Identification of Root-Knot Nematode Species Occurring on Tomatoes in Tanzania and Resistant Lines for Their Control

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ABSTRACT

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This was a 5-year study that included surveys during the first 2 years, followed by field evaluations of improved tomato lines over the next 3-year period. Surveys were conducted in 12 regions of Tanzania from 1993 to 1995 to identify the causal nematodes of tomato root-knots. Eighty-seven samples were collected and assayed for presence of *Meloidogyne* spp. *M. hapla*, *M. incognita*, and *M. javanica* were detected at incidences of 1, 19, and 89%, respectively. Species mixtures were common within samples. Results indicated the presence of races 1 and 2 of *M. incognita* in tomato-growing regions of Tanzania. Reactions of eight advanced tomato breeding lines to the three species in greenhouse and field tests indicated that three lines, namely ARP 365-2, 367-1, and 367-2, were resistant to *M. incognita* races 1 and 2 and to *M. javanica*, but all lines were susceptible to *M. hapla*.

Additional keywords: *Lycopersicon esculentum*, *Mi* gene, southern Africa

Root-knot nematodes, *Meloidogyne* spp., are important pests of tomato (*Lycopersicon esculentum* Mill.) worldwide (9,15). Four major species, namely *M. arenaria*, *M. hapla*, *M. incognita*, and *M. javanica*, have been reported to infect tomatoes in the tropics (14). These species cause galls or root-knots on infected plants. Other symptoms include stunted growth, wilting, and poor fruit yield. Infection by *M. incognita* can increase root weight and decrease shoot weight (6).

In the tropics, estimated production losses of tomatoes due to *Meloidogyne* spp. reach as high as 50%; however, the overall impact on tomato is highly variable, as disease intensity is influenced by many biotic and abiotic factors (15).

Several control strategies, such as host plant resistance, rotation with nonhosts, sanitation and avoidance, destruction of residual crop roots, and judicious use of nematicides, have been reported to effectively control root-knot nematodes (1). However, the use of resistant varieties remains the most viable option, particularly for small-scale farmers with limited resources. A single dominant gene, *Mi*, confers resistance to certain species of *Meloidogyne*. This resistance has been introgressed in many commercial tomato varieties (19).

Tomato is one of the most important vegetables in Tanzania, ranking first in acreage and second only to cabbage in production and economic value (11). The average yield of tomato in Tanzania is reported to be 8 t/ha (5). Root-knot nematodes are often cited as major limiting factors of tomato production (16). Despite their relative importance, the biology and management of tomato root-knot nematodes have not been fully addressed in Tanzania.

The present study was conducted to identify the *Meloidogyne* populations infecting tomatoes in the major production regions of Tanzania and to evaluate the resistance of advanced tomato breeding lines being popularized in Tanzania and other countries in southern Africa.

MATERIALS AND METHODS

Collection and isolation of *Meloidogyne* spp. Isolates of *Meloidogyne* spp. were collected from naturally infected tomato plants during surveys conducted in 12 major tomato growing regions of Tanzania from 1993 to 1995 (Fig. 1). Tomato roots with galls symptomatic of root-knot were collected from the surveyed areas. Samples were placed in plastic bags and transported to the laboratory. At least 10 samples were collected in each field surveyed. Samples collected within a field were pooled as one sample. Forty to 50 egg masses from the same field were selected and placed beneath the roots of susceptible tomato cv. Rutgers seedlings in 12-cm pots filled with sterile forest soil. In some cases, soil samples (approximately 500 g) were also collected around galled tomato roots

in each surveyed field. These subsamples (about 250 cm³) were mixed with an equal volume of pasteurized sand. The resulting mixture was then planted with the susceptible tomato cv. Rutgers in 12-cm-diameter pots to allow the development of adult females for identification. Six weeks after inoculation of tomato seedlings, females were extracted from the roots for identification and characterization.

Identification and characterization of isolates. Root-knot nematode populations were identified to species and race based on differential host tests and perineal pattern characteristics (8).

Differential hosts. Root samples from infected Rutgers tomatoes were immersed in 0.5% sodium hypochlorite, and the eggs collected on the 500-mesh sieve were rinsed gently with tap water for 5 min to remove all residual bleach. The differential host set included cotton (*Gossypium hirsutum* cv. Deltapine 61), tobacco (*Nicotiana tabacum* cv. NC 95), pepper (*Capsicum annuum* cv. California Wonder), watermelon (*Citrullus lanatus* cv. Charleston Gray), groundnut (*Arachis hypogaea* cv. Florunner), and tomato (*L. esculentum* cv. Rutgers). These were grown in 12-cm-diameter pots filled with sterile clay-loam forest soil, pH 6.5. Five seedlings (4- to 6-week-old) of each differential host were inoculated by pipetting approximately 2,000 eggs in 10 ml of water into each pot. Sixty days after inoculation, plants were removed from the pots and the root systems washed free of soil and stained with Phloxine B (15 mg/liter of tap water) for 20 min. The nematode reproduction was assessed on each plant of the differential set by counting the number of egg masses.

Perineal patterns. Perineal patterns of mature females were prepared for each root-knot nematode isolate. The root tissues were teased apart with forceps and half spear to remove adult females. The head and neck region of the nematode was excised and the posterior placed in a solution of 45% lactic acid to remove all body tissues. Then, the perineal pattern was trimmed and transferred to a drop of glycerine and processed as described by Hartman and Sasser (8). At least 10 perineal patterns were examined to make the identification of nematode species of each sample.

Greenhouse evaluation of tomato breeding lines for resistance to root-knot nematodes. Nine tomato breeding lines developed at the Asian Vegetable Research

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and Development Center (AVRDC) were evaluated under greenhouse conditions for resistance to *M. hapla*, *M. incognita* races 1 and 2, and *M. javanica*. The AVRDC breeding lines derived from crosses between the South African highland tomato variety Rodade and AVRDC's tropical tomatoes. Rodade is known to carry the *Mi* gene for resistance to root-knot nematodes. Tomato breeding lines ARP 365-1, ARP 365-2, ARP-365-3, ARP 367-1, ARP 367-2, ARP 366-1, ARP 366-3, ARP 366-4, and one susceptible check, MoneyMaker, were grown in 12-cm pots filled with sterile forest soil and arranged on greenhouse benches in a randomized complete block design with three replications. In each replication, 10 5-week-old seedlings of each line were inoculated separately with one representative of the isolates of root-knot nematodes characterized earlier. The inoculation procedure was the same as described for identification and characteri-

zation tests. Sixty days after inoculation, plants were removed from the pots, and the root systems were washed free of soil and stained with Phloxine B. The reaction of tomato lines, expressed as the egg mass production, was scored as follows: 0 = no egg masses, 1 = 1 to 2 egg masses, 2 = 3 to 10, 3 = 11 to 30, 4 = 31 to 100, and 5 = more than 100 egg masses.

Field evaluation of tomato breeding lines for resistance to root-knot nematodes. The AVRDC tomato breeding lines tested for resistance in the field were selected based on previous reports of their yield and adaptability to highland conditions. The trials were conducted over three seasons, 1995-96, 1996-97, and 1997-98, at the Makutopora Research Station in Dodoma. Based on previous survey results, the field used was known to be highly infested with *M. javanica*. Five-week-old seedlings of ARP 365-1, 365-2, 365-3, 367-1, 367-2, 366-1, 366-2, 366-3, 366-4,

and two local checks, Marglobe and MoneyMaker, were transplanted on double-row beds measuring 7 × 1.5 m. Transplants were spaced 50 cm apart in rows spaced 60 cm apart with 12 plants per row. All trials were laid out in a randomized complete block design with three replications. Fertilizer was applied preplant at the rate of 60:80:60 kg of NPK per hectare, sidedressed with 60:0:60 at 3 weeks, and top-dressed with 60:0:60 at 5 weeks after transplanting. For protection against early blight and late blight, plants were sprayed at 14-day intervals with metalaxyl plus mancozeb (Ridomil-Mz) at 1.2 kg/ha. Weed control was done by manual hoeing. At final harvest, all plants were uprooted and the incidence of plants with galled roots was assessed.

Statistics. Prior to statistical analyses, data were checked for normality and homogeneity of variance. Data were analyzed by analysis of variance to determine treatment effects, and mean comparisons were made using Duncan's multiple range test. All analyses were performed using the Statistical Analysis System CoStat (Cohort Software, Minneapolis, MN).

RESULTS

Determination of root-knot nematode distribution and characterization. Three species of root-knot nematodes, *M. hapla*, *M. javanica*, and *M. incognita*, were identified from 87 tomato isolates (Table 1). *M. arenaria* was not detected. *M. javanica* was the most common and most widespread species associated with root-knot of tomatoes. This species was detected in 78 samples from 13 districts. *M. incognita* was detected in 17 samples from eight districts. A few samples of *M. incognita* were mixed with *M. javanica*. One sample of *M. hapla* was found in Sumbawanga region, and this was mixed with *M.*

Fig. 1. Map of Tanzania showing regions surveyed for tomato root-knot nematodes.

Table 1. Distribution of *Meloidogyne* species^x associated with tomato crops in Tanzania

District	Region	Elevation above sea level (m)	No. of samples	Mh	Mi	Mj	Mx
Arumeru	Arusha	1,000-1,300	25	0 ^y	6	19	0
Dodoma	Dodoma	1,260	5	0	0	4	1A ^z
Hai	Kilimanjaro	1,200	6	0	0	6	0
Iringa	Iringa	1,400-1,500	7	0	0	7	0
Kilosa	Morogoro	500	1	0	1	0	0
Kisarawe	Coast	250	1	0	1	0	0
Kyela	Mbeya	450	1	0	1	0	0
Lushoto	Tanga	1,600-1,700	5	0	0	5	0
Mbeya	Mbeya	1,700-1,800	5	0	0	5	0
Mpanda	Sumbawanga	1,600	5	0	0	5	0
Muheza	Tanga	200	2	0	0	0	2A
Mwanza	Mwanza	1,200	6	0	0	3	3A
Rombo	Kilimanjaro	1,560	3	0	0	3	0
Shinyanga	Shinyanga	1,200	3	0	0	3	0
Sumbawanga	Sumbawanga	1,900	4	0	0	3	1B
Tabora	Tabora	1,300	3	0	0	3	0
Urambo	Tabora	1,250	5	0	0	3	2A
Total			87	0	9	69	9

^x *M. hapla* (Mh); *M. javanica* (Mj); *M. incognita* (Mi); mixture (Mx).

^y Number of isolates.

^z A = mixture of *M. javanica* + *M. incognita*; B = mixture of *M. hapla* + *M. javanica*.

javanica. Based on the differential host test, two races (1 and 2) of *M. incognita* were found. All isolates of *M. incognita* reproduced on pepper, tomato, and watermelon but varied in the reproduction on tobacco. Isolates from Kyela, Mwanza, and Urambo, which did not reproduce on tobacco cv. NC 95, were classified as race 1. Isolates from Arumeru, Kilosa, Kisarawe, Muheza, and Dodoma, which reproduced on tobacco cv. NC 95, were race 2. None of the isolates reproduced on cotton or groundnut.

Reaction of tomato lines to root-knot nematodes. Of the tomato lines tested, ARP 365-2, ARP 367-1, and ARP 367-2 were highly resistant to *M. javanica* and *M. incognita* races 1 and 2, and did not develop root-knot symptoms (Table 2). ARP 365-1, ARP 365-3, and ARP 366-1 showed an intermediate reaction to *M. javanica* and *M. incognita* races 1 and 2. Disease reaction of these lines ranged from 1.7 to 4. ARP 366-3 and ARP 366-4 lines were susceptible to *M. javanica* and *M. incognita* races 1 and 2 with mean disease severity ratings higher than 4. All AVRDC tomato breeding lines were susceptible to *M. hapla*. The check, Moneymaker, was susceptible to all *Meloidogyne* spp. tested.

Field evaluation of tomato lines for resistance to root-knot nematodes and

their yield characteristics. Nine tomato lines and two check cultivars, Marglobe and Moneymaker, were evaluated at Dodoma for three successive years for resistance to root-knot nematodes in a field known to be highly infested with *M. javanica*. Disease incidence among lines was comparable during the first 2 years (Table 3). Disease incidence in ARP 365-1, 366-2, 366-3, and 366-4 ranged from 30 to 37% in year 1 and year 2, while disease incidence in ARP 365-2, 365-3, 367-1, 367-2, and 366-1 ranged from 0 to 9%. In year 3, disease incidence of ARP 366-2, 366-3, and 366-4 ranged from 24 to 46%, while disease incidence in ARP 365-1, 365-2, 365-3, 367-1, 367-2, and 366-1 ranged from 0 to 15%. During the three test seasons, disease incidence in Marglobe and Moneymaker ranged from 42 to 53%.

Pathogenicity tests conducted under greenhouse conditions with isolates from field infected plants ARP 365-2, ARP 367-1, and ARP 367-2 indicated that, 60 days after inoculation, plants of tomato cv. Rutgers developed root-knot symptoms but plants of ARP 365-2, 367-1, and 367-2 were not infected.

The yield of tomato lines varied from year to year (Table 3). The yield of AVRDC breeding lines ranged from 19 to

57 t/ha. The yield of the susceptible checks, Marglobe and Moneymaker, ranged from 21 to 45 t/ha.

DISCUSSION

This study shows that three nematode species, namely *M. hapla*, *M. javanica*, and *M. incognita*, are associated with tomato root-knot in Tanzania. Root-knot nematodes were found in all surveyed tomato growing regions of the country. Infected tomato plants developed root-knot galls two or three times as large in diameter as the healthy roots, indicating the high population densities of the pathogens. *M. javanica* was the most widely distributed species in the tomato growing regions. This species was recorded in 89% of tomato root-knot infected samples, which is consistent with another report from the region by Saka (13), who reported that *M. javanica* was the most common species in Malawi, Zimbabwe, and Zambia. *M. incognita* is reported to be the most important root-knot nematode species worldwide (10). The relative importance of *M. javanica* in Southern Africa countries could be attributed to climate. It has been shown that *M. javanica* may be the predominant species in regions with a distinct dry season and less than 5 mm of precipitation per month for three or more successive months (4). *M. hapla* is considered a nematode of cooler climates (10,17), although this species can occur also in tropical countries at high elevations (14). In our study, *M. hapla* was detected mixed with *M. javanica* in one region, Sumbawanga, which is situated at 1,900 m above sea level. This result concurs with previous findings and indicates that *M. hapla* is predominantly distributed at high elevations in Tanzania.

Owing to the importance and widespread distribution of root-knot nematodes in Tanzania, the incorporation of resistance to *M. javanica* and *M. incognita* into improved tomato cultivars is essential. A breeding program by the Africa Regional Program of AVRDC, in Arusha, Tanzania,

Table 2. Disease reaction^z of tomato breeding lines to isolates of *Meloidogyne* spp.

Tomato line	<i>Meloidogyne</i> spp.			
	<i>M. javanica</i>	<i>M. incognita</i> race 1	<i>M. incognita</i> race 2	<i>M. hapla</i>
ARP 365-1	2.96 c	3.03 c	3.13 c	4.16 bc
ARP 365-2	0.00 e	0.03 e	0.06 e	3.96 c
ARP 365-3	2.93 c	3.10 c	3.43 c	4.76 ab
ARP 367-1	0.06 e	0.00 e	0.00 e	4.43 abc
ARP 367-2	0.00 e	0.00 e	0.00 e	4.53 abc
ARP 366-1	1.73 d	1.83 d	2.00 d	4.83 a
ARP 366-3	4.30 b	4.20 b	4.16 b	4.83 a
ARP 366-4	4.50 ab	4.40 b	4.36 b	4.96 a
Moneymaker	5.00 a	4.93 a	5.00 a	5.00 a
CV %	13.1	11.16	10.35	7.4

^z Disease reaction is on a scale of 0 to 5 with 0 = no egg masses, 1 = 1 to 2 egg masses, 2 = 3 to 10, 3 = 11 to 30, 4 = 31 to 100, and 5 = more than 100 egg masses. Means followed by the same letter within columns do not differ significantly at 5% according to Duncan's multiple range test.

Table 3. Yield (t/ha) and disease incidence (%) of nine AVRDC tomato breeding lines and two tomato cultivars grown in *Meloidogyne javanica*-infected plots during three successive seasons: 1995-96 (year 1), 1996-97 (year 2), and 1997-98 (year 3)^z

Line	Year 1		Year 2		Year 3	
	Yield	Incidence	Yield	Incidence	Yield	Incidence
ARP 365-1	26.00 d	35.11 ab	19.38 d	34.00 c	48.22 a	0.00 e
ARP 365-2	40.68 bc	0.00 d	37.17 abc	0.00 f	52.83 a	14.75 cde
ARP 365-3	37.25 bc	13.74 cd	34.52 bc	18.68 d	57.06 a	0.00 e
ARP 367-1	46.45 ab	4.30 d	40.31 ab	6.81 e	43.17 a	0.00 e
ARP 367-2	45.88 ab	8.61 d	37.82 abc	5.65 ef	57.78 a	7.59 de
ARP 366-1	42.84 ab	8.36 d	36.30 bc	15.28 d	41.00 a	9.45 cde
ARP 366-2	43.07 ab	34.78 ab	41.17 ab	36.76 c	50.50 a	24.23 bcd
ARP 366-3	38.70 bc	30.67 bc	34.40 bc	33.40 c	44.72 a	28.54 abc
ARP 366-4	53.15 a	31.00 bc	47.77 a	35.01 c	52.61 a	45.82 a
Marglobe	23.65 d	45.52 ab	21.03 d	45.34 b	45.39 a	43.11 ab
Moneymaker	30.90 cd	52.93 a	27.82 cd	51.75 a	26.11 b	42.13 ab
CV %	15.8	41.1	16.7	14.2	18.2	54.2

^z Means followed by the same letter within columns do not differ significantly at 5% according to Duncan's multiple range test. Incidence data were arc-sine transformed before analysis of variance.

aimed at developing improved tomato varieties with multiple disease resistance for the African highlands, showed that among eight advanced breeding lines, three, namely ARP 365-2, 367-1, and 367-2, exhibited a high level of resistance to *M. javanica* and to both race 1 and 2 of *M. incognita*. However, they were susceptible to *M. hapla*. The *Mi* gene, which has been transferred into ARP tomato lines during the breeding process, confers resistance to *M. incognita*, *M. javanica*, and *M. arenaria* (19). *Mi* gene is known to be ineffective against *M. hapla* (2). Sources of resistance to *M. hapla* have been identified (18). However, incorporation of resistance to *M. hapla* into cultivated tomatoes is not justified, as the distribution of this species in Tanzania is limited mostly to high altitudes where tomato is not often grown.

The advanced ARP breeding lines also expressed resistance to root-knot nematodes under field conditions. However, a few plants of ARP 365-2, 367-1, and 367-2 were infected by *M. javanica* in the field during the three growing seasons. Pathogenicity tests showed that root-knot nematode isolates from ARP-resistant tomato lines do not represent virulent populations. Environmental factors such as high temperatures could explain the susceptibility of ARP 365-2, 367-1, and 367-2 to *M. javanica* under field conditions. Indeed, it is well documented that resistance mediated by *Mi* is lost at temperatures above 28°C (3).

In greenhouse experiments, tomato variety Moneymaker had the highest susceptibility reaction to each root-knot nematode species tested. Moneymaker and Marglobe also had a high disease incidence in field trials. These results confirmed previous observations that Moneymaker is susceptible to *M. javanica* and *M. incognita* (7). The incidence of root-knot nematodes in Marglobe and Moneymaker varied from season to season in the Dodoma field trials. In years 1 and 2, the incidence in Moneymaker and Marglobe plots was comparable. However, in year 3, disease incidence was low compared with previous years. This observation could be due to the low amount of inoculum available in the experimental plots in 1997-98. The variation of disease incidence in Moneymaker and Marglobe may also be due to the uneven distribution of the pathogen population among the plots.

With the exception of ARP 365-1, all ARP tomato lines outyielded Marglobe and

Moneymaker. It was not possible to evaluate the tomato lines in a root-knot nematode free environment because all allocated plots at the experimental site were found to be infested with *M. javanica*. However, in a separate yield trial conducted at a different site with nematode-free plots, it was found that ARP lines outyielded Marglobe and Moneymaker; yields of ARP lines were comparable and were not significantly different from each other (12).

ARP lines 365-2, 367-1, and 367-2 showed a good level of resistance under both controlled and field conditions. In addition, they outyielded the commonly grown tomato varieties Marglobe and Moneymaker in several field trials. ARP 367-2 was officially released in Tanzania in 1997 under the commercial name Tengeru 97. This cultivar has become popular in major tomato growing regions of the country. In addition to resistance to root-knot nematodes, Tengeru 97 is also resistant to Fusarium wilt and *Tomato mosaic virus* (12). This cultivar has been promoted to other southern African countries such as Malawi, Zambia, and Zimbabwe, where root-knot nematodes are equally important, and where susceptible cultivars such as Moneymaker remain the cultivar of choice for many farmers.

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