Reactions of Selected Bean Pure Lines and Accessions to *Meloidogyne* Species

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ABSTRACT

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Over 150 bean (*Phaseolus vulgaris*) pure lines and accessions were evaluated in growth chamber and greenhouse trials for reactions to one or more populations of root-knot nematodes (*Meloidogyne* spp.) collected from Colombia or the United States. Bean pure lines and accessions were evaluated for root galling severity and nematode egg mass production on a 1–9 scale, where 1 = no root galling or no egg mass production and 9 = 76–100% of root system galled or >100 egg masses per root system. A resistance index (RI) was generated for each pure line or accession by combining the root galling severity and nematode egg mass production ratings such that RI = (root galling severity rating^2 + egg mass production rating^2). Reaction classes were defined as immune (RI = 2), highly resistant (RI = 3–8), resistant (RI = 9–18), moderately resistant (RI = 19–32), intermediate (RI = 33–50), moderately susceptible (RI = 51–72), susceptible (RI = 73–98), and highly susceptible (RI = 99–162). Only about 30 bean lines and accessions had a response of moderately resistant or better (RI <33) to the populations of *Meloidogyne* spp. used. Among those highly resistant to root-knot nematodes were A 211, Carioca, Manoa Wonder, Nemasnap, and PI 313709. These pure lines and accessions can be used as valuable parental materials in the development of root-knot-resistant bean cultivars adapted for Colombia, Peru, and other countries.

Common bean (*Phaseolus vulgaris* L.), an important food crop and source of protein, is highly susceptibile to the root-knot disease caused by *Meloidogyne* spp. (4,22). In Colombia, yield losses of 60% or more can occur when beans are heavily infected with root-knot nematodes (10). A few commercially acceptable bean cultivars with resistance to root-knot nematodes have been developed (3,21), but the dry bean cultivars grown commercially in developing countries are usually highly susceptible to root-knot nematodes. In addition, bean cultivars reported as resistant in a given location may not be resistant to root-knot nematodes in another location. This may be attributed to many factors, including differences in the predominant species of root-knot nematodes and their relative virulence (14,20). Accordingly, the identification and characterization of various sources of resistance to root-knot nematodes in *P. vulgaris* are of special interest to national and international research programs currently involved with improving the yield and nutritional value of beans. To stabilize yield in beans, the incorporation of resistance to foliar and soilborne pathogens has been one of the main objectives of such research programs.

The objective of this study was to determine the reactions of selected bean pure lines and accessions, including those previously reported as resistant, to populations of root-knot nematodes obtained from Colombia and the United States.

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MATERIALS AND METHODS

Germ plasm sources. Bean pure lines and accessions used in this study were obtained primarily from the Genetic Resources Unit of the Centro Internacional de Agricultura Tropical (CIAT) and from the CIAT bean breeding and pathology programs. The bean cultivar Nemasnap was obtained from G. Fassuliotis (USDA-ARS, Vegetable Research Laboratory, Charleston, SC), and the cultivar California Dark Red Kidney was purchased from the Agway Cooperative Store in Geneva, New York. Bean identification codes used for CIAT germ plasm are: G = germ plasm accession number from the Genetic Resources Unit, CIAT; A = advanced breeding line developed at CIAT; BAT or XAN = selection from the common bacterial blight nursery; CAS = bush type with Canario-type (medium-sized, yellow) seeds from Peruvian drought tolerance selection program; NAG = black-seeded bush type bean from Guatemala; PVA = bush type with Calima-type seed; RIZ = selection from breeding program to enhance *Rhizobium* nodulation efficiency; V = selection from climbing bean improvement program; Cifem = Blanco type (medium-sized, white) from bean improvement program of Instituto Nacional de Investigación Agraria y Agro-Industrial (INIAA) in Peru; and Cifac = Canario type (medium-sized, yellow) from INIAA (Peru). The origin, seed color, and seed size of the germ plasm utilized here have been described elsewhere (6).

Nematode sources and extraction. Several populations of root-knot nematodes were utilized. A population of *M. incognita* (Kofoid & White) Chitwood host race 3 was obtained from naturally infected beans in a field near Popayán, Cauca Department, Colombia, and a mixed population of *M. incognita* and *M. javanica* (Treub) Chitwood was collected from naturally infected beans near Candelaria, Valle Department, Colombia. Another population of *M. incognita* host race 3 was provided by K. R. Barker (Department of Plant Pathology, North Carolina State University, Raleigh), and a population of *M. hapla* Chitwood was collected from lettuce grown on organic soil near Fulton, New York. All populations were increased on tomato (*Lycopersicon esculentum* Miller) cv. Rutgers and were maintained in a growth chamber at 21–22 C or the greenhouse under fluctuating temperatures (18–27 C). Root-knot nematode eggs were extracted using NaOCl (5).

Growth chamber and greenhouse methods. One or two untreated bean seeds were planted per 10-cm-diameter pot filled with pasteurized sand/sandy loam (1:1, v/v). In some trials, seeds were pregerminated in a peat mixture for 1–3 days, then rinsed with water and planted. Beans were inoculated at time of planting with the appropriate nematode population by pipetting a suspension of 10,000 eggs onto seeds and surrounding soil. Treatments were replicated three to eight times, depending on the experiment. To reduce the possibility of high temperatures modifying the resistance response (9), pots were maintained in a growth chamber (21–22 C) for 2–3 wk before being transferred to a greenhouse or screenhouse for the duration of the experiment. Pots were arranged in a randomized complete block design on the greenhouse bench and were watered and fertilized as needed. Additional light was supplied on overcast days for a minimum of 12 hr daily.

Harvest and evaluation. Six to 10 wk after inoculation, plant tops were cut off at the soil line and roots were washed free of soil and scored for severity of root galling and for approximate numbers of nematode egg masses produced. Total egg production per plant was determined in some cases. Egg masses were stained with phloxine B to facilitate enumeration (15). Root galling severity was assessed on a 1–9 scale by estimating proportion of roots galled: 1 = no galling, 2 = ≤5% roots galled, 3 = 6–10%, 4 = 11–18%, 5 = 19–25%, 6 = 26–50%, 7 = 51–65%, 8 = 66–75%, and 9 = 76–100% of roots galled (16). Egg mass production was also assessed on a 1–9 scale: 1 = no egg masses detected, 2 = 1 or 2 egg masses, 3 = 3–6, 4 = 7–10, 5 = 11–20, 6 = 21–30, 7 = 31–60, 8 = 61–100, and 9 = over 100 egg masses produced per plant (expanded from Sasser et al [15]). A resistance index (RI) was developed to incorporate both parameters of resistance (reduced root galling severity and nematode egg mass production) into a single value, such that: RI = (root galling severity rating^2 + egg mass production rating^2). In this scheme, the reaction of a plant to root-knot nematodes was classified as: RI of 2 = immune (Im), RI of 3–8 = highly resistant (HR), RI of 9–18 = resistant (R), RI of 19–32 = moderately resistant (MR), RI of 33–50 = intermediate (I), RI of 51–72 = moderately susceptible (MS), RI of 73–98 = susceptible (S), and RI of 99–162 = highly susceptible (HS). Where actual nematode egg production was determined, eggs were extracted from each root system with NaOCl (5), counted, and expressed as a ratio of total eggs produced/initial inoculum density utilized (P_f/P_i). Analysis of variance was used to analyze data, and means sepa-

Table 1. Reactions of bean pure lines and accessions to a population of *Meloidogyne incognita* from Popayán, Colombia

Bean line or accession	Resistance parameter[a] Gall	EM	RI	RC	Bean line or accession	Resistance parameter[a] Gall	EM	RI	RC
Calima	7.0	7.7	111	HS	G 1380	8.0	8.3	134	HS
Jamapa	8.7	8.3	145	HS	G 1560	5.0	7.0	74	S
Manoa Wonder	1.0	2.0	6	HR	G 1610	7.7	7.3	114	HS
San Cristobal 83	5.3	7.0	78	S	G 1616	5.3	8.3	99	HS
EMP 81	4.3	7.0	68	MS	G 1636	8.3	7.7	129	HS
NAG 39	2.0	4.0	20	MR	G 1805	4.0	5.7	50	I
V 8025	2.3	5.0	32	MR	G 2005	7.0	8.0	113	HS
A55	8.0	8.3	134	HS	G 2546	5.0	7.0	74	S
A 107	1.3	2.7	12	R	G 2575	3.3	5.3	46	I
A 211	1.0	1.3	3	HR	G 2884	8.0	6.7	110	HS
A 252	1.7	2.3	9	R	G 3645	8.7	8.0	139	HS
A 315	9.0	7.0	130	HS	G 4000	4.3	6.0	56	MS
A 328	4.0	6.3	58	MS	G 542	9.0	8.3	151	HS
A 445	4.5	6.0	57	MS	G 604	7.7	7.3	113	HS
Cifem 87071	8.7	8.3	145	HS	G 691	7.5	7.0	106	HS
G 69	8.0	7.0	113	HS	G 827	8.0	8.0	128	HS
G 89	7.0	7.7	108	HS	G 899	1.0	1.5	4	HR
G 152	5.3	6.7	76	S	G 917	8.7	8.0	139	HS
G 231	8.7	8.3	145	HS	G 1007	6.7	7.3	103	HS
G 285	8.7	7.7	134	HS	G 1110	3.5	7.0	64	MS
Canario Divex	8.0	7.7	124	HS	G 1126	6.7	7.0	94	S
CAS 1651	8.5	9.0	154	HS	G 1135	5.3	7.0	81	S
Nemasnap	2.3	2.3	13	R	G 1218	8.0	8.3	134	HS
BAT 1297	3.7	6.0	50	I	G 1301	7.7	7.3	115	HS
IPA 7419	4.6	6.7	68	MS	G 1309	6.7	8.0	111	HS
RIZ 30	3.0	5.7	42	I	G 1535	6.0	7.0	88	S
A 30	8.0	8.3	134	HS	G 1584	4.0	4.3	36	I
A 63	1.3	2.7	12	R	G 1613	7.7	8.3	129	HS
A 113	2.0	5.0	32	MR	G 1618	5.0	7.0	75	S
A 235	1.0	1.3	3	HR	G 1706	1.7	3.7	20	MR
A 300	3.7	6.3	56	MS	G 1876	5.3	7.0	78	S
A 322	5.3	7.0	78	S	G 2530	2.7	4.0	25	MR
A 439	1.3	2.3	11	R	G 2553	7.7	7.7	118	HS
Cifem 87070	7.0	8.0	117	HS	G 2883	6.7	7.0	8	S
G 42	5.3	7.0	78	S	G 2587	1.0	1.3	3	HR
G 78	9.0	8.0	145	HS	G 3709	9.0	7.7	140	HS
G 151	8.5	8.0	137	HS	G 4017	1.0	1.7	5	HR
G 170	9.0	8.0	145	HS	G 4225	1.0	4.3	23	MR
G 278	3.3	6.7	63	MS	G 4823	3.0	6.3	52	MS
G 300	4.7	7.0	71	MS	G 5059	3.7	5.3	42	I
G 327	7.0	8.0	114	HS	G 7263	7.0	8.0	113	HS
G 592	8.3	8.3	141	HS	G 13059	3.0	6.7	54	MS
G 647	7.3	7.3	110	HS	G 15481	9.0	7.5	136	HS
G 725	1.0	3.7	15	R	G 20505	1.3	4.7	25	MR
G 868	4.3	6.3	63	MS	G 4450	5.3	7.0	78	S
G 915	6.0	7.7	96	S	G 4830	4.3	5.0	56	MS
G 927	7.7	8.3	130	HS	G 5478	2.7	4.7	34	I
G 1104	8.0	7.5	121	HS	G 8108	4.0	6.3	56	MS
G 1124	8.3	7.0	121	HS	G 14192	8.0	8.7	140	HS
G 1128	2.0	3.0	18	R	G 18872	5.0	7.0	75	S
G 1141	9.0	7.3	135	HS	G 20509	7.3	7.3	109	HS
G 1229	1.0	1.7	4	HR	$LSD_{0.05}$	1.8	1.6	36	
G 1305	5.7	6.3	73	S					

[a]Gall = root galling severity rating (1 = no galling, 9 = 76–100% of roots galled); EM = egg mass production rating (1 = no egg masses, 9 = >100 egg masses per plant); RI = resistance index (root galling severity rating^2 + egg mass production rating^2); RC = host reaction class based on RI (Im = immune, HR = highly resistant, R = resistant, MR = moderately resistant, I = intermediate, MS = moderately susceptible, S = susceptible, HS = highly susceptible).

ration were performed with LSD values.

Reactions of bean pure lines and accessions to *M. incognita*. In two trials, 104 entries were evaluated for reactions to the Popayán population of *M. incognita*. Included were approximately 90 bean accessions from the Genetic Resources Unit at CIAT that had been reported as highly to moderately resistant to *M. incognita* (3,7,12,13,17,18). Treatments were replicated three times, and the plants were harvested and evaluated 7 wk after inoculation.

Reactions of bean pure lines and accessions to a mixed population of *M. incognita* and *M. javanica*. In two experiments, 96 bean pure lines and accessions were evaluated for host suitability to the Candelaria population of *M. incognita* and *M. javanica*. Treatments were replicated four times. Plants were incubated in a growth chamber (21 C) for 2 wk, then transferred to a greenhouse (23–28 C); plants were harvested and evaluated 8 wk after inoculation.

Reactions of bean pure lines and accessions to *M. incognita* and *M. hapla*. In this trial, 13 bean accessions or cultivars were screened for reactions to three populations of *Meloidogyne: M. incognita* from North Carolina, *M. incognita* from Popayán, Colombia, and *M. hapla* from New York. One additional entry (RIZ 30) was tested only against the populations of *M. incognita*. Treatments were replicated eight times, and plants were harvested and evaluated 8 wk after inoculation.

Comparison of virulence of two populations of *M. incognita* on beans. Two populations of *M. incognita* were retested and compared on selected bean accessions to confirm differences in reactions within designated host races. Bean pure lines selected for this trial were Canario Divex (susceptible check), BAT 1297, A 211, A 252, A 445, and G 4823. Treatments were replicated five times.

Table 2. Reactions of bean pure lines and accessions to a population of *Meloidogyne incognita* and *M. javanica* from Candelaria, Colombia

Bean line or accession	Resistance parameter[a]				Bean line or accession	Resistance parameter[a]			
	Gall	EM	RI	RC		Gall	EM	RI	RC
Calima	8.3	9.0	149	HS	G 2587	2.3	3.7	21	MR
Ikinimba	4.3	7.3	77	S	G 2935	3.7	5.3	44	I
Nemasnap	2.0	4.3	24	MR	G 3645	5.0	7.0	75	S
San Cristobal 83	3.3	6.0	52	MS	G 3736	3.3	5.0	37	I
BAT 93	6.7	7.3	99	HS	G 4014	8.0	8.7	140	HS
BAT 1276	7.3	8.7	130	HS	G 4225	2.3	4.7	34	I
BAT 1373	7.3	7.3	108	HS	G 4823	3.3	5.3	45	I
EMP 81	5.3	6.7	75	S	G 5059	7.0	7.7	109	HS
ICA Pijao	2.3	3.7	27	MR	G 5478	6.7	7.0	95	S
NAG 39	4.7	6.3	69	MS	G 5681	3.0	4.3	29	MR
PVA 782	7.3	9.0	13	S	G 5752	4.0	4.7	55	MS
PVA 1261	8.8	9.0	158	S	G 5773	5.7	7.0	82	S
V 8025	3.7	4.7	37	I	G 6572	9.0	8.0	145	HS
A 21	7.7	7.3	114	HS	G 6731	8.0	9.0	145	HS
A 55	2.7	5.7	40	I	G 7467	1.7	4.3	25	MR
A 89	7.0	7.3	108	HS	G 8108	4.3	6.0	66	MS
A 114	8.3	8.0	134	HS	A 315	5.0	6.7	70	MS
A 211	1.5	2.1	8	R	A 328	5.0	6.7	70	MS
A 252	2.0	2.3	14	R	A 443	1.0	1.0	2	Im
A 286	5.7	6.0	69	MS	A 493	7.0	7.7	109	HS
Canario Divex	6.0	7.0	88	S	G 725	1.0	1.0	2	Im
Manoa Wonder	1.7	4.3	21	MR	G 1128	5.0	6.3	69	MS
Sanilac	4.7	7.0	71	MS	G 1320	1.3	2.7	15	R
Seafarer	3.7	5.0	43	I	G 1805	3.0	4.3	33	I
BAT 477	2.3	6.0	42	I	G 2530	1.3	3.0	16	R
BAT 1297	2.3	4.0	28	MR	G 2618	4.7	6.0	60	MS
BAT 1641	6.3	7.3	95	S	G 2936	4.0	5.0	41	I
ICA L24	8.0	9.0	145	S	G 3709	7.3	7.0	103	HS
IPA 7419	3.7	6.0	51	MS	G 3844	6.3	7.0	92	S
PVA 476	7.8	9.0	142	S	G 4017	1.0	1.7	5	HR
PVA 916	8.7	8.3	147	S	G 4450	6.3	7.7	99	HS
RIZ 30	1.7	4.3	24	MR	G 4830	6.0	7.3	92	S
XAN 112	3.0	5.7	47	I	G 5477	7.3	7.3	108	HS
A 30	6.0	7.3	93	S	G 5496	7.0	7.7	108	HS
A 56	1.3	2.7	11	R	G 5694	3.0	6.0	46	I
A 107	4.0	7.0	66	MS	G 5753	4.3	5.7	71	MS
A 179	8.0	7.7	124	HS	G 6374	1.5	2.5	11	R
A 247	4.7	6.3	63	MS	G 6726	5.7	7.7	95	S
A 268	5.0	6.7	70	MS	G 7453	6.0	7.0	86	S
A 292	8.0	8.0	129	HS	G 7726	5.3	6.3	72	S
A 300	3.3	7.0	64	MS	G 8768	9.0	8.3	151	HS
A 322	5.5	7.0	82	S	G 9132	7.7	7.7	116	HS
A 439	1.7	4.7	27	MR	G 11236	5.3	6.3	70	MS
A 445	2.0	1.7	8	HR	G 12727	2.7	5.3	36	I
G 76	8.7	7.7	135	HS	G 11206	6.3	7.3	96	S
G 899	1.0	2.3	10	R	G 12488	6.3	7.3	94	S
G 1229	1.0	1.3	3	HR	G 20505	5.3	7.3	85	S
G 1706	3.3	6.6	57	MS	$LSD_{0.05}$	2.5	3.0	41	
G 2472	5.3	6.3	71	MS					

[a]Gall = root galling severity rating (1 = no galling, 9 = 76–100% of roots galled); EM = egg mass production rating (1 = no egg masses, 9 = >100 egg masses per plant); RI = resistance index (root galling severity rating^2 + egg mass production rating^2); RC = host reaction class based on RI (Im = immune, HR = highly resistant, R = resistant, MR = moderately resistant, I = intermediate, MS = moderately susceptible, S = susceptible, HS = highly susceptible).

Plants were maintained in a greenhouse and harvested and evaluated 6 wk after inoculation. This experiment was repeated once.

RESULTS

Reactions of bean pure lines and accessions to *M. incognita*. Data from the two trials were pooled because LSD values were similar; the larger of the LSD values for each parameter is given (Table 1). The range of host responses to root-knot nematodes was wide. Twenty-one entries showed a moderately resistant or better reaction (RI <33) to the population of *M. incognita* from Popayán. Most of these were small black seed types, although several small white and red and medium yellow, black, cream, and brown types also were represented. Among the best materials were A 63, A 107, A 211, A 235, A 252, A 439, G 725, G 899, G 1128, G 1229, G 2587, G 4017, Nemasnap, and Manoa Wonder. Canario Divex and Calima, commercial cultivars used extensively in coastal Peru and Valle Department, Colombia, respectively, were highly susceptible. Other pure lines and accessions were also moderately to highly susceptible in this trial.

Reactions of bean pure lines and accessions to a mixed population of *M. incognita* and *M. javanica*. Data from the two trials were pooled because LSD values were similar; the larger of the LSD values for each parameter is given (Table 2). Twenty-one bean pure lines and accessions showed moderately resistant to immune reactions to the Candelaria population of *Meloidogyne* spp. Several of these had also expressed a resistant reaction to the Popayán population of *M. incognita* (Table 1). The most resistant pure lines and accessions were A 56, A 211, A 252, A 433, A 445, G 725, G 899, G 1229, G 1320, G 2530, G 4017, and G 6374. Seed types represented by these included small red/cream, black, or red and medium yellow or white. Canario Divex was susceptible and Calima was highly susceptible.

Reactions of bean pure lines and accessions to *M. incognita* and *M. hapla*. The bean pure lines and accessions included in this trial showed reactions ranging from highly resistant to highly susceptible (Table 3). In general, germ plasm identified as resistant to one nematode population was also resistant to the other populations. The two exceptions were G 4823 and RIZ 30, which were more resistant (or less susceptible) to the North Carolina population of *M. incognita* than to the Popayán population. G 4823 was also resistant to *M. hapla*. Most of the pure lines were moderately to highly resistant to root-knot nematodes. The cultivar Canario Divex was susceptible or highly susceptible to both *M. incognita* populations.

Comparison of virulence of two populations of *M. incognita* on beans. The reactions of BAT 1297, G 4823, and Canario Divex to the two populations of *M. incognita* differed ($P < 0.05$) (Table 4). All resistance parameters for BAT 1297 were greater ($P < 0.01$) with the North Carolina population than with the Popayán population. G 4823 showed greater ($P < 0.01$) egg mass production with the North Carolina population (the reverse of the previous test), whereas Canario Divex showed more ($P < 0.05$) root galling, a higher resistance index, and a higher P_f/P_i. In the other bean pure lines, the two nematode populations were not distinguished by any parameter.

DISCUSSION

Approximately 30 bean pure lines and accessions evaluated in this study bear potentially useful levels of resistance to Colombian and/or American populations of root-knot nematodes. These included advanced bean lines A 211, A 252, and A 445 (all derived from the resistant land race Carioca), bean cultivars Manoa Wonder and Nemasnap, and G 2587 (= PI 313709). Each of these expressed resistance both to *M. incognita* and to a mixed population of *M. incognita* and *M. javanica*. Mixtures of species, particularly of *M. incognita* and *M. javanica*, occur frequently in Colombia (10). Thus, germ plasm resistant to both species would be useful to breeders seeking to incorporate nematode resistance into locally adapted bean cultivars for Colombia. Bean line A 211, among the most resistant pure lines or accessions evaluated in this study, also has expressed strong resistance to *M. incognita* from coastal Peru (*unpublished*) and is currently being used by Peruvian bean breeders as a source of resistance to these nematodes. Other studies have been conducted to further characterize the resistance in A 211 to root-knot nematodes (8,9,11).

Resistance in bean pure lines to several of the most important species of root-knot nematodes has been reported (3,12,13,17,18,21). However, most of these pure lines or accessions were moderately to highly susceptible to the populations of root-knot nematodes utilized in this study. Because of these apparent differences in virulence, it may be necessary to confirm reported sources of resistance to root-knot nematodes in beans and possibly other crops to local populations of these nematodes. Addi-

Table 3. Reactions[a] of bean pure lines and accessions to one population of *Meloidogyne incognita* from North Carolina, one of *M. incognita* from Popayán, Colombia, and one of *M. hapla* from New York

Bean line or accession	*M. incognita*										*M. hapla*				
	North Carolina					Popayán									
	Gall	EM	RI	P_f/P_i	RC	Gall	EM	RI	P_f/P_i	RC	Gall	EM	RI	P_f/P_i	RC
Canario Divex	4.9	8.4	99	6.0	HS	7.5	4.0	73	···	S	4.8	4.8	46	···	I
California Dark Red Kidney	5.0	8.6	101	3.7	HS	6.8	4.0	62	···	MS	5.3	4.7	52	···	MS
Nemasnap	1.1	3.8	18	0.2	R	1.8	3.0	13	···	R	2.3	2.8	14	···	R
RIZ 30	2.0	3.4	19	0.2	R	3.0	5.7	39	···	I	···	···	···	···	···
A 211	1.0	1.5	4	0.1	HR	1.0	0.3	2	···	HR	3.3	2.8	20	···	MR
A 252	2.5	4.5	29	0.1	MR	3.4	···	···	0.4	MR	2.8	···	···	0.2	R
A 322	5.0	8.8	105	5.0	HS	6.6	···	···	0.2	I	4.3	···	···	3.4	I
A 445	2.2	2.1	12	0.1	R	3.6	···	···	0.1	MR	2.5	···	···	0.1	R
G 2587	1.0	1.5	4	0.1	HR	1.0	···	···	0.4	HR	2.0	···	···	0.1	R
G 3773	6.2	8.8	108	6.5	HS	7.2	···	···	0.2	MS	5.2	···	···	4.3	S
G 4450	6.0	8.8	114	3.2	HS	6.3	4.0	56	···	MS	4.8	4.8	46	···	I
G 4823	2.4	5.0	35	0.8	I	3.0	6.3	52	0.7	MS	2.8	···	···	0.4	R
G 6278	1.3	2.0	8	0.1	HR	1.8	···	···	0.1	R	2.3	···	···	0.2	R
G 12727	1.3	1.8	10	0.1	R	2.3	···	···	0.8	R	2.0	···	···	0.1	R
$LSD_{0.05}$	0.8	1.5	26	1.9		1.1	0.7	21	0.8		0.9	0.9	14	1.5	

[a] Gall = root galling severity rating (1 = no galling, 9 = 76–100% of roots galled); EM = egg mass production rating (1 = no egg masses, 9 = >100 egg masses per plant); RI = resistance index (root galling severity rating^2 + egg mass production rating^2); P_f/P_i = ratio of total eggs produced/initial inoculum density; RC = host reaction class based on RI (Im = immune, HR = highly resistant, R = resistant, MR = moderately resistant, I = intermediate, MS = moderately susceptible, S = susceptible, HS = highly susceptible).

Table 4. Comparison of virulence of two populations of *Meloidogyne incognita* to selected bean pure lines[a]

Bean line or accession	North Carolina					Popayán, Columbia				
	Gall	EM	RI	P_f/P_i	RC	Gall	EM	RI	P_f/P_i	RC
Canario Divex	7.8	8.8	139	30.3	HS	5.8	8.6	110	11.8	HS
BAT 1297	3.6	6.9	62	4.8	MS	2.2	3.8	27	0.2	MR
A 211	1.0	1.0	2	0.1	HR	1.0	1.4	4	0.1	HR
A 252	2.7	4.3	34	1.6	I	2.1	4.1	28	0.3	MR
A 445	3.5	5.0	41	0.5	I	3.4	4.4	35	0.1	I
G 4823	3.0	6.5	61	7.1	MS	2.4	4.0	33	2.7	I
$LSD_{0.05}$	1.2	2.1	28	9.3		1.3	2.4	26	4.3	

[a]Gall = root galling severity rating (1= no galling, 9 = 76–100% of roots galled); EM = egg mass production rating (1 = no egg masses, 9 = >100 egg masses per plant); RI = resistance index (root galling severity rating^2 + egg mass production rating^2); P_f/P_i = ratio of total eggs produced/initial inoculum density; RC = host reaction class based on RI (Im = immune, HR = highly resistant, R = resistant, MR = moderately resistant, I = intermediate, MS = moderately susceptible, S = susceptible, HS = highly susceptible).

tionally, several bean pure lines differentiated among two populations of *M. incognita* designated as the same host race. This suggests that the host race designation as determined by nematode reproduction on tobacco and cotton (19) may not adequately describe the virulence of these nematodes to beans. Breeders wishing to utilize resistance to root-knot nematodes in crop improvement may find it necessary to classify nematode virulence within each crop species. Further research on this subject is needed with these results in mind.

In Colombia and Peru, beans are frequently produced in regions with poor soils that receive only limited applications of pesticides and fertilizer. Beans grown in these soils usually face a wide range of stresses, such as soil compaction, diseases, insects, and nutritional problems, that are rarely corrected or controlled. The development of improved bean cultivars for these countries necessitates the incorporation of resistance or tolerance to many pathogens, insects, and other factors. The ease with which the resistance factor(s) can be transferred will depend on the number and nature of genes conditioning the resistance as well as the seed type and origin of both the resistant and the adapted bean germ plasm. Generally, beans with small (<25 g/100 seeds) seed types, such as those of line A 211, are difficult to cross with those that are medium-sized or larger. The availability of a wide range of desirable genetic traits in germ plasm that includes seed types from each center of domestication would reduce this problem.

Genotypes of many crops have been screened for resistance to root-knot nematodes (7,13,14,19). Although root galling severity and nematode reproduction together are accepted parameters of root-knot nematode resistance and a terminology for the classification of host reaction based on these parameters exists (1,2), researchers frequently rely on only one of the two to classify germ plasm as susceptible or resistant (13,14). Additionally, the categories of hypersusceptible and tolerant, as proposed by Dropkin and Nelson (2) and Canto-Saenz (1), are difficult concepts to apply in plant breeding when quantitative ratings are desired. In our study, we utilized a new system of host reaction classifications in which the two components of root-knot nematode resistance are combined and equally weighted to generate a resistance index (RI). The host reaction classification is quantitatively defined by a range of RI values. With this system, the RI is inflated disproportionately as either or both parameters are increased and thus can be used to flag germ plasm with intermediate or greater ratings as unsuitable. This is desirable for plant breeders who wish to retain only the clearly resistant germ lines. Because plant responses to root-knot nematodes generally occur as a continuum rather than in four discrete categories, the eight host reaction classifications assigned to ranges of RI scores in this system are intuitively applicable and relevant to applied nematology.

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