HORTSCIENCE 38(7):1417–1421. 2003.

Resistance of Watermelon Germplasm to the Peanut Root-knot Nematode

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Additional index words. *Citrullus lanatus* var. *lanatus*, *C. lanatus* var. *citroides*, *C. colocynthis*, nematode resistance, *Meloidogyne arenaria* race 1

Abstract. **Root-knot nematodes [*Meloidogyne arenaria* (Neal) Chitwood, *Meloidogyne incognita* (Kofoid & White) Chitwood, and *Meloidogyne javanica* (Treub) Chitwood] are serious pests of watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai var. *lanatus*] in the southern United States and worldwide. Watermelon cultivars with resistance to any of these nematode pests are not available. Therefore, we evaluated all accessions of *Citrullus colocynthis* (L.) Schrad.(21) and *Citrullus lanatus* (Thunb.) Matsum. & Nakai var. *citroides* (L.H. Bailey) Mansf.(88), and about 10% of *C. lanatus* var. *lanatus* (156) accessions from the U.S. Plant Introduction (PI) *Citrullus* germplasm collection for resistance to *M. arenaria* race 1 in greenhouse tests. Only one *C. lanatus* var. *lanatus* accession exhibited very low resistance [root gall index (GI) = 4.9] and 155 *C. lanatus* var. *lanatus* accessions were susceptible (GI ranged from 5.0 to 9.0, where 1 = no galls and 9 = ≥81% root system covered with galls). All *C. colocynthis* accessions were highly susceptible (GI range = 8.5 to 9.0). However, 20 of 88 *C. lanatus* var. *citroides* accessions were moderately resistant with a GI range of 3.1 to 4.0; overall GI range for the *C. lanatus* var. *citroides* accessions was 3.1 to 9.0. Resistance to *M. arenaria* race 1 identified in the *C. lanatus* var. *citroides* accessions was confirmed on a subset of accessions in a replicated greenhouse test. The results of our evaluations demonstrated that there is significant genetic variability within the U.S. PI *Citrullus* germplasm collection for resistance to *M. arenaria* race 1 and also identified *C. lanatus* var. *citroides* accessions as potential sources of resistance.**

Watermelon is an important vegetable crop in the United States and throughout the world. Fresh market production of watermelons in the United States in 2000 was 37,152,000 hundredweight valued at $236,286,720 [U.S. Dept. of Agriculture (USDA), 2001]. Root-knot nematodes (*Meloidogyne arenaria*, *M. incognita*, and *M. javanica*) cause serious damage to watermelon throughout the southern United States (Sumner and Johnson, 1973; Thies, 1996; Thomason and McKinney, 1959; Winstead and Riggs, 1959). In addition, root-knot nematodes increased the severity of Fusarium wilt, a disease of watermelon that occurs throughout watermelon growing areas of the United States and the world, in both Fusarium wilt-resistant and susceptible cultivars (Sumner and Johnson, 1973). Greater percentages of watermelon plants wilted in field soils that were naturally infested with both *M. incognita* and *Fusarium oxysporum* Schlechtend.:Fr. f. sp. *niveum* (E.F. Sm.) W.C. Snyder & H.N. Hans. (Sumner and Johnson, 1973). In greenhouse experiments, Sumner and Johnson (1973) observed that *M. arenaria* reduced foliage weights in both Fusarium wilt-resistant and susceptible watermelon cultivars and increased wilting in the moderately resistant 'Charleston Gray'.

Currently, root-knot nematodes are controlled in watermelon by pre-plant fumigation with methyl bromide or with other nematicide treatments. About 6% of all methyl bromide used for pre-plant soil treatment is used for melons (*Cucumis melo* L.) and watermelon to control nematodes, weeds, and soil-borne pathogens (USDA, 1993). The proposed removal of methyl bromide from the U.S. market in 2005 has focused significant interest in developing alternatives for managing plant-parasitic nematodes and other soil-borne crop pests in high value vegetable crops. Additionally, many other nematicides are likely to be lost from the U.S. market because of prohibitive re-registration costs and environmental concerns. Alternative strategies must be developed for managing root-knot nematodes in the highly susceptible watermelon crop. Host plant resistance, if available, would provide an inexpensive and environmentally compatible alternative to methyl bromide, as well as other fumigant and non-fumigant nematicides, for managing root-knot nematodes in watermelon.

Resistance to *M. arenaria*, *M. javanica*, and *M. incognita* has been difficult to identify in *Citrullus* spp. However, cultivated watermelon, *C. lanatus* var. *lanatus*, is considered a poor host for *M. hapla* (Sumner and Johnson, 1973). Seventy-eight watermelon cultivars and five breeding lines evaluated by Winstead and Riggs (1959) were susceptible to *M. incognita*, *M. incognita acrita*, *M. arenaria arenaria* and *M. javanica*, but were resistant to *M. hapla* Chitwood. Thomason and McKinney (1959) reported that the watermelon cultivar Striped Klondike was susceptible to *M. incognita acrita* and *M. javanica*, but resistant to *M. hapla*. In Puerto Rico, 10 watermelon cultivars evaluated for their responses to *M. incognita* were all susceptible (Montalvo and Esnard, 1994). There are no reports of resistance in watermelon cultivars or *Citrullus* germplasm to root-knot nematode species that are known to cause serious damage to watermelon. Therefore, our objectives were to determine the range of genetic variation within the U.S. Plant Introduction (PI) *Citrullus* germplasm collection for reaction to *M. arenaria* race 1 and to identify accessions that will be potentially useful sources of resistance to *M. arenaria* race 1.

Materials and Methods

Inoculum. *Meloidogyne arenaria* race 1 (obtained from S. Lewis, Clemson Univ., Clemson, S.C.) was cultured on 'Rutgers' tomato (*Lycopersion esculentum* Mill.) and 'Kentucky Wonder 191' pole bean (*Phaseolus vulgaris* L.) in isolated soil benches in the greenhouse. Egg inocula were extracted from infected tomato and bean roots using 0.5% sodium hypochlorite (Hussey and Barker, 1973).

Greenhouse evaluation procedures. Seeds of each watermelon genotype were sown in the greenhouse in plastic growing trays containing 50 individual 0.2-L cells filled with Metro-Mix 360 (The Scotts Co., Marysville, Ohio). Ten days later, an aliquot of 3-mL distilled water containing ≈2,500 eggs of *M. arenaria* race 1 was pipetted into the soil surrounding each root system at a 1-cm depth. Plants were fertilized 2 and 5 weeks after sowing with N at 83 $mg \cdot L^{-1}$ (2% nitrate, 18% ammoniacal) from a 20N–20P–16K water soluble fertilizer (Peter's Fertilizer; United Industries Corp., St. Louis). The greenhouse air temperature was maintained between 26 °C and 31 °C. Eight weeks after inoculation, the shoots of all plants were severed at the crown (juncture of roots and shoots), and the roots were removed from the plastic cells and carefully washed. The roots of each plant were then immersed in a 15% solution of McCormick's red food color (McCormick & Co., Hunt Valley, Md.) (Thies et al., 2002) for ≈15 min to stain the egg masses, rinsed gently under running tap water, and evaluated for galling severity and egg mass production using a 1 to 9 scale where 1 = 0, 2 = 1% to 3%, 3 = 4% to 12%, 4 = 13% to 25%, 5 = 26% to 38%, 6 = 39% to 50%, 7 = 51% to 65%, 8 = 66% to 80%, and 9 = 81% to 100% of root system galled or covered with egg masses, respectively (Thies and Fery, 1998). Ratings of 1 to 2.9 = high resistance, 3.0 to 4.0 = moderate resistance, 4.1 to 4.9 = low resistance, 5.0 to 6.9 = susceptible, and 7.0 to 9.0 = highly susceptible. The primary criterion for designating resistance and susceptibility of the accessions was the root gall severity index. Egg mass data was also presented because it provides additional information about the reaction of the

Received for publication 15 Mar. 2002. Accepted for publication 22 May 2002. We thank S. Merrill, E.L. Corley, Jr. (retired), R. Reeves, P. Berland, and L. Pence for technical assistance in conducting the experiments. Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agriculture and does not imply its approval to the exclusion of other products or vendors that also may be suitable.
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accessions to *M. arenaria* race 1. However, accessions were considered resistant only if both the root gall index and the egg mass index were ≤4.9.

Plant material. All available accessions of *C. colocynthis* (21) and *C. lanatus* var. *citroides* (88), and ≈10% of the *C. lanatus* var. *lanatus* (156) accessions from the U.S. PI *Citrullus* germplasm collection were evaluated for resistance to *M. arenaria* race 1 in greenhouse tests. 'Charleston Gray', 'Crimson Sweet', and 'Dixie Lee' (*C. lanatus* var. *lanatus*) were included as susceptible reference check cultivars in all tests.

Evaluation of C. lanatus var. lanatus accessions. The 156 *C. lanatus* var. *lanatus* PIs evaluated in this test represented at least 10% of the accessions from each country of origin. These accessions were selected in the following manner: First, the entire *C. lanatus* var. *lanatus* portion of the USDA *Citrullus* collection database was sorted in ascending order by PI accession number within each geographic origin (country) group. Then, the first PI (lowest accession number) and each successive 10th PI was selected in each country group, so that ≈10% of each country group was represented. If there were fewer than 10 PIs per country group, then the last PI in the group was selected. Ten seeds of each of the 156 *C. lanatus* var. *lanatus* PIs were planted and the plants were evaluated for reaction to *M. arenaria* race 1 in an unreplicated greenhouse test using evaluation procedures previously described.

Evaluation of C. lanatus var. citroides accessions. Ten seeds of each of the 88 *C. lanatus* var. *citroides* accessions were planted and the plants were evaluated for reaction to *M. arenaria* race 1 in an unreplicated test as previously described.

Evaluation of C. colocynthis accessions. Fifteen seeds of each of the 21 *C. colocynthis* accessions were planted in a randomized complete-block design with 3 replicates and 5 plants per replicate. Plants were evaluated for reaction to *M. arenaria* race 1 as previously described.

Table 1. Reactions of *Citrullus lanatus* var. *lanatus* U.S. Plant Introduction (PI) accessions and control cultivars to the peanut root-knot nematode, *Meloidogyne arenaria* race 1.[z]

Origin	Accession (PI No.)	Gall index[y]	Egg mass index[y]
Afghanistan	207471	9.00	4.00
Afghanistan	219906	8.57	3.71
Algeria	222137	9.00	5.14
Angola	306367	9.00	3.25
Argentina	162667	8.00	5.00
Australia	504519	8.67	6.33
Belize	269676	9.00	1.78
Bolivia	543212	8.38	5.00
Botswana	459074	4.90	3.10
Botswana	542119	5.50	4.00
Brazil	441722	9.00	5.33
Cameroon	535947	9.00	3.22
Cameroon	535948	9.00	2.40
Chad	549160	9.00	5.00
Chile	241689	8.78	4.67
China	113326	9.00	5.80
China	192938	8.67	4.56
China	430615	9.00	4.63
China	435085	9.00	5.00
China	435991	9.00	5.20
China	505935	8.75	3.13
China	512332	9.00	6.50
China	532809	9.00	4.43
China	532811	7.63	5.38
Cuba	208740	9.00	6.89
Egypt	183217	8.20	2.80
Egypt	525090	9.00	4.60
El Salvador	200732	7.67	3.11
Ethiopia	193490	8.80	4.00
Former Soviet Union	345543	8.44	4.33
Former Soviet Union	518612	9.00	4.50
Ghana	271750	8.60	2.60
Greece	212208	7.80	4.40
Guatemala	163572	8.50	5.20
Honduras	415095	8.60	3.20
Hungary	270522	8.80	5.80
Hungary	507867	6.56	3.22
India	163202	8.56	4.78
India	164633	8.14	2.43
India	164737	7.00	3.00
India	179878	6.90	1.50
India	180278	7.88	4.75
India	183124	8.63	4.00
Indonesia	470246	8.40	4.80
Iran	211849	9.00	3.13
Iran	222713	8.70	3.60
Iran	229604	7.67	4.78
Iran	344395	7.89	3.56
Iraq	179241	8.56	3.89
Israel	177331	8.43	5.43
Italy	525100	5.60	2.10
Japan	227202	8.75	5.33
Japan	279460	7.20	3.10
Kenya	385964	8.33	6.33
Korea, South	161373	9.00	4.50
Lebanon	181740	9.00	5.00
Liberia	164247	7.17	2.00
Maldives	536448	9.00	4.00
Maldives	536458	9.00	2.20
Mali	490375	8.75	3.38
Mauritania	549159	8.75	3.50
Mexico	165448	9.00	4.20
Moldova	506439	8.80	2.80
New Zealand	234603	9.00	2.00
Nigeria	184800	6.56	2.33
Nigeria	307609	8.56	5.78
Nigeria	559996	6.63	1.25
Nigeria	560006	7.78	2.00
Nigeria	560016	7.70	3.00
Pakistan	217937	7.89	2.44
Pakistan	426625	8.78	3.56
Pakistan	537273	8.86	3.71
Paraguay	458738	9.00	7.00
Philippines	188808	9.00	3.50
Portugal	234287	8.00	2.00
Russian Federation	518606	8.50	4.50
Senegal	246559	8.80	4.60
Senegal	254744	9.00	5.22
Somalia	271982	8.44	4.56
SouthAfrica	255139	9.00	2.89
SouthAfrica	296332	7.50	3.38
Spain	512339	9.00	4.33
Spain	512349	7.43	3.00
Spain	512360	7.00	2.20
Spain	512370	9.00	6.33
Spain	512382	6.67	3.11
Spain	512393	8.75	3.75
Spain	512404	8.80	3.80
Spain	537470	9.00	3.89
Sudan	254622	9.00	4.40
Syria	177330	9.00	4.00
Syria	534534	6.89	3.11
Syria	534591	9.00	5.25
Taiwan	306365	8.67	3.17
Thailand	249559	9.00	2.20
Tunisia	271132	8.50	2.50
Turkey	105445	8.56	3.44
Turkey	167124	8.40	3.50
Turkey	169237	8.80	5.00
Turkey	169242	7.67	3.33
Turkey	169247	9.00	4.80
Turkey	169257	8.80	3.40
Turkey	169267	9.00	4.60
Turkey	169277	8.20	2.80
Turkey	169287	8.20	5.60
Turkey	169297	9.00	4.60
Turkey	171586	8.82	5.91
Turkey	172794	7.60	3.00
Turkey	172804	8.40	4.80
Turkey	174104	6.88	2.25
Turkey	175654	7.75	5.00
Turkey	175664	9.00	6.67
Turkey	176493	8.75	5.25
Ukraine	476325	8.78	5.67
UnitedStates	595202	9.00	4.25
Uruguay	331106	9.00	8.00
Uzbekistan	476327	8.88	3.50
Venezuela	266028	7.44	3.44
Yugoslavia	190050	9.00	3.80
Yugoslavia	357663	8.67	3.00
Yugoslavia	357673	8.57	5.57
Yugoslavia	357683	8.60	4.40
Yugoslavia	357693	9.00	3.40
Yugoslavia	357703	8.50	2.00
Yugoslavia	357713	8.80	5.60
Yugoslavia	357723	9.00	5.11
Yugoslavia	357733	9.00	5.33
Yugoslavia	357743	9.00	3.50
Yugoslavia	357754	7.80	4.40
Yugoslavia	379224	8.20	2.70
Zaire	378612	9.00	2.70
Zambia	494815	8.60	4.80
Zambia	500306	6.44	1.78
Zambia	500316	8.67	4.44
Zambia	500329	5.89	3.56
Zambia	500344	8.88	4.25
Zambia	505584	7.13	1.00
Zambia	505594	9.00	4.33
Zimbabwe	225557	9.00	2.00
Zimbabwe	482258	7.10	3.70
Zimbabwe	482271	9.00	3.00
Zimbabwe	482288	6.22	3.89
Zimbabwe	482305	8.78	3.33
Zimbabwe	482328	6.40	2.40
Zimbabwe	482349	7.00	3.22
Zimbabwe	482357	8.11	2.33
Zimbabwe	482371	8.90	3.20
Zimbabwe	482378	8.22	2.78
Zimbabwe	526231	5.40	2.70
Zimbabwe	526237	9.00	2.11
Zimbabwe	276657	8.50	5.50
C. lanatus var. lanatus controls			
Charleston Gray		8.93	4.41
Crimson Sweet		8.86	4.15
Dixie Lee		8.81	4.86

[z]Means of 10 plants.

[y]1 to 9 scale where 1 = no galling or visible egg masses present, 2 = 1% to 3%, 3 = 4% to 10%, 4 = 11% to 25%, 5 = 26% to 35%, 6 = 36% to 50%, 7 = 51% to 65%, 8 = 66% to 80%, and 9 = 81% to 100% of root system galled or covered with egg masses, respectively.

Replicated evaluation of selected accessions. Selected accessions that represented the lowest and highest root gall indices were re-evaluated in a replicated greenhouse test. This test included 11 *C. lanatus* var. *citroides* accessions (482379, 482338, 282303, 542119, 189225, 500331, 244018, 512854, 244017, 248774, and 288316) that exhibited the least amount of root galling [gall index (GI) = 3.10 to 4.57], and two *C. lanatus* var. *citroides* accessions (299378 and 532666) and three *C. colocynthis* accessions (432337, 386015, and 525082) that exhibited the most root galling (GI = 7.30 to 9.00) in the initial tests. The three susceptible control cultivars Crimson Sweet, Dixie Lee, and Charleston Gray were also included in the test. Twenty seeds of each accession were planted and the plants were evaluated for reaction to *M. arenaria* race 1 as previously described. The experimental design was a randomized complete block with four replicates and five plants per replicate (one plant in each of five cells in the plastic growing tray). Each plant was rated for severity of root galling and egg mass production eight weeks after inoculation with *M. arenaria* race 1. Then, the entire root systems of all plants of each accession in a replicate were cut into 1 to 2 cm-pieces, the total root weight was recorded, and *M. arenaria* eggs were extracted from the root sample using 1.0% NaOCl (Hussey and Barker, 1973). Numbers of eggs were counted using a stereomicroscope. Nematode reproduction was assessed by calculating the reproductive index (RI) in which RI = P_f/P_i, where P_i = the initial inoculum level and P_f = final egg recovery (Sasser et al., 1984). Eggs per gram fresh root and nematode reproductive index data were $\log_{10}$ (x+1) transformed before analysis. Data were analyzed using the GLM procedure of SAS for Windows, v. 6.12 (SAS Inst., Cary, N.C.), and means were separated using Duncan's multiple range test.

Table 2. Reactions of *Citrullus colocynthis* U.S. Plant Introduction (PI) accessions and control cultivars to the peanut root-knot nematode, *Meloidogyne arenaria* race 1 in greenhouse tests.[z]

Origin	Accession (PI No.)	Gall index[y]	Egg mass index[y]
Afghanistan	220778	9.00	9.00
Afghanistan	269365	9.00	7.00
Algeria	542616	9.00	9.00
Chad	549161	9.00	9.00
Cyprus	432337	8.93	7.60
Egypt	525082	9.00	7.75
Egypt	525083	9.00	5.00
Ethiopia	195927	8.78	5.17
India	Grif 14201	9.00	9.00
India	Grif 14202	9.00	9.00
Iran	386014	9.00	7.00
Iran	386015	9.00	8.11
Iran	386016	8.67	7.76
Iran	386018	9.00	7.67
Iran	386019	9.00	7.17
Iran	386021	9.00	8.33
Iran	386024	8.50	8.00
Iran	386025	9.00	7.78
Iran	386026	9.00	7.78
Morocco	388770	9.00	9.00
Pakistan	537277	9.00	8.00
C. lanatus var. lanatus controls			
Charleston Gray		9.00	7.32
Crimson Sweet		8.83	6.90
Dixie Lee		9.00	7.53
$LSD_{0.05}$		NS	NS

[z]Means of three replicates of five plants per replicate (n = 15).

[y]1 to 9 scale where 1 = no galling or visible egg masses present, 2 = 1% to 3%, 3 = 4% to 10%, 4 = 11% to 25%, 5 = 26% to 35%, 6 = 36% to 50%, 7 = 51% to 65%, 8 = 66% to 80%, and 9 = 81% to 100% of root system galled or covered with egg masses, respectively.

[NS]Nonsignificant.

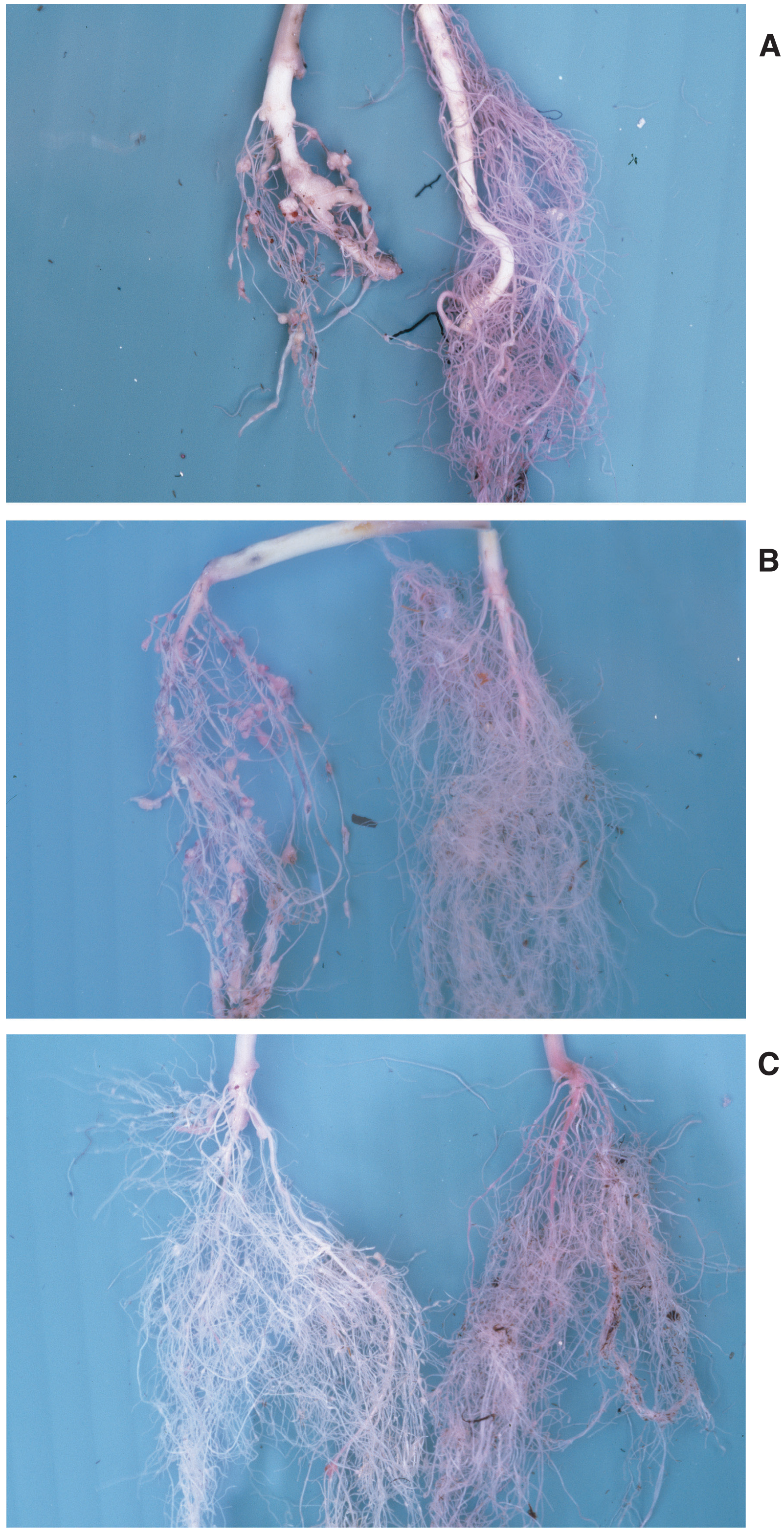

Fig. 1. Root systems of (**A**) *Citrullus colocynthis* PI 432337, (**B**) *C. lanatus* var. *lanatus* 'Charleston Gray', and (**C**) *C. lanatus* var. *citroides* PI 189225 8 weeks after inoculation with the peanut root-knot nematode, *Meloidogyne arenaria* race 1. Roots of inoculated plants are shown on the left and roots of uninoculated control plants are shown on the right.

Table 3. Reactions of *Citrullus lanatus* var. *citroides* U.S. Plant Introduction (PI) accessions and controls to the peanut root-knot nematode, *Meloidogyne arenaria* race 1 in greenhouse tests.[z]

Origin	Accession (PI No.)	Gall index[y]	Egg mass index[y]
Afghanistan	346082	9.00	9.00
Botswana	485583	4.00	1.33
Botswana	542114	4.20	3.30
Botswana	542119	3.20	2.10
Botswana	542123	5.00	5.00
Egypt	525081	6.33	6.67
India	179881	6.33	3.44
India	288316	3.50	1.50
Namibia	248774	4.57	3.86
Namibia	485579	6.00	5.50
South Africa	244017	3.50	2.50
South Africa	244018	3.20	2.60
South Africa	244019	3.60	2.00
South Africa	255137	4.00	2.44
South Africa	270562	9.00	5.00
South Africa	270563	3.70	1.90
South Africa	271767	5.29	3.43
South Africa	271769	5.50	4.50
South Africa	271770	4.29	1.86
South Africa	271771	4.50	3.00
South Africa	271773	3.88	3.38
South Africa	271775	4.30	3.30
South Africa	271779	5.13	3.88
South Africa	295850	7.00	6.00
South Africa	296334	4.11	2.90
South Africa	296335	4.29	3.43
South Africa	296337	6.43	4.86
South Africa	296339	5.00	4.00
South Africa	296341	5.86	4.57
South Africa	296342	5.10	2.60
South Africa	296343	6.50	4.70
South Africa	299378	7.55	4.55
South Africa	299379	5.40	3.10
South Africa	532659	4.33	2.67
Spain	512385	6.70	4.70
Spain	512854	3.80	2.90
Swaziland	532664	7.30	4.50
Swaziland	532666	7.30	1.40
Swaziland	532667	7.33	5.67
Swaziland	532668	7.67	4.17
Yugoslavia	379243	6.33	4.22
Zaire	189225	3.10	1.40
Zambia	500331	4.30	2.20
Zambia	500332	4.30	3.30
Zambia	505604	4.63	3.88
Zimbabwe	482246	5.33	3.44
Zimbabwe	482252	4.67	3.30
Zimbabwe	482257	5.90	3.40
Zimbabwe	482259	3.70	2.70
Zimbabwe	482261	5.10	3.70
Zimbabwe	482265	4.70	3.10
Zimbabwe	482273	5.50	3.00
Zimbabwe	482276	4.80	3.00
Zimbabwe	482277	5.11	3.33
Zimbabwe	482279	5.10	3.00
Zimbabwe	482282	6.00	4.00
Zimbabwe	482283	5.00	3.44
Zimbabwe	482286	4.89	2.56
Zimbabwe	482293	4.88	3.11
Zimbabwe	482298	4.90	1.70
Zimbabwe	482299	5.20	2.20
Zimbabwe	482300	5.12	2.00
Zimbabwe	482301	4.10	1.80
Zimbabwe	482302	4.70	4.00
Zimbabwe	482303	3.50	1.60
Zimbabwe	482307	3.89	2.11
Zimbabwe	482308	4.40	2.40
Zimbabwe	482309	5.00	2.89
Zimbabwe	482311	5.00	3.00
Zimbabwe	482312	4.90	3.30
Zimbabwe	482315	4.30	2.50
Zimbabwe	482316	4.60	1.70
Zimbabwe	482319	3.80	2.20
Zimbabwe	482321	4.20	1.30
Zimbabwe	482322	4.70	2.10
Zimbabwe	482324	3.80	1.90
Zimbabwe	482326	4.27	2.27
Zimbabwe	482331	5.11	3.67
Zimbabwe	482333	4.00	1.88
Zimbabwe	482334	6.00	4.46
Zimbabwe	482335	5.43	3.71
Zimbabwe	482336	4.20	1.80
Zimbabwe	482338	3.56	2.33
Zimbabwe	482342	4.00	2.40
Zimbabwe	482379	3.22	1.44
Zimbabwe	532624	4.00	1.70
C. lanatus var. lanatus controls			
Charleston Gray		8.15	5.29
Crimson Sweet		8.16	4.66
Dixie Lee		8.08	6.18

[z]Means of 10 plants.
[y]1 to 9 scale where 1 = no galling or visible egg masses present, 2 = 1% to 3%, 3 = 4% to 10%, 4 = 11% to 25%, 5 = 26% to 35%, 6 = 36% to 50%, 7 = 51% to 65%, 8 = 66% to 80%, and 9 = 81% to 100% of root system galled or covered with egg masses, respectively.

Results and Discussion

Citrullus lanatus var. lanatus. All but one of the 156 *C. lanatus* var. *lanatus* accessions were susceptible (Table 1). Root gall severity indices ranged from 4.90 to 9.00 and egg mass indices ranged from 1.00 to 8.00. Only PI 459074 from Botswana had a reaction that could be classified as low resistance (GI = 4.90 and EMI = 3.10). The control cultivars (Charleston Gray, Crimson Sweet, and Dixie Lee) were highly susceptible; root gall severity indices ranged from 8.81 to 8.93 and egg mass indices from 4.15 to 4.86.

Citrullus colocynthis. All of the *C. colocynthis* accessions evaluated were highly susceptible (Table 2). The root gall severity indices ranged from 8.50 to 9.00 and egg mass indices ranged from 5.00 to 9.00. The control cultivars also were highly susceptible (gall indices ranged from 8.83 to 9.00 and egg mass indices from 6.90 to 7.53). Although the gall severity indices of the control cultivars were numerically similar to those of the *C. colocynthis* accessions, the galls on roots of the *C. colocynthis* accessions were much larger than those of the control cultivars (Fig. 1 A and B).

Citrullus lanatus var. citroides. Twenty of the *C. lanatus* var. *citroides* accessions appeared to be moderately resistant (GI = 3.1 to 4.0), but none were highly resistant (GI = 1.0 to 2.9) (Table 3). Root gall severity indices for the *C. lanatus* var. *citroides* accessions ranged from 3.1 to 9.0 and egg mass indices ranged

Table 4. Gall indices, egg mass indices, numbers of *Meloidogyne arenaria* race 1 eggs per gram fresh root, and reproductive indices of *M. arenaria* race 1 for selected *Citrullus* spp. Plant Introduction (PI) accessions and control cultivars inoculated with *M. arenaria* race 1, in a replicated greenhouse test.[z]

Taxon/ Origin	Accession (PI No.)	Gall index[y]	Egg mass index[y]	Eggs/g fresh root	Reproductive index[x]
Citrullus lanatus var. citroides					
Zimbabwe	482379*	3.05 a[v]	2.00 a	1,880 a[u]	0.33 a[u]
Zimbabwe	482338*	3.21 ab	2.17 ab	2,901 a–c	0.59 a–c
Zimbabwe	482303*	3.30 ab	2.50 ab	2,261 ab	0.40 ab
Botswana	542119*	3.29 ab	2.94 ab	3,500 a–d	0.70 a–c
Zaire	189225*	3.74 a–c	3.01 ab	4,716 a–e	0.69 a–c
Zambia	500331*	3.95 a–d	3.55 a–c	6,488 c–f	1.13 b–d
South Africa	244018*	4.15 a–d	3.25 ab	6,738 b–e	0.80 a–c
Spain	512854*	4.15 a–d	3.65 a–c	6,530 c–f	1.19 b–d
South Africa	299378**	4.35 a–d	3.45 a–c	4,724 a–e	0.95 a–d
South Africa	244017*	4.45 b–d	3.55 a–c	6,624 c–f	0.91 a–d
Namibia	248774*	4.70 cd	3.95 b–d	11,262 e–h	1.48 c–e
India	288316*	4.99 cd	5.04 cd	16,696 f–h	2.53 d–f
Swaziland	532666**	5.17 d	3.55 a–c	8,770 d–g	1.04 b–d
Citrullus colocynthis					
Cyprus	432337**	7.73 e	6.79 ef	9,649 e–g	1.79 c–e
Iran	386015**	7.83 e	8.67 g	43,033 i	3.72 ef
Egypt	525082**	8.12 e	7.25 fg	26,940 i	3.94 ef
C. lanatus var. lanatus controls					
Crimson Sweet		8.00 e	5.44 de	11,424 e–h	2.78 d–f
Dixie Lee		8.17 e	7.46 fg	7,475 c–g	1.80 c–e
Charleston Gray		8.56 e	7.36 fg	19,209 g–i	5.43 f

[z]Means of four replicates of five plants per replicate (n = 20).
[y]1 to 9 scale where 1 = no galling or visible egg masses present, 2 = 1% to 3%, 3 = 4% to 10%, 4 = 11% to 25%, 5 = 26% to 35%, 6 = 36% to 50%, 7 = 51% to 65%, 8 = 66% to 80%, and 9 = 81% to 100% of root system galled or covered with egg masses, respectively.
[x]Reproductive index = P_f/P_i, where P_i = initial inoculum level and P_f = final egg recovery.
[v]Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$.
[u]Data were $\log_{10}$ (x+1) transformed before analysis. Back transformed data are shown.
*Accessions with gall indices = 3.10 to 4.57 in the unreplicated test.
**Accessions with gall indices = 7.30 to 9.00 in the unreplicated test(s).

from 1.3 to 9.0. Accessions with gall severity indices ≤4.00 originated from: Botswana (2 of 4 PI), India (1 of 2), South Africa (6 of 24), Spain (1 of 2), Zaire (1 of 1), and Zimbabwe (9 of 41). All of the check cultivars, Charleston Gray, Crimson Sweet, and Dixie Lee, were highly susceptible; root gall severity ratings ranged from 8.08 to 8.16 and egg mass indices ranged from 4.66 to 6.18.

Replicated evaluation of selected accessions. Ten accessions of *C. lanatus* var. *citroides* that exhibited low to moderate resistance in the initial unreplicated test and one accession, PI 299378, that appeared to be susceptible in the initial test (Table 3), exhibited low to moderate resistance to *M. arenaria* race 1 in the replicated greenhouse test (Table 4). The gall indices of the 11 resistant accessions ranged from 3.05 to 4.70, egg mass indices ranged from 2.00 to 3.95, numbers of eggs per gram fresh root ranged from 1,880 to 11,262, and reproductive indices (RI) ranged from 0.33 to 1.48. Two accessions of *C. lanatus* var. *citroides* (PI 288316, moderately resistant in the unreplicated test, and PI 532666, susceptible in the unreplicated test) exhibited intermediate to susceptible reactions in the replicated test. Gall indices for PI 288316 and PI 532666 were 4.99 and 5.17, egg mass indices were 5.04 and 3.55, numbers of eggs per gram fresh root were 16,696 and 8,770, and RI were 2.53 and 1.04, respectively.

Galling of root systems of the *C. lanatus* var. *citroides* accessions was minimal to moderate, and generally the root systems were more fibrous than those of the *C. lanatus* var. *lanatus* and *C. colocynthis* accessions (Fig. 1, A–C). Eight of the *C. lanatus* var. *citroides* accessions had RI <1, suggesting that they are resistant to *M. arenaria* race 1. In general, the three *C. lanatus* var. *citroides* accessions from Zimbabwe and the *C. lanatus* var. *citroides* accession from Botswana (PIs 482379, 482338, 482303, and 542119, respectively) had lower ($P \leq 0.05$) root gall severity indices (mean = 3.21) and egg mass indices (mean = 2.40), supported fewer ($P \leq 0.05$) *M. arenaria* race 1 eggs per gram fresh root (mean = 2,635), and had lower ($P \leq 0.05$) RI (mean = 0.50) than the *C. colocynthis* accessions and the *C. lanatus* var. *lanatus* control cultivars.

All of the re-evaluated *C. colocynthis* accessions were highly susceptible to *M. arenaria* race 1 (Table 4). Gall indices ranged from 7.73 to 8.12 and egg mass indices ranged from 6.79 to 8.67. Galls on root systems of the *C. colocynthis* accessions were larger than galls on roots of the *C. lanatus* var. *citroides* accessions and the *C. lanatus* var. *lanatus* control cultivars (Fig. 1A–C). Numbers of eggs per gram fresh root ranged from 9,649 to 43,033 and reproductive indices (RI) ranged from 1.79 to 3.94.

The three control cultivars (‘Crimson Sweet’, ‘Dixie Lee’, and ‘Charleston Gray’) were also susceptible (Table 4). Gall indices ranged from 8.00 to 8.56, egg mass indices ranged from 5.44 to 7.46, numbers of eggs per gram fresh root ranged from 7,475 to 19,209 eggs per gram fresh root, and RI ranged from 1.80 to 5.43 for the control cultivars.

The resistance to *M. arenaria* race 1 observed in *C. lanatus* var. *citroides* in the present study may be attributed to the greater genetic divergence in this *Citrullus* subspecies compared to that found in *C. lanatus* var. *lanatus* (Jarret et al., 1997; Levi et al., 2002; Navot and Zamir, 1987). Several of the resistant *C. lanatus* var. *citroides* accessions identified in this study may contain root-knot nematode resistance genes that can be introgressed into cultivated watermelon (*C. lanatus* var. *lanatus*). However, in order to make significant gains in developing resistant watermelon cultivars, it will be necessary to determine the modes of inheritance of resistance to root-knot nematodes.

Conclusions

The results of the present studies demonstrate that there is significant genetic variability within the USDA *Citrullus* germplasm collection for reaction to *M. arenaria* race 1. Numerous *Citrullus lanatus* var. *citroides* accessions were identified as potential sources of resistance to *M. arenaria* race 1. Thus, future germplasm evaluations for resistance to *M. arenaria* race 1 and to other *Meloidogyne* species should initially focus on *C. lanatus* var. *citroides* accessions.

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