Differential species traits of *Trichostrongylus tenuis* (Nematoda, Trichostrongylidae)

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Keywords: trichostrongylosis; goose; nematodes; helminth eggs; differential diagnostics.

Introduction

Parasitism is one of the life forms that present multifaceted biological phenomena. They also are one of the factors forming biological diversity. Thirdly, they ensure the circulation of matter and energy flows at the level of the parasitic systems (Ewald, 1995; Zelmer, 1998; Araújo et al., 2003). Thirdly, they ensure the circulation of matter and energy flows at the level of the parasitic systems (Ewald, 1995; Zelmer, 1998; Araújo et al., 2003).

The causative agent of trichostrongylosis, *Trichostrongylus tenuis* Mehlis, 1846 is a helminth species that parasitizes in the gastrointestinal tract of birds and causes trichostrongylosis. Research on the differential features of the pathogen at various stages of development facilitates timely finding of the foci of infection and providing recommendations for prevention and control. In the present study, the differential species traits of male and female *Trichostrongylus* nematodes parasitizing in the domestic goose were examined. The nematodes were obtained in helminthological dissection of the intestine of birds kept at farms and private households in Poltava region, Ukraine. It was revealed that the morphological features of *T. tenuis* females that should be considered in species identification include the structural specifics of the reproductive system and the tail end. 22 metric parameters were suggested for species identification, including the female body measurements for different parts, specifics of vulva and anus location, sizes of the ovjector, sphincter, ejector and vulval area. Differences were found in the metric parameters of the lateral crests of the cuticle in female nematodes in relation to the position of crests on the parasite’s bodies. The cuticular crests were absent at 0.1 mm from the head and tail ends, and the length of crests was 9.3 mm in total. The longest and widest crests were observed in the middle of the body, the shortest were found in the anus area, and the narrowest crests were from the anterior part of esophagus to its middle. The distance between crests varied 0.2–3.0 μm, the longest at the transition of esophagus into the intestine and the shortest in area between the vulva and the anus. The metric parameters of *T. tenuis* eggs obtained from bird feces and in the nematode uterus differed significantly by 5 characters. The collected data on the morphological and metric parameters of females and eggs of *T. tenuis* can be used in species identification and understanding of the taxonomic position of that species.

Keywords: trichostrongylosis; goose; nematodes; helminth eggs; differential diagnostics.

*Yevstafieva, V. O., Starodub, Y. S., Pisarenko, V. M., Barabolia, O. V., & Nikiforova, O. V. (2020). Differential species traits of Trichostrongylus tenuis (Nematoda, Trichostrongylidae). Regulatory Mechanisms in Biosystems, 11(3), 449–454. doi:10.15421/022069*
this species is not only of general biological interest, but also of great practical importance in planning and carrying out measures to combat and prevent infection.

Most of the criteria used in the classification of Trichostrongyloidea, and in particular in the identification of T. tenuis, are morphological. The main morphological diagnostics is carried out for male nematodes, since they have a greater number of structures in the reproductive apparatus. The structure of the caudal bursa, the features of the interposition of its rays, the structure of the genital cone, the shape and size of the spicules, the presence or absence of a gubernaculum are taken into account. Attention is also paid to the general morphology of the nematode body, namely: the presence or absence of mouth capsule and the nature of its ornamentation, the presence of a vesicle and papillae at the head end and chitinous ornamentation of the cuticle (Gibbons & Khalil, 1982; Durette-Desset, 1992; Durette-Desset et al., 1993). At the same time, the morphology of T. tenuis has been described in separate works, which do not fully contain information on the taxonomic characters of Trichostrongylus (Ryzhikov, 1967; Atkinson et al., 2008). This, in turn, complicates their differential diagnosis and requires additional study of the morphology of T. tenuis at various stages of development.

When classifying Trichostrongyloidea genera and species, attention is now paid principally to the structure of the system of cuticular crests, which are a character of a rather high taxonomic value. Individual crests can be more developed than others to the point of forming lateral wings (Hoberg, 1996; Lichtenfels et al., 1996; Lichtenfels & Piltz, 2000). It is generally accepted that these characters are reliable and very promising in solving the problems of differential diagnosis of species and genera, improving the system of the superfamily Trichostrongyloidea.

The aim of present study is to research the differential morphometric species characters of the mature females and eggs of T. tenuis nematodes, parasitizing in domestic goose.

Materials and methods

The studies were carried out at the laboratory of the Department of Parasitology and Veterinary-Sanitary Examination of the Faculty of Veterinary Medicine of the Poltava State Agrarian Academy in 2018–2020. The nematodes were collected during helminthological investigation of the intestine of 287 domestic geese (Anser anser dom.) (Skryabyn, 1928) on farms in Poltava region (Ukraine). The nematode species was identified by Skryabyn et al. (1954). In total 302 adult female T. tenuis nematodes were collected. The prevalence of infection was 31.7% according to the results of helminthological dissection. 2,271 specimens of domestic goose were studied using coproscopy, and the prevalence of infection was 22.9%. In Poltava region, T. tenuis infection in domestic goose was in the range 17.2–26.7%. Notably, the prevalence of infection was higher in geese kept in private farm plots and households (24.4%) compared to that in geese reared in specialized bird farms (16.1%) (Yevstafieva & Starodub, 2020). The morphological and metric parameters of T. tenuis eggs were examined after collection from the feces of infected geese and directly in the uterus of female nematodes. The studied characters included the shape, surface of the shell, length, width of egg, eggshell thickness, as well as the areas of the inner and outer surface of egg.

The morphometric parameters of T. tenuis eggs and nematodes were studied using ImageJ 1.52 f (version 2.00) in interactive mode using a ×10, ×40, ×100 objective and a ×10 photo eyepiece. To calibrate the image analyzer, the ruled scale of aocular micrometer was calibrated with the scale of stage micrometer included in a MicroMed microscope kit. Microphotography was performed using a digital camera attached to a MikroMed 5 Mpix microscope (China).

Standard deviation (SD) and average values (x) were calculated. Significance of difference between average values in the studied T. tenuis eggs was established using one-way analysis of variance and F-test for 95% confidence level.

Results

The morphological study of adult T. tenuis females revealed the following species traits. The nematodes are small, thin, filiform, somewhat translucent. Length of the roundworm body was 9.5 ± 0.9 mm, slightly tapered to head and tail ends. This is confirmed by metric parameters with width of body being 13.6 μm at mouth opening, 69.7 μm at the middle of body, and 26.4 μm at the anus area (Table 1).

Table 1

| Characters                  | Min – max | x ± SD |
|-----------------------------|-----------|--------|
| Length of body, mm          | 7.8–11.1  | 9.5 ± 0.9 |
| Length of esophagus, mm     | 1.2–1.4   | 1.3 ± 0.1 |
| Distance from head end to excretory pore, μm | 111.4–132.1 | 123.8 ± 5.6 |
| Length of body covered by lateral cuticular crests, mm | 8.0–10.8 | 9.3 ± 0.9 |
| Distance from head end to lateral cuticular crests, mm | 0.13–0.15 | 0.14 ± 0.01 |
| Distance from anus to tail end, μm | 60.2–71.1 | 65.9 ± 4.5 |
| Distance from vulva to tail end, mm | 1.0–1.8 | 1.4 ± 0.2 |
| Width of body at, μm        |           |         |
| – mouth opening             | 12.2–14.2 | 13.6 ± 0.6 |
| – excretory pore            | 21.9–27.0 | 23.9 ± 2.1 |
| – beginning of cuticular stration | 23.5–28.2 | 25.6 ± 1.7 |
| – middle part of esophagus  | 28.1–31.1 | 29.3 ± 0.9 |
| – transition of esophagus to intestine | 40.2–46.1 | 42.2 ± 2.2 |
| – the middle of body        | 68.8–71.0 | 69.7 ± 0.7 |
| – vulva                     | 73.4–78.9 | 76.9 ± 1.7 |
| – anal opening              | 24.1–27.6 | 26.4 ± 1.1 |
| Length of slit-like opening of vulva, μm | 52.3–64.3 | 58.0 ± 3.4 |
| Length of ovjector, μm      | 314.4–362.1 | 339.5 ± 15.2 |
| Length of sphincter, μm     | 41.1–49.1 | 45.7 ± 2.1 |
| Width of sphincter, μm      | 52.3–58.1 | 55.5 ± 2.1 |
| Length of ejector, μm       | 109.6–136.5 | 123.9 ± 8.4 |
| Width of ejector, μm        | 55.9–65.1 | 60.3 ± 2.7 |

The mouth organs were weakly developed, and the mouth opening was surrounded by three inconspicuous lips. The lips were slightly depressed in the middle. The oral capsule, neck papillae and other cuticular formations were absent at head end. The esophagus was thin and elongated (Fig. 1). Additional differential morphological characters of T. tenuis females were found in the present study, including vulva structure, specifics of the copulatory apparatus and tail end. 22 metric parameters are also suggested for use in the species identification of females (Table 1). Thus, the copulatory apparatus of females included vulva, paired ovjector and uterus (Fig. 2a). The vulva had a slit-like opening without protrusions, 58.0 μm in length. It is located in the posterior body part, as confirmed by metric parameters, at 1.4 mm to tail end. The ovjector was well-developed, 339.5 μm long and consisted of a funnel linked to the uterus and preceding the muscle sphincter and the distally located ejector (Fig. 2a). The sphincter was round-oval in shape (45.7 × 55.5 μm), and the ejector was elongated (123.9 × 60.3 μm). The bends of the uterus diverged in opposite directions and were filled with eggs.

Fig. 1. Head end of T. tenuis: Es – esophagus, L – lips
Tail end of female nematodes was cone-shaped and ended with a small, digitate process. The anus was well-developed (Fig. 2 b) and located at 89.0 μm to the tail end.
Fig. 2. Morphological features of ♀ *Trichostrongylus tenuis*: a – copulatory apparatus, b – tail end; Va – vulva area; O – paired ovijector, Sp – sphincter, U – uterus, Ej – ejector, E – eggs, An – anus, Dp – digitate process.

We have also found that the lateral crests (wings, growths) of the cuticle were different in height, width and position to each other at all areas of *T. tenuis* females’ bodies. This was confirmed in morphological studies (Fig. 3). Thus, in females the lateral crests began and ended at 0.1 mm from head and tail ends (Table 1). The crest’s height and width at that body area were 1.3 ± 0.1 and 1.1 ± 0.03 μm, respectively (Fig. 4a, b).

Fig. 3. Morphology of lateral cuticular crests of body of ♀ *Trichostrongylus tenuis* in: a – middle part of esophagus; b – transition of esophagus to intestine; c – anterior to vulva.

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Fig. 4. Metric parameters of lateral cuticular crests of bodies of ♀ *Trichostrongylus tenuis* (n = 10): a – height, b – width, c – distance between crests (μm); small square corresponds to the mean value; the vertical line and segments directed up and down from the small square correspond to the minimum and maximum values.
In the middle of the esophagus, the crests became gradually elongated by 40.9% to 2.2 ± 0.02 μm and slightly narrower, by 20.7% to 1.0 ± 0.04 μm. At the transition of the esophagus to the intestine, the lateral cuticular crests became shorter, by 28.6% compared to the former parameters to 1.5 ± 0.05 μm, and wider, by 66.0%, to 3.0 ± 0.03 μm. In the middle of the nematode body, the height and width of crests were maximal (3.4 ± 0.13 and 5.1 ± 0.08 μm respectively), higher by 54.0% and 40.9% than the abovementioned values. Near the tail end of the female roundworm, the crests gradually became smaller. In the vulva area, the height and width of crests were respectively 1.1 ± 0.04 and 4.0 ± 0.06 μm (by 66.6% and 20.5% compared to the abovementioned values). In the anus area, the crests were shorter and narrower by 14.9% and 32.5% than the other noted values (0.9 ± 0.10 and 2.7 ± 0.14 μm).

The distance between crests was measured and the position of crests to each other was shown to vary in different areas of female T. tenuis bodies in a certain way (Fig. 4c). At the head end, the crests were located at a distance of 1.7 ± 0.03 μm between each other. At the middle part of the esophagus, this distance slightly increased by 19.5% (to 2.1 ± 0.03 μm). At the transition of the esophagus to the intestine, the distance between crests was maximal, to 3.0 ± 0.04 μm (larger by 30.7% compared to the abovementioned value). Near the tail end, the distance between crests gradually decreased. In the middle of the body that distance decreased by 71.5% (to 0.8 ± 0.05 μm), in the vulva area by 50.5% (to 0.4 ± 0.05 μm). The minimal distance between crests was in the anus area, 0.2 ± 0.04 μm (smaller by 48.8% compared to the distance in the vulva area).

T. tenuis eggs had an outer structure characteristic for nematodes of the order Strongylida: oval, with thin, smooth, well-developed eggshell. The colour varied from light grey to light brown. The eggs in the nematode uterus and bird feces contained embryos at the stage of cleaving (Fig. 5).

The obtained data can be used in species identification of T. tenuis nematodes by females and eggs, taking the sampled substrate into account.

Discussion

The nematodes, similarly to insects, are one of the most numerous and widely spread groups of multicellular organisms that have mastered a huge range of habitats and are at the stage of rapid biological progress, many of which lead a parasitic lifestyle. The reason for this lies in the peculiarities of their morphology and biology among other things. This is also the basis for the taxonomic characterization of parasites (Kennedy & Hamett, 2013; Carlson et al., 2017). Therefore, the study of the morphological features of parasitic nematodes, the expansion and revision of already existing data are an urgent area of research.

We have conducted a morphometric analysis of adult and embryonic stages of development of Trichostrongylus tenuis Mehlin, 1846 nematodes which parasite in birds. Most of the studies indicate that the species differentiation of nematodes of the order Strongylida is most effective on the basis of the morphological specifics of males. Their tail end is equipped with a characteristic caudal cuticular bursa, the species features of which are described in detail in a number of works. The structure of spicules, gubernaculum and other reproductive structures is also taken into account (Cram & Wehr, 1934; Jacquiet et al., 1997). Thus, the ratio of the distance between individual rays of the genital bursa in male T. tenuis is a differential species parameter. Moreover, this feature can vary depending on the type of host in which the Trichostrongylus roundworms parasitize. The ratio of the distance between third and fourth and second and third rays of the caudal bursa is 1:2.7 (in the range of 1:2.2 – 1:3.5) in T. tenuis isolated from the red grouse (Lagopus scoticus), 1:3.1 (in the range of 1:2.3 – 1:3.8) in roundworms obtained from the grey partridge (Perdix perdix) and 1:2.9 (in the range of 1:2.2 – 1:3.9) in those collected from the common peacock (Pavo cristatus) (Durette-Desset et al., 1993). However, it is not always possible to identify male nematodes, hence the necessity to differentiate the females or eggs of parasites.

It was shown that the morphology of T. tenuis females has a similar structure as in other strongylids. The mouth opening is surrounded by three weakly expressed lips, there are no oral capsule or other specific formations at the head end. Therefore, we suggest taking into account 22 morphometric parameters that characterize the size of the esophagus and body in its various parts (10 parameters), the location of the anus and excretory pore (2 parameters), the size of the ovivector, sphincter, ejector, vulva and its location on the body of the parasite (7 parameters). Scientific works have already pointed to the copulatory apparatus of females, since its morphological and metric parameters are of great importance in species identification (Ederli & Oliveira, 2014; Sukee et al., 2018). According to the data of Skriabyn et al. (1954), it was proposed to take into account 7 parameters that characterize the total length, width at the vulva area, the location of the nerve ring, vulva, and anus, the size of the vulva slit, as well as the ovivector in the metric identification of T. tenuis females. And Ryzhikov (1967) suggests using only three of metric parameters, which also characterize the total length of body, its width in the vulva area and

![Fig. 5. Eggs of Trichostrongylus tenuis nematodes: a – obtained from feces of infected birds, b – in uterus of parasite females](image-url)
location of the vulva. Other taxonomic features proposed to be used in the identification of Trichostrongylus are the specifics of the morphological structure and location of the lateral cuticular crests (wings, outgrowths) on the body of the parasite. Based on these features, keys have been proposed that increase the efficiency of differentiation of this group of nematodes (Lee, 1965; Hoberg & Lichtenfels, 1994; Lichtenfels et al., 1996; Yevstafieva et al., 2019). Studies have shown that the lateral cuticular crests on the entire body in T. tenius females have different sizes in terms of height, width, and location relative to each other. Thus, lateral crests appear and end at a distance of 0.1 mm from the head and tail ends, respectively; their total length is 9.3 mm. The height and width of the crests gradually increase from the head end to the middle of the body, where they reach their maximum values. Towards the tail end, the crests gradually become shorter and narrower. When studying the location of crests relative to each other, it can be noted that the distance between crests increases in the direction from the head end to the tail, and the crests are rarest in the area of transition of esophagus to the intestine. From the middle point of the body posteriorly, the distance between crests decreases sharply, almost 4 times, and they are located most densely in the anus area. Studies by other authors have shown that the lateral wings on the anterior part of the body of T. tenius nematode are flattened, and close to the posterior part of the body they become larger and change from a morphological point of view. The authors found that the morphology of lateral wings varies in the shapes of crests, hooks and spines. In their opinion, such sharp differences in the structure of cuticular processes characterize the adaptation of the parasite to fixation in the thick mucous membrane of the bird’s intestine (Razeyev et al., 2020).

We also propose to identify T. tenius by eggs isolated from various substrates. Notably, there are significant differences by 5 parameters (length and width of egg, eggshell thickness, and area of the outer and inner egg surfaces). Thus, the eggs located in the uterine cavity of the female nematode turned out to be longer (P < 0.001), narrower (P < 0.01), and with a thinner shell (P < 0.001) as compared to the eggs isolated from the bird feces. At the same time, area of the inner surface was larger (P < 0.001) in the eggs located in the uterine cavity, and the outer surface area was smaller (P < 0.01) in comparison with the analogous parameters in eggs obtained from the bird feces. We did not find such comparative data of the morphometric parameters of T. tenius eggs depending on the method of isolation in the previous publications.

The obtained data on the morphological and metric parameters of females and eggs of T. tenius nematodes can be used in species identification and clarifying the taxonomic position of this species.

Conclusion

The parasitic female nematodes of the species Trichostrongylus tenius Mehlis, 1846, isolated from domestic goose, have a morphological structure characteristic of helminths of the superfamily Trichostrongyloidea. Typical species characters include features in the structure of the copulatory apparatus and tail end. To facilitate the differentiation of T. tenius females, it is proposed to use additional morphometric parameters, 10 of which characterize the size of the esophagus and body at various areas, 2 characterize the location of the anus and excretory pores, and 7 features describe the size of the ovijector, sphincter, ejector, vulva and its location on the parasite’s body. The specifics of location and metric parameters of the lateral cuticular crests at bodies of T. tenius females can be used for their identification. Three parameters were identified that characterize the location of the crests, namely: the distance from the head and tail ends to crests, the total length of the nematode body bearing crests. It is proposed to take into account the height and width of the lateral crests, and the distance between them in 6 different parts of body (head end, the middle of esophagus, the transition of the esophagus to the intestine, the middle of the body, and areas of vulva and anus). The highest and widest crests are observed at the middle part of body, the shortest crests are near the anus, and the narrowest crests are at the anterior part of the parasite’s body. The distance between crests reaches its maximum in the area of transition of the esophagus to the intestine, and the parameter is reduced towards the caudal end. It was found that T. tenius eggs have 5 differential morphometric parameters, which differ significantly in eggs isolated from the feces of infected birds and those located in the uterine cavity of female roundworms.

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