

Notes on morphological characteristics of 25 cyst nematodes and related Heteroderidae

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Summary. Based on the study of type specimens and other reliably identified nematode material, data supplementing or correcting the original descriptions of 18 *Heterodera* species (including four species mostly considered as *species inquirendae*), two *Meloidodera* and two *Globodera* species and one species each of the genera *Cactodera*, *Camelodera* and *Cryphodera* are presented. The main focus is on morphological characters of second-stage juveniles.

Key words: *Cactodera estonica*, *Camelodera eremophila*, *Cryphodera nothophagi*, diagnosis, *Globodera mali*, *Globodera millefolii*, *Heterodera* spp., identification, *Meloidodera* spp., morphology, taxonomy.

More than 160 species in the family Heteroderidae have been described so far, making identification of individual species increasingly difficult. Problems with correct identification are in part due to the fact that many species were poorly described and that a number of descriptions were based on insufficient material. Morphological details, which subsequently proved to be of diagnostic significance, were often not reported or not considered as ‘essential’ at the time of description. Among such characters were, in particular, data on second-stage juveniles. Lack of data may in part be due also to inadequate microscopical equipment. This situation resulted in a number of subsequent synonymisations, and a number of nominal species were considered as *species inquirendae*.

The objective of this paper is to provide supplementary information on morphological characters of a number of cyst nematodes and a few other heteroderid species based on the study of type specimens and other reliably identified nematode material in order to provide more data for reliable species identification. Most of the species included had been described from the former Soviet Union. Available for study were, in particular, permanent nematode microscope slides deposited in the nematode collection of the Zoological Institute of the Russian Academy of Sciences, St. Petersburg, Russia; nematode collection at the Institute of

Zoology, University of Tartu, Estonia, and the German Nematode Collection (DNST), Julius Kühn-Institut (formerly: Biologische Bundesanstalt für Land- und Forstwirtschaft), Münster, Germany. Some type or voucher specimens on permanent slides were used also from the Institute of Zoology, Uzbek Academy of Sciences, Tashkent, Uzbekistan; Rothamsted Research, Harpenden, UK; Nematode Department, Wageningen Agriculture University, Wageningen, The Netherlands; National Nematological Research Centre, University of Karachi, Pakistan; National Nematode Collection of New Zealand, Landcare Research, Auckland, New Zealand. In addition, nematode material collected by the author and deposited in the German Nematode Collection was used.

Some taxonomic problems within the family Heteroderidae and concerning particular species and their identity had been studied and discussed already earlier (Wouts & Sturhan, 1978; Sturhan & Wouts, 1995; Sturhan & Rumpfenhorst, 1996; Mor & Sturhan, 2000; Sturhan, 2002; Sturhan & Krall, 2002; Tanha Maafi *et al.*, 2007).

GENUS *HETERODERA*

Heterodera arenaria Cooper, 1955

According to the redescription of the species by Robinson *et al.* (1996) phasmids of the second-stage juveniles are “not prominent, found posterior to

anus and slightly anterior to hyaline tail". But in juveniles from the Gibraltar Point population, which was used for the redescription, as well as in second-stage juveniles from The Netherlands and Germany, phasmids are distinct with lens-like extension in the cuticle, in a position 2-4 annules posterior to the anus (voucher specimens in DNST Münster). All four incisures in the lateral field are only rarely fully developed.

***Heterodera cajani* Koshy, 1967**

The synonymisation of *H. vigni* Edward & Misra, 1968 with *H. cajani* by Kalha and Edward (1968) has been accepted in most subsequent publications, but curiously in several identification keys both species were still treated separately (Wouts, 1985; Golden, 1986; Shahina & Maqbool, 1995; Wouts & Baldwin, 1998), with four incisures in the lateral field of *H. cajani* and three in *H. vigni*, as originally reported for this species. Being a member of the *H. schachtii* group, four incisures in the lateral field are likely to be correct. The presence of four lateral incisures is confirmed for *H. cajani* second-stage juveniles, collected by G. Swarup and deposited in DNST Münster; the lateral fields in these specimens were irregularly areolated, the phasmids very faint.

***Heterodera cardiolata* Kirjanova & Ivanova, 1969**

Paratype second-stage juveniles from the St. Petersburg collection and from the Tashkent collection (the latter possibly used by Narbaev, 1987, for redescription of the species) had 20-20.5 µm long stylets with well separated slightly concave knobs of 4-4.5 µm diameter, three lip annules, lateral fields with three incisures (*vs* four according to the original description, three according to Narbaev, 1987) and a hyaline tail portion of 18-19 µm. The cyst wall showed a strong punctuation.

***Heterodera graduni* Kirjanova in Kirjanova & Krall, 1971**

The species has been considered as *species inquirenda* by Hesling (1978), Wouts (1985) and in subsequent publications. From two paratype slides examined (St. Petersburg collection and DNST Münster) it appears unlikely that the fenestra generally attains the peculiar shape which had been considered as a diagnostic character in the original description. In unhatched juveniles within eggs a stylet of 22.5-23.5 µm length (against 25 µm given in the original description for a single juvenile observed inside an egg), a hyaline tail portion of 21-24 µm, four equally developed lip annules and four

incisures in the lateral field were observed. Eggs measured 94 (92-98) x 41 (40-43) µm (n = 12), giving an average length/width ratio of 2.3, which is slightly less than that given in the original description (2.41).

***Heterodera koreana* (Vovlas, Lamberti & Choo, 1992) Mundo-Ocampo, Troccoli, Subbotin, Del Cid, Baldwin & Inserra, 2008**

Paratype second-stage juveniles deposited in the Wageningen nematode collection showed phasmids with large lens-like structure in a position 4-7 annules posterior to the anus.

Large phasmids were also seen in second-stage juveniles identified as *H. koreana* (stylet length 16-18 µm) isolated from a soil sample collected by the author from around bamboo in a natural forest in southern Thailand (voucher specimens in DNST Münster).

***Heterodera menthae* Kirjanova & Narbaev, 1977**

Poorly fixed second-stage juveniles on slides from the St. Petersburg collection and in DNST Münster had a hyaline tail portion of 24-26 µm, which are about two-thirds of the tail length given as 33.6-42 (39.4) µm in the original description. The measurements of 6.4-8 (7.6) µm originally mentioned for the hyaline tail length is incorrect. The lateral fields are irregularly areolated. Phasmids are punctiform. The lip region has three annules plus a labial disc. The stylet base is flat and the knobs are anteriorly projected.

***Heterodera mothi* Khan & Husain, 1965**

Controversial data exist with regards of the number of incisures in the lateral field of the second-stage juveniles. While Khan and Husain (1965), Sharma and Swarup (1984), Taya and Bajaj (1986) and Maqbool and Shahina (1986) report the presence of three incisures, Shahina and Maqbool (1991, 1995) and Tanha Maafi *et al.* (2004) give four incisures. In specimens collected by the present author in Iran and in second-stage juveniles obtained from Pakistan by M.A. Maqbool, three incisures were seen with the inner incisure occasionally diverging into two in a few juveniles.

***Heterodera oxiana* Kirjanova, 1962**

According to the original description this species is mainly characterised by the presence of two underbridges in the vulval cone. Examination of paratypes (St. Petersburg collection and DNST Münster) confirmed the presence of a long

underbridge deep below the fenestrae and irregular 'muscle strands' attached to the vagina mostly in right angle at a level between (lower) underbridge and fenestrae. The only data on juveniles given in the original description includes juveniles within eggs with a stylet length of 25 μm . Unhatched juveniles within eggs on a paratype slide revealed the following characters: stylet (n=13) = 25 (24-26) μm long, stylet base = 5-6 μm in diameter, stylet knobs with concave anterior faces, tail = 53 (48-57) μm long (n=3), hyaline tail portion = 29 (26-31) μm long (n=8), posterior lip annule wide, anterior lip annules indistinct, lateral field with four incisures, phasmids punctiform. *Heterodera oxiana* has been considered as *species inquirenda* by Hesling (1978) and Wouts (1985).

***Heterodera pakistanensis* Maqbool & Shahina, 1986**

Second-stage juvenile paratype slides deposited at the University of Karachi were available for study. The morphological characters of the juveniles largely agreed with the original description of the species, but the lateral fields had mostly only three lines (instead of four according to the original description), with occasional splitting of the inner line into two lines (mostly less distinct) and presence of a distinct areolation. The head was weakly offset, the lip annules were indistinct. The stylet knobs were rounded (not anteriorly directed) and the stylet base was rather small (about 3 μm in diameter). The phasmids were small but distinct (not lens-like), located 24-28% of the tail length posterior to the anus. The tail measured 64-77 μm , the hyaline tail portion 28-34 μm (= 43-46% of the total tail length), ratio c' was 5.7-6.9 (n=10).

***Heterodera paratrifolii* Kirjanova, 1963**

Data on morphology of the second-stage juveniles were previously unknown. In juveniles within eggs on a paratype cyst slide deposited in DNST Münster, stylet lengths of 25-26 μm were measured; the stylet knobs were deeply concave, the stylet base was 5 μm in diameter. These juvenile characters support correctness for the synonymisation of *H. paratrifolii* with *H. trifolii* by Krall (1977).

***Heterodera phragmitidis* Kazachenko, 1986**

Paratype second-stage juveniles deposited in the Tartu nematode collection largely agreed with the original description: three distinct lip annules, stylet 18.7-20 μm long (vs 18-18.6 μm according to

original description) with flattened and only slightly concave knobs of 4.2-4.4 μm diameter, lateral field with three incisures (vs four according to original description) and irregular areolation, slender and pointed tail with hyaline part (26-34 μm) mostly longer than half total tail length, phasmids indistinct.

***Heterodera rosii* Duggan & Brennan, 1966**

In second-stage juveniles (specimens from Ireland in DNST Münster, collected by J. Duggan) lateral field only exceptionally areolated in mid-body region; phasmids indistinct, punctiform, 10-12 annules posterior to the anus; in general only the posterior one or two lip annules distinct; $c' = 4.6-5.2$. The juvenile tail figured under Fig. 4D in the original description of the species probably does not belong to *H. rosii*.

***Heterodera rumicis* Poghossian, 1961**

For developed juveniles inside eggs a tail length of 55 μm and a hyaline tail portion of 30-32 μm were observed and measured, a stylet length of 28-30 μm , the lip region with only the posterior annule distinct and wide and the lateral field with four incisures; cyst cone characters resembled *H. trifolii* (slides from the St. Petersburg nematode collection and DNST Münster). Synonymisation of *H. rumicis* with *H. trifolii* by Wouts (1985) seems justified, although similarity to *H. rosii* may even be greater and both species have *Rumex* species as type hosts.

***Heterodera salixophila* Kirjanova, 1969**

Descriptions and data on morphology were presented by Kirjanova (1969), Kirjanova and Krall (1971), Mulvey (1972) and Krall (1977), but Brzeski (1998) already pointed out that the species "needs redescription as the original description lacks important morphological details". Paratype slides deposited in the St. Petersburg collection and additional material collected in Estonia and Germany from around *Salix* sp. were available for the present study.

Paratype cysts showed low semifenestrae and a vulva slit considerably extending beyond the fenestra width, distinct bullae in the vulva cone, most of them slender conoid but none were molar-shaped (similar to figs. 91 and 92 of Mulvey, 1972, but underbridge less developed). Cysts collected by E. Krall from *Salix* sp. at several sites in Estonia showed the same cyst cone characteristics, in particular the slender bullae; but bullae were absent in immature cysts.

From paratype second-stage juveniles ($n = 10$) the following measurements were taken: stylet = 28 (27.5-28.5) μm , width and height of stylet base = 6.3 (5.8-6.4) μm x 2.9 (2.6-3.2) μm , width and height of lip region = 10 (9.6-10.7) μm x 4.8 (4.6-4.9) μm , length of tail = 67 (64-71) μm , length of hyaline part of tail = 36 (32-42) μm . Some of these recent measurements differ from those given in the original description (stylet = 30 μm , height of lip region = 6.4-7.2 μm). In the paratype juveniles the anterior faces of the stylet knobs are flat to slightly concave; the lip region has three (occasionally four) distinct annules of almost the same diameter, the lateral fields show four incisures and no distinct areolation, the phasmids are small but distinct and situated 8-11 annules posterior to the anus (= approximately one anal body diameter), the tail terminus is slender and often slightly offset.

Specimens from Germany collected from *Salix* sp. agree closely with the type specimens. Cysts generally show the slender bullae, and the semifenestras even of older cysts are often still covered by the cuticle. Second-stage juveniles have three (occasionally four) lip annules, the stylet knobs are concave anteriorly, the lateral fields are only irregularly areolated. The following measurements of second-stage juveniles ($n = 23$) are below those of the type specimens: L = 453 (410-495) μm , stylet = 25.5 (24.5-26) μm , tail = 58 (50-65) μm , hyaline part of tail = 32 (27-39) μm . The species appears to be widespread in Germany (Sturhan, 2006).

***Heterodera scleranthii* Kaktina, 1957**

Two slides from the St. Petersburg collection and one slide deposited in DNST Münster containing cyst cones and eggs with a few developed juveniles, not particularly designated as types, but determined by Kaktina and collected 10.09.1955, were available for study. Additions to the original description and the complementary description given by Kirjanova and Krall (1971): cyst cone with fenestra similar to *H. trifolii*, underbridge rather thick, bullae cone-shaped. Juveniles within eggs: stylet = 26-28 μm ($n=6$), stylet base = 6.3 μm in diameter, knobs robust, anterior faces cupped, three lip annules plus labial disc, lateral fields with four incisures, hyaline tail portion = 31-35 μm long ($n=5$), phasmids punctiform. Synonymisation of *H. scleranthii* with *H. trifolii* by Wouts (1985) appears justified.

***Heterodera tadshikistanica* Kirjanova & Ivanova, 1966**

The only information about second-stage juveniles given in the original description is that

juveniles within eggs had a stylet length of 23.4-26 μm . The study of a paratype slide (St. Petersburg collection) with cyst remnants and a few eggs with developed, unhatched juveniles revealed the following characters: stylet = 24-25 μm long, stylet base diameter = 4.5 μm , stylet knobs rounded with anterior faces flat to slightly cupped, lip region rather high, with 5-6 annules and posterior lip annule of almost the same diameter as other lip annules, lateral field with four incisures and irregular areolation, tail terminus more or less pointed, hyaline portion 21 μm long, phasmids punctiform.

***Heterodera turangae* Narbaev, 1988**

On two slides from the Tashkent nematode collection second-stage juveniles squashed from eggs had a 21 μm long stylet ($n=3$), which is slightly above the length given in the original description (mean = 19.4 μm).

Cyst characters such as the shape of the fenestra (semifenestras almost rounded) and absence of bullae, short stylet in second-stage juveniles, four lines in lateral field and the type host being *Populus pruinosa* in Salicaceae, which are distantly related to Urticaceae, are indications that *H. turangae* appears to be a member of the *H. humuli* species group and does not belong to the *H. goettingiana* group as originally suggested (Narbaev, 1988).

***Heterodera uzbekistanica* Narbaev, 1980**

The study of cysts from three slides (in Tashkent nematode collection and DNST Münster) from *Salix olgae* in the Tashkent region confirmed the characters in addition to those mentioned in the original description (no bullae, very weak underbridge). Second-stage juveniles and eggs were not available for observation. Fenestration type with rather high semifenestras, absence of bullae and hosts in Salicaceae indicate putative placement in the *H. humuli* group.

Other Heteroderidae genera

***Cactodera estonica* (Kirjanova & Krall, 1963) Krall & Krall, 1978**

From paratype slides deposited in the St. Petersburg collection the following characters of second-stage juveniles (most of them unhatched and some partly squashed from eggs) could be ascertained: lip region rounded, weakly set off, 9.0-9.5 μm in diameter and 4.0-4.8 μm high, with six (rarely five) annules; stylet 22.7 (22.2-23.6) μm long ($n=15$), with 4.0-4.8 μm wide knobs, which are

rounded and slightly inclined posteriad; tail 38.5 and 40 µm long (n=2), hyaline tail portion 19 (17-21.5) µm (n=8); $c' = 2.6$ and 3.0; tail terminus blunt; phasmids small, 8-10 annules posterior to the anus; lateral field with four incisures, areolation present, including central band. Stone (1986) and Sturhan (2002) already pointed out that the originally reported number of five incisures in the lateral field was incorrect. *Cactodera estonica* is an amphimictic species; males could be recovered from roots of the type host, but have not been described so far (Krall, 1977).

***Camelodera eremophila* Krall, Shagalina & Ivanova, 1988**

In a paratype second-stage juvenile (St. Petersburg nematode collection) the lateral field showed three incisures instead of four as reported by Krall *et al.* (1988). Other characters agreed with the original description. The phasmids are distinct but probably not lens-like, in a position nine annules posterior to the anus.

***Cryphodera nothophagi* (Wouts, 1973) Luc, Taylor & Cadet, 1978**

Re-examination of paratype second-stage juveniles (Auckland nematode collection) revealed three incisures in the lateral field, with the inner incisure occasionally diverging into two. Thus all known six *Cryphodera* species are characterised by the presence of basically three lateral incisures. Consequently, the key presented by Karssen and Van Aelst (1999) needs correction. In all described *Cryphodera* species the phasmids are lens-like.

***Globodera mali* (Kirjanova & Borisenko, 1975) Mulvey & Stone, 1976**

Sturhan (2002) refused synonymisation of *Heterodera chaubattia* Gupta & Edward, 1973 with *Heterodera mali* by Wouts (1985), a synonymy already suggested by Krall (1977), and proposed to consider *H. mali* as valid species in *Globodera*. The original description of the latter species had been based exclusively on cysts (see also Krall, 1977), measurements of eggs were given, but no data on females, males and juveniles.

On paratype slides deposited in the St. Petersburg collection and in DNST Münster, eggs with unhatched juveniles and juveniles partly squashed from eggs were found. The following characters could be ascertained: stylet (n=20) = 22 (21.5-22.5) µm, tail (n=5) = 41 (39-43) µm, hyaline tail portion (n=20) = 17 (13-20) µm, stylet knobs rounded and slightly inclined posteriad, 4 µm in diameter, lip region 8.2-8.5 µm wide and 3.6-3.8 µm

high with four annules, tail end rather blunt, annule width at mid-body about 1.5 µm.

***Globodera millefolii* (Kirjanova & Krall, 1965) Behrens, 1975**

The description of this species is based on a single immature cyst; males and juveniles were not described, eggs measured 132 x 49 µm. Krall (1977) considered *G. millefolii* as *species inquirenda*. A re-examination of the type slides deposited in the St. Petersburg collection did not reveal morphological characteristics in addition to those already published (Kirjanova & Krall, 1965; Krall, 1977).

A few cysts and juveniles squashed from eggs, collected by E. Krall in September 1972 at the type locality Tallinn-Pirita, Estonia (see Krall, 1977), around *Achillea millefolium* were used for the present study (slides deposited in DNST Münster). Cysts pale brown, in two of three cysts 6 and 9 irregularly rounded bullae of up to 25 µm in diameter at some distance below fenestra, one cyst without bullae-like structures. Two perineal areas had the following characteristics: fenestra 22 and 25 µm long, 30 and 22 µm wide, anus 25 and 35 µm apart from edge of fenestra, only in one cyst encircled with cuticular rings (thus, this is not a general characteristic as suggested from observations by Mulvey, 1972), 5 and 6 irregular cuticle ridges between anus and fenestra, Granek's ratio = 1.1 and 1.4. Second-stage juveniles (n = 10): L = 445 (420-470) µm, a = 28 (26-31), c = 9.8 (9.1-10.5), $c' = 3.9$ (3.6-4.4), stylet = 26 (25-27) µm, tail = 46 (42-52) µm, hyaline tail portion = 25.5 (21-29) µm. Lip region with four annules, 7.5-8 µm in diameter and 3-4 µm high; stylet knobs rounded, occasionally with slight anterior projection, 4.0-4.4 µm in diameter and 2.5-3.0 µm high; four incisures in the lateral field; phasmids punctiform, situated 8-9 annules posterior to the anus; tail conical with narrowly pointed terminus.

***Meloidoderaalni* Turkina & Chizhov, 1986**

In second-stage juveniles from *Alnus* sp. and *Betula* sp. from the Moscow region and from *Alnus glutinosa* and *A. incana* from several sites in Germany the phasmids were large, lens-like, 4-9 annules posterior to the anus. In males from Russia and Germany indistinct phasmids with only slightly lens-like swelling in the cuticle were seen close to tail terminus; the lateral field was irregularly areolated. Re-measured paratype second-stage juveniles (n=6) had a body length of 400 (385-425) µm and a stylet length of 31 (30.5-31) µm; the respective measurements of juveniles from Germany

were (n=44): L = 438 (405-490) µm and stylet = 31.5 (29.5-34) µm.

***Meloidodera tianschanica* Ivanova & Krall, 1985**

In second-stage juveniles deposited in the Tartu nematode collection the phasmids are distinct with lens-like structure in the cuticle, not pore-like as given in the key presented by Cid del Prado (1991).

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D. Sturhan. Заметки о морфологических особенностях 25 видов цистообразующих нематод и близких к ним Heteroderidae.

Резюме. На основе переисследования типового материала, а также достоверно определенных до вида особей нематод, предлагаются дополняющие или корректирующие первоописания сведения по 18 видам *Heterodera* species (включая виды, обычно рассматриваемые как *species inquirendae*), по двум видам *Meloidodera* и двум видам *Globodera*, а также по одному виду из родов *Cactodera*, *Camelodera* и *Cryphodera*. Большая часть рассматриваемых морфологических особенностей относится к личинкам второй стадии.
