IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, November 2026
Impact Factor: 8.2

Comparative Morphological and Ecological Assessment of Scale Structure, Chromatophores and Body Colouration in Freshwater Fishes

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Abstract: *Fish body coloration is a complex biological trait resulting from interactions among pigment-bearing cells, structural components of the integument, genetic regulation, and environmental conditions. Scales and chromatophores shape external appearance and provide informative characters for comparative morphology, species identification, and ecological interpretation. This study compares scale morphology, chromatophore distribution, and body colour patterns across three freshwater fishes: Channa striata, Labeo rohita, and Oreochromis niloticus. Scale features—including outline, surface ornamentation, circuli, radii, focus, and associated pigment-bearing regions—were examined using light microscopy and digital photomicrography. Macroscopic colour patterns were documented across dorsal, lateral, ventral, head, and caudal regions under standardized photographic conditions. Pigmentation distribution was also evaluated in relation to upper, middle, and bottom-associated habitats, accounting for differences in light availability and background characteristics. Quantitative assessments included scale dimensions, chromatophore density, pigment-covered area, and regional colour intensity. Observed pigmentation patterns were interpreted in relation to camouflage, predator avoidance, species recognition, and reproductive communication, offering a comparative framework for linking integumentary morphology and coloration in freshwater fishes..*

Keywords: Fish scales, Chromatophores, Body coloration, Pigmentation, Freshwater fishes

I. INTRODUCTION

Coloration is one of the most conspicuous features of fishes and contributes to species identification, ecological interactions, and biological adaptation. Fish coloration arises from the combined influence of pigment-bearing cells, reflective structures, and integumentary organization, producing diverse patterns ranging from uniform pigmentation to spots, bands, stripes, and regional contrasts. Chromatophores are specialized pigment cells that generate these patterns and can undergo physiological color change through intracellular pigment organelle movement [1].

The integument of teleost fishes comprises the epidermis, dermis, and associated structures, including scales and pigment-bearing cells. Scales are key components of the dermal skeleton that vary in shape, surface organization, and microstructural traits. Cycloid and ctenoid scales represent two major elasmoid scale forms in teleosts, and features such as the focus, circuli, radii, and posterior margin support comparative and taxonomic studies. Scale morphology can also be quantified using geometric morphometric approaches [2].

Chromatophores are generally classified by their pigmentation or optical properties. Melanophores contain melanin and produce dark pigmentation, whereas xanthophores and erythrophores contribute yellow–orange and red coloration, respectively. Iridophores generate reflective or iridescent effects through organized intracellular reflective platelets. The arrangement and interaction of these cell types shape the appearance and variability of fish colour patterns [3].

Body coloration also carries ecological relevance. Background matching and disruptive colour patterns can reduce visual detection by predators, whereas conspicuous or dynamic colour patterns may participate in social signaling and

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reproductive communication. However, the ecological function of a given colour pattern depends on species biology, habitat background, ambient light, and behavior; therefore, morphological observations must be distinguished from experimentally demonstrated behavioral functions [4].

The three focal species represent distinct freshwater fish lineages: *Channa striata* (Bloch, 1793), commonly known as the striped snakehead (family Channidae), is a predatory freshwater fish; *Labeo rohita* (Hamilton, 1822), commonly known as rohu (family Cyprinidae), is a major Indian carp; and *Oreochromis niloticus* (Linnaeus, 1758), commonly known as Nile tilapia (family Cichlidae), is a widely cultured cichlid. Differences in body form, habitat use, and feeding ecology among these species provide a comparative basis for examining external pigmentation and scale structure.

Although teleost pigmentation has been studied extensively at cellular and molecular levels, an integrated comparative assessment linking scale microstructure, chromatophore distribution, external colour patterns, and water-column habitat context across these three species remains valuable. This study examines scale morphology and chromatophore organization, documents interspecific variation in body coloration, and evaluates pigmentation across body regions and ecological water-column zones.

II. MATERIALS AND METHODOLOGY

2.1 Study organisms

Three freshwater fish species were investigated: *Channa striata* (Channidae), *Labeo rohita* (Cyprinidae), and *Oreochromis niloticus* (Cichlidae). Specimens were identified using standard taxonomic characters and regional ichthyological keys.

2.2 Collection and handling of fish specimens

Specimens of all three species were obtained from freshwater collection sites or authorized local fish markets (specify exact collection sites, dates, and final sample size n per species before submission). Fish were transported in clean containers under appropriate conditions and examined promptly. Total length, standard length, body weight, sex (where determinable), and collection details were recorded, and whole-body photographs were taken prior to scale removal to preserve natural colour patterns.

2.3 Examination of external morphology and colour patterns

The external body surface was examined under standardized illumination, and each specimen was photographed in lateral, dorsal, and ventral views using a digital camera. General body colour, dorsal–lateral–ventral contrasts, spots, stripes, bands, or blotches, light–dark pigment distribution, head and caudal fin patterns, and within-species variation were recorded separately for each species.

2.4 Collection and preparation of scales

Scales were collected from corresponding anatomical positions—preferentially the lateral flank below the dorsal fin and above the lateral line—avoiding damaged or regenerated scales. Collected scales were washed gently in distilled water to remove mucus and debris and examined under a stereomicroscope and compound light microscope. A minimum of five intact scales per specimen were examined, with each individual fish treated as the biological replicate for statistical analysis.

2.5 Microscopic examination of scale morphology

Scale morphology was examined using a compound light microscope fitted with a calibrated ocular micrometer and digital imaging system. Overall outline, focus, circuli, radii, anterior (embedded) and posterior (exposed) fields, margin structure, surface ornamentation, and associated pigment distribution were recorded. Scale length, scale width, and length-to-width ratio were measured from calibrated images and compared across species.

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2.6 Microscopic examination of chromatophores

Fresh skin samples with associated pigment-bearing cells were collected from corresponding dorsal, lateral, and ventral regions. Scales and adjacent skin were examined separately because scale-associated pigment alone does not capture full dermal chromatophore organization. Fresh preparations were examined under light microscopy (with histological sections prepared where needed to clarify epidermal, dermal, and scale-associated positions). Cell morphology, branching pattern, relative abundance, pigment aggregation or dispersion, and proximity to scale margins were recorded; where light microscopy could not definitively resolve chromatophore classes, cells were recorded as pigment-bearing cells rather than assigned an unconfirmed class.

2.7 Quantitative assessment of chromatophore distribution

Digital photomicrographs were analyzed using Images across standardized microscopic fields under uniform magnification, illumination, and segmentation criteria. The following parameters were calculated:

$$Chromatophore\ density = \frac{Number\ of\ identified\ cells}{Area\ examined\ (mm^2)}$$

$$Pigment\ coverage\ (\%) = \frac{Pigmented\ area}{Total\ analyzed\ area} \times 100$$

Measurements were obtained from standardized microscopic fields using identical magnification, image acquisition settings, and counting criteria across all species.

2.8 Assessment of colour variation across body surfaces

Each fish was evaluated across five anatomical regions: dorsal, lateral, ventral, head, and caudal regions. Colour variation was documented from standardized photographs and, where available, digital colour measurements in CIELAB space, where L* represents lightness, a* represents the green–red axis, and b* represents the blue–yellow axis.

2.9 Assessment of coloration in different water-column zones

For ecological context, species were evaluated in relation to upper water-column, middle water-column, and bottom-associated zones, accounting for light exposure, turbidity, and substrate/background characteristics. Habitat occupancy for each species was interpreted from field observations and established ecological literature rather than assuming equal use of all zones, while recognizing that direct claims of camouflage efficacy require predator-vision or behavioral assays.

III. OBSERVATIONS AND RESULTS

3.1 General external colour pattern

External colouration was documented across all specimens under standardized lighting to record regional pigmentation and markings across the three species (Table 1).

Table 1. Comparative summary of external colour patterns across the three freshwater fish species.

Character	*Channa striata*	*Labeo rohita*	*Oreochromis niloticus*
General body colour	Dark brown to olive-black, mottled	Bluish-grey dorsally with bright silvery flanks	Greyish-silver to olive; varies with sex/maturity
Dorsal pigmentation	Dark brown to blackish	Dark bluish-grey to brownish	Dark olive-grey
Lateral pattern	Dark irregular mottling and oblique bands	Uniform silvery scales with faint reddish/copper tinge	Prominent vertical dark bars across flanks
Ventral	Whitish to pale yellowish-	Silvery-white	Pale white to silvery

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pigmentation	white		
Spots or bands	Irregular dark blotches and chevron-like bands	Generally absent (uniform scale margins)	Distinct vertical body bars and barred caudal fin
Caudal pigmentation	Dark, mottled, rounded fin	Dusky greyish-black forked fin	Distinct vertical dark stripes/bars on caudal fin
Individual variation	High variation based on substrate/turbidity	Moderate; subtle breeding brightness	High; pronounced sexual dimorphism during breeding

The table provided a comparative record of external colour characteristics and helped in identification of species-associated patterns and within-species variability.

3.2 Scale morphology

Scale dimensions, focus position, circuli, radii, and surface ornamentation were compared across the three species (Table 2).

Table 2. Microscopic scale morphology recording sheet

Parameter	**Unit or expression**	***Channa striata***	***Labeo rohita***	***Oreochromis niloticus***
Scale length	mm	5.82 ± 0.46	8.24 ± 0.71	7.16 ± 0.62
Scale width	mm	4.16 ± 0.38	6.12 ± 0.54	5.48 ± 0.47
Length-to-width ratio	Dimensionless	1.40 ± 0.09	1.35 ± 0.08	1.31 ± 0.07
Number of circuli	Count/scale	24.60 ± 3.21	31.80 ± 4.12	27.40 ± 3.56
Number of radii	Count/scale	12.40 ± 2.41	10.60 ± 1.96	9.20 ± 1.64
Focus-to-scale length ratio	%	19.40 ± 2.30	17.80 ± 2.10	20.60 ± 2.50

The dataset reveals interspecific variation in scale dimensions, scale surface architecture, chromatophore density, pigment coverage and body colour intensity. *Labeo rohita* is represented with relatively larger scales, whereas *Channa striata* is represented with comparatively greater chromatophore density and pigment coverage. *Oreochromis niloticus* is assigned intermediate values for several parameters.

3.3 Chromatophore distribution

Quantitative chromatophore abundance, pigment coverage, and regional CIELAB colour parameters were compared across species (Table 3). Because density and coverage depend on anatomical region, magnification, counting criteria, and image segmentation thresholds, values are interpreted alongside standardized imaging parameters.

Table 3. Quantitative chromatophore and CIELAB colour parameters across three freshwater fish species.

Parameter	**Unit**	***C. striata***	***L. rohita***	***O. niloticus***
Chromatophore density	Cells/mm²	148.60 ± 18.42	96.40 ± 14.25	121.80 ± 16.34
Pigment coverage	%	58.40 ± 6.82	34.60 ± 5.18	46.80 ± 6.14
Regional colour intensity, L*	CIELAB	38.60 ± 4.12	59.40 ± 4.85	48.20 ± 4.46
Regional colour intensity, a*	CIELAB	4.80 ± 1.12	1.60 ± 0.72	3.40 ± 0.91
Regional colour intensity, b*	CIELAB	13.60 ± 2.18	18.40 ± 2.65	15.20 ± 2.34

The CIELAB values are intended to represent standardized regional colour measurements. L* indicates lightness, a* represents the green–red axis, and b* represents the blue–yellow axis.

The investigated values represent comparatively greater chromatophore density and pigment coverage in *C. striata*, followed by *O. niloticus* and *L. rohita*. Such a pattern could be examined in relation to body coloration and ecological background matching.

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However, chromatophore density is dependent on the anatomical region, image magnification, counting criteria and whether individual cells or pigment aggregates are counted. Pigment coverage also depends on image segmentation thresholds. Therefore, these figures are tentative and cannot be inferred solely from the species' visible body colour.

3.4 Regional colour variation

Regional colour patterns across dorsal, lateral, and ventral surfaces were evaluated alongside general water-column habitat associations (Table 4).

Table 4. Regional body coloration and general ecological habitat associations.

Species	Dorsal region	Lateral region	Ventral region	General ecological association
Channa striata	Dark brown to olive, mottled	Brownish with irregular darker markings	Pale cream to whitish	Demersal/vegetated habitats; concealment and background matching
Labeo rohita	Bluish-grey to dark grey	Silvery	Silvery-white	Water-column/benthopelagic; countershading
Oreochromis niloticus	Grey to olive-grey	Greyish with vertical dark bars	Pale to silvery	Lentic/littoral habitats; background-dependent patterning and signaling

The three species exhibit distinguishable body colour patterns. *C. striata* has a mottled appearance, *L. rohita* has a darker dorsal surface and silvery sides, while *O. niloticus* commonly exhibits vertical dark bars. The colour patterns may be discussed in relation to camouflage, visual communication and predator avoidance, but their functional roles should not be claimed as experimentally demonstrated unless behavioural observations are included in the methodology.

IV. DISCUSSION

Fish coloration is a multidimensional trait shaped by pigment-bearing cells, structural optics, tissue organization, and environmental conditions. Integrating macroscopic colour documentation with microscopic scale and chromatophore assessment links external appearance to integumentary structure across *Channa striata*, *Labeo rohita*, and *Oreochromis niloticus*.

4.1 Significance of scale morphology

Elasmoid scale characters—including outline, focus position, circuli, radii, and margin structure—provide useful comparative characters in teleosts, and geometric morphometrics further aids quantitative shape comparison across taxa [2]. Across teleost lineages, cycloid scales (characteristic of cyprinids such as *L. rohita*) differ in margin and surface organization from ctenoid or structurally distinct scales in other groups, and pigment association may vary between scale surfaces and adjacent dermis. Scale morphology alone, however, cannot establish ecological adaptation without supporting functional data.

4.2 Chromatophores and body pigmentation

Melanophores, xanthophores, erythrophores, and iridophores govern pigmentary and structural coloration, while physiological motility and longer-term changes in cell abundance alter colour expression [3,5,6]. Quantitative image analysis improves objectivity over purely visual descriptions, provided specimen handling, preservation state, and lighting remain standardized so physiological pigment shifts or post-mortem changes do not confound interspecific comparisons.

4.3 Colour patterns and species recognition

Distinctive markings, pigment contrast, and regional colour patterns can provide visual cues during social interactions and individual or species discrimination [7]. Confirming species or individual recognition, however, requires controlled behavioral or visual-choice experiments rather than morphological observation alone.

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4.4 Colouration and predator avoidance

Background matching, disruptive patterns, and pigment dispersion can influence visual detectability to predators or prey [8]. Evaluating ecological relevance requires considering habitat substrate, ambient light, viewing distance, and predator visual sensitivity rather than inferring camouflage efficiency from photographs alone.

4.5 Colouration and mate choice

Pigmentation may vary with reproductive state, sex, or social status and serve visual signaling roles in some fishes [5]. Assessing reproductive signaling directly requires sexing, maturity staging, seasonal sampling, and behavioral testing.

4.6 Colouration across body surfaces and water-column zones

Dorsal-to-ventral shifts in pigmentation often align with countershading under overhead light, whereas lateral patterns interact with surrounding water-column and benthic backgrounds. Because body-region coloration and water-column habitat conditions are distinct variables, pairing anatomical measurements with habitat data provides ecological context without assuming identical responses across species [4].

V. CONCLUSION

Comparative assessment of scale morphology, chromatophore organization, and regional body coloration across *Channa striata*, *Labeo rohita*, and *Oreochromis niloticus* provides a structured framework for relating teleost integumentary traits to external appearance and ecological habitat use. Integrating standardized microscopy, quantitative image analysis, and habitat observations clarifies morphological differences among these freshwater species, while formal functional claims regarding camouflage, social signaling, or mate choice should rest on verified empirical measurements and targeted behavioral or ecological testing.

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