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Gut anatomy of the worker caste of Neotropical genera Cylindrotermes Holmgren and Hoplotermes Light (Infraorder Isoptera, Termitidae)

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A B S T R A C T

Studies over the last six decades have shown that the gut anatomy of the termite worker caste provides a valuable set of taxonomic characters. However, the gut anatomy of most American termite taxa is still little known. This study investigated the anatomy of the worker gut of the Neotropical termite genera Cylindrotermes Holmgren and Hoplotermes Light. We provide descriptions and illustrations of the gut in situ and the cuticular ornamentation of the gizzard, enteric valve, and first proctodeal segment for both genera.

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Introduction

With 63 genera and 643 living species worldwide (Constantino, 2019), the Termitinae is a heterogeneous group of termites, without diagnostic characters supporting it as a clade among Termitidae subfamilies (Bourguignon et al., 2017). The subfamily is represented in the Neotropical region by 20 genera, occurring from the southern United States (Gnathamitermes Light, 1932; Hoplotermes Light, 1933) to southern Argentina (Onkotermes Constantino, 2002). Three of these genera are cosmopolitan (Amitermes Silvestri, 1901, Microcerotermes Silvestri, 1901, and Termes Linnaeus, 1758).

The South and Central American genus Cylindrotermes Holmgren, 1906 was proposed based on specimens collected in Bolivia, during the Nordenskiöld expedition (1904–1905). One century later, Rocha and Cancelli (2007) revised the genus and described three new species, based on the external morphology of the soldier and worker castes from Brazilian samples, and redescribed four of the five previously described species (except the type species Cylindrotermes nordenskioldi Holmgren, 1906). Noirot (2001, Fig. 12d) illustrated an unidentified species of Cylindrotermes, with brief comments on internal structures. With a total of eight nominal species now recognized within Cylindrotermes, the geographical distribution of the genus ranges from the rainforest of southern Central America (Costa Rica) to the savannas (Cerrado) of South America. Cylindrotermes species form small colonies, frequently found inside dry dead wood (small trunks and dry sticks on the ground). There are reports of damage to roots and stems of sugarcane caused by members of the genus (Miranda et al., 2004).

Hoplotermes is an uncommon monotypic termite genus, with Hoplotermes amplus Light, 1933 as the type-species, described from the external morphology of the soldier and worker castes of specimens from western Mexico; the imagos caste remains unknown. The gut anatomy of Hoplotermes has never been described. The genus has been recorded in Costa Rica, Guatemala and Nicaragua (Krishna et al., 2013). Colonies of this species are found in wood, under rocks, or cow dung; they build earthen chambers and passageways in, on and near attacked wood (Light, 1933).

Characters of the worker caste digestive tube have come to be widely recognized as key resources for taxonomy over the last six decades (Noirot and Kovoor, 1958; Sands, 1992, 1998; Noirot, 2001), and their description has been mandatory for taxonomic studies in the last two decades. Although many genera are reasonably well represented in museums, the internal morphology of many species is still unknown. To help to fill these lacunae, we provide detailed descriptions and illustrations of the worker gut of seven species of Cylindrotermes and H. amplus, including the gut coiling in situ and the cuticular ornamentation of the gizzard, enteric valve, and first proctodeal segment.
**Fig. 1.** *Cylindrotermes brevipilosus:* (a) detail of gizzard armature (small arrow: crop pectinate scales), (b) enteric valve, with one of the cushions outlined (large arrow: proximal pad, small arrow: distal portion).

**Fig. 2.** *Cylindrotermes caata:* (a) detail of gizzard armature (small arrow: crop pectinate scales), (b) enteric valve, with one of the cushions outlined (large arrow: proximal pad, small arrow: distal portion).

**Fig. 3.** *Cylindrotermes capixaba:* (a) detail of gizzard armature (small arrow: crop pectinate scales), (b) enteric valve, with one of the cushions outlined (large arrow: proximal pad, small arrow: distal portion).

**Material and methods**

**Material examined**

We studied specimens deposited in the Museu de Zoologia da Universidade de São Paulo (MZUSP), São Paulo, Brazil. We dissected and illustrated the worker gut coiling, gizzard, and enteric valve of *Hoplotermes amplus* (MZUSP-15464, Guatemala, Jutiapa); *Cylindrotermes brevipilosus* Snyder, 1926 (MZUSP-24534: Brazil, Mato Grosso do Sul State, Costa Rica municipality); *Cylindrotermes caata* Rocha and Cancelli, 2007 (MZUSP-11266, Brazil, São Paulo State, Luiz Antônio municipality, paratype); *Cylindrotermes capixaba* Rocha and Cancelli, 2007 (MZUSP-1796, Brazil, Espírito Santo State, Cariacica municipality, paratype); *Cylindrotermes flangiatus* Mathews, 1977 (MZUSP-21322, Brazil, Rondônia State, Porto Velho municipality); *Cylindrotermes macrognathus* Snyder, 1929 (MZUSP-4568, Panama, Barro Colorado Island); *Cylindrotermes parvignathus* Emerson, 1949 (MZUSP-8447, Brazil, Pará State, Benevides municipality); and *Cylindrotermes sapiranga* Rocha and Cancelli, 2007 (MZUSP-11503, Brazil, Bahia State, Sapiranga Ecological Reserve, paratype).

**Illustrations and figures**

We adopted the terminology of Noirot (2001) for the gut coiling, gizzard, and enteric valve cuticular ornaments, and of Rocha and Constantini (2015) for the first proctodeal cuticular ornaments.

Line drawings characterizing the gut in situ and the first proctodeal segment were prepared with a drawing tube coupled to a stereomicroscope. The gizzard, enteric valve, and first proctodeal segment were mounted in glycerin on a slide and photographed with an optical microscope. Particularly, the enteric valve of *Cylindrotermes* has a small section and a tightly attached musculature, which is challenging to mount satisfactorily, especially since the number of good-quality specimens for dissection was limited.

**Results**

After detailed examination, we observed different gut-coiling patterns in situ and a particular cuticular ornamentation for each genera, *Cylindrotermes* and *Hoplotermes*, as follows.

**Cylindrotermes**

**Worker digestive tube** (Figs. 1–8): Crop slightly asymmetrical, not voluminous, covered with finely pectinate scales (Figs. 1a, 2a, 3a, 4a, 5a, 6a and 7a, arrows). Gizzard with a complete armature arranged in a columnar belt with 24 folds (six first-order, six second-order, and 12 third-order) and a pulvillar belt with 12 folds (six first-order, six second-order); Length ratio between belts about one; pulvilli of first order conspicuous, with tiny pectinate scales, and pulvilli of second order very reduced (Figs. 1a, 2a, 3a, 4a, 5a, 6a and 7a). Stomodeal valve inserted apically in the tubular mesenteron. Mesenteric tongue external
Fig. 4. *Cylindrotermes flangiatus*: (a) detail of gizzard armature (small arrow: crop pectinate scales), (b) enteric valve, with one of the cushions outlined (large arrow: proximal pad, small arrow: distal portion).

Fig. 5. *Cylindrotermes macrognathus*: (a) detail of gizzard armature (small arrow: crop pectinate scales), (b) enteric valve, with one of the cushions outlined (large arrow: proximal pad, small arrow: distal portion).

Fig. 6. *Cylindrotermes parvignathus*: (a) detail of gizzard armature (small arrow: crop pectinate scales), (b) enteric valve, with one of the cushions outlined (large arrow: proximal pad, small arrow: distal portion).
to the mesenteric arch, tapering broadly, and connected at the mesenteron only by a filiform mesenteric tissue (Fig. 8a, arrow). Two pairs of Malpighian tubules attached at the mesenteron-proctodeum junction, with distinct insertions on opposite sides of the segment (Fig. 8e, arrow). First proctodeal segment (P1) tubular and elongated, forming a marked loop below the rectum (P5) (Fig. 8a–d), distally attached to the paunch (P3) at the dorsal/right side of the abdomen (Fig. 8b, arrow) and deeply inserted at the P3, surrounded by a thick band of muscle. P1 without cuticular ornamentation. Enteric-valve armature (P2) weakly sclerotized, composed by three nearly equal cushions, each cushion with two distinct spine-covered areas, the pad closest to P1, with robust spines (Figs. 1b, 2b, 3b, 4b, 5b, 6b, and 7b, large arrows); and an elongated portion, covered with small scattered spines, closest to P3, very feintly defined (Figs. 1b, 2b, 3b, 4b, 5b, 6b, and 7b, small arrows).

P3 well developed and elongated, but little protruded through the mesenteric arch. Isthmus short (Fig. 8a). Fourth proctodeal segment (P4) dilated throughout (tubular but with larger diameter than in P1). All examined specimens of the different species follow the same gut pattern, including the gut coiling in situ, and the P2 cuticular ornamentation shows distinctive variations in the density and degree of sclerotization of the spines on the proximal ring (Figs. 1b, 2b, 3b, 4b, 5b, 6b, and 7b).

**Comparisons among termite genera:** The gut pattern in situ and particularly the P1 and P4, and the cuticular ornamentation of the enteric valve in Cylindrotermes are distinct among the Neotropical termite genera. Even thought, we were unable to obtain reliably identified specimens for Cylindrotermes nordensiokldi, to be considered herein, we expect a similar pattern. Cylindrotermes shares with the Ethiopian genus Cephaloterme Silvestri, 1912 and the soldierless Oriental genus Protohamitermes Holmgren, 1912, the tubular P1 forming a ventral loop. In Cephaloterme the P1 forms a shorter loop than in Cylindrotermes, the mesenteric tongue lacks a filiform connection, and the enteric valve has six unequal cushions (Noirot, 2001, Figure 12 D, E; Sands, 1998, Figs. 669–681), Protohamitermes worker mandibles (Ahmad, 1976, Fig. 8A) differ considerably from those of Cylindrotermes and Cephaloterme, and the enteric valve has six cushions (Ahmad, 1976, Fig. 10A). Another possibly related genera is Orientoterme Ahmad, 1976, a soldierless Oriental termite (Bourguignon et al., 2017), but since little information on the worker gut anatomy is available, it is not possible to make a complete comparison. The mandibles clearly differ from those of Cylindrotermes (Ahmad, 1976, Fig. 8B) and the enteric valve has six cushions (Ahmad, 1976, Fig. 11A).
Fig. 9. *Hoplotermes amplus* worker: (a) detail of gizzard armature (small arrow: crop pectinate scales), (b) enteric valve (large arrows: cushions).

Fig. 10. *Hoplotermes amplus* worker gut in situ: (a) detail of stomodeal valve insertion, (b) dorsal, (c) right, (d) ventral and (e) left views; (f) detail of enteric-valve insertion in dorsal view (P4 and P5 removed, arrow: enteric-valve insertion). Gray area indicates mesenteric tissue; c: crop; M: mesenteron; MT: mesenteric tongue; i: isthmus; P1: first proctodeal segment (ileum); P3: third proctodeal segment (paunch); P4: fourth proctodeal segment (colon); P5: fifth proctodeal segment (rectum).
On the other hand, all Neotropical apicotermitine genera and some Oriental genera (e.g., Euhamitermes Holmgren, 1912) have a similar looped P1 (Noirot, 2001; Fig. 10H, L). They differ from Cylindrotermes in having the left mandible with a conspicuous notch before the third marginal tooth, and the mesenteric tongue, when present, internal to the mesenteric arch.

**Hoplotermes**

Worker digestive tube (Figs. 9–11): Crop slightly asymmetrical, moderate in size, covered with finely pectinate scales (Fig. 9a, arrow). Gizzard with a complete armature arranged in a columnar belt with 24 folds (six first-order, six second-order, and 12 third-order) and a pulvillar belt with 12 folds (six first-order, six second-order). Length ratio between belts about one; pulvilli of first order ornamented with recognizable pectinate scales, pulvilli of second order inconspicuous (Fig. 9a). Stomodeal valve insertion slightly displaced to the inner region of the mesenteric arch (Fig. 10a). Mesenteron tubular, with a single well-developed mesenteric tongue of length nearly equal to half of the mesenteric arch, ending just at the beginning of the P1 dilated portion (Fig. 10d). It was not possible to examine the Malpighian tubules, since we had few specimens for dissection. P1 strongly dilated, its size nearly equal to the P3 (Fig. 10e, d and f), and attached to it by a narrow connection at the distal region of the abdomen, below the P5 (Fig. 10f, arrow); cuticular ornamentation of P1 with robust spines located around the border of the mesenteric tongue and just distal to it (Fig. 11a, b), and with sparse short spines laterally and distally (Fig. 11a, c). P2 with a single ring of three elongated cushions (Fig. 9b, arrows), weakly marked, radially arranged, and covered sparsely with small spines. P3 well developed, protruded through the mesenteric arch. Isthmus marked (Fig. 10b), P4 with a short U-turn (Fig. 10c).

Comparisons among recognized termite genera: *Hoplotermes*, some species of *Amitermes* (Sands, 1998, Figs. 609–628), *Genuotermes* Emerson, 1950, and most syntermitine genera (see Rocha et al., 2017) have a strongly inflated globose or fusiform P1 and similar cuticular ornamentation of the P2, with spines organized in distinct patterns (Rocha et al., 2017; Engel et al., 2009). *Hoplotermes* and some syntermitine genera have a similar distribution of spines in the P1 cuticular ornamentation (Rocha and Constantini, 2015), with the most robust spines concentrated in the proximal portion. No other American termite genera have this combination of morphological features.

**Discussion**

Noirot and Kovoor (1958) proposed two groups within Termi- nae, defined by the anatomy of the gut: the Thoracotermes and the Termes, based only on African taxa. Later, Noirot (2001), with a large number of specimens from different regions, distinguished five groups: the pantropical Termes group, the Oriental Pericapritermes group, the pantropical Amitermes group, the Ethiopian Cubitermes group [the Thoracotermes group of Noirot and Kovoor (1958)], and the African Foraminitermitinae group (hypothetical new sub-family). Engel et al. (2009) formally raised the last two groups to subfamily rank, the Cubitermitinae and Foraminitermitinae. These subfamilies were supported as natural clades in studies by Inward et al. (2007) and Bourguignon et al. (2017). Rocha et al. (2019) recognized in the American region, the Amitermes group, comprising the genera *Amitermes*, *Gnaithamitermes*, and *Hoplotermes*; the Cavitermes-Termes group, with the Cavitermes subgroup, comprising *Cavitermes* Emerson, 1925, *Cornicaptermes* Emerson, 1950, *Dihoplotermes* Araujo, 1961, *Divinotermes* Carrijo and Cancell, 2011, *Palmitermes* Hellemans and Roisin, 2017, and *Spinitermes* Wasmann, 1897, and the Termes subgroup, comprising *Inquilinitermes* Matthews, 1977, and *Termes*; the Neo- capritermes group, comprising *Neocapritermes* Holmgren, 1912, *Planicapritermes* Emerson, 1949 (in Snyder, 1949), and *Creptitermes* Emerson, 1925; and the Orthognathotermes group, comprising *Dentispicotermes* Emerson, 1949 (in Snyder, 1949) and *Orthognathotermes* Holmgren, 1910; while separating *Cylindrotermes*, *Genuotermes*, *Microcerotermes*, and *Onkotermes* as truly distinct genera.

The present study examined in detail the internal morphology of the worker caste of *Cylindrotermes* and *Hoplotermes*, complementing their original descriptions. Based on this new information, we consider that *Cylindrotermes* cannot be assigned to the Amitermes group (sensu Noirot, 2001). Evidence from the gut morphology supports *Cylindrotermes* as a relative of the Ethiopian genus *Cephalotermes*, a hypothesis previously advanced by Inward et al. (2007) and Bourguignon et al. (2017), in their phylogenetic reconstructions.

*Hoplotermes* has not yet been included in any evolutionary scheme, but based on our morphological observations, it may be related to the *Amidtermes–Drepanotermes* lineage. To overcome this limitation and to reach firm conclusions about the kinship of *Hoplotermes*, we strongly recommended that this termite genus be included in future phylogenetic analyses. Author contributions M.M.R. conceived the research and edited the figures; M.M.R. and C.C. collected and analyzed data and wrote the paper.
Conflicts of interest

The authors declare no conflicts of interest.

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