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Scale characteristics of *Carangoides bajad* (Forsskål, 1775) and *Caranx melampygus* (Cuvier, 1833) from the Southern Red Sea, Egypt

Usama M Mahmoud, Sahar F Mehanna and Ashraf S Mohammad

Abstract
The present study aimed to screening and documenting the diversity of scale characteristics of *Carangoides bajad* and *Caranx melampygus* from the Red Sea, Egypt. The valid useful scale characteristics for systematic purposes were determined in the term of morphometry and scanning electron microscopic techniques. A wide spectrum of size-free intraspecific variations between different body regions was recorded in each species in terms of morphometric indices. The scale characters included the overall form of the scales and their morphometrics, shape of the first circuli, form of circuli, the outer lateral and inner lateral circuli, granulation of caudal field. Moreover, the forms of the lateral line canal scales were valid in differentiation between species under study.

Keywords: Scale characteristics, *Carangoides bajad*, *Caranx melampygus*, scanning electron microscope, Red Sea, Egypt

1. Introduction
Carangid fishes, commonly known as jacks, are important predators of reef fishes in tropical and sub-tropical oceans [1]. *Carangoides bajad* (Forsskål, 1775) is known in the Indian Ocean from Madagascar and the Comoros Islands to the Red Sea and is the most common jack seen on inshore reefs in the Arabian Gulf and Gulf of Oman [2]. *Caranx melampygus* (Cuvier, 1833) is a large-sized common piscivore fish widely distributed across Indo-Pacific coral reefs [3]. *Caranx melampygus* feeds almost exclusively on fishes and is considered to be the most important large predator of diurnal reef fishes in the Indo-Pacific, a single individual estimated to consume 48 kg fish yr−1 [4].
The importance of scale structure as a research material in fish taxonomy and fisheries increased with great developments in the field of microscopy. Application of scanning electron microscopy (SEM) to reveal morphology, ultrastructure and surface ornamentation of fish scales had facilitated its utility to distinguish the taxonomic groups over a continuum ranging from higher taxa to species.
Many authors have strongly emphasized on the validity of scale morphology and ultrastructural characteristics for fish taxonomy and phylogeny [5-21]. In addition to the systematic status, the functional approach of the ultrastructure and superficial ornamentation of teleost scales also attracted the attention of the aforementioned recent authors.
Studies that use the morphometric characteristics of scales from different body regions in fish taxonomy were rare [e.g. 22, 23, 9, 10, 8, 12, 13, 18]. Most of these studies aimed to establish a wide range of valuable scale characters that can reflect a well-defined taxonomic status and a well-founded phylogenic tree of fish taxa.
The present study aimed to screening and documenting the diversity of scale characteristics of *Carangoides bajad* and *Caranx melampygus* from the Red Sea, Egypt. In an attempt to determine the valid scale characters for fish identification and to give an interpretation for the surface scale ornamentation in terms of functional approaches.

2. Materials and Methods
2.1 Specimens collection
A total of 880 scales were collected from *Carangidae* species. 480 scales from *Carangoides bajad* (145 – 515 mm in Standard Length (SL) and 400 scales from *Caranx melampygus*(145 – 631 mm in SL) were examined to elucidate their scale structure characteristics.

These specimens were randomly collected from the southern Red Sea, at Elba National Park (Shalateen fishing port) 520 Km south of Hurghada, Egypt during the period from November 2013 to October 2014.

2.2 Scale Preparation and measurements

The examined scales were gently removed from eight regions on the left side of the body (Fig. 1):

1. Region A, below the anterior part of the second dorsal fin region (BDFS).
2. Region B, anterior lateral line region (ALLS).
3. Region C, middle lateral line region (MLLS).
4. Region D, posterior lateral line region (PLLS).
5. Region E, behind the operculum region (BOS).
6. Region F, beside pelvic fin base region (BPS).
7. Region G, beside the anterior part of anal fin region (BAS)
8. Region H, a level behind the pectoral fin region (LBPS).

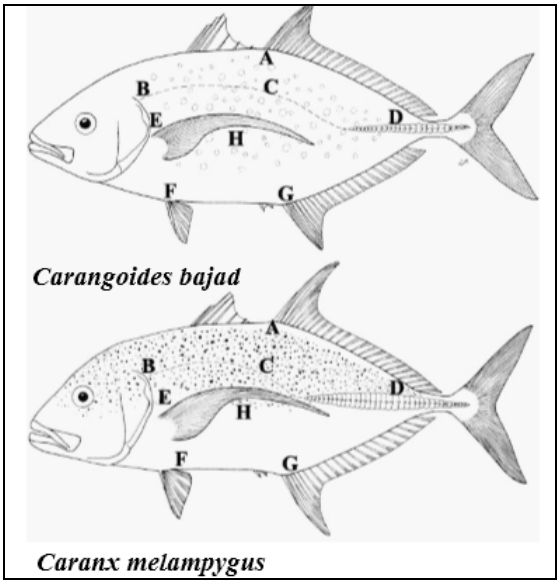


Fig 1: Schematic drawing of *Carangidae* species showing regions of scales collection.

The Examined scales were cleaned carefully to remove the adhering tissues debris without damage in the scale surface. Then they were immersed in a solution of 10% ammonia for 24-48 h to soften adhering tissues and to clean them. Cleaned scales were dried on a filter paper and kept them between two glass slides. The scales of the eight regions were used for morphometric measurements. Scales forming the lateral line canal were examined to show the lateral line pattern.

Figure 2 shows the structure of a sectioned scale and the morphometric measurements considered; (L: scale length; L_1: caudal field length; L_2: rostral field length; and W: scale width). The raw data were treated in terms of indices (L_1/L, L_2/L, L_1/L_2 and W/L).

2.3 Statistical analysis

Basic statistics of scale characteristics were estimated. To clarify intraspecific variations of both species *Carangoides bajad* and *Caranx melampygus*, ANOVA was applied on the morphometric indices of scales using SPSS package, release 9.0.0 (SPSS, 1998) [24].

2.4 Electron Microscopy

Scanning Electron Microscopy (SEM) was used to study the morphology and microstructures of the scales in the rostral, lateral and caudal regions. The cleaned and dried scales that are used for Scanning Electron Microscope (SEM) examination were mounted and fixed by sticker tape on a specimen holder and coated with a 30 nm layer of gold. The electron micrographs were produced on GAOL, GSM5400LV, SEM in back scattering mode and on a Stereo Scan Cambridge Mark 2A (15 kv) in Assiut University Electron Microscope Center, Assiut, Egypt.

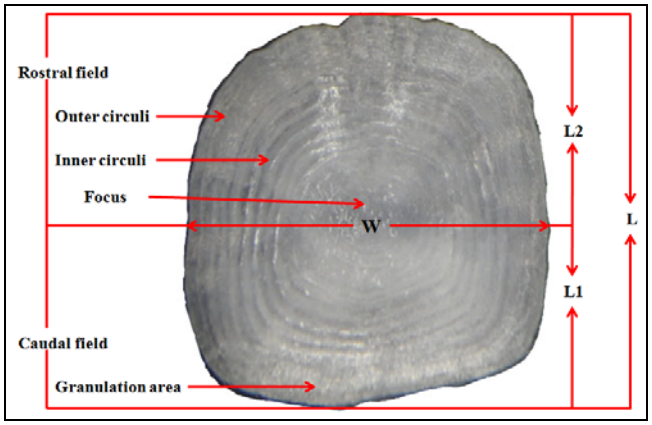


Fig. 2: A photograph of a representive scale of *Carangoides bajad* showing the different regions, terms, and morphometric measurements used to study scales of *Carangidae* species L: Scale length; L_1: Caudal field length; L_2: Rostral field length; W: scale width.

3. Results

3.1 General morphology of the scales

All scales of *Carangoides bajad* and *Caranx melampygus* are mainly of the cycloid type on all parts of the body (Fig. 3). No ctenii found in the granulation area of the caudal field. All the selected scales of the *Carangoides bajad* and *Caranx melampygus* were simple scales (i.e. without radii). The scales of the two species were smooth. The scales of *Carangoides bajad* and *Caranx melampygus* were in two forms: Form (1): with small rounded focus, long rostral field and big scale width (Fig. 3A). Form (2): with a large rounded focus, short rostral field and small scale width (Fig. 3B). The form (1) was found to be predominant in all scales considered.

3.2 Morphometrics

Tables 1 and 2 show the basic statistics of the scale morphometric indices (L_1/L, L_2/L, L_1/L_2 and W/L) of *Carangoides bajad* and *Caranx melampygus* from eight different body regions. The indices of *Carangoides bajad* and *Caranx melampygus* show highly significant intraspecific variations in different body regions ($P<0.01$). Such morphometric indices were size-free in the two species under investigation (Tables 3 and 4).

(a) (b)

Fig 3: Two representative scales forms of *Caranx melampygus* from the southern Red Sea of Egypt. A: form 1; B: form 2.

Table 1: Basic statistics (Mean±SD and Range) of the morphometric indices of scales from eight regions of *Carangoides bajad* from the southern Red Sea of Egypt.

Index	Region A (N=21) Mean±SD(Max-Min)	Region B (N=21) Mean±SD(Max-Min)	Region C (N=21) Mean±SD(Max-Min)	Region D (N=21) Mean±SD(Max-Min)
L1/L%*	56.2±1.3(54.0-59.3)	56.2±1.9(53.6-61.1)	54.9±1.2(52.5-57.1)	54.7±1.4(51.1-56.6)
L2/L%*	43.8±1.3(40.7-46)	43.8±1.9(38.9-46.4)	45.1±1.2(42.9-47.5)	45.3±1.4(43.4-48.9)
L1/L2%*	128.4±7.1(117.4-145.8)	128.7±10.6(115.4-157.1)	122±5.9(110.5-133.3)	120.7±6.8(104.7-130.5)
W/L%*	108.5±20.7(82.9-141.9)	110.8±17.4(82.4-138.5)	104.1±17.4(80.9-137.3)	109.7±15.4(84-134.6)
Index	**Region E (N=21) Mean±SD(Max-Min)**	**Region F (N=21) Mean±SD(Max-Min)**	**Region G (N=21) Mean±SD(Max-Min)**	**Region H (N=33) Mean±SD(Max-Min)**
L1/L%*	55.1±1.5(52.9-58.2)	55.1±1.2(52.9-57.3)	55.2±1.1(53.3-57.4)	57±2.3(53.9-61.5)
L2/L%*	44.9±1.5(41.8-47.1)	44.9±1.2(42.7-47.1)	44.8±1.1(42.6-46.7)	43±2.3(38.5-46.1)
L1/L2%*	123±7.7(112.1-139.3)	122.9±5.8(112.5-134.3)	123.5±5.4(114.3-134.6)	133.2±12.9(117.1-159.6)
W/L%*	114.3±14.5(91.3-141.7)	109±14.1(84.1-134)	118.5±15.5(97.8-150)	99.5±6.8(87.8-116.7)

*. Differences are highly significant at the 0.01 level.

Table 2: Basic statistics, Mean±SD (Range) of the morphometric indices of scales from eight regions of *Caranx melampygus* from the southern Red Sea of Egypt.

Index	Region A (N=21) Mean±SD(Max-Min)	Region B (N=21) Mean±SD(Max-Min)	Region C (N=21) Mean±SD(Max-Min)	Region D (N=21) Mean±SD(Max-Min)
L1/L%*	55.8±2(51.1-59.3)	55.3±1(53.3-57.8)	56.1±1.2(53.5-58.3)	55.5±1.3(52.9-58.3)
L2/L%*	44.2±2(40.7-48.9)	44.7±1(42.2-46.7)	43.9±1.2(41.7-46.5)	44.5±1.3(41.7-47.1)
L1/L2%*	126.6±10.4(104.3-145.5)	123.7±5.2(114.3-137)	127.9±6.3(115.1-139.6)	124.9±6.4(112.2-139.6)
W/L%*	109.7±16.4(85.5-138)	114.2±12.5(89.6-132.4)	104±13.3(86.2-132.9)	106.2±12.7(85.5-138.9)
Index	**Region E (N=21) Mean±SD(Max-Min)**	**Region F (N=21) Mean±SD(Max-Min)**	**Region G (N=21) Mean±SD(Max-Min)**	**Region H (N=33) Mean±SD(Max-Min)**
L1/L%*	56.3±1.3(54.1-58.4)	56.3±1.4(53.3-59.2)	55.5±0.9(53.7-57.1)	55.5±1.6(53.2-58.3)
L2/L%*	43.7±1.3(41.6-45.9)	43.7±1.4(40.8-46.7)	44.5±0.9(42.9-46.3)	44.5±1.6(41.7-46.8)
L1/L2%*	128.8±6.8(117.9-140.5)	128.9±7.2(114.3-145)	125±4.3(116.1-133.3)	124.9±8.3(113.9-139.6)
W/L%*	107±16.2(87.4-146.2)	105.2±21.1(74.6-150)	99.3±12.4(81.1-127.3)	93.7±8(81.7-110.4)

*. Differences are highly significant at the 0.01 level.

Table 3: Correlations of the morphometric indices of scales from eight regions of *Carangoides bajad* from the southern Red Sea of Egypt.

Carangoides bajad		**SL**	**L1/L%**	**L2/L%**	**L1/L2%**	**W/L%**
SL	R^2					
L1/L%	R^2	0.083				
L2/L%	R^2	0.083	0			
L1/L2%	R^2	0.072	0	0		
W/L%	R^2	0.076	0.086	0.086	0.084	

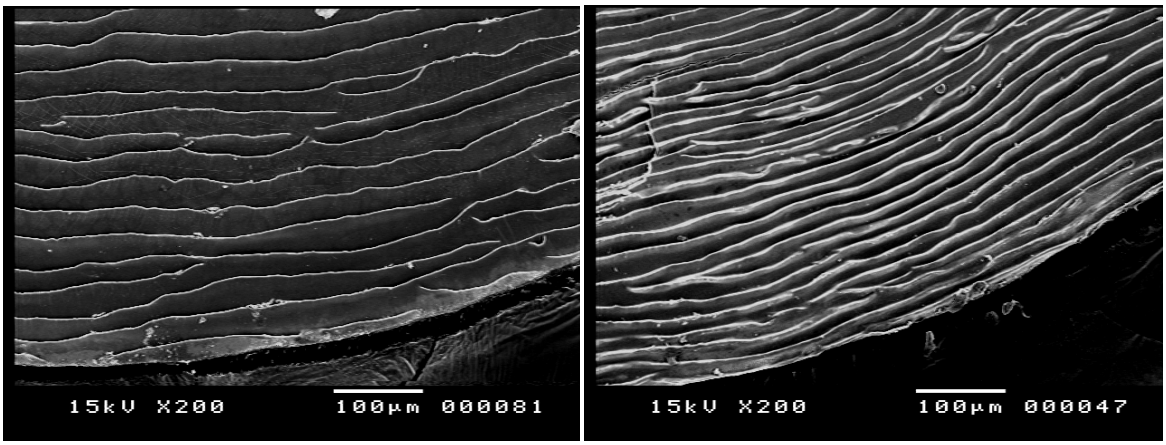
Table 4: Correlations of the morphometric indices of scales from eight regions of *Caranx melampygus* from the southern Red Sea of Egypt.

Caranx melampygus		SL	L1/L%	L2/L%	L1/L2%	W/L%
SL	R^2					
L1/L%	R^2	0.114				
L2/L%	R^2	0.114	0			
L1/L2%	R^2	0.123	0	0		
W/L%	R^2	0.019	0.268	0.268	0.269	

3.3 Scanning Electron Microscopy

3.3.1 Rostral field

The first rostral circuli are convex in the rostral rims of the scales for *Carangoides bajad* and *Caranx melampygus*. No tongues or radial spaces were observed. The circuli are thin with wide grooves in *Carangoides bajad* (Fig. 4A). Such circuli are thick with narrow grooves in *Caranx melampygus* (Fig. 4B).

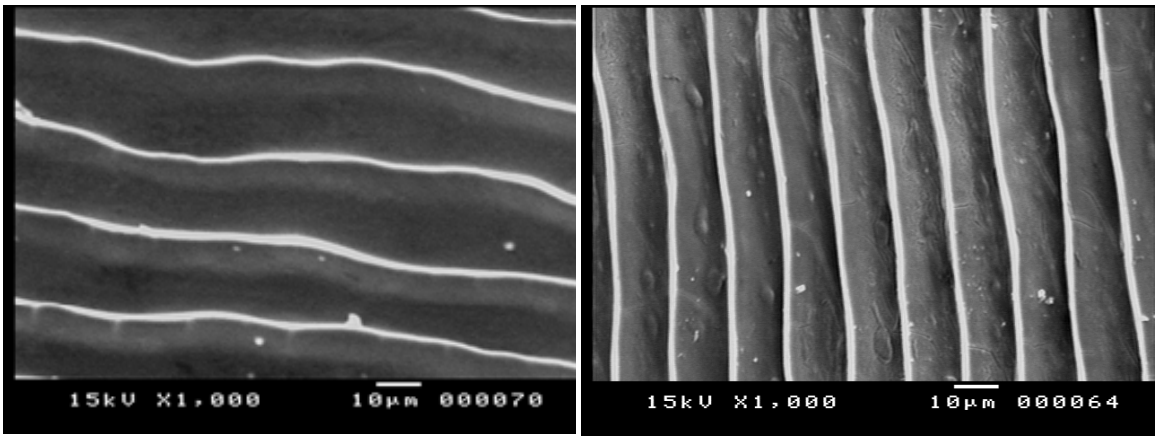


(a) **(b)**

Fig 4: Scanning electron micrographs in the rostral field of the scales (A and B) show no tongues or radial spaces and the first rostral circuli are convex, (A) The circuli are thin with wide grooves in *Carangoides bajad*, (B) The circuli are thick with narrow grooves in *Caranx melampygus*.

3.3.2 Outer rostrolateral circuli

The outer rostrolateral circuli of the two *Carangidae* species are free of denticles. The outer rostrolateral circuli are thin with wide and flat grooves in *Carangoides bajad* (Fig. 5A), while they are thick with narrow grooves in *Caranx melampygus* (Fig. 5B).

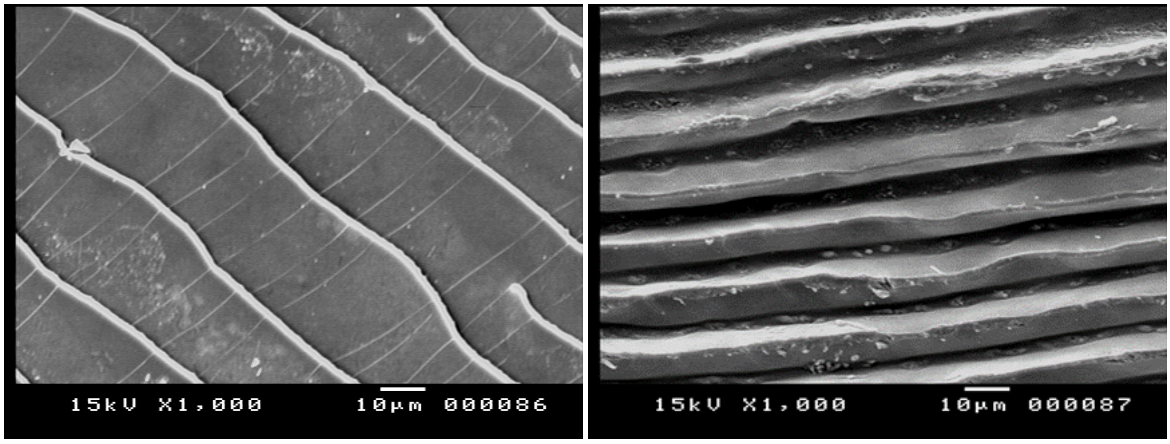


(a) **(b)**

Fig 5: Scanning electron micrographs in the outer rostrolateral circuli and grooves of *Carangoides bajad* and *Caranx melampygus* from the southern Red Sea of Egypt; (A) The outer rostrolateral circuli are thin with wide and flat grooves in *Carangoides bajad*; (B) The outer rostrolateral circuli are thick with narrow grooves in *Caranx melampygus*.

3.3.3 Inner rostrolateral circuli

The inner rostrolateral circuli of the two *Carangidae* species are free of denticles. The inner rostrolateral circuli are thin with wide and flat grooves in *Carangoides bajad* (Fig. 6A); while they are thick, with narrow U shape grooves in *Caranx melampygus* (Fig. 6B).

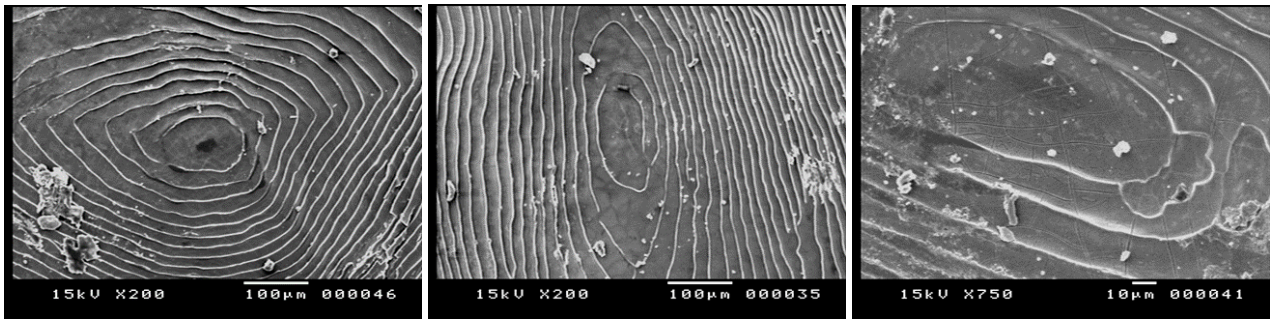


(a) **(b)**

Fig 6: Scanning electron micrographs in the inner rostrolateral circuli and grooves of *Carangoides bajad* and *Caranx melampygus* from the southern Red Sea of Egypt; (A) The inner rostrolateral circuli are thin with wide and flat grooves in *Carangoides bajad*; (B) The inner rostrolateral circuli are thick, with narrow U shape grooves in *Caranx melampygus*.

3.3.4 Focus region

The focus is circular or oval in *Carangoides bajad* (Fig. 7A and 7B). Such focus is oval with fingers-shape in *Caranx melampygus* (Fig. 7C).

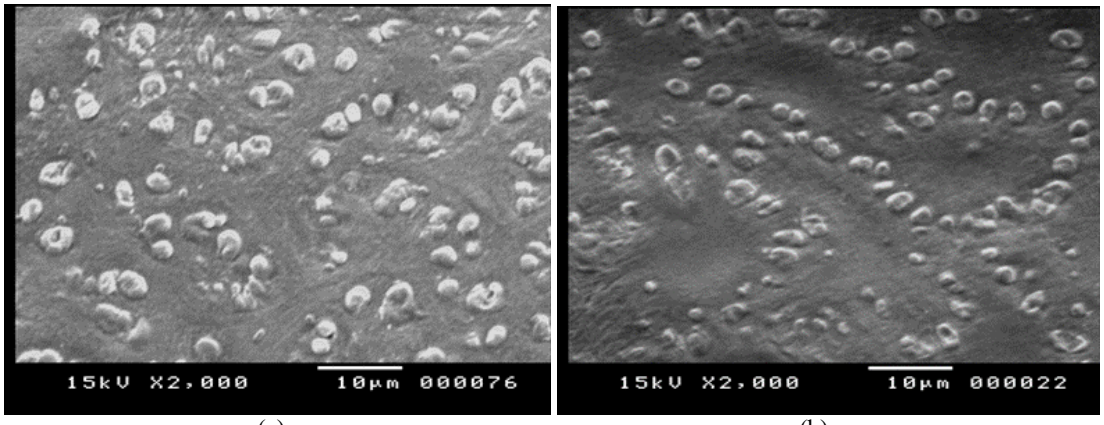


(a). **(b)** **(c)**

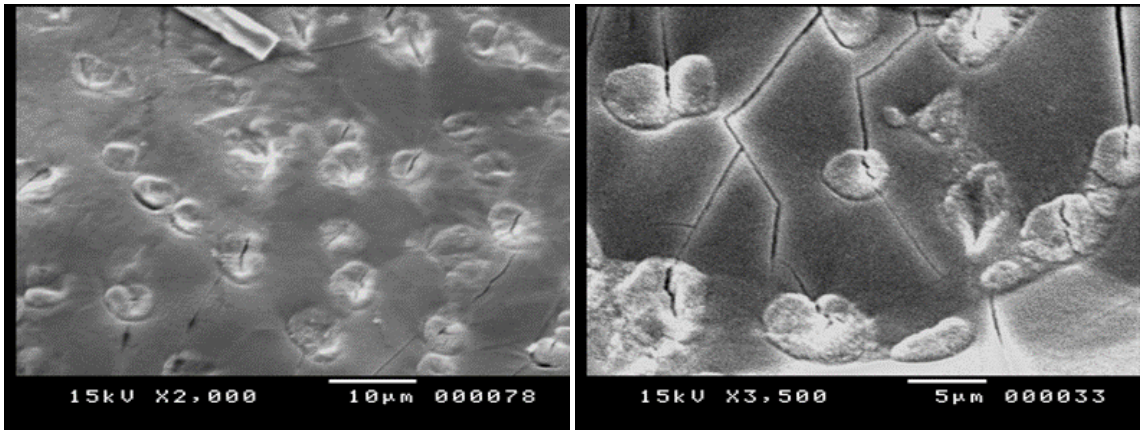
Fig 7: Scanning electron micrographs in the focus region of *Carangoides bajad* and *Caranx melampygus* from the southern Red Sea of Egypt; the focus is circular or oval in *Carangoides bajad* (A and B); the focus is Oval with fingers-shape in *Caranx melampygus* (C).

3.3.5 Caudal field

The caudal field granulation patterns in the scales of *Carangoides bajad* are spherical or small oval-like projections (Fig. 8A and B). The granulations of *Caranx melampygus* have large irregular granulation patterns in the form of spherical or big oval-like projections in (Fig. 8C and D).



(a). (b)



(c) **(d)**

Fig 8: Scanning electron micrographs in the granulation patterns of the caudal field of *Carangoides bajad* and *Caranx melampygus* from the southern Red Sea of Egypt; (A and B) the granulation patterns of *Carangoides bajad*. (C, D) The granulation patterns of *Caranx melampygus*.

3.3.6 Lateral Line Canal

In the present study there is no lateral line canal in the scales of *Carangoides bajad* and *Caranx melampygus*. Lateral line pores are formed by the two adjacent overlapped scales representing the lateral line canal**.** Each scale has a notch at the anterior portion of its rostral field and the two notches form such pore with the posterior end of the preceding scales. Two overlapped lateral line scales forming the lateral line pore in *Carangoides bajad* (Fig. 9A). Sometimes the pore of the lateral line is forming by one scale in *Caranx melampygus* (Fig. 9B).

(a) **(b)**

Fig 9: The lateral line and auxiliary scale of the two Carangid species from the southern Red Sea of Egypt. **(A)** Two preceding overlapped lateral line scales with two auxiliary scales in between from *Carangoides bajad.* **(B)** One scale forms the lateral line of *Caranx melampygus*.

4. Discussion

In the present study, intraspecific variations were reflected on the bases of quantitative scale characters in terms of size-free morphometric indices of the scales from different body regions. [22, 9, 10, 8, 25, 12, 13, 18] used similar morphometric indices for identification of some teleosts.

Many authors have been studied the stability of surface structure and surface ornamentation of the rostral and caudal field of scales [5-21]. In the present work, it was noted that, in spite of the fact that *Carangoides bajad* and *Caranx melampygus* are reef-associated and inhabit shallow coastal waters, the scales of both species reflected the stability of the surface structures of rostral and caudal field.

The present study revealed that the shape of the first circuli was convex. In contrast, other shapes were recorded for different fish species [9, 21].

In the present work it was noted that the outer and inner rostrolateral circuli of the two *Carangidae* species are free of denticles. In contrast, the outer and inner rostrolateral circuli denticles were recorded for different fish species [22, 23, 10, 12, 21].

Focus is the first part of the scale to be formed during ontogenesis and has different locations in different species [26, 27]. Its position and shape in different species may vary, being oval, circular, rectangular, or triangular [28]. In the present study the focus is circular or oval in *Carangoides bajad* and oval with fingers-shape in *Caranx melampygus*.

In the present study, the caudal field granulation patterns in the scales are spherical or small oval-like projections in *Carangoides bajad*. In *Caranx melampygus* the granulations are spherical or big oval-like projections. The large degree of morphological variations exhibited between species and genera of the same family and a complete change in morphology for several species outside the family were evident [9, 8, 12, 18]. These findings suggest and emphasized on the importance of the caudal field of scales as a taxonomic character not only at the level of species or genera but also at families level [29, 22, 23, 10, 8, 12, 18].

Lateral line scales have been utilized by several investigators to prove their potential in fish classification and taxonomy [26]. The relative position of the openings of the lateral line canal

on the scale is among the most interesting scale characteristics [30, 15]. In the present work there is no true lateral line canal on the scale of Carangidae species studied. Pores formed by two adjacent overlapping scales represented the lateral line canal. Each scale has a notch at the anterior portion of its rostral field and the two notches form this pore with the posterior end of the preceding scales.

5. Conclusions

The application of scanning electron microscope to reveal morphology, ultrastructure and surface ornamentation of fish scales had facilitated its utility to distinguish the taxonomic groups over a continuum ranging from higher taxa to species. The quantitative and qualitative characters of scales exhibit a lot of intra- and interspecific variations of the two Carangid species studied.

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