



Effect of Environmental Variability on the Pigmentation of Fishes

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Abstract

A wide range of functions in animal species depends on the pattern of color. The pigmentation pattern in fish depends on the spatial combination and number of chromatophore types. Color in the animal also depends on the species. During life, color can change, and the changes are a response to abiotic and biotic environmental factors. Nutritional quality, UV light incidence, the intensity of light, and social interactions also change the pigmentation pattern in fishes. Quality criteria decide the market value of ornamental fish species, and culture species for fish is the pigmentation system of the skin. The external signal infers its condition of culture and its welfare. The pattern of pigmentation defects is a significant cause of loss in aquaculture production. In the case of fish exhibiting diverse pigmentation patterns, the pigmentation pattern depends on the stage of development. Despite the use of various methodologies to enhance the production of freshwater and marine water species, pigment abnormalities are still being reported at higher rates in larvae. The reason for pigmentation abnormalities is unknown; the most probable cause for the color abnormalities is the interaction between genetic and environmental factors.

Keywords

Pigmentation · Chromatophores · Photoreceptor · Melanin · α -MSH

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1 Introduction

Aquaculture now plays a critical role in revenue generation, food and nutrition security, and preserving local biodiversity and cultural traditions, particularly in undeveloped countries (Belton et al. 2018). Several types of chromatophore and their number and spatial arrangement determine the pattern of skin pigmentation, which is species-specific. This trait can change throughout time, as for as during the reproduction cycle or in response to abiotic and biotic environmental factors (nutrition and social interactions). Because it functions as an external signal to understand its well-being and the culture conditions utilized, the most crucial factor for quality criteria for fish species is fish skin pigmentation, speaking to the market value, which further depicts the requirements of quality dictating the market value of fish for consumption for human and decorative use (Harpaz and Padowicz 2007). Pigmentation pattern failings are the most common causes of loss of aquaculture production. Patterns of color in animals, mainly fish, are involved in various tasks. Several studies have shown to learn more about the mechanisms that underpin fish pigmentation and the impact that rearing settings have on it.

2 Pigmentation/Coloration in Fishes

Color consists of two types of pigments: structural and pigmentary. Light and tissue nanostructure interaction produces structural color (Parker and Martini 2006; Roberts et al. 2012). Reflection of light in iridophores (fish, reptiles, and amphibians) (Kawaguti 1965; Rudh and Qvarnström 2013; Olsson et al. 2013), scattering of light in bird barbules (Roulin and Ducrest 2013), or diffraction gratings in antenna hairs of crustaceans are all responsible for structural hues (Parker and Martini 2006). Chemical pigments deposited in specialized chromatosomes within pigment cells (chromatophores) produce pigmentary shades (Prum 2006; Roulin and Ducrest 2013). Because pigment cells are spread in layers in integument structures, pigmentary colors are usually associated with structural colors.

Two different pigmentation patterns determine the coloration of an adult fish. In adult Zebra fish, two separate pigment-patterning mechanisms contribute to the coloration of fish, i.e., an ancient mechanism behind dorsal-ventral patterning involving the expression of dorsal-ventral differential *asip1* gene and a newer striping based on the mechanism of cell-cell interaction (Ceinos et al. 2015). But these genetically shaped mechanisms of pigment-patterning can be altered to some extent in response to various environmental factors and characterize the most captivating features of pigmentation in fish. Additionally, during the state of development, fish can show multiple patterns of pigmentation. But the phenotype color of the larva is different from its adult phenotype (Parichy et al. 2011). The standard color of body pattern in larvae of fish occasionally results in faulty pigmentation in adults. Several pigmentary flaws may arise during the metamorphosis of larvae, from the phenotype of larvae to the phenotype of adults (Bolker and Hill 2000; Ceinos et al. 2015). All organisms have modified their behavior and purposes in response to

variation in the external indicators. An indicator such as the light-dark and 24 h LD cycles is the most prominent. Still, other factors such as water salinity, temperature or rainfall, and food availability can also affect rhythms. Several functions are observed in daily rhythms like shoaling behavior, food intake, thermoregulation, skin pigmentation, and oxygen consumption during larval development (Ekström and Meissl 1997).

In fish, larval development, sedation, locomotory behavior, oxygen consumption, skin pigmentation, feed consumption, thermoregulation, and behavior shoaling are among several functions that show daily rhythms (Ekström and Meissl 1997).

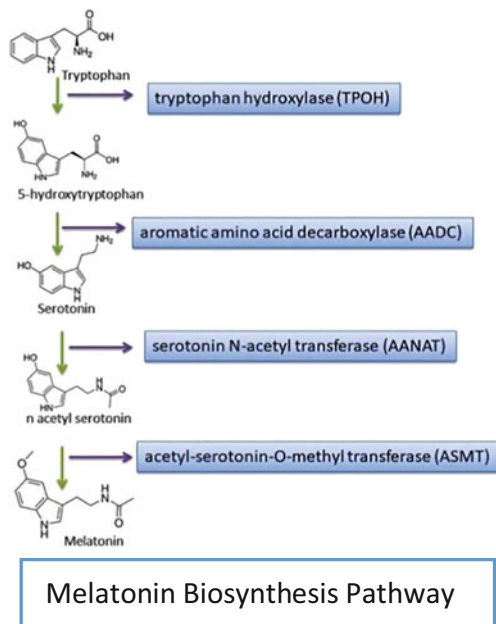
3 Sources of Melatonin Production

The pineal photoreceptors are structurally analogies to the retinal cones (Ekström and Meissl 1997). They are highly light-sensitive, with similar composition in lipids and proteins of the phototransduction cascade. Excitatory neurotransmitters (aspartate or glutamate) is inhibited by cell hyperpolarisation in response to light stimuli. The excitatory neurotransmitter grasps the ganglion cell directly to the pineal organ. Those signals are reflected by the response's photoreceptor cells, which is a luminance detector that delivers information on the light intensity, day duration time, and spectral content. It is essential to know that the retinal ganglion cells and pineal gland may target comparable brain areas, mainly in the thalamus and pretectum (Ekström and Meissl 1997). In addition to the excitatory neurotransmitter, the pineal and retinal photoreceptors produce melatonin at night by cell depolarization (Falcon 1999).

4 Mechanism of Melanin Production

Pineal cells take tryptophan for the synthesis of melatonin. Two enzymatic steps permit the arrangement of serotonin from tryptophan: tryptophan hydroxylation allows the incorporation of hydroxytryptophan, which is decarboxylated by the aromatic amino corrosive decarboxylase, driving the structure of serotonin.

Another two enzymatic step transformations of serotonin to melatonin are as follows: formation of *N*-acetylserotonin by the catalysis of arylalkylamine *N*-acetyltransferase (AANAT), and the hydroxy indole-*O*-methyltransferase (HIOMT) converts the *N*-acetyl serotonin into melatonin (Falcón et al. 2007). During the daytime, the level of serotonin is high and low at night, and melatonin is a shift pattern with an elevated pattern day and night (Falcon 1999; Bromage et al. 2001). The rise in melatonin production at nighttime by the pineal reflects an increase in the activity of arylalkylamine *N*-acetyltransferase. In contrast, hydroxy indole-*O*-methyltransferase activity remains relatively steady throughout the LD cycle.



5 Role of Temperature on Melatonin Biosynthesis

Since fish are ectotherms, their body temperature is directly affected by the peripheral temperature, which varies on a seasonal and daily basis. Various studies have shown that the temperature modulates melatonin secretion directly by regulating AANAT2 in the pineal organ (Benyassi et al. 2001). Remarkably, (a) there is a good correlation between the fish's optimum physiological temperature and the peak of responses of AANAT2 (*Oncorhynchus mykiss* at 12 °C, *Esox Lucius* at 20 °C, *Sparus aurata* at 27 °C); (b) the enzyme response towards the temperature is its intrinsic property as similar response curves were found from cultured pineal organ homogenates or recombinant AANAT2 enzymes. There is no effect of temperature on the stage and period of the circadian rhythm in the case of fish pike (Falcon et al. 1994).

Thus, the synchronized photoperiod action that regulates the period of the melatonin signal and the temperature that governs its amplitude is supposed to deliver accurate definitions of both the diurnal and annual cycles. The temperature changes related to global warming and husbandry condition may have dramatic effects on the time-keeping system of fish. Melatonin is the principal hormonal secretion of the pineal organ. The involvement of the control process in daily and seasonal rhythms is widely acknowledged but not fully demonstrated yet. The daily rhythms in fish by melatonin/pineal organs involve food intake, locomotion of activity, thermal preference, skin pigmentation, vertical migration, rest and shoaling

behavior, growth, reproduction, and annual processes, including for migrating salmonids (Falcón et al. 2007).

6 Effects of Melatonin on Fishes

A previous study deals with the effect of photoperiod manipulation, melatonin treatment, and/or pinealectomy, which led to contradictory assumptions concerning the part melatonin plays in regulating neuroendocrine (Bromage et al. 2001; Falcón et al. 2007). The reason is that the studies were carried out under various experimental trials (the time of the experiment was crucial), within the same or different species, historical status, and animals of other sex. Melatonin mediates the effects of photoperiod by coming to light on numerous neuroendocrine and behavioral functions. In wholly developed gonads in fish, in vitro release of LH from pituitary cells in culture stimulates the low concentrations of melatonin; in vivo, melatonin causes significant elevations in LH in plasma late throughout the photo phase of the day-night cycle, when managed in the basal diencephalon.

For larvae's development, minimal light intensity is needed for normal growth and development. In diurnal fish species, the case of older fish also responds to photoperiod manipulations; long days largely influence growth performance. "Day length" and "food availability" are essential for the growth and development of the fish effect synergistically.

In the hypothalamus of cultured carp species, melatonin causes a reduction in the level of dopamine, which results in an amplified secretion of LHb (Popek et al. 2006). Melatonin's critical role in the regulation of the annual testicular action was achieved from studies in *Catla Catla* (Bhattacharya et al. 2007). The action of Maturational inducing hormone (MIH) increases up to 4 h earlier in the incubation medium due to the addition of melatonin (Chattoraj et al. 2005); conversely, serotonin hinders the MIH actions as well as a dose of melatonin on the MIH induced the carp oocyte maturation (Chattoraj et al. 2005).

Generally, larvae need a minimum intensity of light for development and normal growth. Old fish also react to photoperiod manipulation; naturally, growth is stimulated in diurnal fish species by longer days. Food availability and the day's length are essential and synergistically affected. Food intake, digestion, and growth are specific behavioral rhythms, and reproduction and controlling the pineal organ or melatonin are thought to operate here (Ekström and Meissl 1997). But the results are often conflicting. For example,

1. Melatonin administration i.p. for a short time to goldfish, but not long, usually several days, causes an increase in growth and weight gain (De Vlaming 1980).
2. Increased weight gain after melatonin inserts in Atlantic salmon parr (*Salmo salar*; Porter et al. 1999); however, it reduces the body weight and growth rate in trout (Taylor et al. 2005). Keeping in view from a feeding point of view, it has been found to reduce fish's food intake by acute treatments of melatonin (López-Olmeda et al. 2006), but fish grow differently subject to the diurnal time feeding.

In vitro, it was challenged with physiological concentrations of melatonin in trout pituitary, which released increasing levels of GH (Falcón et al. 2003).

The precursor of melatonin is serotonin, which plays a direct role in locomotion activities responses in different species of fish and contributes to the synchronization of these everyday activities. Therefore, in sockeye salmon, serotonin amplified locomotor activity mainly only during the dark period, while during the light phase, melatonin decreases the locomotory activity (Byrne 1970). The supplementation of melatonin also reduces the overall activity of locomotion in sea bass (Herrero et al. 2007) to encourage surfacing behavior in goldfish and to endorse sleep (Zhdanova et al. 2001) to decrease aggressiveness responses of the cichlid fish *Aequidens pulcher* (Munro 1986). In fish, melanin has various functions like pigmentation, immunity, skin protection, and stress responses (Kittilsen et al. 2009). Another melanin-concentrating hormone (Mch) released by the brain, regulates variations in body color involving controlling the dispersion and cohesion of melanin in the chromophore (Baker et al. 1995).

7 Color Changes

The color changes of fish are by two mechanisms: physiological and morphological.

7.1 Physiological Color Changes

The physiological color change is due to and is related to the dispersion and aggregation of granules of pigments (chromatosomes) of chromatophores in the skin (Sköld et al. 2016) or variations in the distance and angle among light-reflecting platelets in motile iridophores (Fujii 2000). Both endocrine and sympathetic systems control the physiological color change in fish. In the case of the sympathetic nervous system, noradrenalin has been inducing chromatosome aggregation, while many hormones are involved in pigmentation. Melanin-concentrating hormones (Mch1 and Mch2) play an essential role in pigment accumulation (Mizusawa et al. 2013). The dispersion of pigment granules is encouraged by melanocyte-stimulating hormone (Msh) (Fujii 2000; Yamanome et al. 2007).

Another hormone, adrenocorticotrophic hormone (Acth), which is mainly involved in stress-related responses (Wendelaar Bonga 1997), has been found to have the capability to disperse chromatosomes (Fujii 2000). Melatonin act as a chromatosome aggregator (Aspengren et al. 2012; Sköld et al. 2008) involved in color change and dispersing of pigment effect in xanthophores and erythrophores prolactin (Fujii 2000; Sköld et al. 2008). MCH and noradrenalin are generally released on light backgrounds during physiological color change. By contrast, the level of α -Msh in plasma is amplified on dark backgrounds (Sugimoto 2002; Mizusawa et al. 2013).

Remarkably, the degree of acetylation can control the α -Msh dispersion ability. Monoacetyl- α -Msh dispersed the pigment, which has been reported in tilapia *Oreochromis mossambicus*, Japanese flounder *Paralichthys olivaceus*, goldfish *Carassius auratus*, and barfin flounder *Verasper moseri* (Kobayashi et al. 2012; van der Salm et al. 2005). α -Msh also shows the high capacity of dispersion pigment during deacetylation in xanthophores of goldfish (Kobayashi et al. 2012), and the capability of dispersion of desacetyl- α -Msh has also been found in both Japanese flounder and barfin (Kobayashi et al. 2011).

7.2 Morphological Color Changes

Color change morphologically is caused by long-term stimuli. It is mediated by apoptosis or the skin chromatophores' proliferation and changes in their amount of pigment and morphology (Sköld et al. 2016). Several studies have confirmed fish color change due to increasing or decreasing number, morphology, and melanophore size adaptation under long-term light or dark background (van der Salm et al. 2005).

In vivo, α -Msh long-term treatment promotes and increases the density of melanophore in tilapia (Van Eys and Peters 1981) and barfin flounder (Yamanome et al. 2007), and in trout level of plasmatic α -Msh is high during black background adaptation. Interestingly, the dynamics of plasmatic α -Msh levels during background adaptation are not similar in all the species (Baker et al. 1986; Mizusawa et al. 2013; van der Salm et al. 2005). Due to the existence of different isoforms of α -Msh with varying strengths of bioactivity, possibly by multiple endocrine control in fish, or role of α -Msh, an adaptation of background may differ from species to species (Leclercq et al. 2010).

8 Environmental Factors Affecting Color Change

8.1 Light

Chromatophores act instantly to an incident of light. The “responses of primary color” can be seen during the development of the embryo and stages of larval rearing, when chromatophores are not stimulated or under endocrine control, as well as in adulthood regardless of the presence of both nervous and endocrine systems (Fujii 2000).

Usually, the response of melanophores varies between 380 and 580 nm wavelengths by dispersing of melanosomes (Chen et al. 2013), and erythrophores accumulate or spread pigment depending on exposure to wavelengths (short or medium) (Sato et al. 2004; Chen et al. 2013).

The photo response of iridophores depends on the intensity of incident light. The highest photoresponsivity is observed with a wavelength of 500 (Kasai and Oshima 2006). Also, the photic environment affects fish pigmentation by regulating endocrine and nervous systems. To date, very few studies have been conducted on the

effect of different types of wavelengths on the pigmentation of fish. Thus, there is a broad scope for research in this area.

Light Intensity

Luminescence has been known to affect the behavior of fish, growth, physiology, and coloration in various fish species, such as *Paralichthys woolmani* (Han et al. 2005). Santos et al. (2019) demonstrated the effect of light on food intake, food conversion, behavior, and cortisol level plasma of *Lophiosilurus alexandri* juveniles. However, no skin pigmentation effect was reported.

Melanogenesis is incited by light, and the synthesis of melanophore increases, resulting in darker body coloration (Odiome 1957). Various studies have been conducted to study the effects of light intensity on body growth, coloration, survival rate, swimming behavior, feeding patterns, and other physiological activity (Batty et al. 1990; Reichard et al. 2002; Richmond et al. 2004; Lee et al. 2017).

Depending on the environmental condition, some fish may change their color, behavior, and physiology to protect themselves from predators (Mizusawa et al. 2013). This property is called camouflage, making it difficult for them to be spotted. Photo receptivity in environments may change according to their developmental stage (Boeuf and Le Bail 1999). It is reported that the absence of light increases the growth of catfish larvae (Brito and Pienaar 1992; Han et al. 2005; Kitagawa et al. 2015). While cleaning care should be taken, since this behavior species is to remain in the bottom of the aquarium; its visualization default. The ideal light intensity level may improve fish growth without causing stress.

The body color of cultured fish tends to reduce in quality compared to wild fish (Booth et al. 2004), which is problematic because the values of cultured fish commercially decrease. The rearing and culturing of fish under different light intensities affect their body color. To conclude this, fish are cultured under different intensities of light conditions and examined for the occurrence of expression of genes related to the melanin and changes in body color radiance.

Melanin plays multiple roles in fish, including, among others, immunity, protection of skin, pigmentation, and responsiveness to stress (Amiya et al. 2008; Kittilsen et al. 2009; Cal et al. 2017). Melanin-concentrating hormone (MCH) changes body color by controlling the dispersion and cohesion of melanin in the chromophore (Baker et al. 1995). If the light intensity is stronger, MCH mRNA is highly expressed.

- Coldwater fishes are generally color-wise best in the autumn and winter when the low temperature causes the pigment in a chromophore to scatter throughout the cell. During mid-summer, when temperatures are high, the reverse occurs, and the fish color appears less intense.
- Goldfish and Koi, which live in ponds rich in algae for some time, are observed to be intensely colored due partly to the lower photic conditions and partly to the algae's impact on the water.

The darkening of the skin observed was due to an increase in the concentration of melanin compared with that of fish held under the intensity of low light. The intensity of light at the surface of the water of a cage with sunshine is higher than the intensities of light used in our laboratory experiment, and this is a significant reason for the observed higher hypermelanosis reared in floating cages in red porgies (Kolios et al. 1997).

Photoperiod

Photoperiod is an essential factor that can also cause changes in skin color; melatonin not only acts directly over chromatophores but also changes other pathways of the endocrine that affect the pigmentation of the skin. In neon tetra, erythrophores and melanophores produced red and brown colors, reduced at night, indicating the color regulation by an endogenous circadian rhythm (Lythgoe and Shand 1982). The skin pigmentation differences due to daylength were also reported during the larval development of Japanese flounder after metamorphosis when comparing the effects of continuous illumination (LL) to natural light conditions (Mizutani et al. 2020). Lyon and Baker (1993) also described that in rainbow trout, MCH secretion reached a peak during the photoperiod, and then it slowly reduced before night when the lowest concentrations were observed. The skin paleness color of animals is directly related to hormonal differences.

8.2 Water Temperature

Water temperature is a vital environmental factor for cold-blooded animals' metabolism, homeostasis, growth, and development. Many ectotherms are dark-colored when cold and lighten when warmed (Norris 1967; Kats and Van Dragt 1986; Sherbrooke and Frost 1989). Fernandez and Bagnara (1991) observed that frogs, *Rana chiricahuensis*, held in gray backgrounds and exposed to low temperature (5 °C) were significantly darker in both the ventral and dorsal side of the skin area than frogs held at 25 °C temperature. However, in the same study, it was reported that there was no water temperature effect on the skin color of *Rana pipiens*. Also, it was concluded that dark coloration stimulates cryptic behavior and/or enhances absorption of solar radiation; hence the achievement facilitates more temperature of the body for the normal activity of the animal (Norris 1967; Fernandez and Bagnara 1991).

Other factors like crowding, handling, transportation, hydrostatic pressure, temperature change, salinity, and oxygen difference can affect chromatophores' physiology and thus alter fish pigmentation. Some of these stimuli have a direct effect on chromatophores and are less studied, though it is accepted that higher temperatures accumulate chromatosomes while they spread at lower temperatures (Fujii and Oshima 1994).

8.3 Tank Color

In aquaculture, structures of rearing tanks are a significant factor to be considered since it has been reported that they can cause stress on fish (Ishibashi et al. 2013), and have an effect on growth and survival of the fish (Martinez-Cardenas and Purser 2011; Wang et al. 2017), lead to anomalies of the skeletal system (Cobcroft and Battaglene 2009), and also have an effect on the behavior of fish (Cobcroft and Battaglene 2009) and skin coloration (van der Salm et al. 2005; Eslamloo et al. 2015). Background adaptation is observed mainly in fish and infers the capability to body color change in response to environmental luminance, as in the case of dark or fluorescent backgrounds. This characteristic is utilized in aquaculture to enhance the pigmentation of the skin.

In the case of goldfish, red and blue backgrounds are always stressful, whereas a white background improves the growth of fish but causes a loss of skin color (Eslamloo et al. 2015). Dark-colored tanks in *Lophiosilurus alexandri* supported an increase in the level of plasma cortisol. They reduce the skin brightness while using light colors leads to lighter skin color (Costa et al. 2017).

The adaptation to black background resulted in pigment spread in melanophores within a few hours, associated with increased plasma melanocyte-stimulating hormone (α -MSH) levels (Mizusawa et al. 2013). Arends et al. (2000) observed that gilthead sea bream adapted to a white background for 15 days showed a rise in the level of α -MSH in plasma compared to those adapted to black or gray backgrounds.

9 Hormone Regulators

Teleost fish, unlike other vertebrates, exhibits a dual hormonal mechanism for regulating skin color (Bertolesi et al. 2019). Two hormones with antagonistic effects, skin lighting and darkening, have been presented as significant physiological and morphological changes in color regulators. These two hormones, melanin-concentrating hormone (MCH) and melanocyte-stimulating hormone (MSH), are derived from proopiomelanocortin.

10 Neuronal Control

The sympathetic postganglionic systems control the speedy chromatosomes conglomeration. The cells in the eyes capture the chromatic signals through the optic tectum and motoneurons in the medulla and are processed to chromatophores via direct nervous connections (Grove 1994; Fujii 2000). The noradrenaline hormone from nerve terminals surges or declines, reliant on diverse stimuli (Fujii and Oshima 1994). Other research revealed that ATP acts as a co-transmitter along with noradrenaline hormone. In the synaptic cleft, it is dephosphorylated to adenosine, which works for more extended periods and opposites noradrenaline action, causing re-scattering of pigment after the finish of the stimulus (Fujii and Oshima 1994).

11 Impact of Malpigmentation on Aquaculture

In commercial fish production, malpigmentation is a common problem and common cause of loss of aquaculture. Several species have been reported with abnormal pigmentation, such as flatfish (Akyol and Şen 2012; Macieira et al. 2006). In flatfish, characteristics of normal pigmentation are a high number of melanophores on the ocular side, and on the blind side the number of melanophores is low (Bolker and Hill 2000). Common pigment defects in flatfish are:

- Albinism, hypomelanosis, or pseudo-albinism: the complete absence of pigmentation to white areas on the ocular side (Bolker and Hill 2000).
- Hypermelanosis: complete pigmentation to blind-side pigmented areas (Bolker and Hill 2000).

The defects of pigment are not restricted to cultured fish. Several cases of malpigmented adults in the wild have been reported in various flatfish species like common sole *Solea solea* (Akyol and Şen 2012; Cerim et al. 2016) and lined sole *Achirus lineatus* (Macieira et al. 2006). The highest pigmented abnormalities are reported in the case of flatfish (Bolker and Hill 2000).

12 Pigment Abnormalities

In the fish, the pigment complexity pattern makes it difficult to reduce the probability of pigment defects occurring in aquaculture species—generally, two hypotheses to explain the pigment abnormalities in flatfish.

13 Based on Nutrition

The deficiency of nutrition during the development of larvae causes visual defects, which affect the endocrine signaling pathway, which is necessary for the differentiation of melanophores. Deficient ratios of essential fatty acids (EPA, DHA) and vitamin A produce rhodopsin malformation in the eyes of flatfish (Kanazawa 1993). Some studies reported that the normal and abnormal tissue of neurons is affected by the Content of EPA and DHA (Estevez and Kanazawa 1996). The deficient intake of fatty acids and amino acids alters neural and eye degeneration in flatfish (Estevez et al. 1997).

First hypothesis: The pathway of signal to the central nervous system (CNS) from the retina could be disturbed by deficiencies in nutrition. The inappropriate α -Msh production from the pituitary gland might cause nutritional deficiencies, which could produce abnormalities of the pigment in flatfish (Bolker et al. 2005). Metamorphosis process like pigmentation in fish larvae, can interfere with iodine levels which causes a decrease in the level of the thyroid hormone (Th) level (Hamre et al. 2005; Wang et al. 2019).

The interaction between vitamin A and fatty acids and also the interaction between vitamin A and thyroid hormone are key nutrients for the stimulation of normal pigmentation, at the nuclear receptor level (Hamre et al. 2005). A high dose of retinoic acid stimulating the development of chromatophore in flatfish of blind side is influenced by vitamin A (Miwa and Yamano 1999).

Many fish species own their bright coloration to carotenoids, which are the predominant pigments in erythrophores and xanthophores. Thus, carotenoid must be obtained from the diet, *de novo*, fish is not able to biosynthesize (Bjerkeng 2008). Several culture species required carotenoid supplementation to avoid skin paleness (Bjerkeng 2008).

Most of the carotenoid used in aquaculture is astaxanthin in feeds, and their sources are obtained from chemical synthesis, from algae, fungi, bacteria, and yeast (Lim et al. 2018). In addition, astaxanthin is a source of pinkish-red pigments also to improve growth, survival, tolerance of stress, reproductive performance, disease resistance, and gene expression of immune-related genes (Lim et al. 2018).

14 Based on Genetics

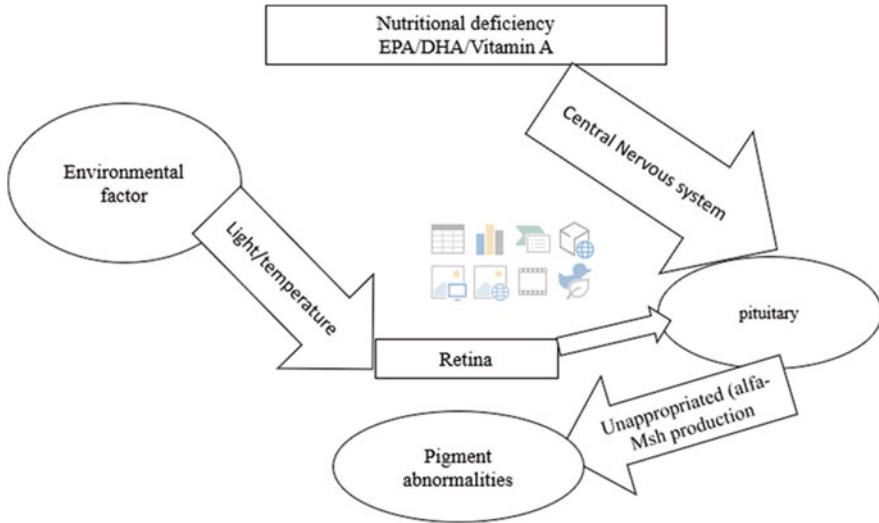
The second hypothesis proposes that the pigmentation defects during larval metamorphosis are responsible for the deregulation of the blind-side and ocular structures of skin in the flatfish (Seikai and Matsumoto 1994). Normal malpigmented, pigmented skin, and abnormalities of pigment histologically analyzed on the incorrect side may be caused by the normal regulatory pathway (Bolker et al. (2005).

Several other genes are responsible and also deregulate the defects of pigmentation in adults flatfish (Darias et al. 2013; Guillot et al. 2012). In malpigmented fish, *asip1* gene is commonly more expressed in blind-side skin and is deregulated. Guillot et al. (2012) noted that the levels of *asip1* are higher in ocular-side light spots and are similar to blind-side.

The cause of malpigmentation is due to nutritional imbalance of sole fish larvae is accompanied by upregulation of *asip1* mRNA in comparison to normally pigmented fish (Darias et al. 2013). The potential cause of pseudo-albinism is downregulation of *asip1* (Darias et al. 2013; Guillot et al. 2012). However, the regulation of *asip1* seems to have a crucial role in abnormalities of fish pigment.

In malpigmented flatfish, additional genes also have been seen to be deregulated. For example, Darias et al. (2013) suggested that, surprisingly, in pseudo-albino sole differentiation of melanophore is stimulated by somatolactin (SL) gene upregulation, which is implicated in differentiation of melanophore (Fukamachi et al. 2009). Other genes are also involved in the development of melanocyte, like paired box protein 3 (*pax3*) (Kubic et al. 2008) and tyrosinase (*tyr*) gene. The master regulator gene considered for melanogenesis is *mitf* gene (García et al. 2005).

Both hypotheses reveal the effect of various mechanisms and regulation of melanocortin systems by different melanogenic genes (Bolker and Hill 2000).



15 Conclusion

Quality criteria of the fish decide the market value for both the consumption for humans and also use for ornamental purposes. The natural skin color can be negatively affected by the rearing condition, nutrition quality, color of tank, light intensity and duration of light, interaction of light and social interaction. The pattern of skin pigmentation in fish is species-specific and depends on the number and types of chromatophores. Recent studies have identified the change in color by the control of the endocrine and nervous system. Some regulators like the melanocortin system and melanogenic genes, such as *Sl*, *Asip*, and *Th*, seem to play an important role in the regulation of pigmentation. Pigmentation pattern can be improved by utilization of feed additives like carotenoids so future studies associated with the mechanism behind the absorption of carotenoids and sources of other types of additives and sources of pigment for the farmer and entrepreneurs are required. Future studies are needed to identify the pigmentation related to control endocrine factors that are being modulated when fish are reared under suboptimal conditions.

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