	2.5	2.1
PI 482357	Zimbabwe	3.3	1.5	10	2.4	0.7	7	4.5	1.6
PI 357677	Yugoslavia	3.3	1.5	4	2.8	2.2	5	3.6	0.4
PI 277979	Turkey	3.3	1.9	19	3.0	2.2	10	3.8	0.9
PI 482297	Zimbabwe	3.3	1.1	10	3.0	1.1	5	3.9	0.9
PI 270546	Ghana	3.3	1.1	11	3.1	1.2	5	3.6	1.1
PI 482374	Zimbabwe	3.3	1.3	21	3.1	1.1	10	3.8	1.6
PI 482307	Zimbabwe	3.3	1.0	11	3.1	1.0	5	3.9	0.8
PI 500323	Zambia	3.3	1.7	12	3.2	1.9	5	3.4	1.3
PI 296342	South Africa	3.3	1.2	13	3.2	1.0	9	3.6	1.5
PI 490376	Mali	3.3	1.1	9	3.3	1.2	1	2.7	0.0
PI 482343	Zimbabwe	3.3	0.9	11	3.3	0.7	6	3.4	1.2
PI 357678	Yugoslavia	3.3	1.6	7	3.3	1.8	3	3.4	1.2
PI 482293	Zimbabwe	3.3	1.3	21	3.4	0.9	12	3.3	1.9
PI 482260	Zimbabwe	3.3	1.5	14	3.4	1.4	8	3.3	1.6
PI 274035	South Africa	3.3	2.4	9	3.6	2.6	3	2.5	2.0
PI 482326	Zimbabwe	3.3	1.4	11	3.8	1.3	7	2.7	1.5
PI 189225	Zimbabwe	3.8	1.2	20	3.7	0.9	14	4.0	1.5
				Most susceptible PI accessions					
PI 278041§	Turkey	6.1	1.6	5	5.8	0.5	4	6.6	2.5
PI 534597§	Syria	6.1	1.0	6	6.0	1.1	6	6.2	1.0
PI 525084§	Egypt	6.1	0.9	10	6.0	1.0	3	6.6	0.2
PI 226445§	Israel	6.1	1.4	11	6.6	1.3	6	5.0	0.9
PI 223764§	Afghanistan	6.2	1.0	17	6.3	1.0	13	6.2	1.1
PI 169286§	Turkey	6.3	1.1	18	6.5	0.8	15	6.0	1.3
PI 183398§	India	6.3	1.9	9	7.0	2.1	5	5.1	1.0
				Check cultivars					
Mickylee	Univ. of Florida	3.1	1.0	16	3.2	0.8	10	2.9	1.3
Cream of Saskatch.	Unknown	3.3	1.4	15	3.0	1.3	3	4.6	1.0
Allsweet	Univ. of Kansas	3.4	2.1	19	3.4	2.3	8	3.4	1.5

Continued next page.

Table 4. Continued.

Cultigen name	Seed source	Overall		Greenhouse			Field		
		Mean	SD	Replications	Mean	SD	Replications	Mean	SD
Peacock WR60	R. Peacock	3.5	1.6	8	3.1	1.4	6	4.0	1.9
Dixielee	Univ. of Florida	3.5	0.9	19	3.6	1.0	10	3.3	0.8
Tastigold	Unknown	3.5	1.3	18	3.8	1.1	10	3.2	1.7
Tendersweet O.F.	Unknown	3.6	1.1	17	3.7	1.0	6	3.5	1.5
Navajo Sweet	Unknown	3.7	1.5	18	3.2	1.4	7	4.8	1.3
Petite Sweet	Univ. of Kansas	3.7	1.1	10	3.5	1.1	2	4.4	1.1
Graybelle	Robson Seeds	3.7	0.9	20	3.6	0.8	4	4.1	1.5
Calsweet	D. Layton, C. Hall	3.7	1.5	19	3.7	1.5	9	3.6	1.7
Yellow Rose	Syngenta Seeds	3.7	1.4	20	3.9	1.3	14	3.3	1.3
Minilee	Univ. of Florida	3.9	1.2	18	3.6	0.9	9	4.4	1.6
Garrisonian	USDA-ARS	3.9	1.3	12	4.1	1.7	10	3.7	0.9
Yellow Baby	Unknown	4.0	1.2	17	4.0	1.0	6	4.1	1.8
Starbrite	Asgrow	4.0	1.4	20	4.3	1.0	13	3.6	1.9
AU-Gold. Producer	Auburn Univ.	4.1	1.1	10	3.8	1.0	8	4.4	1.1
Crimson Sweet	Univ. of Kansas	4.1	1.1	17	3.8	1.1	10	4.5	0.8
Jubilee	Univ. of Florida	4.1	1.2	18	3.8	1.2	9	4.7	1.2
Regency	Petoseed	4.1	1.2	20	4.1	0.9	12	4.1	1.6
Calhoun Gray	Louisiana St. U.	4.1	1.2	19	4.5	1.2	13	3.4	1.1
Kleckley Sweet	W.A. Kleckley	4.1	1.9	18	3.9	2.0	3	4.9	0.9
Yellow Shipper	Willhite	4.2	1.2	14	3.8	1.3	11	4.6	1.0
Stars'N'Stripes	Asgrow	4.2	1.4	20	4.3	1.5	13	4.1	1.4
AU-Jubilant	Auburn Univ.	4.2	1.5	9	4.1	1.2	9	4.3	1.8
Peacock Shipper	R. Peacock	4.3	1.3	19	3.9	1.4	7	5.3	0.5
Super Gold	Abbott & Cobb	4.3	1.6	9	5.0	1.0	6	3.2	1.7
Black Diam. Y.F.	Unknown	4.4	1.6	13	4.3	1.7	6	4.6	1.4
Peacock Striped	R. Peacock	4.4	1.4	20	4.3	1.1	6	4.6	2.2
Blackstone	USDA-ARS	4.4	1.0	19	4.5	0.9	11	4.0	1.1
Summer Gold	Abbott & Cobb	4.5	1.2	17	4.6	1.0	8	4.2	1.7
Black Diamond	Watson Seeds	4.5	1.7	15	4.6	1.9	4	4.5	1.1
Fairfax	USDA-ARS	4.7	1.0	9	4.7	1.2	7	4.8	0.8
Congo	USDA-ARS	4.7	1.7	28	4.9	1.7	17	4.5	1.7
Yellow Crimson	Unknown	4.7	1.3	18	5.0	1.1	12	4.2	1.3
Klondike Stripe 11	Unknown	4.8	1.2	12	4.7	1.4	5	5.1	0.5
King&Queen	Unknown	4.8	1.1	17	4.9	1.2	10	4.7	1.0
Sugar Baby	M. Hardin	4.8	1.2	20	5.1	1.1	8	3.9	1.1
Verona	Mississippi State University	4.9	1.2	4	4.9	1.2	0	0.0	0.0
N.H. Midget	Univ. N. Hamp.	4.9	1.1	13	5.1	1.2	5	4.4	0.3
Florida Favorite	Unknown	4.9	1.4	16	5.4	1.0	6	3.4	1.2
AU-Producer	Auburn Univ.	5.0	1.6	10	5.0	1.9	10	5.0	1.2
Tendergold	Unknown	5.0	0.9	19	5.1	0.8	8	5.0	1.1
Charleston Gray	USDA-ARS	5.0	1.4	41	5.4	1.5	24	4.4	1.1
Red'N'Sweet	Calhoun Res. St.	5.1	1.6	20	4.9	1.8	7	5.5	0.6
AU-Sweet Scarlet	Auburn Univ.	5.1	1.7	10	5.6	2.0	9	4.5	1.2
Smokylee	Univ. of Florida	5.5	1.8	4	5.1	1.4	2	6.2	3.0
Golden Honey	Robson Seeds	5.5	1.4	20	5.4	1.2	6	6.2	1.7
LSD (0.05)		0.4	–	–	0.3	–	–	0.2	–
F ratio		4.0***	–	–	3.8***	–	–	2.4***	–
Minimum		1.5	–	–	0.9	–	–	1.1	–
Maximum		6.4	–	–	7.0	–	–	7.7	–

† Disease assessment scale adopted for evaluating watermelon for resistance to gummy stem blight: 0 = immune; 1 = yellowing on leaves (suspect of disease only); 2 to 4 = symptoms on leaves only; 5 = some leaves dead, no symptoms on stem; 6 to 8 = symptoms on leaves and stems; 9 = plant dead.
‡ PI accessions chosen as most resistant (low mean, low variability, and high number of replications tested), to be used in future development of resistant cultivars.
§ PI accessions chosen as most susceptible (high mean, low variability, and high number of replications tested), to be used in future assays as susceptible checks.

sources of resistance for allelism, and development of resistant cultivars.

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