

Melanization of the alimentary tract in lizardfishes (Teleostei, Aulopiformes, Synodontidae)

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Abstract Investigating the alimentary tract in several species of lizardfishes (Synodontidae, Teleostei) of the genera *Saurida*, *Synodus* and *Trachinocephalus*, from various sites of their distribution, revealed melanization of the tract wall. This phenomenon was observed in several species of the genus *Saurida*, but not in the other two genera. This melanization is caused by layers of melanosomes rich in melanin granules and deposited within the connective tissue of the *submucosa*, between the muscular wall and the *muscularis submucosa*. From this site this black *submucosa* extends into the folds of the mucosa. In *S. tumbil* and *S. filamentosa*, the entire alimentary tract is black, whereas in *S. macrolepis* only the stomach is partially

or entirely black. This phenomenon and its possible importance are discussed.

Keywords Lizardfishes · Alimentary tract · *Saurida* · Submucosal melanization

In numerous species of bony fish, the peritoneal mesothelium that envelopes the alimentary tract (*serosa*) is rich in melanocytes and melanosomes, which are laden with dark pigment granules that consequently blacken the exterior of the gut. However, the formation of a melanized layer within the intestinal wall of fishes is a rare phenomenon, described until now in moray eels (Böhlke 1989; Fishelson 1994), cardinal fishes (Fishelson et al. 1997), some Antarctic Nothoteniids (Eastman and DeVries 1997) and in the scalloped ribbonfish, *Zu cristatus* (Bottaro et al. 2005). It was suggested (Fishelson 1994; Fishelson et al. 1997) that this dark cover within the gut shields the light of possibly bioluminescent food items hunted and engulf by these night-active predators. In close related and shallow-water species such melanization was not observed.

The present study compares the morphology and melanization of the alimentary tract in lizardfishes (Synodontidae) of the order Aulopiformes (Euteleostei), focusing on a group of species belonging to three major genera of the family: *Saurida*, *Synodus* and *Trachinocephalus* (Table 1). The lizardfish studied reach up to

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Table 1 Data on the studied lizardfishes and their alimentary tracts (lengths in mm)

Species	Origin	No. of specimens	SL	Stomach length	Stomach color	Intestine color
<i>Saurida macrolepis</i> (Tanaka, 1917)	RS, EM	20	45–320	20–85	pale	pale
<i>Saurida macrolepis</i>	EM	4 ^a	80–287	40–120	partly black	pale
<i>Saurida argentea</i> (Macleay, 1881)	AU (GBR)	2	182,230	40, 70	pale	pale
<i>Saurida filamentosa</i> Ogilby, 1910	AU (GBR)	3	180–210	75–100	black	black
<i>Saurida undosquamis</i> (Richardson, 1848)	AU (GBR)	2	325,360	96,110	pale	pale
<i>Saurida tumbil</i> (Bloch, 1975)	SRS, SA, GA	10	35–470	25–125	black	black ^c
<i>Saurida gracilis</i> (Quoy & Gaimard, 1924)	Taiwan	5	128–109	60–65	black	pale
<i>Synodus ariegates</i> (Lacepede, 1803)	GA, RS, SA	12	60–145	42–60	pale	pale
<i>Synodus kaianus</i> (Günther, 1880)	Hawaii	2	110,120	70–78	pale ^b	pale
<i>Synodus saurus</i> (L., 1758)	MS	4	110–165	68–72	pale	pale
<i>Trachinocephalus myops</i> (Forster, 1801)	GA	10	86–115	30–36	pale	pale

AU Australia; GBR Great Barrier Reef; RS northern Red Sea; SRS southern Red Sea; SA South Africa; GA Gulf of Aqaba; EM East Mediterranean; SL standard length (in mm);^a, 60–100 m deep; ^b, peritoneum black; ^c, in some fish of this species the intestine is pale, collections

600 mm standard length (SL), are epi-benthic, and predominantly found in the tropical and subtropical marine littoral and on the continental shelves of the Indo-Pacific and Atlantic, though some species, like *Saurida undosquamis*, have expanded into the cooler waters of the Mediterranean (Golani 1993). The bathymetric range of some species extends from the shallow waters to about 800 m deep. Sections of the gut disclosed that all are mainly piscivorous, feeding on a variety of fish (small groupers, anchovy, sardines, sparids, smaller lizardfishes and ophiichthids), but feed also on crustaceans and cephalopods.

The studied lizardfishes were collected along the Israeli part of the Eastern Mediterranean, the Red Sea, and off the Great Barrier Reef (GBR) of Australia. Specimens well preserved in ethanol were also donated by various museums (Table 1); such preservation does not affect the melanization found in the body (Fishelson, personal observations). Freshly collected fishes were preserved on ice until processing. Following the removal of food items, the guts was dissected out and fixed in 3.5% glutaraldehyde+1% formaldehyde for electron microscopy (EM), and in Bouins solution for light microscopy (LM) (More about the methods see Fishelson et al. (2010a, b)).

In all the studied species, the esophagus is short and wide, opening at its distal end into the cardiac part of the stomach, adjacent to the opening of the pyloric part of the intestine bearing the ceca (Fig. 1a, b). The

stomach (ST) is fusiform with thick walls. Its length differs among the species, and in general increases with increase in fish length. In adult specimens the empty stomach is 6.0–8.0 mm thick externally at the apical part, widening to about 10.0 mm in the middle, and narrowing to 2.0–3.0 mm at the tapering caudal end (Fig. 1a). The stomach wall is strong, enveloped by a delicate *serosa*, and mainly formed by a 350–500 µm thick *muscularis* consisting of smooth muscle fibers. The *submucosa*, rich in blood capillaries, is formed by a wide outer layer of collagen fibers and a more inner layer of loose connective tissue rich in elastic fibers. Adjacent to the mucosal epithelium is the delicate ring of *muscularis submucosa*, located adjacent to the *lamina propria* (Fig. 1b, c). The distal, tapered (“vermiform”) part of the stomach is partly separated by a muscular sphincter from the main stomach. The wall of this part is very strong, especially toward the apex, and its inner folds are lined by a mucosal epithelium prominent in dense and elongated villi. The present study complements the more general study of the alimentary tract of lizardfishes by Fishelson et al. (2011).

The black appearance of the alimentary tract was observed in several species of the genus *Saurida* (Table 1); collected by us and by colleagues (Tables 2 and 3). Dark parts of stomachs in some lizardfishes were also noted by Dutt and Vidya Sagar (1981). This phenomenon was found here to be most prominent in

Fig. 1 The black gut of *Saurida tumbil*. **a**, Total length of the gut; **b**, Cross-section of the stomach at the pylorus, SEM; **c**, ibid in the mid-stomach; gb, gall-bladder; i, intestine; l, lumen of the stomach; li, liver; mc, melanized caeca; mv, folds of mucosa; po, opening of pylorus; s, stomach; sp, spleen; sw, stomach wall; v, distal tapering end of stomach; arrowhead, melanin in the *submucosa*, between folds and along the villi

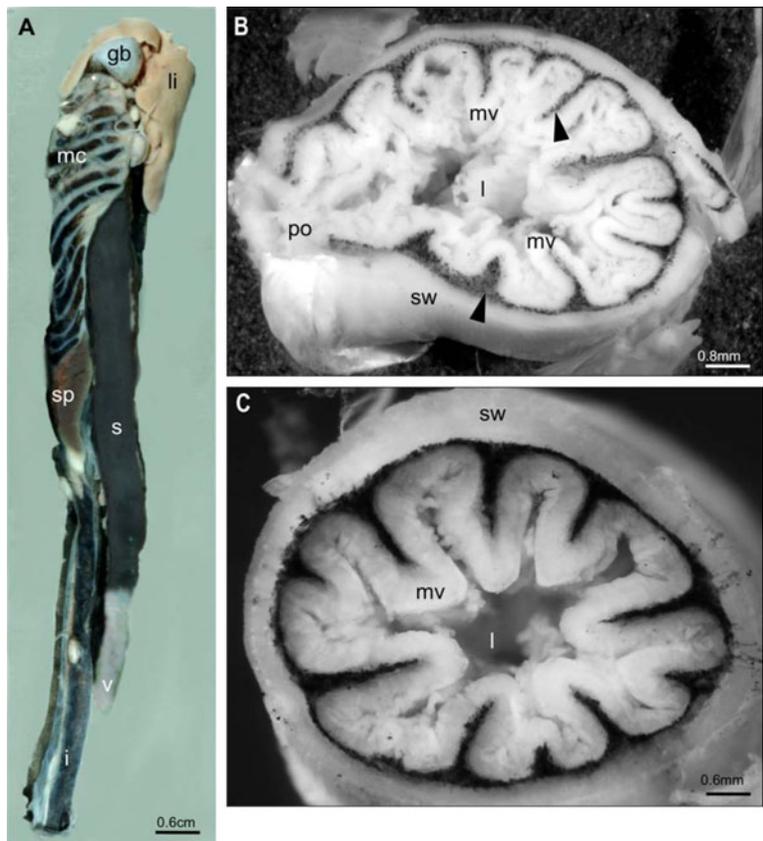


Table 2 Additional data on lizardfish from museum collection dissected for microscopy

Species	Museum	Lot number	N. of fish	Collection site
<i>Saurida tumbil</i>	HUJ	6434	6	S. Red Sea
<i>S. tumbil</i>	HUJ	6666	2	Gulf of Aqaba
<i>S. tumbil</i>	SAIAB	52851	2	Near Madagascar
<i>S. macrolepis</i>	ASI	6241	2	Taiwan
<i>S. elongatus</i>	ASI	61980	2	Taiwan
<i>S. filamentosa</i>	CRM	016955	3	GBR Australia
<i>S. undosquamis</i>	ASI	61690	2	Taiwan
<i>S. undosquamis</i>	ICTAU	P 3425	3	Mediterranean
<i>S. argentea</i>	CRM	007128	2	GBR Australia
<i>Synodus variegatus</i>	ICTAU	P9396	4	Gulf of Aqaba
<i>Sy. variegatus</i>	SAIAB	40292	2	KwaZulu, SA
<i>Sy. saurus</i>	ICTAU	P2724	4	Mediterranean
<i>Sy. kaianus</i>	BPBM	24256	2	Malokai, Hawaii
<i>Trachinocephalus myops</i>	ICTAU	P9975	3	Gulf of Aqaba

ASI academia sinica ichthyological collection; BPBM bishop museum ichthyologic collection; CRM site of collection by Barry Russell; HUJ Hebrew University, Jerusalem; ICTAU ichthyologic collection, Tel Aviv University; SAIAB South African institute of biodiversity; SA South Africa

Table 3 Stomach and intestine color in additional species of lizardfish

Species name	Stomach color ^b	Informed by:
<i>Saurida brasiliensis</i>	pale	Ofer Gon, Barry Russell
<i>Saurida carribbaea</i>	pale	Barry Russell
<i>Saurida elongates</i>	pale	Barry Russell
<i>Saurida gracilis</i>	pale	“
<i>Saurida isurankurai</i>	black	Hsun-Ching Ho, Barry Russell
<i>Saurida longimanus</i>	black	Dutt and Sagar, Barry Russell
<i>Saurida micropectoralis</i>	pale	Hsun-Ching Ho, Barry Russell
<i>Saurida nebulosa</i>	pale	“ ”
<i>Saurida normani</i>	pale	Barry Russell
<i>Saurida parri</i>	pale	Barry Russell
<i>Saurida pseudotumbil</i>	black	Dutt and Sagar ^a
<i>Saurida undosquamis</i>	pale	Ofer Gon, Barry Russell
<i>Saurida wanieso</i>	black	Hsun-Ching Ho, Barry Russell

^aDutt and Vidya Sagar (1981) claim that the specimens seen by them had a black stomach

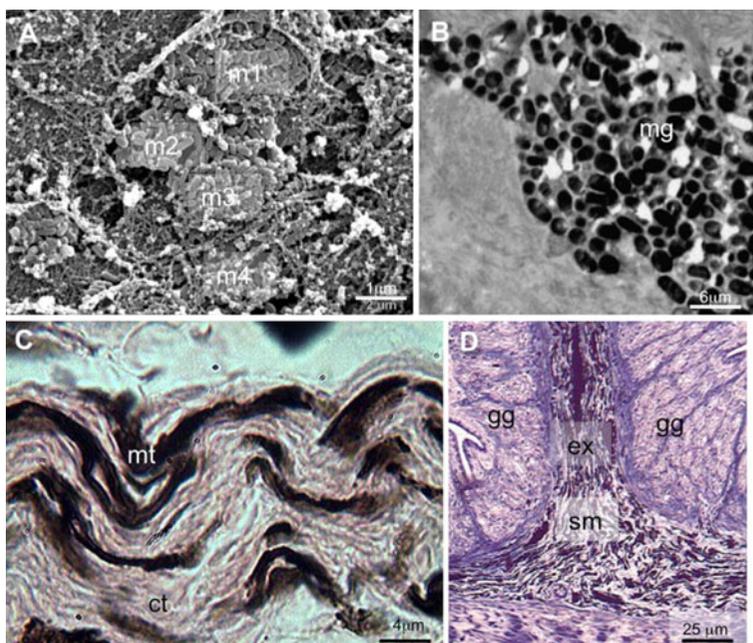
^bPosterior intestine pale in all these species

Saurida tumbil of the Red Sea (Fig. 1a) and *S. filamentosa* from the GBR, in which the black appearance extends along the entire alimentary tract and the pyloric caeca, with only the distal narrow end of the stomach remaining pale. Cross-sections revealed that, from this layer, melanosome-containing extensions of the *submucosa* continue within the folds of the mucosa epithelium (Figs. 1c and 2d). This is in contrast with the pale color of the abdominal peritoneum. This black color is formed by a dense layer of large melanosomes in the *submucosa*, laden with granules of

melanin (Fig. 2a, b). The aggregates of melanosomes form rows between the fibers of the *submucosa* (Fig. 2c), and on some sites, such as the anterior part of the stomach, they color the entire layer black, also extending around the blood vessels and nerves.

In some species, such as in the East-Mediterranean *Saurida macrolepis*, fish captured in shallow water, down to 20 m, possess a pale alimentary tract; however, in fish collected from the depth of 40–100 m the stomach is black while the posterior part of the gut is pale. This phenomenon was also seen in one of the

Fig. 2 Pigmentation in the alimentary tract of *Saurida tumbil*. **a**, Exposed melanosomes with melanin granules from the *submucosa*, SEM; **b**, *ibid* in LM; **c**, Strands of melanin between the *submucosa* fibers, LM; **d**, Extension of the melanized layer into a gastric fold, LM. ct, fibers of *submucosa* connective tissue; ex, extension of *submucosa* between the folds; gg, gastric glands; m1–m4, melanosomes (periphery marked by white); mg, melanin granules; mt, melanin along connective tissue fibers; sm, *submucosa*



studied *S. filamentosa* stomachs, in which a ring of black pigment occurred in the wall without prominent extensions into the folds. In these latter species the density of melanin granules in the stomach gradually declines posterior, fading posterior towards the apex. In juvenile fish the initial stages of melanization can be observed in the gut of 65–75 mm SL fishes, beginning with the anterior part of the stomach.

The occurrence of a black *submucosa* in the walls of the alimentary tract of several species of the genus *Saurida*, not observed in *Synodus* species and *Trachinocephalus*, is remarkable. A dark appearance of the alimentary tract in fishes has mostly been described from the dark *serosa*, a part of the melanised dark peritoneum that envelopes the viscera. Melanization in the sub-muscular connective tissue derives from an entirely different source and has to date been observed in a few fish families only, e.g. moray eels (Böhlke 1989; Fishelson 1994), cardinal fishes (Fishelson et al. 1997), Nototheniid species (Eastman and DeVries 1997) and the trachipterid ribbonfish (Bottaro et al. 2005). Bottaro et al. (2005) situated the black layer in the mucosa; whereas in fact, as in other fish with black alimentary tracts, in the ribbonfish too it is also located in the submucosal connective tissue. Of the studied lizardfishes, the submucosal melanin deposition along the entire alimentary tract was observed in *Saurida tumbil*, a species found in relatively deeper waters, and in the studied specimens of *S. filamentosa*. Depth related tract melanization was also observed in deep-water moray eels (Fishelson 1994). However, a studied specimen of *S. tumbil* collected in the shallow waters of the Persian Gulf had a pale alimentary tract. This interesting difference indicates the need for a taxonomic revision of the *S. tumbil* populations; or the “black gut” and “pale gut” groups are of a single stock, but each represents a morphotype adapted to a different diet or different bathymetric habitat. Partial melanization of the stomach only was found in the studied *Saurida macrolepis* and some related species (see Table 2). Such species-specific melanization can possibly be used as a marker in future phylogenetic studies of the species-rich genus *Saurida*, and contribute to the ecomorphological classification of this family of fishes (Norton et al. 1995; Davis 2010).

As in moray eels (Fishelson 1994), in the studied species of lizardfishes too, the melanosomes, containing 1.5–2.0 μm melanin granules, are dispersed among the fibers of the connective tissue, being

especially dense close to the internal layer of the muscular wall. The extensions of this *submucosa* into the folds of the alimentary tract also places the melanosomes near the mucosal epithelium. The questions that still remain open are: What is the role of the fishes’ internal black layer, between the muscularis and mucosal epithelium; what is the possible function of melanin in the fish physiology; and what environmental factors may have induced the formation of such a cover inside the gut wall? Fishelson (1994), Fishelson et al. (1997) and Eastman and DeVries (1997) found a correlation between melanization of the alimentary tract and nocturnal activity/deep-water habitat, including a diet of bioluminescent prey. As this luminescence does not cease after the bioluminescent fish or crustacean has been swallowed, the melanized cover may dampen the bioluminescence of the consumed prey. Additionally, melanin and its various forms are recognized as effective neutralizers (antioxidants) of the free radicals formed during lipid peroxidation and are also involved in iron regulation (Edelstein 1971). In parallel, it is recognized that environmental stress induces the production of alpha-MSH (melanin stimulating hormone) (Thody 1999). Is melanin deposition in the *submucosa* of fishes, as described for some of the nocturnal or deep-water species, a response to stress, for example to the low levels of illumination or darkness during their activity? Or is melanin a form of iron-storage that enables the recycling of this element, so important for blood-cell production? These very interesting questions should be addressed in the future.

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