Review of Structure and Coloration of Ornamental Koi (Cyprinus carpio) Scale and Its Significance

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ABSTRACT

Background: Scale, a tiny thing, but has a lot of details and still has many hidden information for study. The present review is in the current knowledge regarding fish scale focusing on ornamental koi (Cyprinus carpio). In the first part, we describe the structure, coloration of scales and their significant. In the second part, we illustrate how to induce or enhance the koi coloration due to its popularity in the global market.

Conclusion: Based on the literature reviews, the primary purpose of fish scales is to provide external protection. Moreover, the detail through the morphology, structure, composition and coloration as a useful for the taxonomic, phylogenetic and biomedical application.

INTRODUCTION

Within the last decade, many researchers have been studied the different body color and coloration patterns in fishes [35, 64, 74, 83], amphibians [32, 46], reptiles [51, 78], and poultry [25, 77]. However, there are still not many data available about the structure or coloration of fish scale especially in ornamental Koi (Cyprinus carpio). During the present review searches were done on the scientific databases i.e., Google Scholar, MedlinePlus, Mendeley, PubMed, ScienceDirect, SpringerLink, and etc. Different combinations of keywords were used during the searches. The objectives of this review article were provided the information of the structure, coloration of scales and their significant. Moreover, how to induce or enhance the coloration of scales.

Function of coloration in fish:

Fish coloration patterns are important phenotypic traits associated with the survival and reproduction activities [80], including their adaptation to background color [30, 70], light intensity [89], confinement stress [47, 79], environmental pollution [66], wound healing [75], nutrition [53, 96], camouflage and mimicry [81], speciation and selective mating [76].

Classification of fish chromatophores:

Unlike the mammals which have a single chromatophore cell type termed melanocyte, six main types of chromatophores are commonly distinguished in fish [49]. Each chromatophores giving a specific color range to the observer under white light including black-brown melanophores [8, 26], ochre-yellow xanthophores [54], red-orange erythrophores [43], blue cyanophores [4, 5], white-creamy leucophores, and metallic iridescent iridophores [20, 44]. Chromatophores originate from multipotent pigment cell precursors recruited from a pool of neural crest cells formed during embryogenesis [94]. Chromatoblasts migrate along the dorso-lateral and ventral-lateral pathways and differentiate into mature chromatophores, which are ultimately distributed in the different regions of the integument where they give rise to the broad variety of colors and patterns observed [71]. Chromatophores are divided into light-absorbing and light-reflecting chromatophores [22]. Melanophores, erythrophores, xanthophores, and cyanophores are the first group, and leucophores and iridophores are the latter group, respectively.

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Chemical composition in chromatophores:

Chromatosomes are the pigment organelles in chromatophores for the example melanosomes are melanized organelles in melanophores, the others are xanthosomes, erythrosome, cyanosomes and leucosomes [22]. According to the well-established literature, melanin is mostly located in melanophores [47] and xanthophores contained basically carotenoid (e.g., astaxanthin, canthaxanthin, doradexanthin, lutein, zeaxanthin) and pterinosomes [50]. Drosopterin and carotenoids are located in erythrophores [43]. Guanine and hypoxanthine are located in iridophores and leucophores [20]. For the reason of quinine presences in granular, it so named guanophores [44]. Additional, isoxanthopterin, neopterin, pterin, sepiapterin and xanthopterin are the most abundant pigments found in fishes [49]. However, these are colorless or pale yellow pigments, so the golden color might be due to carotenoids rather than to pteridine groups.

Control of color occurrence:

Fish exhibit different coloration patterns into two categories; one is attributed to rapid motile responses of chromatophores as a result of the dispersion or aggregation [93], and the other is a morphological color change, which results from changes in the morphology and density of chromatophores [83]. The change in chromatophore pattern is under the control of nervous and endocrine systems [2]. Hormones involved are melanocyte-stimulating hormone (MSH) [60], melanin-concentrating hormone (MCH) [59], melatonin [19], and catecholamines [82]. MSH and MCH appear to have antagonistic effects on melanophores, with MSH enhances melanin and stimulating pigment dispersion that results in dark body color, while MCH is promoting pigment aggregation and down regulating secretion of MSH that results in light body color [60, 94].

Taxonomy of Cyprinus carpio:

Cyprinus carpio taxonomic serial no.163344 [31] is in the (Kingdom) Animalia; (Subkingdom) Bilateria; (Infrakindom) Deuterostomia; (Phylum) Chordata; (Subphylum) Vertebrata; (Infraphylum) Gnathostomata; (Superclass) Osteichthyes; (Class) Actinopterygii; (Subclass) Neopterygii; (Infraclass) Teleostei; (Superorder) Ostariophysi; (Order) Cypriniformes; (Superfamily) Cyprinoidea; (Family) Cyprinidae; (Genus) Cyprinus; (Species) C. carpio.

Regional name of Cyprinus carpio:

C. carpio commonly known by such regional names as (Albania) krai; (Australia) carp; (Azerbaijan) sazan; (Bangladesh) scale carp; (Belarus) sazan; (Cambodia) cá dáy; (Canada) carp; (Czech Republic) karp obecný; (Denmark) karp; (Ecuador) carpa común; (Ethiopia) abba samuel; (Finland) karppi; (France) carpat; (Germany): karpen; (Greece) cyprinos; (Hawaii) koi; (Hong Kong) lei uf; (Hungary) ponty; (Iceland) karpar; (India) punjabe gad; (Indonesia) ikan mas; (Iran) kapor-e-maamoli; (Ireland) carban; (Israel) karpion; (Japan) koi; (Laos) pa nai; (Latvia) sazan; (Malaysia) leekoh; (Netherlands) karper; (Norway) karpe; (Philippines) bongka’ong; (Poland) karp; (Portugal) sarmão; (Romania) ciortan; (Russian Federation) grass carp; (Slovakia) kapor; (South Africa) karp; (Sri Lanka) rata pethiya; (Sweden) karp; (Thailand) pla nai; (Turkey) adi pullu; (UK) wild common carp; (Ukraine) karp; (USA) carp; and (Vietnam): cá chép [69].

Important of koi Cyprinus carpio:

C. carpio is a popular ornamental fish and is frequently introduced species in the world with production primarily occurring in Asia. Koi carp (C. carpio koi) is a domesticated subspecies, which is brightly colored with orange, yellow, white and black pattern. The Western Fisheries research Center (WFRC) has utilized koi as model cyprinid species in fish health research [92]. Despite the existing research on fish remains available, but due to lack of the accessible resource of carp chromatophores. Therefore, to provide this deficiency for future studies on the nature of the mechanisms underlying coloration in C. carpio, the present review was designed to provide the squamatology especially in chromatophores detail in the koi carp (C. carpio).

Important of fish scale:

C. carpio scale has been employed for age determination, growth study and various growth parameters [12, 62], which are useful in the formulation of various fishery management. Fish scale morphology and its morphometrics can be employed for taxonomic purposes and or phylogenetic relationships for the example Family Sparidae, Acanthopagrus bifasciatus, and Rhabdosargus sarba from the Red Sea at Jeddah, Saudi Arabia [3]; Family Scaridae, parrotfishes, Scarus fuscopareus, S. pasiitacus, S. collana, Chlorurus gibbus and Cetoscarus bicolor [57]; and Family Lutjanidae, Lutjanus monostigma, L. ehrenbergi and L. bohar from the Red Sea at Hurghada, Egypt [58]; Family Cyprinidae, Barbus arabicus, B. exolatus, Labeo niloticus; Family Centropomidae, Lates niloticus from Sudan and Yemen [33]; Family Cyprinidae, C. carpio in UK [28] and C. carpio communis from Nangal Lake in Punjab, India [38]. As this technique involves removal of scales directly from the fish without killing it and requires no chemical processing, the chances of artifacts are minimal [38].
Classification of fish scale:
The general classification of fish scale includes the plate-like placoid scale of shark [9]; the diamond-shaped ganoid scale of the gar [88]; the thin, smooth, disk-like cycloid scale of most freshwater fish especially in C. carpio and many marine species [28, 38]; and the ctenoid scale with ctenii, the small projections along the posterior margin [68].

Chemical composition in scale:
Collagen is widely used in the food, pharmaceutical, cosmetic, biomedical materials and leather industries due to its excellent biocompatibility and biodegradability, and weak antigenicity [10, 13]. Fish offal, such as bone, skin, as well as scale is very rich in collagen. Therefore, several investigations aimed to isolate and characterize the collagen from the fish scale. Acid-soluble collagen was analyzed from carp scale (C. carpio) in China [13, 98]. The yields of scale acid-soluble collagen was 1.35% of the dry weight. Denaturation temperature was around 28°C. It was type I collagen, which was composed of two α1 and one α2 chains. The molecular weight of α2 chains was 116 kDa. Amino acid composition of acid-soluble collagen from scale were alanine, arginine, aspartic acid, threonine, serine, glutamic acid, glycine, valine, methionine, isoleucine, leucine, tyrosine, phenylalanine, hydrolysine, lysine, histidine, hydroxyproline, and proline. The top five were glycine, alanine, proline, hydroxyproline and glutamic acid [13]. Moreover, C. carpio scales have high contents of total protein, mineral element and unsaturated acids. Chuan et al. [10] reported 51.12% of water content and dry matter of scales was composed of 75.72% total protein, 2.0% total fatty acids, 20.23% mineral element. The content of 17 amino acids was 13.02% essential amino acid, 47.78% non-essential amino acid, and the lysine and glycine content was the highest in essential and non-essential amino acid separately. The content of 19 fatty acids was 23.69% saturated fatty acid, 43.76% monounsaturated fatty acids and 32.55% polyunsaturated fatty acids. The content of mineral element was 62.80 g/kg calcium, 32.90 g/kg phosphorus, 3.54 g/kg magnesium and 0.1 g/kg zinc. Collagens extracted from fish scales have also been reported in tilapia, Oreochromis niloticus, in India [27, 84]; Rohu, Labeo rohita and Indian carp, Catla catla in India [72]; silver carp, Hypophthalmichthys molitrix in China [97] and croaker, Pseudosciaena crocea in China [90]; seabream, Sparus aurata, in Spain [63]; jellyfish, Aurelia aurita, Cotylorhiza tuberculata, Pelagia noctiluca and Rhizostoma pulmo, in France [1]; red seabream, Pagrus major, in Japan [29]; spotted golden goatfish, Parupeneus heptacanthus in Thailand [55].

Character of fish scale:
Patterson et al. [73] described the features on scale as follows: Circuli refers to the elevated marking on the surface, usually appearing as lines that more or less follow the outline of the scale. Focus refers to the first part, often central, of the scale to appear in growth. Radii refers to the groove that radiate from the focus to the scale margin. Primary radii refer the radii that extend from the focus to the margin. Secondary radii refer the radii that begin outward with, not at the focus. Field refers the area of the outer surface of the scale, either real as delimited by angulation of the circuli, or implied if the configuration of the circuli are otherwise. Various adjectives applied to regions are based on their position in relation to the orientation of the scale on a living fish. Anterior region is bounded by imaginary lines connecting the anterolateral corners or their equivalent points on rounded scales. Posterior region is bounded by imaginary lines connecting the posterolateral corners with the focus. Lateral region is the dorsal and ventral field remaining after delimitation of the anterior and posterior regions.

Scanning electron micrograph of scale:
C. carpio [38] and the other fishes with cycloid scale structures have been studied using scanning electron microscopy technique such as Order: Gadiformes in France [42]; Cobitis linea in India [36] Labeo spp. (L. calbasu, L. rohita, L. gonius and L. bata) in India [40]; Capoeta damascina in Iran [18], Alburnoides bipunctatus, Rutulus frisi in Iran [16, 17]; Barbus arabicus, B. exolatus, Labeo niloticus, and Lates niloticus in New Zealand [34]. Dorsal and ventral part: The part which touches the body of the fish is called the ventral part, which is smooth and shining; the opposite part is dorsal, rough to touch and non-shiny. For ultrastructural details of the scale, only the dorsal part has been considered. The general shape of the scale is semi-circular. The thickness of the scale decreases from the central to peripheral part [38]. Central part: At the center, there is a distinct focus, the part of the scale that develops first during ontogenesis. Its position remains the same throughout the life of the individual species [34]. The focus does not occupy the central, but it lies a little towards the posterior side of the scale. Matondo et al. [56] reported no apparent differences exist between the sexes in terms of focus position in the Family: Mullidae, yellow striped goatfish Upeneus vittatus, in the Philippines. Moreover, they reported the arrangement of focus from the different body regions showed all centrally located in the head region, a mixture of central and posterior field in the middle body region while all lower posterior fields in the tail body region. The focus divides the scale into four distinct regions, namely anterior, posterior, left lateral and right lateral regions. Around the focus there are growth lines called circulii. The circulii are arranged in a circular position fashion and correspond to the overall shape of the scale. They are...
more distinct in the anterior and lateral parts compared to the posterior part [56]. They are enclosed by deep, narrow grooves that run radially to the focus. These grooves are called radii. The radii identification might be useful in taxonomy. The number of radii is more in the anterior part compared to the lateral and posterior parts of *C. carpio* scale in India [38]. But these were no consistency in the number of radii within body regions as follows a combination of primary and secondary radii were only presented in head to body regions but it was absent in the tail region of *U. vitatus* in the Philippines [56]. The higher number of radii is correlated with the better nutritive conditions of the fish [36]. Radii also represent scale flexibility [18, 67]. No variation between sexes has been observed in terms of the types of radii [56]. The intracircular distance depicts the growth rate. This distance is more during the summers when the growth rate is high and less during winters, indicating the slow growth rate during the period [39, 87]. The fully formed circuli have row of lepidonts that are tooth shaped structures on the outer surface of the circuli of scales. These structures help scale to remain fixed to the body of the fish and scales to start detaching from the body when these structures are damaged [11, 37].

**Anterior part:** The scales arrange themselves on the body of the fish in an overlapping manner with the anterior part of the scale being covered by the posterior part of the preceding scale [38]. **Posterior part:** It is comparatively thicker than the anterior part and is covered by a fold of skin epidermis having chromatophores arranged in the longitudinal rows. The shape of chromatophores varies from round to oval, semi-oval and even oblong structure. The outer surface of chromatophore is not smooth; on the contrary, it has several warts and wrinkles [38].

**Scale chromatophore distribution in different body colors:**

*C. carpio* scale was evaluated the composition and distribution of chromatophores on back scales, abdomen scales and color pattern scales with different body colors. The results showed that the chromatophores on upper layer were melanin, red pigment and yellow pigment, which were distributed on the back area and accounted for 25%-35% of the scale; the main distributed on the back area, and accounted for 30%-65% of the scale [91]. Kelsh [41] reviewed the distribution of colored pigments throughout the body and the pigment pattern formation in embryonic and adult zebrafish.

**Effect of dietary supplementation in coloration:**

Carotenoids, which are lipid soluble pigments, are responsible for the skin color of ornamental fish. The yellow, orange and red hues found in fish skin or scale are the result of a group of carotenoid pigments, including both carotenes and xanthophylls [95]. As fish cannot synthesize or convert precursor pigments to carotenoids, it need to be supplied on the dietary to achieve its color formation. Several investigations have been performed on the effect of dietary supplement inducing the fish coloration, especially in carp in Thailand [95], in China [50, 85]. Liang et al. [50] studied the effect of astacin on the growth and color formation of a juvenile red-white ornamental carp (*C. carpio*) in China. Astacin, derived from the oxidation of astaxanthin, is a red carotenoid ketone pigment found in crustacean shells. At the end of 50-250 mg astacin/kg diet for 8 weeks, samples of red-white, red, and white skin, and scales were collected for carotenoid content. They found fish weight, specific growth rate, carotenoid content were significantly higher and also showing the brighter body color. The other researchers, Gouveia et al. [23], in Portugal, investigated the skin color enhancement in three chromatic varieties of koi carp (*C. carpio*), namely Kawari (red), Showa (black and red) and Bekko (black and white) by feeding a dietary carotenoid supplement of freshwater microalgal biomass *Chlorella vulgaris*, *Haematococcus pluvialis*, and cyanobacterium *Arthrospira maxima* (spirulina) for 10 weeks, they found all of supplement increased total skin carotenoid content and the most efficient coloring was *Chlorella vulgaris*. In additional, body color intensity of red colored koi carp (*C. carpio*) was measured to evaluate the effect of paprika used as a carotenoid feed additive for 62 days [24]. As similarly, after 99 days feeding with *Spirulina platensis* and synthetic Carophyll® significantly increased the growth, feeding efficiency and carotenoid content in Showa koi (*C. carpio*). They also improved the chroma of the black zone, the redness of the red zone, and the lightness of the white zone of scales [85]. Kim and Lee [45] reported canthaxanthin and paprika could increase the redness of red-white colored fancy carp fingerling after 8 weeks feeding more than spirulina and astaxanthin supplement. The use of natural carotenoid like tea, mulberry and cassava leaves as supplement has also enhanced the serum astaxanthin concentration in fancy carp [96]. Moreover, the hormone melatonin induced the aggregation of the melanin granules towards the nuclei of the melanophore cells in scale of an Indian major carp, *Labeo rohita* [65].

**Adaptation to background color:**

Color or pigment adaptation can occur during fish reproductive period [48], under pollution conditions [6], as well as defense mechanisms [70]. It is well known that there are two mechanisms of color adaptation, first, the aggregation and dispersion of pigment via combine of neural and hormonal process, and second the alteration in the amount of pigment and the number of chromatophores [61, 86]. Hormones involved are melanocyte-stimulating hormone, melanin-concentrating hormone, melatonin, and catecholamines [60].
Papoutsoglou et al. [70] investigated the growth performances and physiological responses of *C. carpio* after 14 weeks in black, green and white color background adaptation. Plasma cortisol levels in white-adapted carp were significantly lower than those in green and black. Since increased cortisol secretion has been accepted as an indicator of fish stress, it could be emphasized that the white adapted carp were the less stressed compared to the green and black groups. Moreover, white-adapted carp showed the highest specific growth rate and the lowest food conversion ratio, whereas green and black-adapted fish exhibited the opposite pattern. In addition, mean (%) increase of body weight in white-adapted carp was 4.66% and 3.58% higher than that in black- and green-adapted fish, respectively. Similarly, results in color background adaptation in scales of the other fish species like Family: Adrianichthyidae, medaka, *Oryzias latipes* in Japan in white and black color background adaptation [21]; Family: Cichlidae, Nile tilapia, *Oreochromis niloticus* in Egypt in yellow, blue, green, red and black color background adaptation after 45 days [15]; Family: Cichlidae, *Cichlasoma dimerus* in Argentina in white and black color background adaptation after 10 days [7]; Family: Cyprinidae, common carp, *C. carpio* in Iran in white, black, red, blue and yellow color background adaptation after 8 weeks [14]; Family: Cyprinidae, zebrafish, *Danio rerio* in UK in white and black color background adaptation after 24 h [52]. It is concluded that different background colors may lead to different growth performances of scaled carp depending upon rearing conditions.

In conclusion, scale structure and coloration in *C. carpio* can be used as a tool in biological, zoological or even in ichthyological research because it’s reliable, non-invasive technique. If it combines with other characteristics such as body morphometry or a light-weight equation, it will be likely to increase the accuracy and precision. This review is expected that it will help taxonomist, biologist, fisheries managers, environmental administrators and other end users select the best available information for their purposes.

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