Journal of Nematology 22(1):56–68. 1990.
© The Society of Nematologists 1990.

Morphological Comparison of Three Host Races of *Meloidogyne javanica*[1]

ABDALLAH RAMMAH[2] AND HEDWIG HIRSCHMANN[3]

Abstract: A morphological and morphometric comparison using light microscopy and scanning electron microscopy was made of six populations of *Meloidogyne javanica* belonging to three host races (infective on pepper, peanut, or noninfective on both). The variability of certain morphological characters was studied within these populations, and the reliability of these taxonomic traits was evaluated for usefulness in species identification. The most useful diagnostic characters of *M. javanica* were head and stylet morphology of males and stylet morphology and perineal patterns of females. Males have an offset head region, usually lacking annulations, and a distinct, narrow head cap with slightly raised labial disc. The stylet has a cone markedly wider than the shaft at the junction and large, transversely ovoid knobs that are offset from the shaft. Females have a robust stylet with a dorsally curved cone and large, transversely ovoid knobs. Perineal patterns are oval to squarish in shape, usually with coarse, broken striae and with conspicuous lateral lines. The host races could not be differentiated on a morphological basis.

Key words: Arachis hypogaea, Capsicum frutescens, host race, light microscopy (LM), *Meloidogyne javanica,* morphology, morphometrics, peanut, pepper, root-knot nematode, scanning electron microscopy (SEM).

Meloidogyne javanica (Treub) Chitwood is one of the most common and important root-knot nematode species. It has a wide host range and is considered a major agricultural pest (23).

Identification of *Meloidogyne* species has been difficult and confusing (11,19,24). Most species have been described from single populations, and the variation of useful morphological characters rarely has been considered. Scanning electron microscopy (SEM) and light microscopy (LM) studies of different populations of *M. hapla* Chitwood (2–7), *M. arenaria* (Neal) Chitwood (1), and *M. incognita* (Kofoid & White) Chitwood (13) have shown that some characters are variable and unreliable for species identification, but others exhibit narrow variation and are species specific. Only one population of *M. javanica* was considered in a previous comparative morphological study of the four most common root-knot nematodes (2,4–8). An evaluation of the intraspecific variation of different morphological characters in several populations of *M. javanica* is much needed.

The use of differential host tests (21) in identification of *Meloidogyne* species can be of only limited value. Observed variation in host preference among populations of the same species, and the occurrence of mixtures of species and races within field populations complicates identification of even the most common root-knot nematode species. Recently, some populations of *M. javanica* were found to attack pepper (*Capsicum frutescens* L.) or peanut (*Arachis hypogaea* L.), plants which normally are not hosts of *M. javanica* (12).

Our study involves a detailed morphological and morphometric comparison, using LM and SEM, of six populations of *M. javanica* belonging to three host races. The main objectives have been to determine the morphological variability within these populations and to evaluate the usefulness of certain morphological characters currently used in species determination.

Materials and Methods

Six populations of *M. javanica* were selected from the culture collection of the

Received for publication 3 January 1989.

[1] Paper No. 11980 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh.

This study was supported in part by the USAID Morocco Project, No. 608-016, administered by the University of Minnesota, St. Paul, and the International Foundation for Science, Stockholm, Sweden. A part of the first author's Ph.D. thesis project.

Use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service of the products named or criticism of similar ones not mentioned.

[2] Associate Professor, Department de Phytopathologie, Institut Agronomique et Veterinaire Hassan II, B. P. 6202, Rabat-Instituts, Rabat, Morocco.

[3] Professor, Department of Plant Pathology, North Carolina State University, Raleigh, NC 27695.

International *Meloidogyne* Project on the basis of their ability to reproduce on peanut or pepper (Table 1). All populations were typical of *M. javanica* with respect to cytology and biochemistry. The somatic chromosome number varied from 42 to 48, and reproduction was exclusively by mitotic parthenogenesis (26). They had the unique esterase phenotype "J3" (9) that has been exhibited only by populations of *M. javanica.*

All populations were maintained on tomato (*Lycopersicon esculentum* Mill. cv. Rutgers) under appropriate greenhouse conditions. Females and egg masses were hand picked from infected roots. Males and second-stage juveniles (J2) were obtained after incubation of infected roots or egg masses in moist chambers at room temperature.

Light microscopy: Males and J2 were fixed in hot (70–80 C) TAF (7 ml 40% formaldehyde, 2 ml triethanolamine, 91 ml distilled water) and mounted in the same fixative for observation. Females were killed in 2% formalin and their anterior portions, including the esophageal region, were severed with an eye knife and mounted in 2% formalin. Perineal patterns were cut from live egg-laying females in 45% lactic acid and mounted in glycerin. At least 100 specimens of each life stage and population were examined for qualitative characters. Twenty-five other specimens of each stage were used to obtain morphometric data. Drawings were made with a Leitz drawing tube, and photographs were taken using a bright field microscope.

Scanning electron microscopy: At least 100 males and J2 from each population were prepared for SEM observations (3). Twenty excised stylets of females and males (6) and 20 spicules of males (20) from each population were also scanned with a JEOL T 200 scanning electron microscope operating at 25 kV accelerating voltage.

TABLE 1. Reproduction of six populations of *Meloidogyne javanica* on pepper and peanut.

Population number†	Origin	Pepper	Peanut
76	Georgia (USA)	−	−
E982	Morocco	−	−
E978	Morocco	+	−
E979	Morocco	+	−
E419	Egypt	−	+
E425	Egypt	−	+

− = resistant host; + = susceptible host.
† Culture number of IMP collection.

OBSERVATIONS

No major morphological differences were observed between populations of the three host races. Qualitative characters—such as female, male, and J2 head and stylet morphologies, perineal pattern, and spicule morphologies and J2 tail shape—varied only slightly within and among the six populations of *M. javanica* studied. Except for J2 characters, no overlap was observed with those same characters of other *Meloidogyne* species. Means and standard error of means of most morphometric characters of the three life stages were very similar; thus the morphometric values for all populations were pooled in the last column of Tables 2–4. Measurements of females had moderately high variability; however, stylet length (CV 5.1%), stylet knob height (7.6), stylet knob width (8.1), and stylet knob width/height (9.5) were quite stable and reliable morphometric characters (Table 2). Useful, stable morphometric characters for differentiation of males were body width at stylet knobs (CV 5.7), stylet length (5.2), stylet knob height (7.6), stylet knob width (6.3), stylet knob width/knob height (8.9), and spicule length (8.8) (Table 3). All morphometric characters of J2 showed low variability with coefficients below 10% (Table 4). The most useful characters were stylet length (CV 3.1), distance of stylet base to head end (2.4), and excretory pore to head end (3.5). Only useful distinguishing characters will be considered in the following description.

Females (Figs. 1, 2D–G, 3A–F; Table 2)

Stylet robust. Stylet cone longer than shaft and knobs, pointed, tapering gradually toward tip, and broadening at junction with shaft (Fig. 3A–F). Cone distinctly

TABLE 2. Morphometric comparison of 25 females each of six populations of *Meloidogyne javanica*.

Character	76-Georgia	E982-Morocco	E978-Morocco	E979-Morocco	E419-Egypt	E425-Egypt	All populations pooled
Body length	789.6 ± 23.81 (599.4–1,012.5)	702.8 ± 21.75 (518.4–972.0)	746.2 ± 18.28 (510.3–972.0)	702.4 ± 12.53 (567.0–834.3)	736.5 ± 15.96 (583.2–850.5)	753.0 ± 20.28 (607.5–947.7)	738.4 ± 8.07 (510.3–1,012.5)
Body width	576.4 ± 14.03 (486.0–729.0)	473.4 ± 12.91 (356.4–607.5)	565.0 ± 14.99 (388.8–720.9)	475.6 ± 10.62 (380.7–623.7)	487.9 ± 11.85 (364.5–607.5)	501.2 ± 15.23 (364.5–607.5)	513.3 ± 6.37 (356.4–729.0)
Vulval slit length	25.4 ± 0.45 (21.5–28.1)	22.1 ± 0.57 (16.7–27.4)	22.1 ± 0.41 (18.8–27.9)	24.3 ± 1.52 (17.2–59.2)	26.4 ± 0.42 (22.2–29.6)	23.1 ± 0.50 (18.1–27.4)	23.9 ± 0.33 (16.7–59.2)
Vulva–anus distance	17.4 ± 0.46 (11.5–21.1)	14.5 ± 0.61 (9.3–23.3)	15.9 ± 0.18 (14.8–17.5)	16.5 ± 0.24 (14.1–18.3)	17.8 ± 0.36 (12.6–20.7)	16.4 ± 0.65 (4.1–19.8)	16.4 ± 0.20 (4.1–23.3)
Interphasmidial distance	27.9 ± 0.49 (24.1–34.2)	22.5 ± 0.69 (16.8–29.6)	23.3 ± 0.48 (19.0–27.5)	23.4 ± 0.68 (14.8–32.3)	24.9 ± 0.76 (20.2–33.3)	24.4 ± 0.67 (16.3–29.6)	24.4 ± 0.29 (14.8–34.2)
Stylet length	15.9 ± 0.18 (14.8–17.8)	16.0 ± 0.15 (14.8–17.2)	16.6 ± 0.11 (15.8–17.9)	15.9 ± 0.15 (13.8–17.0)	15.9 ± 0.16 (14.8–17.4)	16.0 ± 0.19 (14.1–17.4)	16.1 ± 0.07 (13.8–17.9)
Stylet knob height	2.1 ± 0.03 (1.9–2.4)	2.0 ± 0.03 (1.6–2.2)	2.0 ± 0.03 (1.8–2.4)	2.0 ± 0.03 (1.8–2.4)	2.0 ± 0.03 (1.8–2.2)	2.0 ± 0.03 (1.7–2.3)	2.0 ± 0.01 (1.6–2.4)
Stylet knob width	4.9 ± 0.06 (4.4–5.5)	4.6 ± 0.08 (3.9–5.2)	4.9 ± 0.08 (4.2–5.6)	4.8 ± 0.06 (4.1–5.3)	4.9 ± 0.07 (4.1–5.5)	4.5 ± 0.07 (3.7–5.0)	4.8 ± 0.03 (3.7–5.6)
DGO	3.2 ± 0.10 (2.2–4.5)	3.1 ± 0.12 (1.9–4.1)	3.5 ± 0.13 (2.3–4.7)	3.5 ± 0.14 (1.9–4.6)	3.7 ± 0.12 (2.4–5.0)	3.4 ± 0.14 (2.2–4.8)	3.4 ± 0.05 (1.9–5.0)
a	1.4 ± 0.03 (1.0–1.7)	1.5 ± 0.04 (1.0–1.8)	1.3 ± 0.04 (1.0–1.7)	1.5 ± 0.03 (1.1–1.8)	1.5 ± 0.04 (1.1–2.1)	1.5 ± 0.05 (1.1–2.1)	1.5 ± 0.02 (1.0–2.1)
Stylet knob width/height	2.4 ± 0.05 (2.0–2.8)	2.3 ± 0.04 (1.9–2.7)	2.4 ± 0.05 (1.8–2.8)	2.4 ± 0.04 (2.0–2.8)	2.5 ± 0.03 (2.2–2.8)	2.3 ± 0.05 (1.9–2.8)	2.4 ± 0.02 (1.8–2.8)

All linear measurements in μm.
Values are means ± SE (range).

TABLE 3. Morphometric comparison of 25 males each of six populations of *Meloidogyne javanica*.

Character	76-Georgia	E982-Morocco	E978-Morocco	E979-Morocco	E419-Egypt	E425-Egypt	All populations pooled
Body length	1,444.1 ± 34.91 (1,093.5–1,782.0)	1,228.0 ± 33.15 (850.5–1,482.3)	1,471.6 ± 45.30 (1,053.0–2,008.8)	1,306.7 ± 26.23 (1,053.0–1,571.4)	1,204.6 ± 46.0 (826.2–1,919.7)	1,427.9 ± 28.08 (1,182.6–1,757.7)	1,347.1 ± 17.01 (826.2–2,008.8)
Body width	43.8 ± 0.63 (37.0–49.4)	39.8 ± 0.98 (29.6–48.5)	41.1 ± 1.01 (29.6–50.3)	37.2 ± 0.73 (29.6–44.8)	34.3 ± 1.06 (25.9–44.4)	33.8 ± 0.59 (28.9–41.1)	38.3 ± 0.45 (25.9–50.3)
Width at stylet knobs	20.8 ± 0.19 (18.7–22.2)	19.3 ± 0.21 (17.8–22.6)	20.2 ± 0.22 (18.4–22.2)	19.9 ± 0.14 (18.0–20.9)	18.9 ± 0.22 (16.6–21.1)	19.4 ± 0.11 (18.3–20.7)	19.8 ± 0.09 (16.6–22.6)
Stylet length	21.8 ± 0.18 (19.5–23.3)	21.1 ± 0.22 (19.2–22.9)	21.5 ± 0.19 (19.6–23.3)	21.1 ± 0.21 (18.7–23.0)	21.5 ± 0.22 (19.2–23.7)	21.4 ± 0.10 (20.4–22.2)	21.4 ± 0.09 (18.7–23.7)
Stylet knob height	2.5 ± 0.03 (2.2–2.9)	2.6 ± 0.03 (2.4–2.9)	2.7 ± 0.04 (2.2–3.0)	2.5 ± 0.04 (2.1–2.7)	2.6 ± 0.05 (2.0–3.2)	2.6 ± 0.04 (2.3–3.0)	2.6 ± 0.02 (2.0–3.2)
Stylet knob width	5.3 ± 0.06 (4.6–5.8)	5.0 ± 0.05 (4.5–5.6)	5.4 ± 0.07 (4.8–6.3)	5.1 ± 0.05 (4.6–5.6)	5.1 ± 0.07 (4.4–5.7)	5.0 ± 0.06 (4.4–5.6)	5.2 ± 0.03 (4.4–6.3)
DGO	2.8 ± 0.08 (2.2–3.7)	3.1 ± 0.16 (1.1–4.2)	2.9 ± 0.10 (1.9–3.9)	2.9 ± 0.09 (1.9–3.7)	3.3 ± 0.10 (2.4–4.2)	2.8 ± 0.10 (1.3–4.2)	3.0 ± 0.05 (1.1–4.2)
Esophagus length	92.8 ± 1.53 (78.9–107.3)	90.6 ± 1.96 (70.3–111.0)	91.6 ± 1.28 (77.7–102.1)	89.1 ± 1.85 (71.6–107.9)	83.3 ± 1.64 (68.8–99.9)	87.9 ± 1.08 (75.5–99.5)	89.2 ± 0.68 (68.8–111.0)
Excretory pore to head end	166.2 ± 3.47 (133.2–203.1)	152.4 ± 2.87 (114.7–170.9)	161.2 ± 2.43 (139.1–180.9)	151.9 ± 2.44 (123.6–177.6)	141.6 ± 3.35 (115.4–193.9)	159.5 ± 2.60 (139.9–194.9)	155.5 ± 1.33 (114.7–203.1)
Spicule length	31.9 ± 0.37 (29.6–35.3)	28.3 ± 0.47 (22.9–33.6)	30.7 ± 0.49 (25.3–34.8)	28.4 ± 0.43 (25.2–35.2)	29.6 ± 0.41 (25.9–34.3)	28.1 ± 0.47 (23.7–34.6)	29.5 ± 0.21 (22.9–35.3)
Gubernaculum length	8.2 ± 0.15 (7.4–9.4)	7.8 ± 0.13 (6.7–9.3)	8.2 ± 0.15 (6.7–9.6)	8.0 ± 0.11 (7.4–8.9)	7.8 ± 0.19 (5.7–10.1)	7.8 ± 0.13 (6.4–9.4)	8.0 ± 0.06 (5.7–10.1)
a	33.0 ± 0.53 (27.9–40.1)	31.0 ± 0.67 (23.7–37.2)	35.9 ± 0.90 (29.3–43.8)	35.3 ± 0.70 (28.9–44.2)	35.6 ± 1.25 (19.2–47.9)	42.4 ± 0.70 (33.5–47.7)	35.5 ± 0.44 (19.2–47.9)
Stylet knob width/height	2.1 ± 0.03 (1.8–2.4)	1.9 ± 0.03 (1.7–2.3)	2.0 ± 0.04 (1.8–2.4)	2.1 ± 0.03 (1.8–2.4)	2.0 ± 0.04 (1.7–2.4)	1.9 ± 0.04 (1.6–2.3)	2.0 ± 0.01 (1.6–2.4)
Excretory pore %	11.6 ± 0.24 (9.6–15.0)	12.5 ± 0.26 (10.2–15.1)	11.1 ± 0.23 (8.0–13.4)	11.7 ± 0.16 (10.0–13.7)	11.9 ± 0.24 (8.9–14.0)	11.3 ± 0.26 (9.6–15.5)	11.7 ± 0.10 (8.0–15.5)

All linear measurements in μm.
Values are means ± SE (range).

TABLE 4. Morphometric comparison of 25 second-stage juveniles each of six populations of *Meloidogyne javanica*.

Character	76-Georgia	E982-Morocco	E978-Morocco	E979-Morocco	E419-Egypt	E425-Egypt	All populations pooled
Body length	429.7 ± 2.98 (406.4–470.4)	421.4 ± 2.79 (403.2–454.4)	423.8 ± 2.73 (400.0–448.0)	414.1 ± 2.74 (377.6–432.0)	429.4 ± 2.81 (406.4–464.0)	435.6 ± 3.88 (400.0–473.6)	425.7 ± 1.34 (377.6–473.6)
Greatest body width	15.6 ± 0.14 (14.8–16.9)	14.6 ± 0.16 (13.3–16.5)	14.6 ± 0.09 (13.8–15.8)	15.0 ± 0.08 (14.8–16.0)	14.7 ± 0.15 (13.5–16.7)	14.4 ± 0.15 (13.0–16.7)	14.8 ± 0.06 (13.0–16.9)
Body width at anus	10.1 ± 0.06 (9.4–10.6)	9.7 ± 0.09 (8.9–10.5)	9.9 ± 0.06 (9.3–10.4)	9.9 ± 0.07 (9.3–10.5)	9.9 ± 0.08 (9.1–10.7)	9.7 ± 0.08 (9.0–10.7)	9.9 ± 0.03 (8.9–10.7)
Stylet length	11.5 ± 0.06 (10.7–11.9)	11.7 ± 0.08 (10.7–12.3)	11.8 ± 0.04 (11.5–12.2)	11.6 ± 0.06 (11.1–12.1)	11.5 ± 0.05 (11.0–11.9)	11.4 ± 0.11 (10.1–12.2)	11.6 ± 0.03 (10.1–12.3)
Stylet base to head end	15.0 ± 0.05 (14.8–15.5)	14.9 ± 0.08 (13.8–15.7)	15.0 ± 0.05 (14.8–15.5)	14.8 ± 0.05 (14.4–15.2)	15.0 ± 0.05 (14.8–15.5)	14.8 ± 0.12 (13.3–15.7)	14.9 ± 0.03 (13.3–15.7)
DGO	3.7 ± 0.05 (3.2–4.1)	3.4 ± 0.06 (2.7–3.9)	3.5 ± 0.05 (3.0–4.2)	3.8 ± 0.06 (3.3–4.3)	4.0 ± 0.04 (3.7–4.4)	3.5 ± 0.06 (2.4–3.9)	3.6 ± 0.03 (2.4–4.4)
Esophagus length	59.9 ± 0.36 (57.5–64.5)	59.8 ± 0.38 (56.5–64.2)	59.0 ± 0.26 (56.4–61.1)	60.0 ± 0.41 (55.9–64.2)	57.8 ± 0.29 (55.5–61.1)	58.7 ± 0.45 (54.0–62.9)	59.2 ± 0.16 (54.0–64.5)
Excretory pore to head end	83.9 ± 0.37 (80.8–86.7)	83.5 ± 0.46 (80.1–90.3)	83.2 ± 0.39 (78.6–86.8)	82.9 ± 0.99 (61.0–86.4)	81.9 ± 0.50 (78.1–89.4)	83.3 ± 0.47 (77.7–87.8)	83.1 ± 0.23 (61.0–90.3)
Tail length	56.1 ± 0.48 (51.8–60.8)	51.1 ± 0.47 (47.8–58.1)	54.8 ± 0.39 (50.9–59.2)	52.0 ± 0.35 (48.1–55.7)	53.0 ± 0.49 (48.8–59.9)	51.2 ± 0.74 (42.6–56.2)	53.0 ± 0.25 (42.6–60.8)
a	27.5 ± 0.31 (25.0–30.3)	28.9 ± 0.44 (24.8–32.7)	29.0 ± 0.24 (26.4–31.0)	27.6 ± 0.20 (25.5–29.2)	29.2 ± 0.40 (24.4–33.7)	30.3 ± 0.48 (24.8–34.9)	28.8 ± 0.17 (24.4–34.9)
b	7.2 ± 0.04 (6.6–7.6)	7.0 ± 0.04 (6.6–7.5)	7.2 ± 0.04 (6.7–7.6)	6.9 ± 0.06 (6.4–7.6)	7.4 ± 0.06 (6.7–8.0)	7.4 ± 0.05 (6.9–7.9)	7.2 ± 0.03 (6.4–8.0)
c	7.7 ± 0.06 (7.0–8.1)	8.3 ± 0.08 (7.2–8.8)	7.7 ± 0.06 (7.2–8.2)	8.0 ± 0.05 (7.5–8.3)	8.1 ± 0.09 (6.8–8.9)	8.5 ± 0.11 (7.8–9.9)	8.1 ± 0.04 (6.8–9.9)
d	5.6 ± 0.06 (5.1–6.1)	5.3 ± 0.05 (4.7–5.7)	5.5 ± 0.04 (5.1–6.1)	5.2 ± 0.05 (4.7–5.9)	5.4 ± 0.05 (4.9–6.2)	5.3 ± 0.09 (4.2–5.8)	5.4 ± 0.03 (4.2–6.2)
Excretory pore %	19.5 ± 0.10 (18.4–20.7)	19.8 ± 0.15 (18.7–21.1)	19.6 ± 0.09 (18.2–20.5)	20.0 ± 0.24 (14.9–21.3)	19.1 ± 0.16 (17.8–22.0)	19.1 ± 0.14 (17.9–20.6)	19.5 ± 0.07 (14.9–22.0)

All linear measurements in μm.
Values are means ± SE (range).

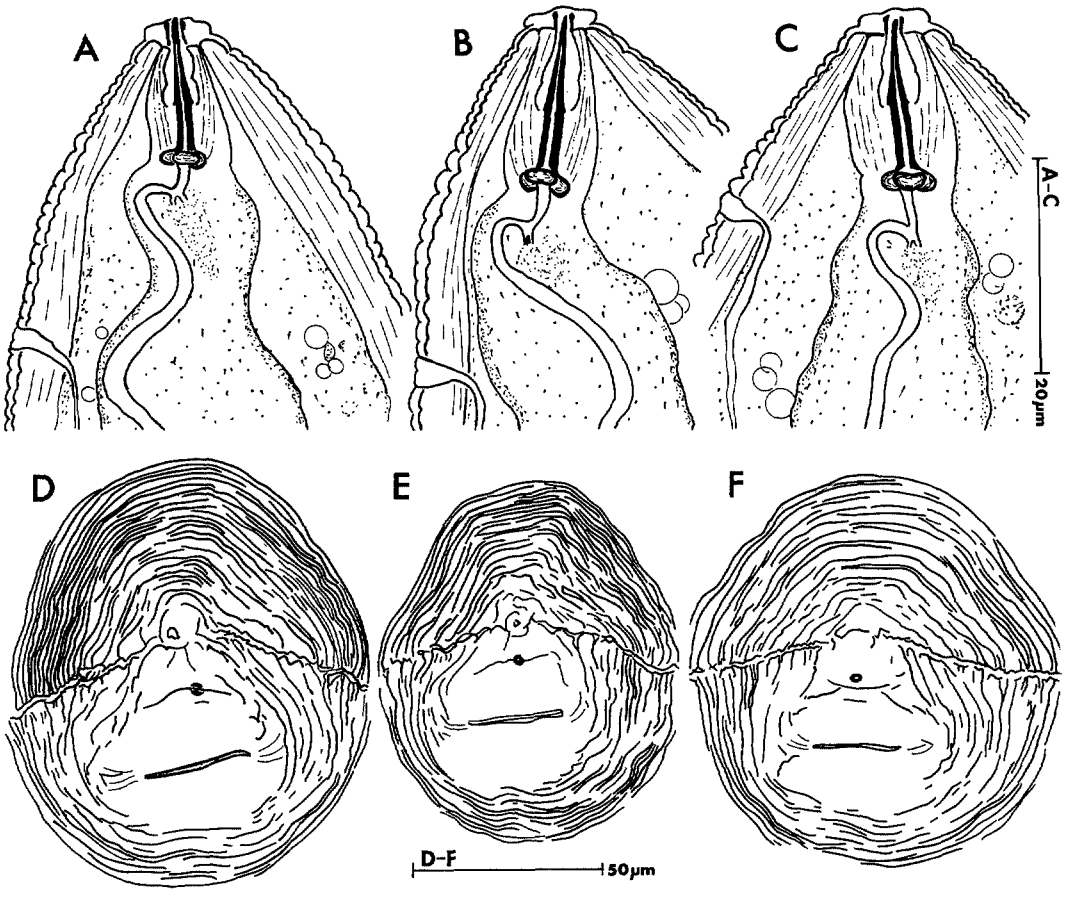


FIG. 1. Line drawings of females of *Meloidogyne javanica*. A–C) Cephalic regions (lateral). D–F) Perineal patterns. A) E982-Morocco. B) E978-Morocco. C) E419-Egypt. D) 76-Georgia. E) E425-Egypt. F) E979-Morocco.

curved dorsally in all populations, except population 76 in which cone curves only slightly (Fig. 3A). Shaft cylindrical, broad at base. Knobs variable in shape, offset from shaft, large, transversely ovoid, sometimes anterior surfaces indented (Fig. 3B, D, F). Distance between stylet base and dorsal esophageal gland orifice (DGO) variable (1.9–5.0 µm). Gland orifice branched into three channels. Excretory pore position variable, usually between stylet base and metacorpus (Fig. 1A–C).

Perineal patterns variable (Figs. 1D–F, 2D–G). Overall shape rounded, oval to slightly squarish. Dorsal arch moderately high and narrow, usually with coarse, broken striae. Lateral lines conspicuous, extending anteriorly. Peri-vulval region free of striae, except near lateral edges of vulval slit. Small whorl usually present at tail tip. Ventral pattern area rounded and with finer striae.

Males (Figs. 2A–C, 3G–L, 4A–D, 5A–C; Table 3)

Head cap narrow, distinctly offset from head region. Labial disc rounded, slightly raised over medial lips, easily visible in LM (Figs. 2A–C, 4A–D). In SEM, medial lips rectangular, with rounded corners and usually slight indentations at junctions with labial disc (Fig. 5A). Indentations more pronounced in some males of population E419 (Fig. 5B). Prestoma hexagonal, surrounded by six inner labial sensilla opening at edge onto labial disc; stoma slit-like.

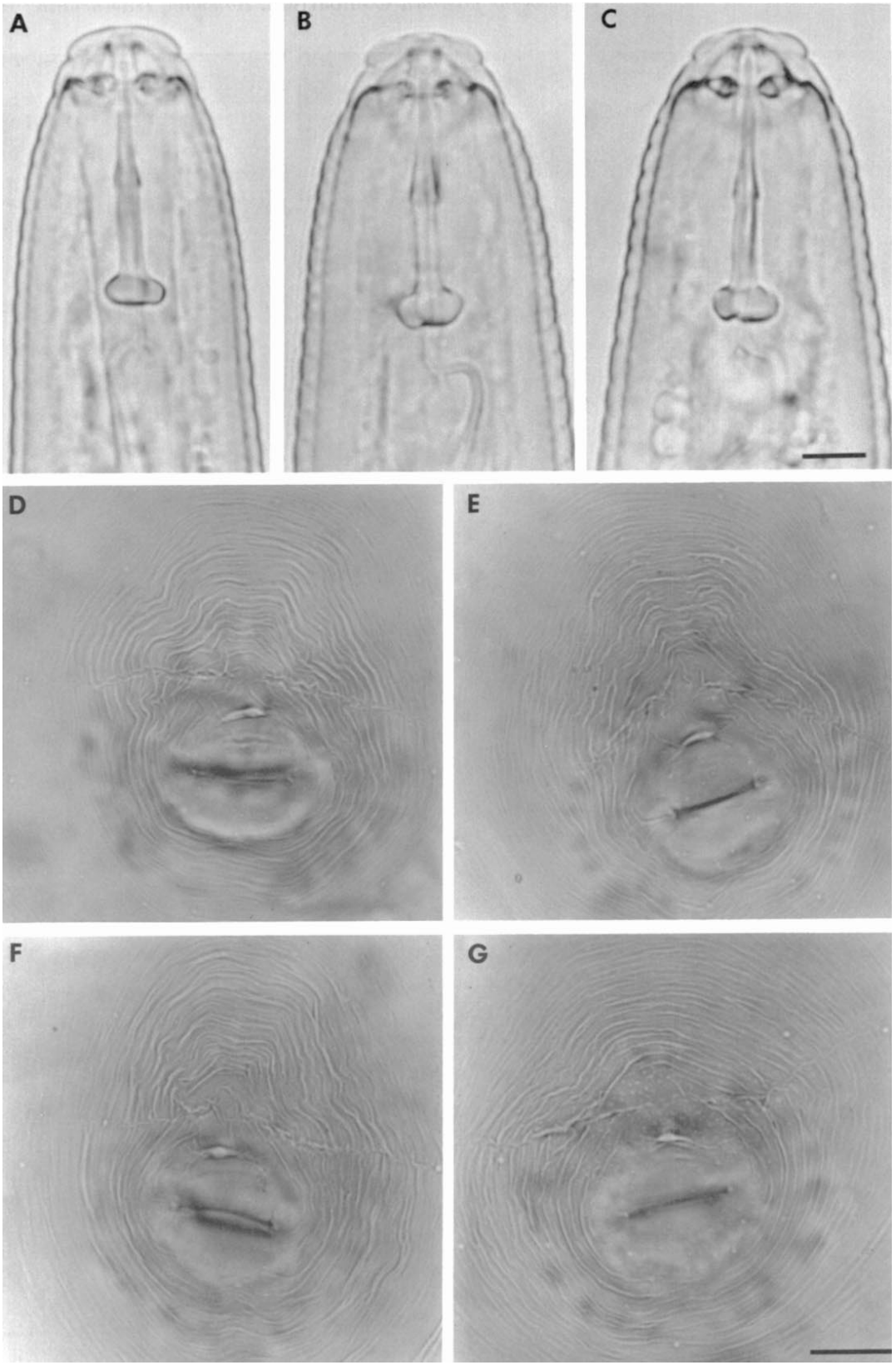


FIG. 2. LM photographs of anterior portions of males and perineal patterns of females of *Meloidogyne javanica*. A–C) Males. D–G) Perineal patterns. A, D) 76-Georgia. B) E978-Morocco. C, E) E979-Morocco. F) E419-Egypt. G) E425-Egypt. A, B same scale as C, bar = 5 μm; D–F same scale as G, bar = 20 μm.

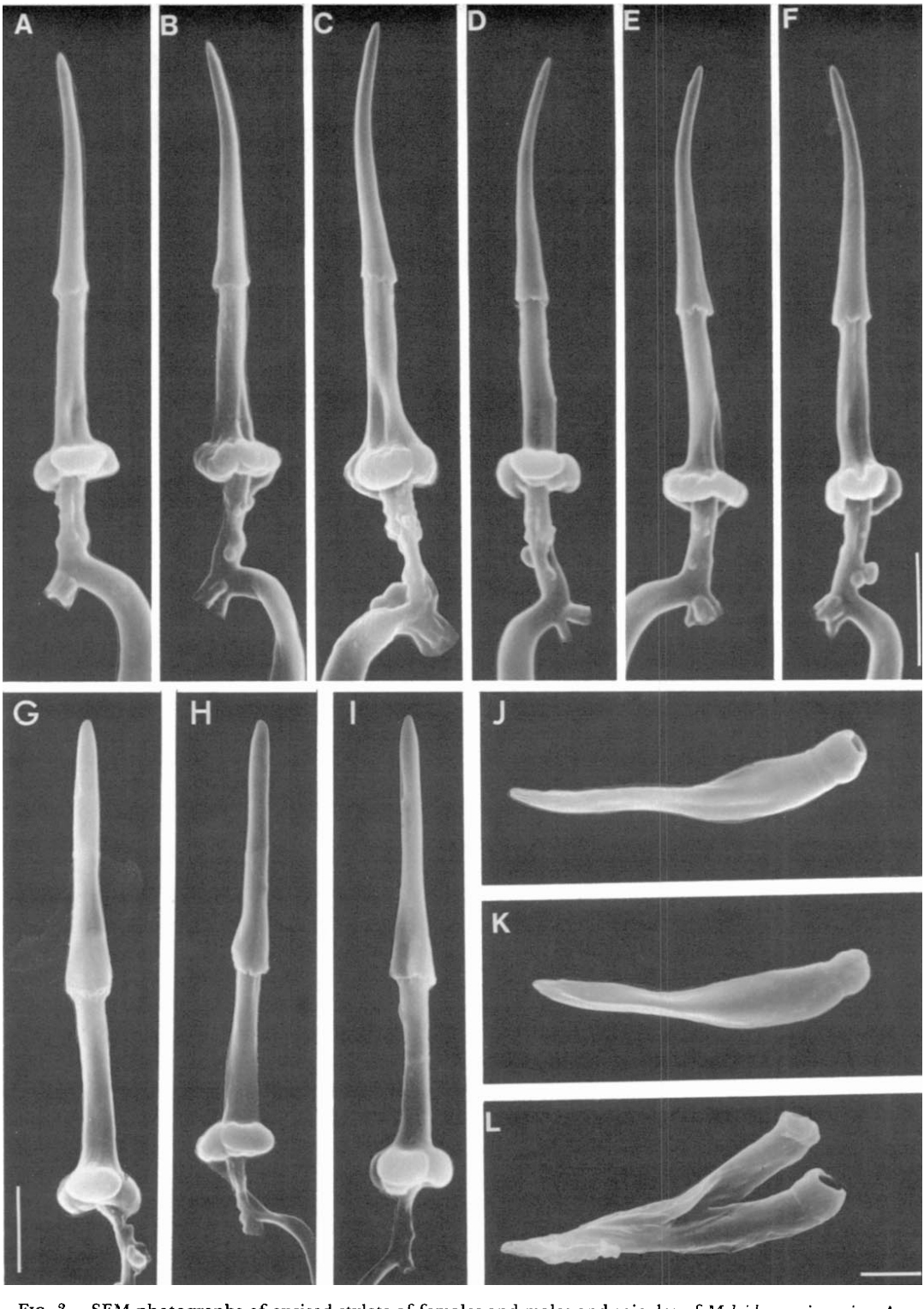


FIG. 3. SEM photographs of excised stylets of females and males and spicules of *Meloidogyne javanica*. A–F) Stylets of females. G–I) Stylets of males. J–L) Spicules. A, G, J) 76-Georgia. B) E982-Morocco. C, H) E978-Morocco. D) E979-Morocco. E, K) E419-Egypt. F, I, L) E425-Egypt. A–E same scale as F, bar = 4 μm; H, I same scale as G, bar = 4 μm; J, K same scale as L, bar = 5 μm.

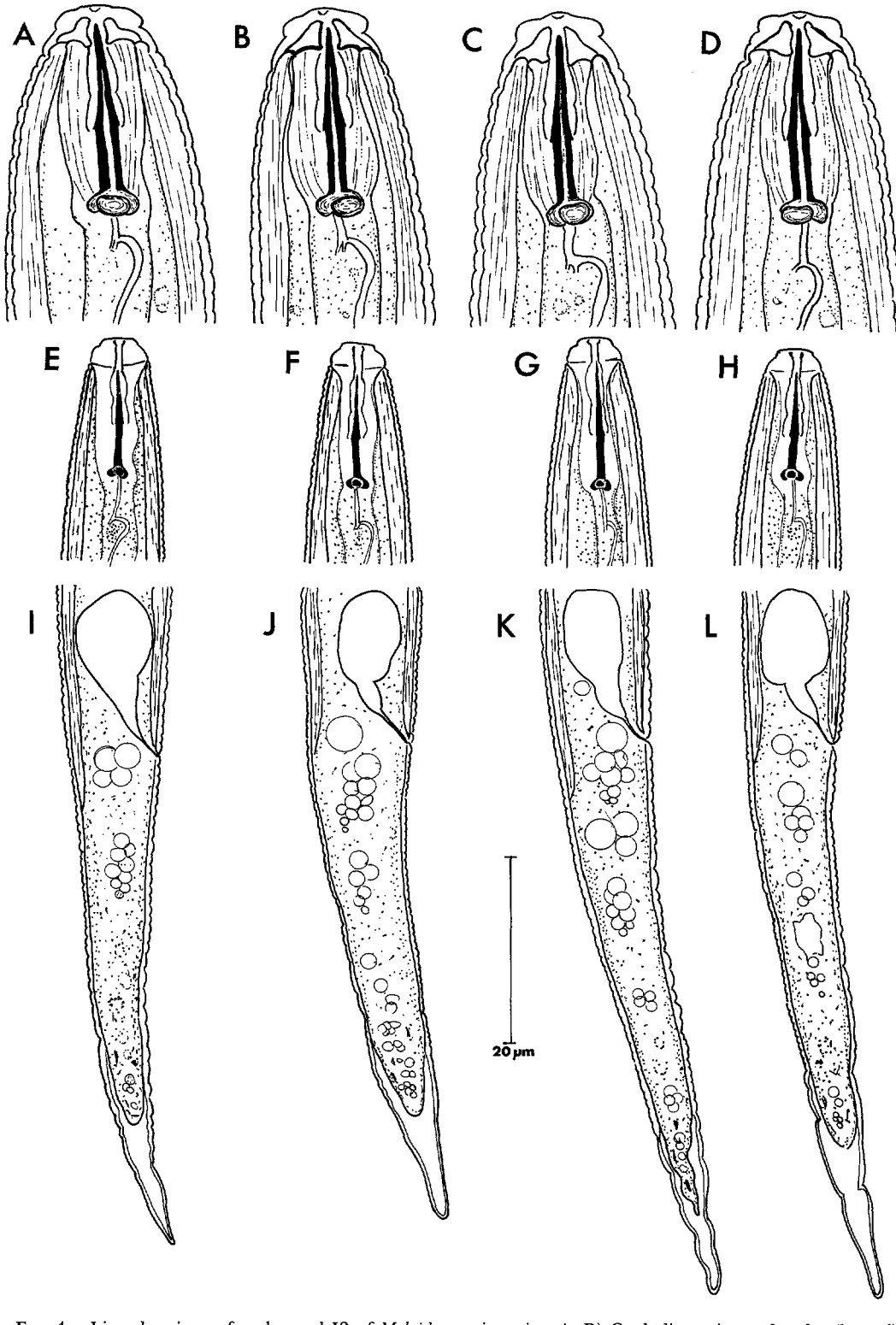


FIG. 4. Line drawings of males and J2 of *Meloidogyne javanica*. A–D) Cephalic regions of males (lateral). E–H) Cephalic regions of J2 (lateral). I–L) Tail regions of J2 (lateral). A, E, I) 76-Georgia. B, F, J) E982-Morocco. C, G, K) E978-Morocco. D, H, L) E425-Egypt.

Amphid openings large, slit-like, situated below lateral edges of labial disc (Fig. 5A, B). Head region usually without annulations. Cephalic framework well sclerotized. Vestibule and vestibule extension distinct (Figs. 2A–C, 4A–D).

In LM, head morphology consistent among populations. In SEM, cephalic characters of E419 and E425 slightly different from those of other populations. Head cap in E419 may be bow-tie shaped, small short annulations may be present on head region (Fig. 5B). Labial disc of E425 raised, larger in diameter than crescent-shaped medial lips.

Stylet shape and size relatively stable among populations. Stylet cone longer than shaft and knobs, pointed and markedly wider than shaft at junction (Figs. 2A–C, 3G–I, 4A–D). Shaft cylindrical, broadens slightly at base. Knobs set off from shaft, transversely ovoid, comparatively large and robust (Figs. 2A–C, 3G–I, 4A–D). Distance from base of stylet to DGO variable (1.1–4.2 μm), usually around 3 μm.

Spicules of all populations similar (Fig. 3J–L). Spicule head cylindrical, well separated from shaft, cytoplasmic core opening slightly lateral on outer spicule surface (Fig. 3J, L). Blade arcuate, curved ventrally, tapering toward tip. Two wing-like vela present on inner surface of spicule (Fig. 3K, L). Blade tip simple with two sensillar pores. Dorsal and ventral vela of both spicules overlap forming channel for sperm transmission during copulation (Fig. 3L).

Second-stage juveniles (Figs. 4E–L, 5D–F; Table 4)

Body slender, vermiform, ending posteriorly in conical tail (Fig. 4I–L). Cuticle with fine transverse annulations; annules irregular and larger in posterior tail region. Head truncate, slightly offset from body; head cap narrower than head region (Fig. 4E–H). In SEM, labial disc rounded to rectangular, slightly raised above medial lips (Fig. 5D–F). Medial lips and labial disc dumbbell shaped. Cephalic sensilla obscure. Lateral lips triangular, sometimes fused with head region, or reduced to remnants (Fig. 5D). Prestoma circular to oval, surrounded by six inner labial sensilla. Amphid openings large, slit-like, below lateral edges of labial disc. Generally, head region not annulated, very short annulations may be present laterally.

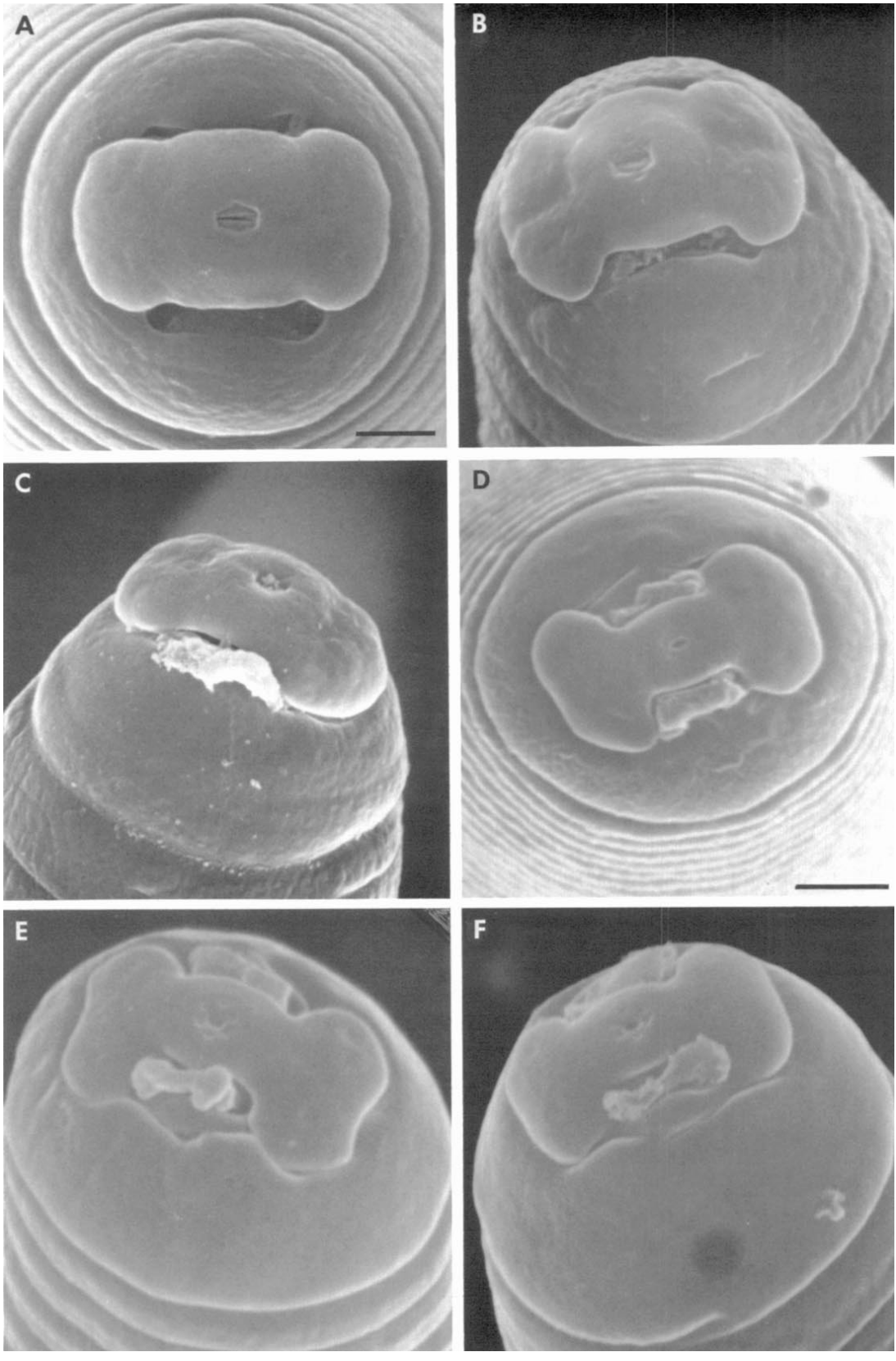
Stylet cone pointed, tip very fine (Fig. 4E–H). Shaft cylindrical, widens slightly at base. Knobs rounded, offset from shaft. Distance from base of stylet to DGO 2.4–4.4 μm.

Tail 42.6–60.8 μm long, conical, tapering to fine, rounded tip (Fig. 4I–L). Hyaline tail terminus distinct, variable in length. Constricting annules present. Rectum dilated.

Discussion

Accurate species and race identification is essential for any effective nematode management program. *Meloidogyne javanica* has a wide host range and populations with different host preferences are known to exist (19,22). The species, *M. javanica,* can readily be identified morphologically (8), cytologically (26) and biochemically (9). Host races do not show major morphological differences and any minor differences observed with SEM and LM are of no practical value. The races can be determined only by a host test. In previous studies, no morphological differences were found between host races of *M. arenaria* (1) and *M. incognita* (13). Since race determination is not possible by morphological, cytological, or biochemical criteria, it is evident that host tests need to be carried out before choosing crop rotations in a given agricultural area. Resistant varieties and nonhosts must be evaluated against different populations of the area.

On the basis of recent morphological studies of different species of *Meloidogyne,* qualitative characters have been shown to be more useful in species determination than measurements (8,14–18). A combination of characters of females, males, and J2 gives reliable identification (14,18). Stylet morphology of females and males, head shape of males, perineal patterns of females, and tail shape and size of J2 have


A
B
C
D
E
F

been suggested as the most stable, species-specific characters. In our evaluation, we found the same characters, except characters of J2, to be diagnostic for *M. javanica.*

Perineal patterns, earlier considered as the primary differentiating character between *Meloidogyne* species (10,11,25,27), have been found to be variable and not reliable in identifying species, especially the four most common ones (19). In our study, perineal patterns of all populations, even patterns resembling *M. arenaria* and *M. incognita,* had distinct lateral lines and could easily be identified as patterns of *M. javanica.*

Stylet morphology of females has been suggested as a reliable character in differentiating between *Meloidogyne* species (7,8,16). The stylet of *M. javanica* has been reported to have a slightly curved cone and wide, low knobs, often indented anteriorly (8). In our SEM studies, the dorsal curvature of the cone was more pronounced. The knobs were large and transversely ovoid, often with anterior indentations. The shaft was usually broadened at its base. In previous SEM studies, populations of *M. javanica* from Iraq and Nepal differed in female stylet morphology (16). Variability of stylet morphology has also been observed among populations of *M. arenaria* (1).

Head shape and stylet morphology of males have been of great practical value in the identification of the four most common species of *Meloidogyne* (4,8). A key based on head shape and stylet morphology of different *Meloidogyne* spp. has been proposed (15). In our LM studies, the male head shape of all six populations of *M. javanica* was similar and consistent, and should be considered as the most stable qualitative character. Our SEM studies showed that the cephalic characters were relatively stable and consistent with previous observations (4,8), although the medial lips were less rounded and the head cap was smaller. Stylet morphology of males was relatively stable and species specific.

In previous SEM studies, J2 of *M. hapla* could be differentiated from the other common species on the basis of cephalic characters (2). Second-stage juveniles of *M. javanica* were described as having bow-tie shaped head caps. Tail shape of J2 was also found to be of value in *Meloidogyne* species identification (17,18). Our study showed that J2 did not exhibit useful differentiating characters. The head morphology of all populations examined was similar and generally characterized by a dumbell-shaped head cap, a feature shared by the other common species. The tail was typically long with narrow tapering tail terminus ending in a finely rounded tip as described for *M. javanica* (17). However, variants with tails resembling *M. incognita, M. arenaria,* and *M. hapla* were frequently observed.

In conclusion, the most useful characters for identification of *M. javanica* are head and stylet morphology of males and stylet morphology and perineal patterns of females.

Literature Cited

1. Cliff, G. M., and H. Hirschmann. 1985. Evaluation of morphological variability in *Meloidogyne arenaria.* Journal of Nematology 17:445–459.

2. Eisenback, J. D. 1982. Morphological comparison of head shape and stylet morphology of second-stage juveniles of *Meloidogyne* species. Journal of Nematology 14:339–343.

3. Eisenback, J. D., and H. Hirschmann. 1979. Morphological comparison of second-stage juveniles of six populations of *Meloidogyne hapla* by SEM. Journal of Nematology 11:5–16.

4. Eisenback, J. D., and H. Hirschmann. 1980. Morphological comparison of *Meloidogyne* males by electron microscopy. Journal of Nematology 12:23–32.

5. Eisenback, J. D., and H. Hirschmann. 1981.

←

FIG. 5. SEM photographs of head regions of males and J2 of *Meloidogyne javanica.* A–C) Males. D–F) J2. A) 76-Georgia. B) E419-Egypt. C, F) E979-Morocco. D, E) E982-Morocco. B, C same scale as A, bar = 2 μm; E, F same scale as D, bar = 1 μm.

Identification of *Meloidogyne* species on the basis of head shape and stylet morphology of the male. Journal of Nematology 13:513–521.

6. Eisenback, J. D., and H. Hirschmann. 1982. Morphological comparison of stylets of male root-knot nematodes (*Meloidogyne* spp.). Scanning Electron Microscopy 2:837–843.

7. Eisenback, J. D., H. Hirschmann, and A. C. Triantaphyllou. 1980. Morphological comparison of *Meloidogyne* female head structures, perineal patterns, and stylets. Journal of Nematology 12:300–313.

8. Eisenback, J. D., H. Hirschmann, J. N. Sasser, and A. C. Triantaphyllou. 1981. A guide to the four most common species of root-knot nematodes (*Meloidogyne* spp.), with a pictorial key. A cooperative publication of the Departments of Plant Pathology and Genetics, North Carolina State University, and the United States Agency for International Development. Raleigh: North Carolina State University Graphics.

9. Esbenshade, P. R., and A. C. Triantaphyllou. 1985. Use of enzyme phenotypes for identification of *Meloidogyne* species. Journal of Nematology 17:6–20.

10. Esser, R. P., V. G. Perry, and A. L. Taylor. 1976. A diagnostic compendium of the genus *Meloidogyne* (Nematoda: Heteroderidae). Proceedings of the Helminthological Society of Washington 43:138–150.

11. Franklin, M. T. 1979. Taxonomy of the genus *Meloidogyne*. Pp. 37–54 *in* F. Lamberti and C. E. Taylor, eds. Root-knot nematodes (*Meloidogyne* species) systematics, biology and control. New York: Academic Press.

12. Hartman, K. M., and J. N. Sasser. 1985. Identification of *Meloidogyne* species on the basis of differential host test and perineal pattern morphology. Pp. 69–77 *in* K. R. Barker, C. C. Carter, and J. N. Sasser, eds. An advanced treatise on *Meloidogyne*, vol. 2. Methodology. Raleigh: North Carolina State University Graphics.

13. Hirschmann, H. 1984. Morphological variability of *Meloidogyne incognita* revealed by light and scanning electron microscopy. Proceedings of the First International Congress of Nematology, Guelph, Ontario, Canada. p. 35 (Abstr.).

14. Hirschmann, H. 1985. The genus *Meloidogyne* and morphological characters differentiating its species. Pp. 79–93 *in* J. N. Sasser and C. C. Carter, eds. An advanced treatise on *Meloidogyne*, vol. 1. Biology and control. Raleigh: North Carolina State University Graphics.

15. Jepson, S. B. 1983. Identification of *Meloidogyne*: A general assessment and a comparison of male morphology using light microscopy, with a key to 24 species. Revue Nématologie 6:291–309.

16. Jepson, S. B. 1983. Identification of *Meloidogyne* species: A comparison of stylets of females. Nematologica 29:132–143.

17. Jepson, S. B. 1983. The use of second-stage juvenile tails as an aid in the identification of *Meloidogyne* species. Nematologica 29:11–28.

18. Jepson, S. B. 1987. Identification of root-knot nematodes (*Meloidogyne* species). Wallingford, Oxon: C. A. B. International.

19. Netscher, C. 1978. Morphological and physiological variability of species of *Meloidogyne* in West Africa and implications for their control. Mededelingen Landbouwhogeschool, Wageningen 3:1–46.

20. Rammah, A., and H. Hirschmann. 1987. Morphological comparison and taxonomic utility of copulatory structures of selected nematode species. Journal of Nematology 19:314–324.

21. Sasser, J. N. 1972. Physiological variation in the genus *Meloidogyne* as determined by differential hosts. OEPP/EPPO Bulletin 6:41–48.

22. Sasser, J. N. 1978. Pathogenicity, host range and variability in *Meloidogyne* spp. Pp. 257–268 *in* F. Lamberti and C. E. Taylor, eds. Root-knot nematodes (*Meloidogyne* species) systematics, biology and control. New York: Academic Press.

23. Sasser, J. N., J. D. Eisenback, C. C. Carter, and A. C. Triantaphyllou. 1983. The International *Meloidogyne* Project—its goals and accomplishments. Annual Review of Phytopathology 21:271–288.

24. Taylor, A. L., and J. N. Sasser. 1978. Biology, identification and control of root-knot nematodes (*Meloidogyne* species). A cooperative publication of the Department of Plant Pathology, North Carolina State University, and the United States Agency for International Development. Raleigh: North Carolina State University Graphics.

25. Taylor, A. L., V. H. Dropkin, and G. C. Martin. 1955. Perineal patterns of root-knot nematodes. Phytopathology 45:26–34.

26. Triantaphyllou, A. C. 1985. Cytogenetics, cytotaxonomy and phylogeny of root-knot nematodes. Pp. 113–126 *in* J. N. Sasser and C. C. Carter, eds. An advanced treatise on *Meloidogyne*, vol. 1. Biology and control. Raleigh: North Carolina State University Graphics.

27. Whitehead, A. G. 1968. Taxonomy of *Meloidogyne* (Nematodea: Heteroderidae) with descriptions of four new species. Transactions of the Zoological Society of London 31:263–401.