GROSS ANATOMY AND HISTOLOGY OF THE ALIMENTARY CANAL OF *Hierodula coarctata* SAUSSURE (MANTODEA: MANTIDAE)

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ABSTRACT

The present study entails the description of the anatomy and histology of the alimentary canal of praying mantis, *Hierodula coarctata* Saussure (Mantodea: Mantidae), a predatory insect. The alimentary canal was isolated, processed and analysed anatomically and histologically by using stereomicroscope and light microscope. The alimentary canal of *H. coarctata* is classically divisible into foregut, midgut, and hindgut. The foregut has the pharynx, oesophagus, crop and proventriculus which has histological layers intima, epithelium, basement membrane and outer muscularia. The midgut is short with eight gastric caeca anteriorly has a single layer of columnar epithelial cells show merocrine secretion and nidi cell groups at regular intervals lined by lamellate peritrophic membrane internally and muscular coat externally. The hindgut consists of the ileum, colon, and rectum with histological layers viz. intima, epithelium, and muscles. The results of the present investigation revealed that the alimentary tract of the carnivorous insect *H. coarctata* was structurally and functionally adapted to digest and absorb protein-rich diet.

Keywords: Anatomy, histology, digestive tract, *Hierodula coarctata*, mantis

ABSTRAK

Kajian ini memperihalkan ke atas anatomi dan histologi salur penghadaman spesies mentadak, *Hierodula coarctata* Saussure (Mantodea: Mantidae) iaitu spesies pemangsa ke atas serangga lain. Salur penghadaman dibedah, proses dan dianalisis anatominya dan histologinya menggunakan mikroskop stereo dan mikroskop cahaya. Salur penghadaman spesies *H. coarctata* dikelaskan dengan jelas kepada usus depan, tengah dan belakang. Usus depan mempunyai farinks, esofagus, tembolok dan proventikulus di mana mempunyai intima, epitelium, membran dasar dan maskular luar. Usus tengah adalah pendek dengan lapan sekum gastrik di bahagian anterior dengan mempunyai selapisan epitalium kolumnar yang menunjukkan rembesan merokrin, serta kumpulan sel nidi tersusun secara berselang-seli dilapisi dengan membran peritrofik berlamela di bahagian dalam dan lapisan otot dibahagian luar . Usus belakang mempunyai ileum, kolon dan rektum dengan lapisan histologinya iaitu intima, epitelium dan otot. Hasil kajian mendedahkan salur penghadaman ke atas spesies karnivor *H. coarctata* mempunyai struktur dan berfungsi beradaptasi untuk menghadam dan menyerap diet tinggi protein.

Kata kunci: Anatomi, histologi, salur pencernaan, *Hierodula coarctata,* mentadak

INTRODUCTION

The alimentary canal is concerned with the ingestion, digestion and absorption of food. The anatomical and histological studies allow discernment of histo and cytoarchitecture of the various components of the digestive system. Praying mantids are carnivorous insects with peculiar habits of prey capture, camouflage, and reproductive behaviour. They play a vital role in the natural control of insect pests, as predators, mainly feed on grasshoppers, crickets, moths, butterflies, flies, aphids etc. (Sureshan 2009) and some species are efficient predators of insect pests associated with crops or ornamental plants (Ambrose 2015). The praying mantis *Hierodula coarctata* Saussure (Mantodea: Mantidae) is a dark green with a yellow tinge insect first described by Sassure (1869) from Bengal (India). It is occurring in Oriental India and Australia (Giglio-Tos 1927) and Pakistan (Roonwal & Bhasin 1951). In India, it has been recorded from Andhra Pradesh (Rao et al. 2005), West Bengal (Sassure 1869), Maharashtra (Mukherjee & Ghate 2010) and Bihar and Uttar Pradesh (Yadav et al. 2018).

Considering the recent study of the anatomy and histology of the alimentary canal of mantids, it appears that only Mani (1982) mentions for the entire Mantodea order that 'alimentary canal usually straight, with a spacious crop, rudimentary proventriculus and eight enteric caeca'. Apart from this context, it is underlined that no anatomy or histology of the alimentary canal of any species of mantids has been studied. The anatomical and histological study of *H. coarctata*'s alimentary canal is being conducted for the first time and this study will be useful in the study of anatomy and histology of the entire mantid group. A review of the available literature confirms a gap in our understanding of the anatomy and histology of the praying mantis. Therefore, it is sought to address this lacuna by describing the anatomy and histology of the alimentary system in *H. coarctata*.

MATERIAL AND METHODS

Adult males and females of *H. coarctata* were collected *in situ* from the foliage of *Vachellia nilotica* (L.) in the Kolhapur, Maharashtra, India from January to March 2018, shifted to the laboratory and acclimatised. Species identity was confirmed following Mukherjee and Ghate (2010). Both male and female specimens were dissected in Insect Ringer solution under a Stereoscopic Dissecting Microscope (Model: Nikon SMZ 800). The alimentary canals were carefully excised and observations recorded. The various parts of the alimentary canal were fixed in Stieve's fixative for 24 hours, to minimise tissue degeneration and slow down rigour mortis changes. Post fixation tissues were treated with Tincture Iodine to wash off Mercuric Chloride crystals of Stieve's fixative. Gradual dehydration of tissue was carried out by immersing the samples for 30 minutes each in ascending grades of ethyl alcohol. Dehydrated tissues were transferred in a mixture of Paraffin Wax and Xylene for 30 minutes and then shifted to the oven set at a temperature of 58°C for another 30 minutes. Paraffin – Xylene wash was repeated thrice. The tissues were then embedded in pure Paraffin Wax (52-54^{0}C) and hardened blocks were trimmed to remove excess wax and ensure proper orientation of the embedded tissue. The wax embedded tissues were sectioned at 5-7 microns by using a microtome (Model: Erma, German). Sections were double-stained with Haematoxylene-Eosin following Humason (1962). Stained sections were observed under a compound microscope (Olympus ES 31) and requisite microphotography was carried out using a digital camera.

RESULTS

The alimentary canal of *H. coarctata* shows a typical digestive system of insect organization, though with some minor specializations and deviations. Characteristic features of the Orthopteran digestive canal i.e. straight alimentary canal with the muscular pharynx, long oesophagus, crop for food storage, proventriculus with the chitinous armature, midgut with gastric caeca and protective peritrophic membrane were evident.

a. Anatomical Observations

The alimentary canal of *H. coarctata* is a simple straight tube measuring about 62 mm and 53 mm long in the male and female respectively. This tube varies in lumenal diameter; starting from the mouth and ending with the anus. In the cephalic region, it is provided with well-developed musculature and tracheal branches. Three distinct divisions of the alimentary canal viz., foregut, midgut, and hindgut are demarcated by respective constrictions at the junctions (Figure 1A). The morphometric data of the alimentary canal in *H. coarctata* is presented in Table 1., which also shows the differences in the measurements of the alimentary canal between the male and female. Comparatively, the alimentary canal is longer in male (62 mm) than the female gut length (53 mm). Considering the relation between total body length and gut length, the alimentary canal is 1.19 times long in males while in females it is 0.96 long. The foregut is longer in male (45 mm) than female (32 mm). On the contrary, the hindgut is slightly longer in female (15 mm) than in male hindgut (12 mm). The midgut length in both the sexes is almost the same.

Table 1. Morphometry of alimentary canal in *Hierodula coarctata*

Specification	**Male (mm)**	**Female (mm)**
Foregut length	45	32
i. Pharynx	2.5	2.5
ii. Oesophagus	32	23
iii. Crop	9	5
iv. Proventriculus	1.5	1.5
Midgut length	5	6
(Gastric caeca length)	(2.5)	(2.5)
Hindgut length	12	15
i. Ileum	7	9
ii. Rectum	3	4
iii. Anal canal	2	2
Alimentary canal total length	62	53
Total body length	52	55
The relation between total body length and alimentary canal	1.19%	0.96%

The foregut is a long, narrow tube that runs from the oral opening in the head, thoracic division and extends up to the first five abdominal segments. It comprises the pharynx, oesophagus, crop, and proventriculus which may be distinguished externally. The pharynx (2.5 mm) extends from the mouth as a straight tube and is provided with muscle attachments that connect the pharynx with the head capsule. The oesophagus is a long, narrow tube measuring about 32 mm in male, whereas it is shorter in female at a length of 23 mm. The oesophagus progressively increases in diameter anteroposteriorly and is filled with air in some regions. Posteriorly just before the crop, it shows a thick-walled twist. The crop is a highly developed portion with a diameter of about 2 mm. It measures about 9 mm and 5 mm long in male and female respectively. The arrangement of muscle bands on the wall surrounding the crop can be externally discernible. The consolidation of longitudinal muscles is seen here (Figure 1B) on the crop wall which is also invested with the trachea. There is also a bunch of muscle fibres as a band on the ventral side. The proventriculus is small, circular and smaller than the crop. It joins the midgut cylindrically in the abdomen (Figure 1C) and measures about 1.5 mm long.

The midgut is the shortest region of the alimentary canal continuing from the proventriculus anteriorly and ileum posteriorly. It is a brown coloured, straight, anteriorly narrow and posteriorly wider cylindrical tube. The length of the midgut is more or less similar in both sexes (5- 6 mm). It appears to be segmented externally and more homogenous in structure than the other parts of the alimentary canal. It is surrounded by many Malpighian tubules at the posterior end and by eight gastric caecae anteriorly. The gastric caecae are outwardly extending brown, cylindrical tubes and supplied with a network of the trachea (Figure 1C). Their total length is 2.5 mm.

The hindgut is situated from the 7th abdominal segment to the abdominal tip. It is surrounded by tracheoles and connected to the last abdominal segment by the muscle bands. It is a straight tube that runs dorsal to the reproductive organs in the female and is arc-like in the configuration because of the underlying ovaries. The hindgut in the female is longer (15 mm) than its male (12 mm) counterpart due to the development of ovaries. It is divisible into two regions the ileum and rectum (Figure 1C). The ileum is a thin-walled, narrow tube measuring about 7 mm (male) and 9 mm (female), whereas the rectum is thick-walled, measuring about 3 mm (male) and 4 mm (female) and opens to the exterior as an anus through the anal canal (2 mm).

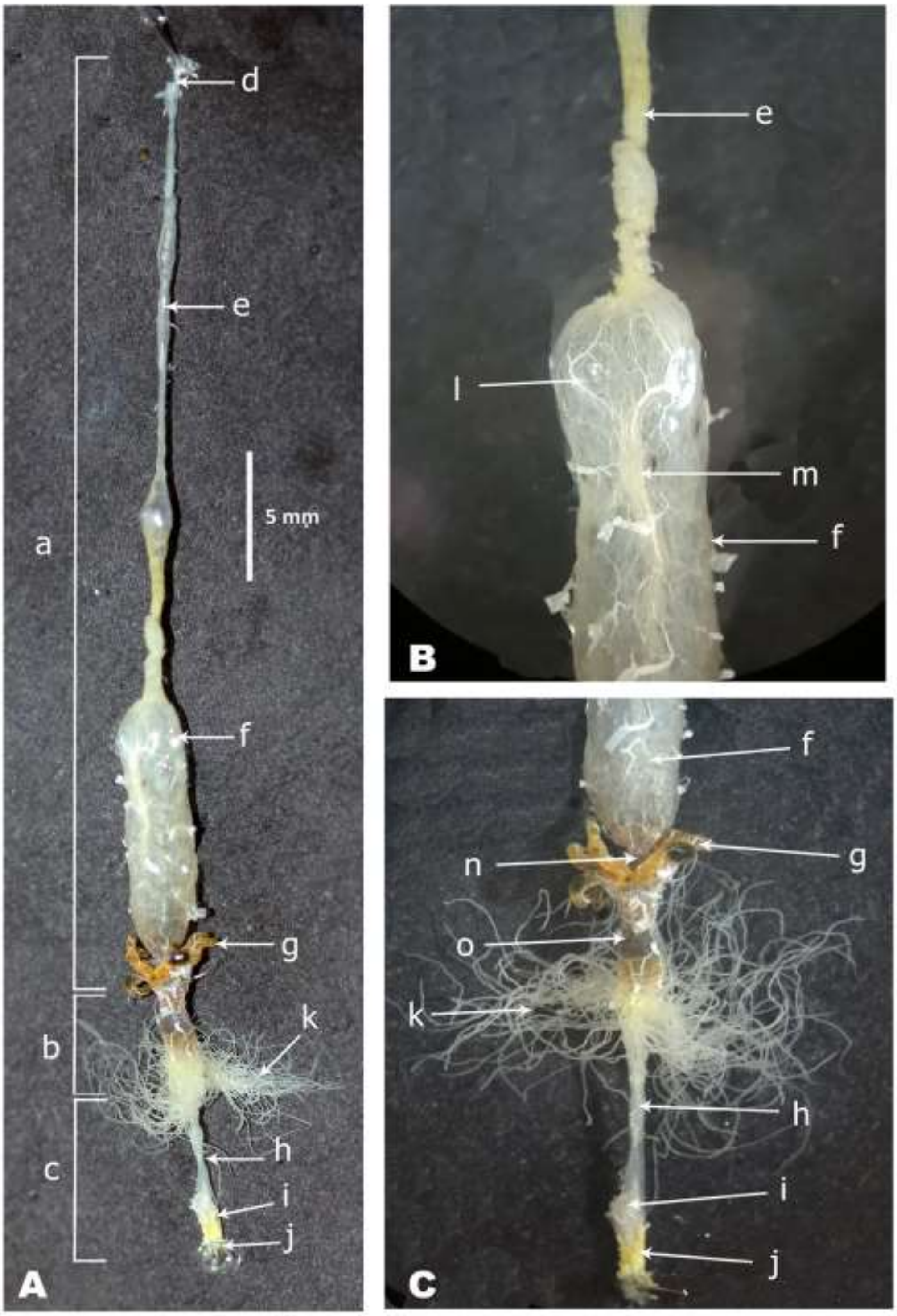

Figure 1. **A.** Dissected alimentary canal of *Hierodula coarctata*. Note the foregut *(a)* midgut *(b)*, hindgut *(c)*, pharynx *(d)*, oesophagus *(e)*, crop *(f)*, hepatic caecae *(g)*, ileum *(h)*, rectum *(i)*, anal canal *(j)* and Malpighian tubules *(k)*. **B.** Magnified portion of oesophagus and crop showing muscular oesophagus *(e)*, crop *(f)*, trachea *(l)* and longitudinal muscle bundles *(m)*. **C.** Magnified part of the posterior alimentary canal. Note the crop *(f)*, hepatic caecae *(g)*, proventriculus *(n)*, ileum *(h)*, rectum *(i)* anal canal *(j)*, Malpighian tubules *(k)* and ventriculus (*o)*

b. Histological Observations

Since the histology of the alimentary canal of males and females is similar, the histology given below is of the alimentary canal of both male and female. The histological observations on the three divisions of the alimentary canal, i.e. foregut, midgut, and hindgut generally shows the outer muscular layer and inner epithelium which is lined by intima in the foregut and hindgut while the midgut lacks intimal lining.

Histologically, the foregut shows the following layers from inside-out, namely: intima, epithelium, basement membrane, and musculature. The connective tissue is very thin surrounding the entire alimentary canal. The epithelium of the pharynx is well developed with cuboidal as well as columnar epithelial cells with centrally placed nuclei. The intimal lining of the epithelium is well developed, thick and show irregular folds. The muscular sheath of the pharynx consists of highly developed circular muscles and a few scattered longitudinal muscles (Figure 2A). The histological observations on the proximal and distal region of the oesophagus show many differences. The epithelium of the proximal oesophagus is syncytial with prominent nuclei (Figure 2B) whereas the distal oesophagus shows well developed cuboidal epithelium with prominent central nuclei (Figure 2C). The entire epithelium of the oesophagus is thrown into irregular longitudinal folds lined with wavy intima in the proximal region and thin, smooth intima in the distal regions of the oesophagus. The outer circular muscles are poorly developed than the pharyngeal circular muscles and the inner longitudinal muscles tend to group in the space of epithelial folds (Figure 2B, C). The crop is highly developed shows numerous longitudinal folds of the epithelium showing cuboidal epithelial cells with central prominent nuclei. The intimal lining in the crop is quite different from the intimal lining in the pharynx and oesophagus as it is well developed thick and sharply toothed. The muscular layer shows well developed outer circular muscles and inner grouped longitudinal muscle bundles prominently in the mid-dorsal region of a crop (Figure 2D). The proventriculus is significantly developed and highly sclerotized and muscular shows a thick layer of circular muscles fibres and few scattered longitudinal muscle fibres. The proventricular epithelium is made up of cuboidal epithelial cells based on the distinct basement membrane and lined with well-developed intima. The epithelium along with the intima shows typical hexaradiate symmetry with six longitudinal folds exhibiting sclerotization in the form of the spiny intima. The intima of the anterior region of the proventriculus is thick and spineless; whereas the posterior region of the proventriculus has spiny and comparatively thin intima (Figure 2E). The dominant feature in the proventriculus is the development of the intima into prominent denticulate teeth and the increased thickness of its muscles.

Innermost peritrophic membrane. The epithelium consists of single-layer columnar epithelial cells and Nidi cells supported by a distinct basement membrane. The epithelial cells are tall, columnar with basal prominent nuclei and granular cytoplasm. The epithelial lining shows merocrine secretion, as seen from the globules of secreted material apically on the cells. The regenerative cells with distinct nuclei lie at the bases of functional epithelial cells in the groups at a regular interval (Figure 2F). Muscularis is juxtaposed to the basement membrane and is weakly developed as compared to that of the foregut. The muscularis consists of a thin layer of circular muscles surrounding the basement membrane and outer longitudinal scattered muscles in the form of bundles. A well developed lamellar peritrophic membrane is present throughout the midgut. It is formed of three to four lamellae (Figure 2F,f). The gastric caecae consists of an outer thin layer of circular muscles and a single layer of epithelium. The epithelial cells are tall columnar with basal nuclei and granular cytoplasm with indistinct boundaries. The entire circlet of gastric caecae is filled with merocrine

secretion in the form of secretory globules in the lumen (Figure 2J). The midgut differs from the foregut in its thicker wall; spongy, thick epithelium; absence of intima and presence of peritrophic membrane, and in the reversed arrangement of the weak fibres in the muscularis.
The histology of the hindgut concerning the cellular arrangement is similar to the histology of the foregut. The epithelium of the ileum is well-developed, highly folded and lined with a thin and smooth layer of the intima. The epithelial cells are cuboidal with centrally placed large, oval, prominent nuclei and rest on the distinct basement membrane. The muscularis consists of a single layer of circular muscle fibres and a few strands of longitudinal muscle fibres (Figure 2G). The rectum shows a thin layer of circular muscles, a few strands of longitudinal muscle fibres and syncytial epithelium-lined with a thin intima. The development of the epithelium is seen only in the dorsal part of the rectum, which forms two dorsolaterally placed rectal pads consisting of syncytial epithelium cells lined with a thin intimal border (Figure 2H). The anal canal is a comparatively thick-walled tube consisting of well-developed muscularis, irregularly much-folded epithelium, and intima. There are several layers of thick, well developed circular muscle fibres surrounding the anal canal and outside of the thin layer closely packed few longitudinal muscle bunches are placed. The intimal lining is well developed and it is separated from the epithelial border, not intimate with the epithelium (Figure 2I).

The longitudinal section of the foregut–midgut junction shows the strong stomodeal valve. It is an everted portion of the posterior end of the foregut wall projecting into the midgut nearly closing the passage between the foregut and midgut. The internal lining of the foregut is very thick towards the proventriculus, but gets gradually thinner passing through the mesenteron and finally disappearing. The epithelium of the stomodaeal valve is cuboidal, then became slightly columnar and elongate, and changes to the epithelium of the mesenteron (Figure 3A). The longitudinal section of the midgut-hindgut junction shows a poorly developed ventricular valve (pyloric valve). This valve lies just anterior to the attachment of Malpighian tubules, indicating that hindgut begins at the pyloric valve. The epithelium of the pyloric valve is cuboidal and lined with a layer of the intima. The musculature of the pyloric valve is not much developed (Figure 3B).

At the junction of the midgut and hindgut just next to the pyloric valve, numerous bundles of Malpighian tubules constitute the basic nephridial excretory system. Histologically, each Malpighian tubule composed of a single layer of epithelium showing 4-5 cuboidal epithelial cells in cross-section. The cells contain large centrally placed oval nuclei with granular cytoplasm. The circular muscles, basement membrane, and intima are indistinct (Figure 3B).

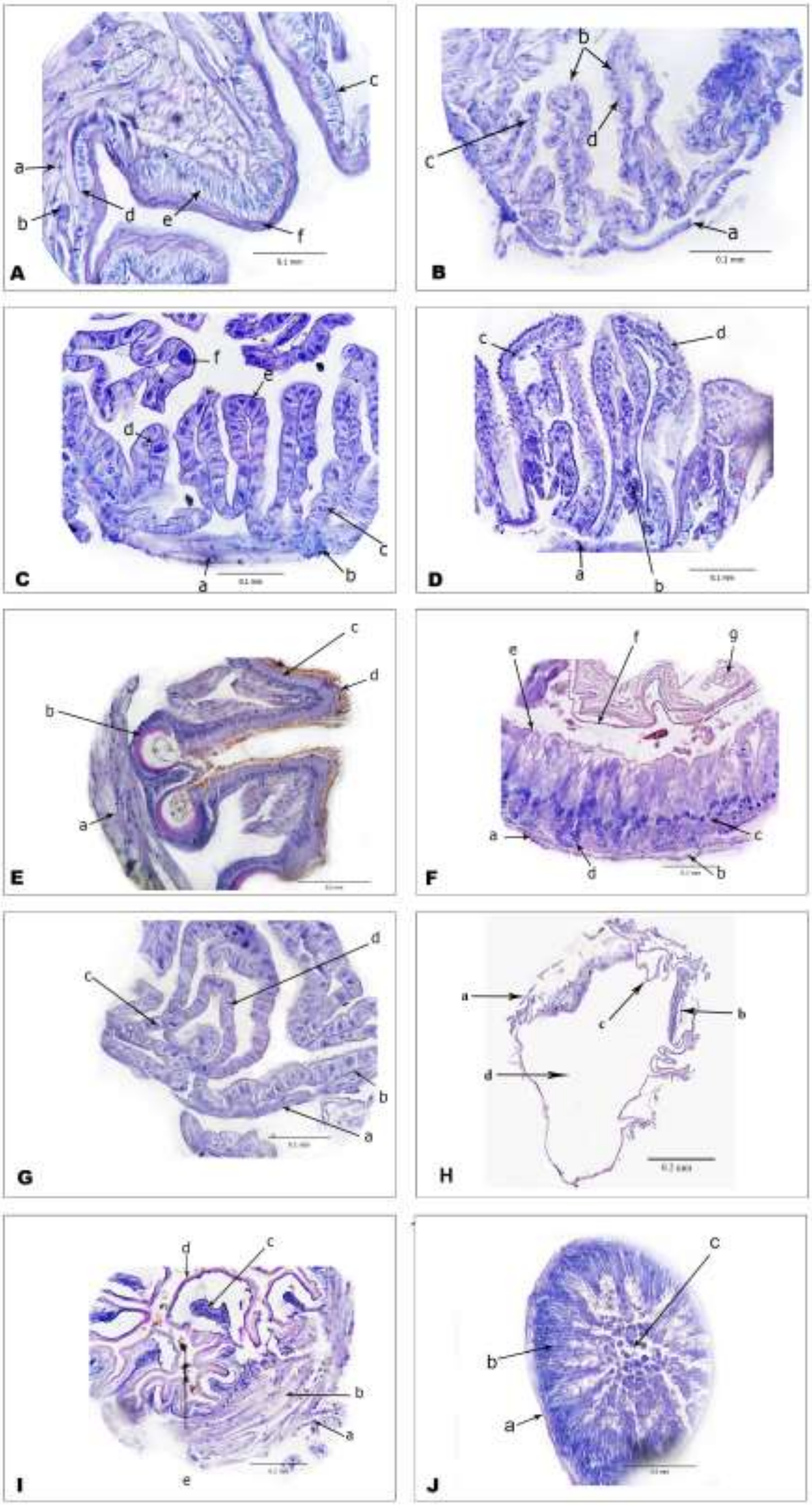

Figure 2. **A.** Cross-section through the Pharynx (100X) showing circular muscles *(a)*, longitudinal muscles *(b)*, basement membrane *(c)*, cuboidal *(d)*, columnar epithelium *(e)* and intima *(f)*. **B.** Cross section through the proximal oesophagus (100X). Note the circular muscles *(a)*, irregularly folded epithelium *(b)*, syncytial epithelium containing prominent nuclei *(c)*, and wavy intimal lining *(d)*. **C.**

Transverse section of the distal oesophagus (400X). Note the circular muscle layer *(a)*, longitudinal muscles *(b)*, basement membrane *(c)*, folded cuboidal epithelium with prominent central nuclei *(d)*, a thin lining of intima *(e)*, and cuboidal epithelial cell with polyploidy nucleus *(f)*. **D.** Cross-section of the crop (400X). Note the circular muscle layer *(a)*, longitudinal muscles *(b)*, cuboidal epithelium with central nuclei *(c)* and toothed intimal lining *(d)*. **E.** T.S. of the proventriculus (400X) showing thick circular muscle layer *(a)*, basement membrane *(b)*, epithelial lining with basal nuclei *(c)* and proventricular teeth with spiny intima *(d)*. **F.** T.S. of the midgut (400X). Note the longitudinal muscles *(a)*, circular muscle layer *(b)*, columnar epithelium with basal nuclei *(c)*, nidi cells *(d)*, merocrine secretion *(e)*, multilayered peritrophic membrane *(f)* and gut content *(g)*. **G.** Cross section through ileum (400X) showing circular muscle layer *(a)*, basement membrane *(b)*, cuboidal epithelium with prominent central nuclei *(c)* and thin intimal lining *(d)*. **H.** Cross section through the rectum (100X) showing well developed circular muscle layer *(a)*, syncytial epithelial rectal pad *(b)*, thin intimal lining *(c)* and lumen *(d)*. **I.** T.S. of the anal canal (400X). Note the longitudinal muscle bundles *(a)*, a thick layer of circular muscle bundles *(b)*, irregularly folded epithelium *(c)*, the irregular lining of intima *(d)* and gut content *(e)*. **J.** Cross-section through gastric caecum (400X) showing circular muscle layer *(a)*, well developed secretory columnar epithelium *(b)* and lumen with secretory globules *(c)*.

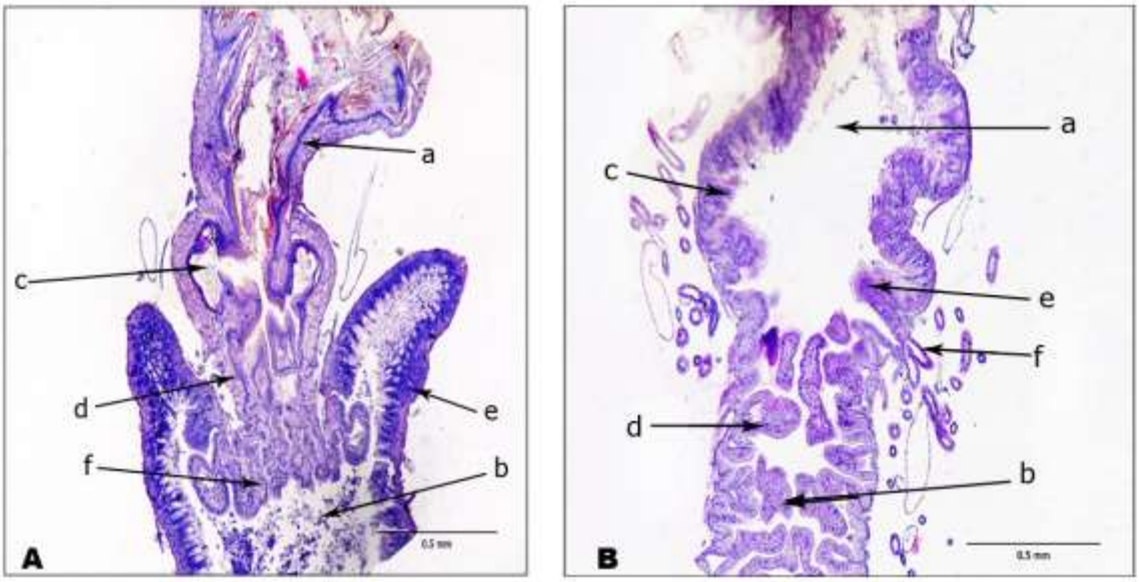

Figure 3. A. L.S. through foregut and midgut junction (100X). Note the posterior foregut *(a)*, anterior midgut *(b)*, proventriculus *(c)*, foregut wall *(d)*, wall of gastric caecum *(e)* and stomodaeal valve *(f)*. **B.** L.S. through midgut and hindgut junction (100X). Note the posterior midgut *(a)*, anterior hindgut *(b)*, midgut wall *(c)*, ileum wall *(d)*, ventricular valve *(e)* and Malpighian tubular openings at the junction *(f)*

DISCUSSION

Insects are the most dominant creature in the world, with each species having a different external and internal structure. Considering the structure of insects, it appears that the external structure of insects is being studied mainly through morphotoxanomy, but when considering their anatomy and histology, very few references to such studies are found. There are some references to such works in recent times e.g. Omotoso and Adedire (2010) studied gross anatomy and histology of the alimentary system of the African Palm Weevil larva, *Rhynchophorus phoenicis*, Gaikwad et al. (2011) studied the anatomy and histology of the alimentary canal of butterfly *Papilio polytes polytes* and Harris et al. (2019) studied the gross anatomy and histology of the alimentary canal of Stick insect *Pylaemenes mitratus*. In Lacewing *Ceraeochrysa cuban* an insect feeder, Vacacela et al. (2017) reported that the alimentary canal consists of foregut (short pharynx, long narrow oesophagus, crop and proventriculus), midgut (enlarged tube with constant diameter) and hindgut (pylorus, ileum and enlarged rectum with rectal pads). The results obtained in the *H. coarctata* are in accordance with the observations made by Vacacela et al. (2017) and Harris et al. (2019) found that the anatomically alimentary canal has three distinct parts viz. foregut, midgut and hindgut and histologically, the innermost layer of the foregut and hindgut is the intima, and the entire gut has an externally circular and longitudinal muscle coat.

Insects feed on a variety of diets and their digestive tract is developed accordingly. Therefore, it is very important to study the morphology and histology of the digestive tract of insects according to their diet. This work is aimed at providing seminal information on gross anatomy and histology of the alimentary canal of *H. coarctata*. Imms (1963), contends that a longer digestive tract is found in insects that feed on liquids, rather than the more solid foods. The gut length is short in carnivorous insects where digestion and absorption occur relatively rapidly, and longer (often convoluted) in phytophagous insects (Gillot 1980). The species under study is carnivorous, showing straight and short gut length which are in agreement with the views of Imms (1963) and Gillot (1980). Generally, the protein content of the diet determines the length of the gut and in particular the midgut, the relation being reciprocal, i.e. higher the protein contents shorter the gut and vice versa. The reason for this variation in gut length is that the diet of the carnivorous animals is protein-rich which is relatively easy to digest while the diet of the herbivorous animals is a plant-based food that is high in cellulose which takes a longer time to digest. The present study shows a short midgut of carnivores *H. coarctata* and supports the above statement. A shorter alimentary canal of carnivorous species has also been confirmed by Pradhan (1939). Sakurai (1968) studied the physiological natures of the digestion between four entomophagous and two phytophagous coccinellid beetles and found that the ratio of total alimentary canal length to the body length in phytophagous coccinellids is about twice as large as that of entomophagous ones (slightly longer gut length than body length). A longer digestive tract is found in the phytophagous and liquid feeding insects than carnivorous and solid feeding insects (Gillot 1980; Imms 1963). In some insects, the digestive gut is very long as compared to their body length such as eight-time longer in *Phanaeus vindex* (Bection 1930) and two times longer in *Platynotus belli* (Sarwade & Bhawane 2013). The above examples are non-carnivorous insects and because of this, the gut is much longer than their body length. As *H. coarctata* is a carnivorous insect, its gut is not much longer than the body length. However, in males of this species, the alimentary tract is longer than the female alimentary tract and is 1.19 times longer than the body length. It is not understood why the male alimentary canal of this species is longer than the female alimentary canal but it needs to be researched in detail. However, it seems that the male's foregut may be long enough to increase his food storage capacity in the crop, as the crop is formed by dilating the hinder portion of the oesophagus and food is stored in it. This will make him strong for mating with the female because in mantids, the female mate with selective males and after mating, she eats him (Mukherjee et al. 1995). The female hindgut of the same species is longer than the male hindgut because the female's abdomen contains fully developed ovaries. So the hindgut has to bend to the dorsal side of the ovaries. Wan et al. (2015) reported that the foregut is the longest section in *Phobaeticus serratipes* similar to the foregut in *H. coarctata* while its hindgut is the shortest part which is in contrast to long hindgut and short midgut in *H. coaarcta* due to difference in diet.

The pharynx leads to the oesophagus which is generally enlarged to form a storage chamber, crop (Triplehorn & Johnson 2005) and in insects that ingest solid food; the proventriculus serves as a grinding organ (Ambrose 2015). This study found a highly developed crop portion for storage of food followed by proventriculus as it feeds on live insects. In many insects crop is present and is a dilatation of the hinder portion of the oesophagus which is extremely variable in form and functions as a food reservoir. It is very capacious and constitutes the major portion of the foregut in *Periplaneta* and Orthoptera (Imms 1963). According to Gullan and Cranston (2010), the food may be available only intermittently (such as when a predator captures prey e.g. praying mantis), in these insects the gut has a large storage capacity. Considering the above, the species *H. coarctata* is very close to *Periplaneta* and Orthoptera in which the crop is large. At the same time, this species does not always get food, it only gets food when it has to wait a long time to catch prey. In such cases, the crop needs to be large for storage so that digestion of stored food can be done slowly. Therefore, in this species, the oesophagus is elongated, and as food continues to enter the alimentary canal, the hinder portion of the oesophagus expands, increasing the size of the crop and increasing its storage capacity. Anteriorly, the wall of the foregut projects into the lumen of the midgut lumen and forms a stomodael valve which prevents regurgitation of gut content from midgut to foregut. Blind pouches (gastric caecae) are known to occur at the anterior end of the midgut (ventriculus) surrounding the stomodeal valve which serves to increase the available surface area for enzyme secretion and absorption of digested food (Gillot 1980). The number of gastric caeca is, in gryllids and some dipterous larvae- two; in Acrididae (grasshoppers)- six, in Blattodea and larval Culicidae- eight, and in some Coleoptera and Heteroptera- large numbers (Chapman 1998). Harris et al. (2019) reported seven gastric caecae in the midgut of *P. mitratus* contains. Similarly, eight gastric caecae were observed at the anterior end of the midgut surrounding the stomodeal valve in the species under study supporting the observations made by Van Gehunchten (1890) who describes a circle of eight small diverticula near the anterior end of the ventriculus. The difference in the number of gastric caeca may be due to the length of the midgut, so insects with short midgut have more gastric caeca and those with relatively long midgut have lower gastric caeca numbers. According to Chapman (1998), the hindgut is differentiated into the pylorus, ileum and rectum. However, the ileum may be undifferentiated from the colon, as in the case of many Orthoptera (Snodgrass 1935) such as the anterior ileum and enlarged posterior rectum found in the hindgut of *H. coarctata*. The pharynx of the species under study has well-developed musculature and intima; as the diet of the species under study is live insects having an exoskeleton. The development of strong muscles and intima possibly helps to break and push the food in a forward direction after ingestion. Our observations on the crop are in agreement with Snodgrass (1935), that the intima of the crop is thick, the epithelium flat, and the walls of the crop, when not stretched by food content, are thrown into numerous lengthwise folds. According to Gillot (1980) in some species, the intima of the crop forms spine or ridges which probably aid in breaking up the solid food into smaller particles and mixing in the digestive fluid. The development of such intimal denticles and highly folded epithelium indicate the churning of solid food inside the crop. The gizzard or proventriculus is situated behind the crop and is best developed in the orthopteroid orders has also been established by Judd (1948). It has been reported as a food grinding and filtering organ with strongly sclerotized denticles as in some Orthoptera (Fontanetti et al. 2002; Snodgrass 1935; Szinwelski et al. 2009). The inner wall of the proventriculus is armed with strong cuticular plates or teeth, in congruence with the observation made by Mani (1982). A similar architecture of the proventriculus is found in the *H. coarctata* which crush the food and allow fine particles to the midgut. The anterior region of proventriculus shows the presence of thick cuticular plates contrasting with the spiny intimal lining of the posterior region indicating filtration of food allowing only fine ground food to the midgut. These observations are following Gillot (1980) who stated that the proventriculus contains spines that offer a filter mechanism to screen the solid material. Snodgrass (1935) described the proventriculus of *Blatta orientalis* and mentioned six rows of overlapping teeth formed by an inner wall as in the *H.corctata* the epithelium along with intima shows hexa-radiate symmetry forming six longitudinal folds. According to Gillot (1980), where the proventriculus acts like a gizzard, grinding up food; the intima is formed into strong, radially arranged teeth and a thick layer of circular muscles cover the entire structure.

The midgut epithelium of the species studied consisted of tall columnar epithelial cells and groups of regenerative cells at the bases of columnar cells. In *Melanophita picta decastigma,* the midgut epithelium is monolayered had medially located nuclei with striated border apically (Kocakoglu et al. 2012). The columnar and regenerative cells are at times actively involved in the secretion of enzymes and absorption of digested food. In most insects, the midgut contains principal, goblet, regenerative (nidi) and endocrine cells (Chapman 1998). Goblet cells are found only in the midgut of some insects like Ephemeroptera and Lepidoptera (Happ 1984). The midgut cell types, principal (columnar) and nidi cells were found in *H. coarctata*, similar to earlier reports for other Orthopteran insects (Biagio et al. 2009; Cakici & Ergen 2012; Marana et al. 1997;). The epithelium of the midgut shows features of merocrine secretion as evident from the apical borders of the secretory columnar epithelial cells having secretory vesicles carrying their contents into the gut (Chapman 1998). Van Gehunchten (1890) and Sarwade and Bhawane (2013) reported secretory vesicle on the free border of the midgut epithelium in *Phychoptera contaminate* and *P. belli* respectively. The findings of the present study i.e. presence of secretory globules on the midgut cells apically, strongly support the above observations. Monteiro et al. (2014) reported merocrine secretion in the anterior midgut and microapocrine secretion in the posterior midgut of *Cladomorphus phyllinus* (midgut is divided into anterior, middle and posterior midgut) which supports the merocrine secretion in the midgut of species under study. The goblet cells reportedly scattered amongst the columnar cells as reported by Chapman (1998) were not observed in the epithelium of the midgut of the investigated species. As mentioned by Gullan and Cranston (2010) the midgut shows a 3-4 layered peritrophic membrane throughout the midgut length covering the gut content in the species under study. Tembhare (1997) has opined that the peritrophic membrane large number of successive concentric lamellae throughout the length of the midgut. According to Chapman (1998) peritrophic envelope prevents the food particles from coming into contact with the microvilli of the midgut cells, perhaps avoiding damage to the cells in insects eating solid food. The species *H. coarctata* is strictly carnivorous and its food consists mainly of different insects. Insects have a hard exoskeleton and when such food reaches the midgut, the hard particles of this food can injure the midgut cells because the midgut does not have an intima as containing foregut and hindgut. A multi-layered lamellated peritrophic envelope is found in the midgut of this species to prevent such injury to midgut epithelial cells. In Orthoptera, Blattodea, larval Hymenoptera and Lepidoptera, and adult Nematocera, the peritrophic laminae are produced by the whole midgut epithelium (Chapman 1998). In many insects, the surface area of the midgut is increased by the development of sac-like diverticula, usually, at the anterior end called the enteric or gastric caeca. The midgut is usually not differentiated into structurally distinct regions apart from the development, the anterior end of the midgut has a varied number of blind endic caeca and they increase the surface area available for enzyme secretion and absorbed digested material (Gillot 1980). Harris et al. (2019) observed that the midgut of *P. mitratus* contains seven gastric caeca and histologically contains pseudostratified columnar epithelial cells. According to Li et al. (2018), the general organization of the gastric caeca is similar to that of the ventriculus in the Orthopteran insect *Gamposcleis gratiosa.* In the species under study, it has been observed that the histology and secretory pattern of gastric caeca are similar to the histology of the midgut except for peritrophic membrane which is absent in it. This proves that due to the small size of the midgut in *H. coarctata*, gastric ceaca are formed to increase the absorbable surface area and their function is only to secrete enzyme and not to absorb digested material as it does not have a peritrophic envelope.

The hindgut consists of the same layers as the foregut except that circular muscles is developed to a varying degree. In the species under study, the epithelium of ileum is cuboidal and thrown into several irregular folds along with the thin intima and the rectum shows two dorsolateral rectal pads made up of syncytial epithelial cells with thin intimal lining. These observations are more or less similar to the observations made by Snodgrass (1935), Chapman (1998) and Triplehorn and Johnson (2005). The hindgut of *P. belli* (Sarwade & Bhawane 2013) and *P. mitratus* (Harris et al. 2019) consists of chitinous intima, cuboidal epithelium, inner longitudinal muscles and outer circular muscles. A similar architecture of the hindgut is found in the hindgut of *H. coarcta* except for the epithelium of the rectum which is syncytial. Similar to *H. coarctata,* Aldigail et al. (2013) in *Epilachna chrysomelina* observed that the epithelium of the ileum is folded with a thin intima on the inside and the epithelium is made up of cuboidal cells. The rectal pads are known to exist in representatives of Plecoptera, Odonata, Orthoptera, Neuroptera, Trichoptera, Lepidoptera, Mecoptera and Hymenoptera (Snodgrasss 1935). The rectal pads are composed of three different cell types: epithelial, secondary and junctional cells in *Schistocerca gragaria* (Jarial 1992) and large cuboidal cells in *P.belli* (Sarwade & Bhawane 2013). However, the rectal pads in the *H. coarctata* are composed of syncytial epithelium. The rectal epithelium thickens in the insect to form rectal pads and their function is to absorb ions, water and small organic molecules from faecal matter (Gullan & Cranston 2010; Wigglesworth 1932). However, according to Snodgrass (1935), the function of rectal pads is not known. The diet of the species under study is insects that are deficient in water and they do not get abundant food. Therefore, it is essential to absorb the essential elements and water from the available food, which seems to have created rectal pads.

The junction of the foregut and midgut is marked by the abrupt transition in the cells of the epithelial layer; from fine cuboidal, shorter to the tall columnar type characteristic of the entire mesenteron. The wall of the proventriculus (foregut) projects into the lumen of the ventriculus and forms a stomodaeal valve in *H. coarctata* as mentioned by Mani (1982). The oesophageal invagination into the midgut is often referred to as the oesophageal valve or stomodaeal valve, which prevents regurgitation from the midgut to the foregut (Wigglesworth 1972). However, the stomodael valve in the present investigation is composed of both foregut and midgut tissues and this arrangement is in agreement with the observations made by Ambrose (2015). At the junction of the midgut and hindgut, the epithelium of the posterior midgut becomes elongated into the circular fold and forms a ventricular valve (pyloric valve) in *H. coarctata*. A similar arrangement has been reported by Fletcher (1930) in *Phyllophaga gracilus.* According to Snodgrass (1935) in some insects, a small internal circular fold from the posterior margin of the mesenteric epithelium projects into the hindgut, forming a ventricular valve while in others an apparatus for closing the entrance into the hindgut is developed in the pyloric region of the anterior end of the proctodaeum and constitutes a proctodaeal valve. However, in the present species, the ventricular valve is evident, though not the proctodaeal valve.

CONCLUSION

The present study based on anatomy and histology of the digestive system contributes to understanding the changes in the alimentary canal according to the eating habits of insects and the nature of their diet. The alimentary canal consists of the long foregut, short midgut, and hindgut, and histologically contains the epithelium (internally lined by chitinous intima in foregut and hindgut while in midgut lined by the peritrophic membrane) and muscular layers. Being a predatory insect, the alimentary canal of *H. coarctata* is short, especially the midgut region, indicative of its carnivorous food habits and ability to digest and absorb a protein-rich diet. Studies on the anatomy and histology of the alimentary canal are more common in phytophagous insects than in carnivorous insects, and no such study has been performed in mantids. This is the first study to provide information about the alimentary canal of a species in the mantid group. The present study will complement and add to the existing knowledge of the alimentary canal of predatory insects and will be useful for further work.

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