

Review Article

## An updated checklist of *Meloidogyne* Göldi, 1887 species, with a diagnostic compendium for second-stage juveniles and males

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**Abstract:** The cosmopolitan root-knot nematodes of the genus *Meloidogyne* are considered as the most important plant-parasitic nematodes damaging almost all higher plant species. This paper provides an updated checklist of 105 valid species of *Meloidogyne*, along with their synonyms and non-valid members. Furthermore, species are grouped based upon their diagnostic characteristics of second-stage juveniles (tail shape, tail length, stylet length and dorsal gland orifice (DGO) distance from stylet base) and males (number of lateral incisures, stylet length, DGO and spicules length).

**Keywords:** Identification, *Meloidogyne*, Morphology, root-knot nematodes, species list, taxonomy

### Introduction

Root-knot nematodes are included in the genus *Meloidogyne* Göldi, 1887 and constitute a relatively small, but important polyphagous group of highly adapted obligate plant parasites (Karssen *et al.*, 2013). Their taxonomic position at family level has been the subject of discussion for many years, and these nematodes have been confused with cyst nematodes (Heteroderidae Filipjev and Schuurmans Stekhoven, 1941) for a long time, and assigning the same or separate families for cyst and root-knot nematodes was controversial.

Chitwood (1949) revised *Meloidogyne* taxonomy for the first time and developed a key for five species (and one subspecies) at

that time. Subsequent reviews on the genus systematics were carried out during 1976-2002, providing identification keys and diagnostic compendia for its species (Esser *et al.*, 1976; Hewlet and Tarjan, 1983; Jepson, 1987; Eisenback and Triantaphyllou, 1991; Karssen and Hoenselaar, 1999; Karssen, 2002). The list of known species, with additional notes on the most important species, has been published by different nematologists, with the number of valid species reaching 54 in Jepson (1987), 68 in Luc *et al.* (1988), 62 in Eisenback and Triantaphyllou (1991), 80 in Siddiqi (2000), 81 in Karssen (2002), 88 in Andrassy (2007), 97 in Hunt and Handoo (2009) and 98 in Karssen *et al.* (2013).

The present study provides an updated list including 105 valid species with their synonyms, as well as lists of *species inquirendae* and *nominanuda*. Moreover, a grouping of recognized species is presented based on diagnostic characters of second-stage juveniles and males.

Handling Editor: Majid Pedram

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Received: 31 July 2019, Accepted: 26 November 2019

Published online: 16 January 2020

**Diagnosis of *Meloidogyne* Göldi, 1887**

Family Meloidogynidae (Skarbilovich, 1959)

Wouts, 1973

Subfamily Meloidogyninae Skarbilovich, 1959

= Meloidogynini (Skarbilovich, 1959) Coomans, 1979

= Meloidoderellinae Husain, 1976

= Meloidoderellini (Husain, 1976) Coomans, 1979

Genus *Meloidogyne* Göldi, 1887= *Caconema* Cobb, 1924= *Spartonema* Siddiqi, 1986= *Hypsoperine* (*Spartonema*) Siddiqi, 1986= *Hypsoperine* Sledge and Golden, 1964= *Hypsoperine* (*Hypsoperine*) (Sledge and Golden, 1964) Siddiqi, 1986

**Female.** Sedentary, white to transparent, rounded to pear-shaped with protruding neck. Body length from 350  $\mu\text{m}$  to 3 mm. Cuticle annulated, posteriorly with a characteristic unique pattern around the perineum called the perineal pattern. Anus and vulva terminal, phasmids near the anus, the latter usually covered with cuticular fold. The perineum sometimes slightly elevated. Head not or slightly set off, cephalic framework distinct but delicate. Labial disc not, to slightly raised, fused with median and lateral lips. Two slit-like amphidial openings and ten small labial sensilla present. Stylet delicate, ranging in length from 8-25  $\mu\text{m}$ , cone in most species slightly curved dorsally, shaft straight with three knobs. Dorsal pharyngeal gland orifice (DGO) 2-12  $\mu\text{m}$  behind the knobs. Secretory-excretory pore between lip region and metacarpus level. Metacarpus relatively large, pharyngeal glands variable in size and shape, ventrally overlapping the intestine. Reproductive system didelphic, the gonads long, partly convoluted. Most of the unembryonated eggs deposited in an egg-sac, formed by six large rectal glands and secreted through the anus.

**Male.** Vermiform, non-sedentary, ranging in length between 600-2500  $\mu\text{m}$ . Cuticle annulated. Lip region composed of a cap and post-labial annulus (annuli). Head cap with rounded labial disc and four fused median

lips. Six inner labial sensilla centered around the stoma and one cephalic sensillum present on each median lip. Large slit-like amphidial openings located between labial disc and lateral lips. The latter reduced or absent in some species. Lip region sometimes set off and/or partly subdivided by transverse incisures. Cephalic framework and straight stylet well developed, the latter ranging in length between 10-33  $\mu\text{m}$ . DGO at 1-13  $\mu\text{m}$  behind the stylet knobs. Metacarpus smaller than that in females. Secretory-excretory pore and hemizonid between metacarpus level and the ventrally-overlapping pharyngeal glands. Hemizonid anterior or sometimes posterior to the pore. Pharyngeal glands nuclei reduced to two. A single long testis usually present, rarely two reduced ones were observed. Lateral field in most species with four, up to 15 incisures in certain species, outer bands often areolated. Tail short, bluntly rounded. Bursa lacking. Phasmids near cloaca. Spicules slender, 18-47  $\mu\text{m}$  long; gubernaculum crescentic, about 10  $\mu\text{m}$  long.

**Second-stage juvenile.** Vermiform, infective stage. Body length 250-600  $\mu\text{m}$ . Cuticle annulated. Lip region structure as in males, but much smaller and with weakly sclerotized cephalic framework. Straight stylet, about 7-23  $\mu\text{m}$  long. DGO 1-8  $\mu\text{m}$  behind the knobs. Metacarpus not well developed. Hemizonid anterior to, at the same level or posterior to the secretory-excretory pore. Three pharyngeal glands ventrally overlapping the intestine. Rectum often inflated. Tail 13-115  $\mu\text{m}$  long, tapering towards hyaline tail part. Lateral field with four incisures.

**Third and fourth-stage juvenile.** Sedentary inside root and swollen, lacking stylet, develop within second-stage cuticle.

**List of *Meloidogyne* species****Type species***Meloidogyne exigua* (Göldi, 1887) Chitwood, 1949

= *Heterodera exigua* (Göldi, 1887) Marcinowski, 1909

#### Other species

*M. aberrans* Tao, Xu, Yuan, Wang, Lin, Zhuo and Liao, 2017

*M. acronea* Coetzee, 1956

= *Hypsoperine acronea* (Coetzee, 1956) Sledge and Golden, 1964

= *Hypsoperine (Hypsoperine) acronea* (Coetzee, 1956) Siddiqi, 1986

*M. actinidiae* Li and Yu, 1991

*M. aegracyperi* Eisenback, Holland, Schroeder, Thomas, Beacham, Hanson, Paes-Takahashi & Vieira, 2019

*M. africana* Whitehead, 1960

*M. aquatilis* Ebsary and Eveleigh, 1983

*M. arabicida* López and Salazar, 1989

*M. ardenensis* Santos, 1968

= *M. deconincki* Elmiligy, 1968

= *M. litoralis* Elmiligy, 1968

*M. arenaria* (Neal, 1889) Chitwood, 1949

= *Anguillula arenaria* Neal, 1889

= *Tylenchus arenarius* (Neal, 1889) Cobb, 1890

= *Heterodera arenaria* (Neal, 1889) Marcinowski, 1909

= *M. arenaria arenaria* (Neal, 1889) Chitwood, 1949

= *M. thamesi* (Chitwood in Chitwood, Specht and Havis, 1952) Goodey, 1963

= *M. arenaria thamesi* Chitwood in Chitwood, Specht and Havis, 1952

= *M. thamesi gyulai* Amin, 1993

= *M. gyulai* Amin, 1993

*M. artiellia* Franklin, 1961

*M. baetica* Castillo, Vovlas, Subbotin and Troccoli, 2003

*M. brevicauda* Loos, 1953

*M. californiensis* Abdel-Rahman and Maggenti, 1987

*M. camelliae* Golden, 1979

*M. caraganae* Shagalina, Ivanova and Krall, 1985

*M. carolinensis* Eisenback, 1982

*M. chitwoodi* Golden, O'Bannon, Santo and Finley, 1980

*M. chosenia* Eroshenko and Lebedeva, 1992

*M. christiei* Golden and Kaplan, 1986

*M. cirricauda* Zhang and Weng, 1991

*M. citri* Zhang, Gao and Weng, 1991

*M. coffeicola* Lordello and Zamith, 1960

= *Meloidodera coffeicola* (Lordello and Zamith, 1960) Kirjanova, 1963

*M. cruciani* Garcia-Martinez, Taylor and Smart, 1982

*M. cynariensis* Fam-Tkhan-Bihn, 1990

*M. daklakensis* Trinh, Le, Nguyen, Nguyen, Liébanas and Nguyen, 2018

*M. decalineata* Whitehead, 1968

*M. dimocarpus* Lio and Zhang, 2001

*M. donghaiensis* Zheng, Lin and Zheng, 1990

*M. dunensis* Palomares-Rius, Vovlas, Troccoli, Liébanas, Landa and Castillo, 2007

*M. duytsi* Karssen, van Aelst and van der Putten, 1998

*M. enterolobii* Yang and Eisenback, 1983

= *M. mayaguensis* Rammah and Hirschmann, 1988

*M. ethiopica* Whitehead, 1968

= *M. brasiliensis* Charchar and Eisenback, 2002

*M. fallax* Karssen, 1996

*M. fanzhiensis* Chen, Peng and Zhang, 1990

*M. floridensis* Handoo, Nyczepir, Esmenjaud, van der Beek, Castagnone-Sereno, Carta, Skantar and Higgins, 2004

*M. fujianensis* Pan, 1985

= *M. fujianensis* Cangsang, Jing and Shengyuan, 1988

*M. graminicola* Golden and Birchfield, 1965

*M. graminis* (Sledge and Golden, 1964) Whitehead, 1968

= *Hypsoperine graminis* Sledge and Golden, 1964

= *Hypsoperine (Hypsoperine) graminis* (Sledge and Golden, 1964) Siddiqi, 1986

*M. hainanensis* Liao and Feng, 1995

*M. hapla* Chitwood, 1949

*M. haplanaria* Eisenback, Bernard, Starr, Lee and Tomaszewski, 2004

*M. hispanica* Hirschmann, 1986

*M. ichinohei* Araki, 1992

*M. incognita* (Kofoid and White, 1919) Chitwood, 1949

= *Oxyuris incognita* Kofoid and White, 1919

= *Heterodera incognita* (Kofoid and White, 1919) Sandground, 1923

- = *M. incognita incognita* (Kofoid and White, 1919) Chitwood, 1949  
 = *M. acrita* Chitwood, 1949  
 = *M. incognita acrita* Chitwood, 1949  
 = *M. elegans* da Ponte, 1977  
 = *M. grahami* Golden and Slana, 1978  
 = *M. incognita grahami* (Golden and Slana, 1978) Jepson, 1987  
 = *M. kirjanovae* Terenteva, 1956  
 = *M. wartellei* Golden and Birchfield, 1978  
 = *M. incognitawartellei* Golden and Birchfield, 1978  
 = *M. polycephannulata* Charchar, Eisenback, Vieira, Fonseca-Boiteux and Boiteux, 2009  
*M. indica* Whitehead, 1968  
*M. inornata* Lordello, 1956  
 = *M. incognitainornata* Lordello, 1956  
*M. izalcoensis* Carneiro, Almeida, Gomes and Hernández, 2005  
*M. javanica* (Treub, 1885) Chitwood, 1949  
 = *Heterodera javanica* Treub, 1885  
 = *Tylenchus (Heterodera) javanicus* (Treub, 1885) Cobb, 1890  
 = *Anguillulajavanica* (Treub, 1885) Laverigne, 1901  
 = *M. javanicajavanica* (Treub, 1885) Chitwood, 1949  
 = *M. javanicabauruensis* Lordello, 1956  
 = *M. bauruensis* (Lordello, 1956) Esser, Perry and Taylor, 1976  
 = *M. lordelloi* da Ponte, 1969  
 = *M. lucknowica* Singh, 1969  
*M. jianyangensis* Yang, Hu, Chen and Zhu, 1990  
 = *M. jianyangensis* Zhu, Lan, Hu, Yang and Wang, 1991 (= objective junior homonym)  
*M. jinanensis* Zhang and Su, 1986  
*M. kikuyensis* De Grisse, 1961  
 = *Spartonema kikuyense* (De Grisse, 1961) Siddiqi, 2000  
*M. konaensis* Eisenback, Bernard and Schmitt, 1995  
*M. kongi* Yang, Wang and Feng, 1988  
*M. kralli* Jepson, 1984  
*M. lini* Yang, Hu and Zhu, 1988  
*M. lopezi* Humphreys-Pereira, Flores-Chaves, Gómez, Salazar, Gómez-Alpizar and Elling, 2014  
*M. luci* Carneiro, Correa, Almeida, Gomes, Mohammad Deimi, Castagnone-Sereno and Karssen, 2014  
*M. lusitanica* Abrantes and Santos, 1991  
*M. mali* Itoh, Ohshima and Ichinohe, 1969  
 = *M. ulmi* Marinari-Palmisano and Ambrogioni, 2001  
*M. maritima* Jepson, 1987  
*M. marylandi* Jepson and Golden in Jepson, 1987  
*M. megadora* Whitehead, 1968  
*M. megatyta* Baldwin and Sasser, 1979  
*M. mersa* Siddiqi and Booth, 1991  
 = *M. (Hypsoperine) mersa* Siddiqi and Booth, 1991  
*M. microcephalus* Cliff and Hirschmann, 1984 (original spelling *microcephala*)  
*M. microtyla* Mulvey, Townshend and Potter, 1975  
*M. mingnanica* Zhang, 1993  
*M. minor* Karssen, Bolk, van Aelst, van den Beld, Kox, Korthals, Molendijk, Zijlstra, van Hoof and Cook, 2004  
*M. moensi* Le, Nguyen, Nguyen, Liébanas, Nguyen and Trinh, 2019  
*M. morocciensis* Rammah and Hirschmann, 1990  
*M. naasi* Franklin, 1965  
*M. nataliei* Golden, Rose and Bird, 1981  
*M. oleae* Archidona-Yuste, Cantalapiedra-Navarrete, Liébanas, Rapoport, Castillo and Palomares-Rius, 2018  
*M. oryzae* Maas, Sanders and Dede, 1978  
*M. oteifai* Elmiligy, 1968 (original spelling *oteifae*)  
*M. ottersoni* (Thorne, 1969) Franklin, 1971  
 = *Hypsoperine ottersoni* Thorne, 1969  
 = *Hypsoperine (Hypsoperine) ottersoni* (Thorne, 1969) Siddiqi, 1986  
*M. ovalis* Riffle, 1963  
*M. panyuensis* Liao, Yang, Feng and Karssen, 2005  
*M. pakistanica* Shahina, Nasira, Salma, Mehreen and Bhatti, 2015  
*M. paranaensis* Carneiro, Carneiro, Abrantes, Santos and Almeida, 1996  
*M. partityla* Kleynhans, 1986  
*M. petunia* Charchar, Eisenback and Hirschmann, 1999

*M. phaseoli* Charchar, Eisenback, Charchar and Boiteau, 2008  
*M. pini* Eisenback, Yang and Hartman, 1985  
*M. piperi* Sahoo, Ganguly and Eapen, 2000  
*M. pisi* Charchar, Eisenback, Charchar and Boiteau, 2008  
*M. platani* Hirschmann, 1982  
*M. propora* Spaul, 1977  
 = *Hypsoperine propora* (Spaul, 1977) Siddiqi, 1986  
 = *Hypsoperine (Hypsoperine) propora* (Spaul, 1977) Siddiqi, 1986  
*M. querciana* Golden, 1979  
*M. salasi* Lopez-Chaves, 1985  
*M. sasseri* Handoo, Huettel and Golden, 1994  
*M. sewelli* Mulvey and Anderson, 1980  
*M. silvestris* Castillo, Vovlas, Troccoli, Liébanas, Palomares-Rius and Landa, 2009  
*M. sinensis* Zhang, 1983  
*M. spartelensis* Ali, Tavoillot, Mateille, Chapuis, Besnard, Bakkali, Cantalapiedra-Navarrete, Liébanas, Castillo and Palomares-Rius, 2015  
*M. spartinae* (Rau and Fassuliotis, 1965) Whitehead, 1968  
 = *Hypsoperine spartinae* Rau and Fassuliotis, 1965  
 = *Spartonema spartinae* (Rau and Fassuliotis, 1965) Siddiqi, 1986  
 = *Hypsoperine (Spartonema) spartinae* (Rau and Fassuliotis, 1965) Siddiqi, 1986  
*M. subarctica* Bernard, 1981  
*M. suginamiensis* Toida and Yaegashi, 1984  
*M. tadshikistanica* Kirjanova and Ivanova, 1965  
*M. thailandica* Handoo, Skantar, Carta and Erbe, 2005  
*M. trifoliophila* Bernard and Eisenback, 1997  
*M. triticoryzae* Gaur, Saha and Khan, 1993

*M. turkestanica* Shagalina, Ivanova and Krall, 1985  
*M. vandervegtei* Kleynhans, 1988

#### **Species inquirendae**

*M. marioni* (Cornu, 1879) Chitwood and Oteifa, 1952  
 = *Anguillula marioni* Cornu, 1879  
 = *Heterodera marioni* (Cornu, 1879) Marcinowski, 1909  
 = *M. goeldi* Lordello, 1951 (= *nomen novum* for *M. marioni*)  
*M. megriensis* (Poghossian, 1971) Esser, Perry and Taylor, 1976  
 = *Hypsoperine megriensis* Poghossian, 1971  
 = *Hypsoperine (Hypsoperine) megriensis* (Poghossian, 1971) Siddiqi, 1986  
*M. poghossianae* Kirjanova, 1963  
 = *M. acronea* apud Poghossian, 1961  
*M. vialae* (Lavergne, 1901) Chitwood and Oteifa, 1952  
 = *Anguillula vialae* Lavergne, 1901  
 = *Heterodera vialae* (Lavergne, 1901) Marcinowski, 1909

#### **Nomina nuda**

*M. californiensis* Abdel-Rahman, 1981  
*M. carolinensis* Fox, 1967  
*M. goeldii* Santos, 1997  
*M. panyuensis* Liao, 2001  
*M. Zhanjiangensis* Liao, 2001

#### **Diagnostic compendium for second-stage juveniles and males of *Meloidogyne* species.**

The stylet length, dorsal gland orifice distance from stylet base (DGO) and spicules length are in  $\mu\text{m}$ . L. L. refers to the number of lateral lines in the males (Tables 1-8).

**Table 1** Group 1 (group 1 in Jepson, 1987) for second-stage juveniles and males of *Meloidogyne* species. J2 tail 16-27  $\mu\text{m}$  long, subcylindrical, its terminus broad and rounded at tip (Fig. 1; G1).

Species name	J2		Male ( $\sigma$ )			
	Stylet length	DGO	L. L.	Stylet length	DGO	Spicules
<i>M. brevicauda</i>	14 - 15	4.0	4	19 - 21	3.0	34 - 43
<i>M. fanzhiensis</i>	8 - 11	3.1 - 4.2	4	10 - 14	4.2 - 7.3	21 - 29
<i>M. indica</i>	10 - 14	?	4	16	3.0 - 4.0	30
<i>M. oleae</i>	11 - 13	2.5 - 3.5	4	13 - 18	4.0 - 6.0	21 - 32
<i>M. nataliei</i>	22 - 23	3.0 - 4.3	5	28 - 29	4.0 - 6.5	41 - 44
<i>M. propora</i>	16 - 19	2.0 - 3.0	4 to 7	18 - 23	5.0	32 - 35

The stylet length, dorsal gland orifice distance from stylet base (DGO) and spicules length are in  $\mu\text{m}$ . L. L. refers to the number of lateral lines in the males.

**Table 2** Group 2 (groups 2 + 3 in Jepson, 1987) for second-stage juveniles and males of *Meloidogyne* species. J2 tail 28 - 40  $\mu\text{m}$  long (except in *Meloidogyne artiella* and *Meloidogyne minganica* is 22  $\mu\text{m}$  and in *Meloidogyne microtyla* is 44  $\mu\text{m}$ ), its terminus broad, gradually tapering with a rounded hyaline part, and generally without any marked cuticular constrictions in the hyaline region (Fig. 1; G2).

Species name	J2		Male ( $\delta$ )			
	Stylet	DGO	L. L.	Stylet	DGO	Spicules
<i>M. acronea</i>	10 - 15	2.2 - 4.5	4	16 - 20	2.1 - 7.2	24 - 36
<i>M. africana</i>	12 - 18	3.0	4, 5	19 - 22	4.0 - 6.0	26 - 35
<i>M. artiella</i>	14 - 16	2.5 - 4.5	4, 5	17 - 27	5.0 - 7.0	25 - 30
<i>M. cirricauda</i>	8 - 11	2.5 - 3.0	4	21 - 24	3.0 - 5.0	32 - 40
<i>M. coffeicola</i>	9 - 11	3.1 - 3.8	4	23 - 26	5.0	20 - 29
<i>M. kikuyensis</i>	12 - 15	3.5 - 5.0	4	17 - 20	4.5 - 6.0	31 - 35
<i>M. mali</i>	9 - 15	3.0 - 6.0	4	17 - 23	4.8 - 13.0	21 - 38
<i>M. microtyla</i>	11 - 12	2.5 - 3.5	4	18 - 20	4.0	28 - 30
<i>M. minganica</i>	9 - 10	2.0 - 3.0	4	23	5.0	37
<i>M. suginamiensis</i>	12 - 15	3.0 - 5.0	4	17 - 21	4.0 - 8.0	24 - 37
<i>M. vandervegtei</i>	10 - 12	4.2 - 5.3	4 to 7	22 - 27	3.3 - 7.6	35 - 44

The stylet length, dorsal gland orifice distance from stylet base (DGO) and spicules length are in  $\mu\text{m}$ . L. L. refers to the number of lateral lines in the males.

**Table 3** Group 3 (group 9 in Jepson, 1987) for second-stage juveniles and males of *Meloidogyne* species. J2 tail 45 - 58  $\mu\text{m}$  long, irregularly tapering, ending in a finely rounded tip (Fig. 1; G3).

Species name	J2		Male ( $\delta$ )			
	Stylet	DGO	L. L.	Stylet	DGO	Spicules
<i>M. jianyangensis</i>	13 - 17	2.1 - 3.7	4	19 - 26	2.5 - 3.5	26 - 34
<i>M. jinanensis</i>	10 - 14	3.2 - 5.3	4	17 - 24	4.0 - 5.6	21 - 35
<i>M. megadora</i>	10 - 15	2.3 - 5.0	4 to 6	18 - 23	4.0 - 8.3	25 - 43
<i>M. microcephalus</i>	9 - 13	2.5 - 3.8	4	19 - 28	2.9 - 7.9	24 - 39

The stylet length, dorsal gland orifice distance from stylet base (DGO) and spicules length are in  $\mu\text{m}$ . L. L. refers to the number of lateral lines in the males.

**Table 4** Group 4 (groups 4 + 5 + 6 in Jepson, 1987) for second-stage juveniles and males of *Meloidogyne* species. J2 tail 40 - 50  $\mu\text{m}$  long, ending in a broadly rounded tip; usually with a deep (sometimes more than one) constrictions along the hyaline region (Fig. 1; G4).

Species name	J2		Male ( $\delta$ )			
	Stylet	DGO	L. L.	Stylet	DGO	Spicules
<i>M. ardenensis</i>	9 - 15	2.0 - 4.0	4, 5	17 - 28	3.0 - 5.0	28 - 38
<i>M. camelliae</i>	11 - 12	3.0 - 4.5	4, 5	21 - 24	4.0 - 7.0	33 - 39
<i>M. caraganae</i>	13 - 16	3.6 - 4.8	4	19 - 21	5.2 - 6.6	29 - 33
<i>M. carolinensis</i>	11 - 13	3.0 - 4.7	4	17 - 22	1.9 - 5.2	27 - 35
<i>M. chitwoodi</i>	9 - 11	2.6 - 3.9	4	18 - 19	2.2 - 3.4	26 - 29
<i>M. christiei</i>	10 - 12	3.5 - 4.7	4	17 - 19	3.5 - 5.3	24 - 26
<i>M. decalineata</i>	11 - 14	4.0	10	19 - 20	4.0	33 - 37
<i>M. donghaiensis</i>	12 - 15	3.0 - 6.0	4, 5	22 - 25	2.5 - 6.1	31 - 43
<i>M. ethiopica</i>	9 - 14	2.0 - 3.0	4, 5	14 - 24	2.0 - 3.5	29 - 42
<i>M. fallax</i>	10 - 11	3.2 - 3.8	4, 5	19 - 21	3.2 - 5.7	22 - 30
<i>M. floridensis</i>	10 - 11	2.5 - 3.0	4	17 - 23	2.5 - 3.5	23 - 35
<i>M. hispanica</i>	9 - 13	2.2 - 5.3	4, 5	20 - 25	1.4 - 7.9	28 - 41
<i>M. incognita</i>	9 - 15	2.1 - 4.0	4	20 - 26	1.7 - 4.7	29 - 40
<i>M. izarcoensis</i>	12 - 13	3.0 - 4.0	4 to 6	23 - 26	4.0 - 7.0	27 - 35
<i>M. kongi</i>	12 - 14	3.9 - 5.8	4	22 - 24	5.8 - 7.5	33 - 38
<i>M. lusitanica</i>	13 - 16	3.5 - 4.5	4	21 - 27	4.0 - 6.0	32 - 45
<i>M. megatyla</i>	14 - 17	4.2 - 5.9	4	22 - 26	4.2 - 6.3	29 - 37
<i>M. oteifai</i>	11 - 13	3.0	4 to 6	19 - 23	3.0 - 4.5	29 - 37
<i>M. paranaensis</i>	13 - 14	4.0 - 4.5	4	20 - 27	3.5 - 5.5	22 - 38
<i>M. partityla</i>	10 - 15	1.7 - 5.6	4, 5	17 - 21	2.3 - 5.3	27 - 35
<i>M. pini</i>	11 - 14	3.1 - 4.4	4	18 - 23	2.3 - 7.0	21 - 35
<i>M. querciana</i>	10 - 12	2.6 - 4.3	4, 5	19 - 20	2.2 - 2.8	32 - 33
<i>M. silvestris</i>	12 - 14	2.0 - 4.0	4	24 - 27	5.3 - 6.7	29 - 38
<i>M. subarctica</i>	13 - 15	2.9 - 4.8	4 to 6	17 - 20	4.1 - 5.8	33 - 37
<i>M. turkestanica</i>	13 - 16	3.0	4	16 - 19	4.0	25 - 34

The stylet length, dorsal gland orifice distance from stylet base (DGO) and spicules length are in  $\mu\text{m}$ . L. L. refers to the number of lateral lines in the males.

**Table 5** Group 5 (group 7 in Jepson, 1987) for second-stage juveniles and males of *Meloidogyne* species. J2 tail 44 - 60  $\mu\text{m}$  long, ending in a finely rounded to pointed tip, usually with more than one constrictions along the hyaline region (some individuals of *Meloidogyne ichinohei* have a short triangular hyaline tail part) (Fig. 1; G5).

Species name	J2		Male (♂)			
	Stylet	DGO	L. L.	Stylet	DGO	Spicules
<i>M. actinidiae</i>	13 - 15	3.5	4	20 - 26	2.6 - 5.9	21 - 33
<i>M. arabicida</i>	9 - 15	2.0 - 4.7	4	16 - 22	3.0 - 5.0	19 - 36
<i>M. arenaria</i>	10 - 13	2.4 - 4.1	4	20 - 28	2.4 - 8.0	22 - 39
<i>M. baetica</i>	13 - 14	3.0 - 5.0	4	16 - 19	3.5 - 5.5	24 - 36
<i>M. chosenia</i>	11 - 13	2.8 - 4.8	4	17 - 21	3.5 - 4.2	22 - 32
<i>M. citri</i>	11 - 12	3.7	4	25	5.0	39
<i>M. cruciani</i>	10 - 12	3.2 - 3.6	4 to 7	19 - 24	3.2 - 7.9	29 - 38
<i>M. cynariensis</i>	11 - 13	3.0 - 3.4	Male unknown			
<i>M. daklakensis</i>	11 - 16	2.0 - 5.0	4	17 - 20	4.0 - 7.0	28 - 34
<i>M. dimocarpus</i>	11 - 15	2.2 - 3.8	4	15 - 23	4.5 - 5.8	25 - 40
<i>M. enterolobii</i>	10 - 13	2.8 - 4.5	4	19 - 26	3.2 - 5.8	26 - 32
<i>M. exigua</i>	9 - 14	2.6 - 5.0	4 or more	14 - 22	3.0 - 6.5	20 - 37
<i>M. fujianensis</i>	13 - 14	4.0	4	22 - 25	4.0 - 8.0	31 - 39
<i>M. ichinohei</i>	10 - 13	3.6 - 6.4	7, 8	16 - 18	6.1 - 6.9	33 - 34
<i>M. inornata</i>	10 - 13	2.5 - 3.5	4 to 6	20 - 25	4.0 - 5.0	26 - 38
<i>M. javanica</i>	10 - 12	2.0 - 5.0	4	15 - 25	4.0 - 6.0	25 - 38
<i>M. konaensis</i>	12 - 14	4.2 - 5.9	4, 5	20 - 27	5.0 - 8.4	22 - 36
<i>M. lini</i>	14 - 17	5.0	10 to 12	15 - 20	6.0	31 - 47
<i>M. lopezi</i>	9 - 13	2.4 - 3.6	4	22 - 24	1.9 - 3.4	29 - 38
<i>M. luci</i>	12 - 14	2.3 - 3.3	4	21 - 23	2.5 - 4.5	24 - 35
<i>M. minor</i>	7 - 10	2.5 - 3.2	4 to 6	17 - 19	3.2 - 4.4	23 - 28
<i>M. moensi</i>	9 - 12	2.9 - 4.1	4, 5	14 - 16	3.0 - 4.8	21 - 28
<i>M. ovalis</i>	?	?	4	18 - 23	3.0 - 5.0	31 - 38
<i>M. pakistanica</i>	10 - 14	2.0 - 4.0	6	20 - 25	4.0 - 6.0	29 - 33
<i>M. panyuensis</i>	13 - 15	3.0 - 4.5	4, 5	22 - 26	5.0 - 7.0	25 - 35
<i>M. petunia</i>	9 - 11	2.8 - 4.0	4	21 - 26	1.3 - 3.4	28 - 37
<i>M. phaseoli</i>	10 - 12	2.9 - 4.2	4	20 - 26	3.8 - 5.9	28 - 40
<i>M. piperi</i>	11 - 13	3.0 - 4.0	Male unknown			
<i>M. pisi</i>	10 - 11	2.5 - 4.2	4	19 - 26	4.2 - 8.4	27 - 37
<i>M. platani</i>	11 - 13	2.7 - 4.0	4 to 8	19 - 24	2.3 - 4.5	25 - 32
<i>M. tadshikistanica</i>	12	3.0	4	22 - 25	5.0 - 5.4	27 - 37
<i>M. thailandica</i>	10 - 11	2.5 - 3.5	4	17 - 20	2.5 - 5.0	25 - 38
<i>M. triticoryzae</i>	11 - 13	2.0 - 3.0	4	17 - 19	3.0 - 4.0	26 - 32

The stylet length, dorsal gland orifice distance from stylet base (DGO) and spicules length are in  $\mu\text{m}$ . L. L. refers to the number of lateral lines in the males.

**Table 6** Group 6 (group 8 in Jepson, 1987) for second-stage juveniles and males of *Meloidogyne* species. J2 tail 53 - 65  $\mu\text{m}$  long, ending in a broadly rounded tip, its hyaline region with more or less parallel sides (Fig. 1; G6).

Species name	J2		Male (♂)			
	Stylet	DGO	L. L.	Stylet	DGO	Spicules
<i>M. aberrans</i>	16 - 17	3.0 - 3.9	11 to 15	18 - 20	3.8 - 5.3	23 - 37
<i>M. aquatilis</i>	10 - 12	2.0 - 4.0	4	13 - 16	3.0 - 4.0	24 - 26
<i>M. graminis</i>	9 - 13	2.0 - 4.0	4	13 - 19	1.7 - 5.0	27 - 34
<i>M. hapla</i>	10 - 13	2.5	4	17 - 23	3.0 - 6.0	20 - 31
<i>M. haplanaria</i>	9 - 12	1.8 - 3.6	4	17 - 22	3.7 - 6.4	36 - 42
<i>M. maritima</i>	12 - 13	2.5 - 3.6	4	18 - 23	2.5 - 3.6	26 - 35
<i>M. marylandi</i>	10 - 14	1.8 - 3.1	Male unknown			
<i>M. morocciensis</i>	11 - 13	3.0 - 4.4	4	23 - 26	3.5 - 6.2	31 - 39

The stylet length, dorsal gland orifice distance from stylet base (DGO) and spicules length are in  $\mu\text{m}$ . L. L. refers to the number of lateral lines in the males.

**Table 7** Group 7 (groups 10 + 11 in Jepson, 1987) for second-stage juveniles and males of *Meloidogyne* species. J2 tail 67 - 75  $\mu\text{m}$  long, ending in a finely rounded to pointed tip, sometimes with fine but marked clavate tip (Fig. 1; G7).

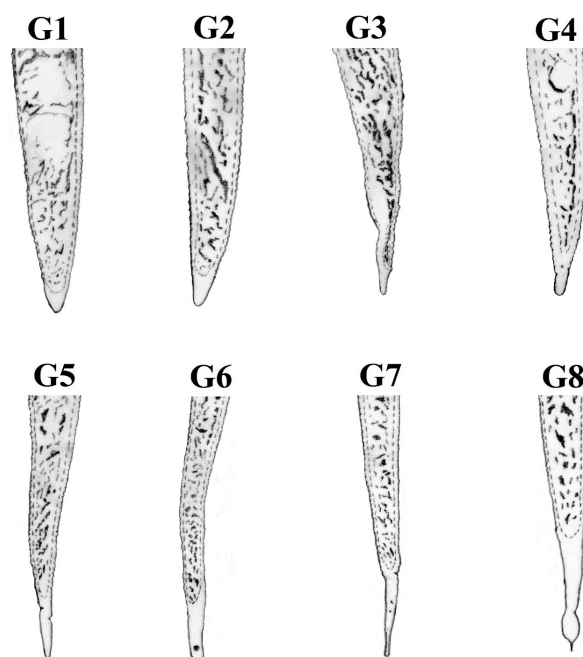
Species name	J2		Male (♂)			
	Stylet	DGO	L. L.	Stylet	DGO	Spicules
<i>M. aegracyper</i>	10 - 12	2.7 - 4.8	4	14 - 17	3.0 - 3.3	22 - 25
<i>M. dunensis</i>	11 - 13	1.5 - 3.0	4 to 6	16 - 22	2.5 - 4.5	29 - 38
<i>M. duytsi</i>	10 - 12	3.2 - 3.8	4	19 - 20	3.8 - 5.1	24 - 27
<i>M. graminicola</i>	9 - 13	2.6 - 3.6	4 to 8	15 - 17	2.8 - 5.8	23 - 29
<i>M. hainanensis</i>	10 - 15	4.7 - 5.2	4 to 8	17 - 20	5.2 - 7.8	29 - 36
<i>M. kralli</i>	10 - 12	3.0 - 4.5	4 to 8	18 - 20	3.5 - 6.0	22 - 28
<i>M. mersa</i>	13 - 16	6.0 - 8.0	4 to 12	20 - 23	6.0 - 9.0	35 - 39
<i>M. naasi</i>	13 - 15	2.0 - 3.0	4	16 - 19	2.0 - 4.0	25 - 30
<i>M. oryzae</i>	14 - 15	3.0	4 to 8	19 - 20	4.0 - 5.0	25 - 34
<i>M. ottersoni</i>	13 - 15	4.0	4	14 - 16	3.0	19 - 23
<i>M. salasi</i>	9 - 13	2.1 - 5.3	4 to 6	12 - 22	2.8 - 5.9	18 - 35
<i>M. sewelli</i>	11 - 12	7.0 - 8.0	4	18 - 20	5.0 - 6.0	28 - 30
<i>M. sinensis</i>	17 - 19	3.7 - 5.8	4	24 - 32	4.0 - 8.0	27 - 40
<i>M. trifoliophila</i>	11 - 14	2.9 - 4.6	8 to 12	17 - 19	3.4 - 6.7	27 - 34

The stylet length, dorsal gland orifice distance from stylet base (DGO) and spicules length are in  $\mu\text{m}$ . L. L. refers to the number of lateral lines in the males.

**Table 8** Group 8 (group 12 in Jepson, 1987) for second-stage juveniles and males of *Meloidogyne* species. J2 tail 79 - 100  $\mu\text{m}$  long, ending in a terminal process (except in *Meloidogyne sasseri*) (Fig. 1; G8).

Species name	J2		Male (♂)			
	Stylet	DGO	L. L.	Stylet	DGO	Spicules
<i>M. californiensis</i>	11 - 13	1.0 - 3.0	4	18 - 28	2.0 - 6.0	20 - 40
<i>M. sasseri</i>	13 - 15	1.5 - 4.5	4	19 - 22	3.0 - 4.0	30 - 36
<i>M. spartelensis</i>	13 - 15	1.5 - 3.0	4	17 - 20	2.5 - 4.0	25 - 31
<i>M. spartinae</i>	14 - 17	4.0 - 6.0	4	17 - 21	3.5 - 7.0	25 - 40

The stylet length, dorsal gland orifice distance from stylet base (DGO) and spicules length are in  $\mu\text{m}$ . L. L. refers to the number of lateral lines in the males.

**Figure 1** Tail terminus shape in second-stage juveniles (J2s) of *Meloidogyne* species based on the grouping given in the present study (redrawn from Jepson, 1987).



## Discussion

The present study has updated the list of *Meloidogyne* species, including some recently described species and a few species which have not appeared in other lists. Moreover, a diagnostic compendium is presented based on the most important diagnostic characters in J2s and males. Such grouping of species in a diagnostic compendium may be helpful in characterization of several species; however, problems in accurate identification of species particularly those in groups 4 and 5 still remain. As stated in Hunt and Handoo (2013), some of the described species are undoubtedly junior synonyms of common, highly variable species. For instance, it may be inferred that certain species in group 4 such as *M. floridensis*, *M. hispanica* and *M. izalcoensis*, and even in group 5 (e. g., *M. enterolobii* and *M. dimocarpus*) could not be easily distinguished from *incognita*, solely based on morphological characters of J2s and males. Although, the diagnostic morphological characters of females, particularly perineal pattern, could be added for better characterization of certain species, intraspecific variation and a large increase in the number of nominal species taking their toll on its utility, particularly for the inexperienced eye (Hunt and Handoo, 2009). Nevertheless, providing diagnostic compendia based upon the features of females may be useful as a supplementary aid completing the present study.

Molecular and biochemical characterization may be considered as additional options to make more precise identifications, as well as to confirm or refute the status of the nominal species. As a wise approach, an integrative taxonomy of the species encompassing their multigene phylogeny, similar to the work conducted for *M. nataliei* (Álvarez-Ortega *et al.*, 2019), is highly recommended to clarify exact intrageneric structure of the genus *Meloidogyne*. Significant advances in sequencing technologies also could provide more detailed information about the intraspecific variation among the problematic taxa (Rashidifard *et al.*, 2019), to finally

address the taxonomic problems in root-knot nematodes.

## Acknowledgements

The first author thanks the Iranian National Science Foundation (INSF; project No. 96008747) and Shiraz University (Iran) for financial support.

## References

- Andrássy, I. 2007. Free-living nematodes of Hungary, II (*Nematoda errantia*). Hungarian Natural History Museum, Budapest.
- Álvarez-Ortega, S., Brito, J. A. and Subbotin, S. A. 2019. Multigene phylogeny of root-knot nematodes and molecular characterization of *Meloidogyne nataliei* Golden, Rose and Bird, 1981 (Nematoda: Tylenchida). *Scientific Reports*, 9: 11788.
- Chitwood, B. G. 1949. "Root-knot nematodes"-part I. A revision of the genus *Meloidogyne* Göldi, 1887. *Proceedings of the Helminthological Society of Washington*, 16: 90-104.
- Eisenback, J. D. and Triantaphyllou, H. H. 1991. Root-knot nematode: *Meloidogyne* spp. and races. In: Nickle, W. R. (Ed.). *Manual of Agricultural Nematology*. Marcel Dekker, New York, pp. 191-274.
- Esser, R. P., Perry, V. G. and Taylor, A. L. 1976. A diagnostic compendium of the genus *Meloidogyne* (Nematoda: Heteroderidae). *Proceedings of the Helminthological Society of Washington*, 43: 138-150.
- Hewlett, T. E. and Tarjan, A. C. 1983. Synopsis of the genus *Meloidogyne* Goldi, 1887. *Nematopica*, 13: 79-102.
- Hunt, D. J. and Handoo, Z. A. 2009. Taxonomy, identification and principal species. In: Perry, R. N., Moens, M. and Starr, J. L. (Eds.). *Root-knot nematodes*. CABI Publication, Wallingford, England, pp. 55-97.
- Hunt, D. J. and Handoo, Z. A. 2013. Root-knot nematodes. In: Manzanilla-López, R. H. and

- Marbán-Mendoza, N. (Eds.). Practical plant nematology. Biblioteca Básica de Agricultura Publication, pp. 359-409.
- Jepson, S. B. 1987. Identification of root-knot nematodes (*Meloidogyne* species). Commonwealth Agricultural Bureaux, Farnham Royal, UK.
- Karssen, G. and van Hoenselaar, T. 1998. Revision of the genus *Meloidogyne* Göldi, 1892 (Nematoda: Heteroderidae) in Europe. *Nematologica*, 44: 713-788.
- Karssen, G. 2002. The Plant-Parasitic nematode genus *Meloidogyne* Göldi, 1892 (Tylenchida) in Europe. Brill, Leiden, The Netherlands.
- Karssen, G., Wesemael, W. and Moens, M. 2013. Root-knot nematodes. In: Perry, R. N. and Mones, M. (Eds.). Plant nematology, 2<sup>nd</sup> edition. King's Lynn, UK, CABI Publishing, Wallingford, England, pp. 73-108.
- Luc, M., Maggenti, A. R. and Fortuner, R. 1988. A reappraisal of Tylenchina (Nemata). 9. The family Heteroderidae Filipjev and Schuurmans Stekhoven, 1941. *Revue de Nématologie*, 11: 159-176.
- Rashidifard, M., Fourie, H., Véronneau, P., Marais, M., Daneel, M. S. and Mimee, B. 2018. Genetic diversity and phylogeny of South African *Meloidogyne* populations using genotyping by sequencing. *Scientific Reports*, 8: 13816.
- Siddiqi, M. R. 2000. Tylenchida, Parasites of Plants and Insects. 2<sup>nd</sup> edition. CABI Publishing, Wallingford, Oxon, UK.

## فهرست گونه‌های جنس *Meloidogyne Göldi, 1887* و گروه‌بندی گونه‌ها براساس ویژگی‌های ریخت‌شناختی لارو سن دو و نر

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دریافت: ۹ مرداد ۱۳۹۸؛ پذیرش: ۵ آذر ۱۳۹۸

**چکیده:** نماتدهای ریشه گرهی *Meloidogyne spp.* که در تمام مناطق دنیا حضور دارند، به‌عنوان مهم‌ترین گروه نماتدهای انگل گیاهی مطرح هستند و قادرند به تمام گونه‌های گیاهان عالی آسیب وارد سازند. پژوهش حاضر فهرست روزآمد شده ۱۰۵ گونه معتبر جنس *Meloidogyne* را به‌همراه فهرست مترادف‌ها و آرایه‌های نامعتبر ارائه داده است. هم‌چنین گروه‌بندی گونه‌ها براساس ویژگی‌های مهم ریخت‌شناختی لارو سن دو (شکل دم، طول دم، طول استایلت و محل ریزش غده پستی مری) و نماتد نر (تعداد شیارهای جانبی، طول استایلت، محل ریزش غده پستی مری و طول اسپیکول‌ها) انجام شده است.

**واژگان کلیدی:** شناسایی، ریخت‌شناسی، نماتدهای ریشه گرهی، فهرست گونه‌ها، آرایه‌بندی، *Meloidogyne*