Effect of various drugs on isolated scale Melanophores of fishes-A Review

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ABSTRACT

Fishes are blessed with specialized cells known as melanophore, which holds hundreds of melanin filled pigment granules, termed as melanosomes. Melanophores transport their pigments in reaction to extracellular cause, neurotransmitters either towards or away from the cell centre in fishes. The scrutiny on the captivating aspect regarding animal behaviour that deal with physiological colour changes, physiological responses, nature of chromatic fibers and occurrence of receptors on the dominant melanophores in fishes in response to various drugs has been taken up to review different mechanisms relating to this aspect in different species of fishes.

Key Words: Fish, Melanophore, Pigments, Drugs, Behaviour

INTRODUCTION

Colouration displayed by a variety of living creatures has been a topic of interest and research in biology for well over a century. A considerable number of the higher metazoan has a labile colouration responsible to relevant environmental changes and this is essentially physiological. The physiological colour change is due to the redistribution of pigment granules within the pigment cells of the organism. This ability permits the animal to modify colour to match the background; functioning as an adaptation allowing the prevention of prey detection or concealment of predator and using this for communication with conspecifics. Thus animal colouration may be considered from two different points of view, one is the value of colours and colour patterns to the animals as signals to other animals for the purpose of recognition, advertisement or warning or for the purpose of avoiding attack by predators and to obtain prey more easily for survival. This is due to the phenomenon of rapid colour change. The other point of view concerns the nature of colouring matters *i.e.,* the pigments, their chemistry and physics, origin of colours from food, and fate of these pigments, if they are to be got rid-off etc.

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Aristotle who is often referred to as the "Father of Natural History" described the colour changes of an *Octopus* and *Chameleon* in his famous book "History of Animal". Although the most perfectphysiological colour change is shown by *chameleon*, it cannot be matched with some teleost fishes to change colours and pattern to match their environment. Fish and some of their non-piscine predators (birds) have very acute vision and good ability to distinguish colour and pattern. All these rapid changes of colour are due to changes in shape, position, or nature of pigment cells controlled by nervous and endocrine systems.

Considerable number of examples among the higher animals ranging from cephalopods, crustaceans to the poikilothermic vertebrates displays the excellent background-related chromatic adaptations (Parker, 1948; Waring, 1963; Fingerman, 1963; Bagnara and Hadley, 1973). Among the poikilothermic vertebrates, teleost is the most widely studied group of animals with regard to mechanism of adaptation to a particular background (Fujii, 1969, 1993a, b, 2000; Fujii and Oshima 1986, 1994). The chromatic systems evolved in fishes are quite complex; many fish species display variable colours and colour patterns (Voss, 1970; Bhargava and Jain, 1974; Lanzing and Bower, 1974; Kohda and Watanabe, 1982a; Kasukawa and Oshima, 1987). These chromatic phenomena have great importance

in social communication besides providing protection and assistance in the survival of species in their habitats. Lot of attention has been paid by many ethologists for examining this aspect of pigmentation (Bearends and Bearends, 1950) and some of them are further trying to explain the formation and disappearance of those patterns in terms of differential neuronal control of chromatophores in a restricted area of the skin (De Groot *et al*., 1969; Lanzing, 1977; Bauer and Demski, 1980; Burton, 1980; Douglas and Lanzing, 1981; Naitoh *et al*., 1985). Muske and Fernald (1987) showed that nervous cues control the very rapid appearance or disappearance of facial stripe, the 'eyebar' which signals territorial ownership and aggressive intent in territorial males.

The body colours of fishes are predominantly dependent on presence of pigmentary substances and/or the light-reflecting microstructures within the integuement (Needham, 1974; Fox, 1979;

Fujii, 1993a, b).The compounds responsible for generation of colour are generally packed within specialized organelles, the "chromatosomes", which are produced and stored in pigment cells called "chromatophores" in the skin. Usually chromatosomes are found in the cytoplasm of the chromatophores. However, they are sometimes detectable in the epidermal cells (keratinocytes) where they have been transferred from the epidermal chromatophores. Chromatophores in the skin tissues of fish are mostly present in the dermis and rather sporadically in the epidermis. The colours of the skin are generated by absorption, reflection and/or scattering of light of certain wavelengths by the contained pigment as well as other cellular microstructures. Each chromatophore is a small entity containing a single type of pigmentary materials.

In fishes chromatophores can be classified into six groups (Fujii and Oshima, 1986 and Fujii, 2000), as presented below in Table (1):

Table.1: Types of chromatophores.

S.No.	Chromatophores	Organelle	Pigment	Colour	Nature	Type
1.	**Melanophores**	Melanosomes	Melanin	Black/ brown	Motile and dendritic in nature	Light absorbing
2.	**Xanthophores**	Xanthosomes	Carotenoids/ pteridines or both	Yellow, orange	Motile and dendritic in nature	Light absorbing
3.	**Erythrophores**	Erythrosomes	Carotenoids/ pteridines or both	Red	Motile and dendritic in nature	Light absorbing
4.	**Cynophores**	Cynosomes	Yet to be characterized	Blue	Motile and dendritic in nature	Light absorbing
5.	**Leucophores**	leucosomes	Guanine/ purine crystals/uric acid	White	Motile and Dedritic	Light reflecting
6.	**Iridophores**	Iridosomes (reflecting platelets)	Purines (Guanine/ adenosine, hypoxanthines/and uric acid)	Light reflectors	May be motile and dedritic,static and commonly round or polygonal	Light reflecting

With the diversity in the distribution of variety of pigment in the skin the resulting colours appear like a mixture of colours. For survival, fish requires the ability to change their hues and colours rapidly and effectively. The chromatophores thus allow the display of a number of intermediate hues almost at will due to the divisionistic effects made possible by them. Thus pigmentary system in fish has evolved predominantly in the dermis where controlling nerve fibers can more easily reach and control the activity of the chromatophores (Fujii, 1993a). In addition capillaries carry blood through the dermis. If the chromatophores are in epidermis, hormonal influences should be weak and delayed. Thus, both

hormonal and nervous commands can move easily and rapidly reach the chromatophores when they are in the dermis.

Chromatophores have common ontogenetic origin as that of nerve cells and are thus fundamentally dendritic cells. Dendritic chromatophores include the melanophores, xanthophores, erythrophores, cynophores and leucophores. Most iridophores lack dendrites, thus they are round, oval or multilateral in shape. The pigmentary organelles (chromatosomes) migrate centripetally (aggregation) or centrifugally (dispersion) in response to various signals received

by the cells. All types of chromatophores are somewhat controlled differently by actions of the complicated and elaborate endocrine and nervous systems. Thus they enable the fish to adapt to background hues over a wide range and to cope with various ethological encounters by delivering chromatic signals. The process, whereby some species can rapidly change colour through mechanisms which translocate pigment and reorient reflective plates within chromatophores and often use it as a type of camouflage, is referred to as "physiological" (transitory or chromomotor) colour change. In physiological colour change, the total amount of pigment and colour generating cells i.e., chromatophores remain unaltered but the intracellular distribution of the pigmented vesicles, changes. "Chromogenic" changes are the more primitive and widespread. All animals even humans are capable of chromogenic" change, which involves change in number/density of chromatophores and in net amount of pigmentary materials in the skin. These "morphological" colour changes occur slowly and frequently are regulated by humoral factors which inturn are regulated by biorhythms (lunar or annual periodicities or environmental trigger perceived through specific sense organs such as thermoreceptors, chemoreceptors by stimuli as smell, vision, taste etc.). A prolonged "physiological" colour change may lead to "morphological" colour change (Sugimoto, 2002).

Light, temperature, mechanical stimulus, electric current, pH, tonicity of media, hydrostatic pressure etc. influence the motility of the chromatophores (Fujii, 1969). Among these physical factors light is most important stimulus associated with background–related chromatic response which induces darkening or lightening skin tone to mimic the hue of the immediate environment. Waring (1963) divided melanophore response to light into two categories i.e. the so called primary (nonvisual) and the secondary (visual). The primary or nonvisual responses occur when light acts directly on the chromatophores, these chromatophores acting as independent effectors or the process brought about by light perception through some extraoptic light receptors like the pineal. Primary colour responses are mainly observable during the embryonic and larval stages. The secondary or indirect responses are the result of reception of light by the lateral eyes and generally depend on the nature of the background (light-absorbing or light scattering). In teleost melanophores it is mediated through neural (rapid) and/or hormonal (slower) mechanisms. It is well established that when chromatophores are denervated or when a blinded or a blindfolded fish is examined, even normal chromatophores respond to light directly (Fujii, 2000).

Nervous control of colour change in fish was studied in the last century. Brucke (1852) was first to illustrate the colour changes of lizard, African Chameleon, concluding that the chromatophores are under the direct control of nervous system. For the first time Pouchet (1876), studied the colour change in certain teleosts like turbot and some flatfish which are under the autonomic nervous control and not the cerebro-spinal as originally suggested by Brucke.

Under the histological studies it was demonstrated that a network of nerve fibers are associated with teleostean melanophores (Ballowitz, 1893 a, b; Eberth and Bunge, 1895). These observations regarding the distribution pattern of chromatic nerves was proved by Falck *et al.,* (1969) with histochemical studies on rainbow trout, *Salmo gardineri*. They observed a plexus of varicose nerve fibres enclosing intimately the melanophores.By means of autoradiography using radiolabelled NE, Yamada *et al*., (1984) succeeded in visualizing the pattern of adrenergic innervation on melanophores of the medaka, *Oryzias latipes* clearly.

According to von Frisch (1911), in the minnow, *Phoxinus phoxinus* the pigment-aggregating axons originate from a centre in medulla and pass along the spinal cord to about the level of 15th vertebra, where they emerge and pass through the rami into the sympathetic chain. On entering to the sympathetic chain these fibres run anteriorly and posteriorly to emerge through all spinal (to supply the trunk and tail melanophores) and trigeminal nerves (to supply to head melanophores) to innervate the melanophores. Many other workers proved the anatomical arrangement for pigment-aggregating nerve fibres innervating melanophores in other teleostean fishes. (Adelman and Butcher, 1937; Healey, 1948; Scott, 1965; Wilhelm, 1969; Finnin and Reed, 1970; Khokhar, 1971; Iwata and Fukuda, 1973; Fernando and Grove, 1974a, b; Bhargava and Jain, 1978; Dwivedi, 1978; Jain and Bhargava, 1979; Rajiv and Bhargava, 1990; Kuruvilla, 1991). However, the level of exit of these fibres from the spinal cord varies depending upon the species.

Parker (1948) claimed that teleost melanophores are inerverated by both pigment-aggregating fibres and pigment-dispersing fibres and postulated that pigment-aggregating fibres were sympathetic (adrenergic) and pigment – dispersing fibres were parasympathetic (cholinergic). Parker *et al.,* (1945) and other workers (Gray, 1956; Healey, 1967; Kinosita and Ueda, 1970), reported that acetylcholine (Ach) could actually be detected in the skin of catfish without identifying chemically the transmitter substance. Visconti and Castrucci (1981) observed in gobiiod and cichlid fishes that muscarinic as well as nicotinic blockers could retard the melanosome dispersion. Other workers, however,

have disagreed with Parker's conclusions and have postulated that teleost melanophores are innervated by sympathetic pigment-aggregating fibres only (Healey, 1957; Waring, 1963; Bagnara and Hadley, 1973; Fujii and Oshima, 1986).
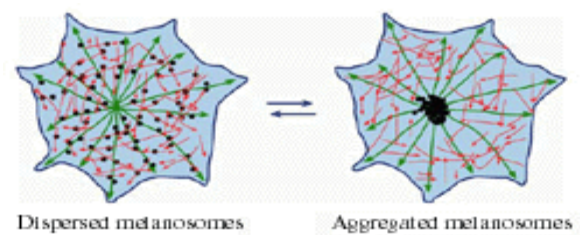
The two types of adrenoceptors that have been reported are designated as α and β adrenoceptors (Ahluqiust, 1948). Adrenoceptors are defined both on the basis of order of potency of a series of adrenomimitics and on the drug that antagonize sympathetic responses. Many workers have used pharmacological studies, to indicate that the peripheral nerve fibres controlling melanosome aggregation are adrenergic, that the transmitter involved may be norepinephrine (Fujii, 1961; Scheline, 1963; Grove, 1969a, b; Reed and Finnin, 1972; Fernando and Groove, 1974a, b; Fujii and Miyashita, 1975; Jain, 1976; Patil and Jain, 1989; Acharya and Ovais, 2007, Amiri, 2009). From all these studies it has naturally been supposed that adrenergic receptors mediating pigment aggregation in teleost melanophores are of alpha nature. On functional basis α-adrenoceptors have been divided into α_1 and α_2 subtype (Langer, 1974). Some of the researchers have demonstrated that receptors mediating the sympathetic melanosome aggregation are the α_2–adrenoceptors (Andersson *et al,* 1984; Karlsson *et al;* 1987, Morishita, 1987; Jain and Patil, 1992; Burton and Vockey, 2000a). Since α_2 agonist have been found to be more effective than α_1-agonist and transmission is more easily blocked by α_2 blockers than by α_1 blockers. The α_1–receptor activation results in the rise of cytosolic calcium concentration. It has been suggested that α_1–receptor activation may cause breakdown of phosphatidyl–inositol in membrane through activation of phospholipase-C, thereby inducing a change in intracellular calcium. This effect does not appear to involve a change in adenylate cyclase activity or cAMP concentration in cells except in certain regions of brain (Hoffman, 1984). The α_2 receptors are thought to lower intracellular cAMP by inhibiting adenylate cyclase via Gi stimulation. It was also found, however, in many investigations that a considerable aggregation of pigment occurred in response to α_1- agonistic stimuli & α_1–type adrenolytics always have inhibitory effects on that process. These observations indicate that in addition to α_2–adrenoceptors, α_1–adrenoceptor is functional at least in some cases (as reviewed by Fujii & Oshima, 1994 and Fujii, 2000). Further in some species the aggregation of pigment may be triggered by increase in levels of Ca^{2+} ions in the cytosol and in addition

Involvement of IP_3 (Inositol 1, 4, 5 triphosphate) in the aggregation of pigment in *Tilapia* melanophores have also been demonstrated (Fujii *et al.*, 1991).

Miyashita & Fujii (1975) suspected a role for epinephrine in chromatic changes in fish. They thought that it is possibly secreted from the chromaffin cells of adrenal tissues. At physiological concentration the hormone disperses melanosomes in melanophores via β–adrenoceptors. Morishita *et al.,* (1985) identified these receptors in *Oryzias* to be of β_2 type. Katayama *et al.,* (1999) reported that both β_1 & β_2 adrenoceptors co-exist in marine gobies. The mechanism of dispersing action of epinephrine appears to be cAMP dependent. β_1 and β_2 receptors activation through adenylate cyclase results in increase of the conversion of ATP to cAMP-a second messenger for many hormone receptor interactions (Hoffman, 1984).

In "Orthodox" regulation (Kasukawa *et al.*, 1986), the pigment aggregation activity of melanophores have been shown to be controlled by sympathetic post-ganglionic fibres where peripheral transmission is proved to be adrenergic and receptors involved are demonstrated to be α-adrenergic (Grove, 1969 a; Reed and Finnin, 1972; Fernando and Grove, 1974 a; Fujii and Miyashita, 1975; Fujii *et al.,* 1980; Anderson *et al.*, 1984, Kumazawa and Fujii, 1984; Kasukawa *et al.*, 1986; Patil and Jain, 1989; Nagaishi and Oshima, 1989; Bylund *et al.*, 1994; Zhong and Minnemann, 1999). β-adrenoceptors on the melanophores are implicated with their dispersion (an opposing response to that of α-receptors) in number of species (Reed and Finnin, 1972; Colley and Hunt, 1974, Miyashita and Fujii, 1975; Patil and Jain, 1991; Bylund *et al.,* 1994; Katayama *et al*.,1999).

Using specific and non-specific adrenoceptor agonists and antagonists, Acharya and Ovais (2007) pointed out that in *Orechromis mossambica* α_2 adrenoceptors are predominantly involved in the aggregatory responses of melanophores. The same has also been demonstrated in other teleosts by Morishita (1987), Martensson *et al.*, (1990), Martinotti (1991), Fujii (1993a) and Burton and Vockey (2000b).

Dispersed melanosomes   Aggregated melanosomes
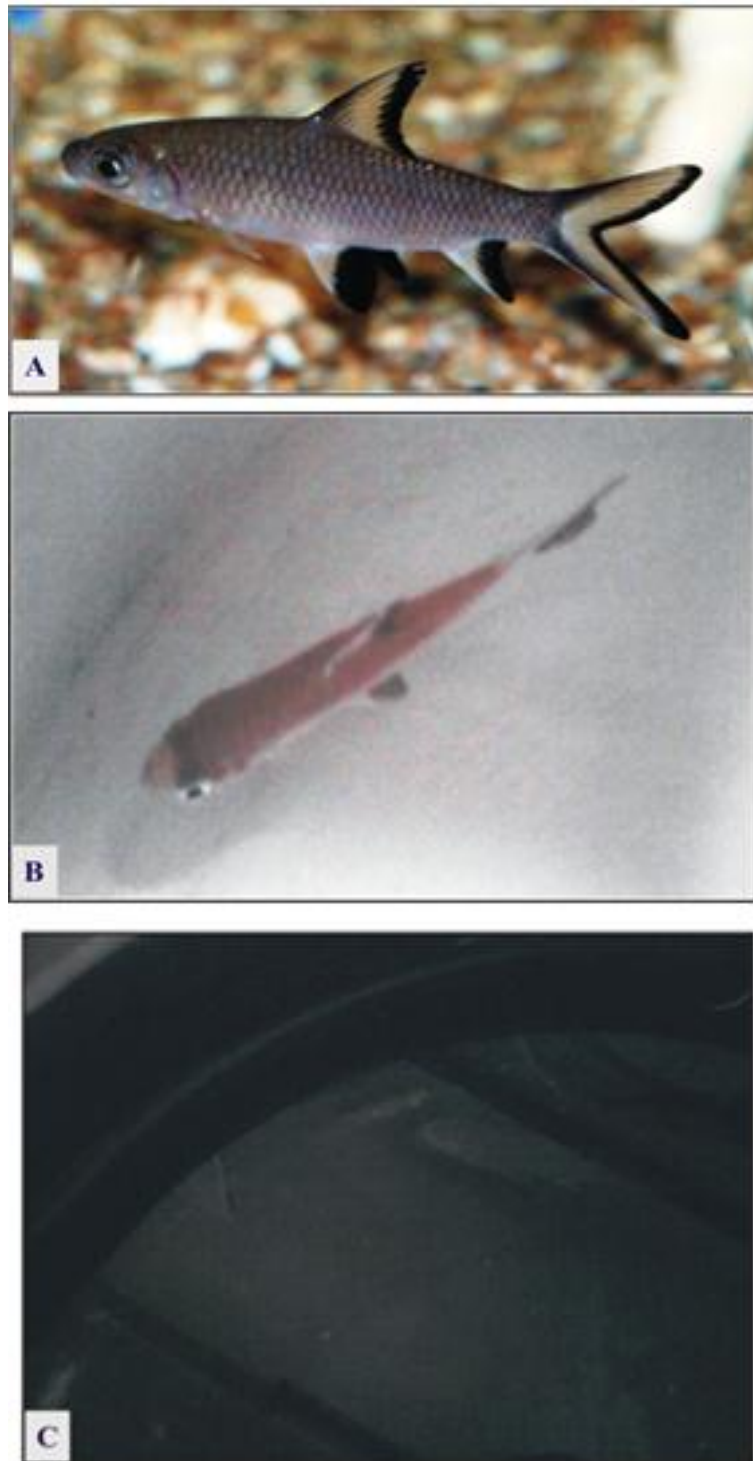
Fig. Fish *Belantiochelios melanopterus* behaviour

Fig. 1: (A) Photograph of freshwater teleost *Balantiochelios melanopterus*.

Fig. 1:   Photograph of freshwater teleost *Balantiochelios melanopterus*.
    (B) Fish adapted to White - background.
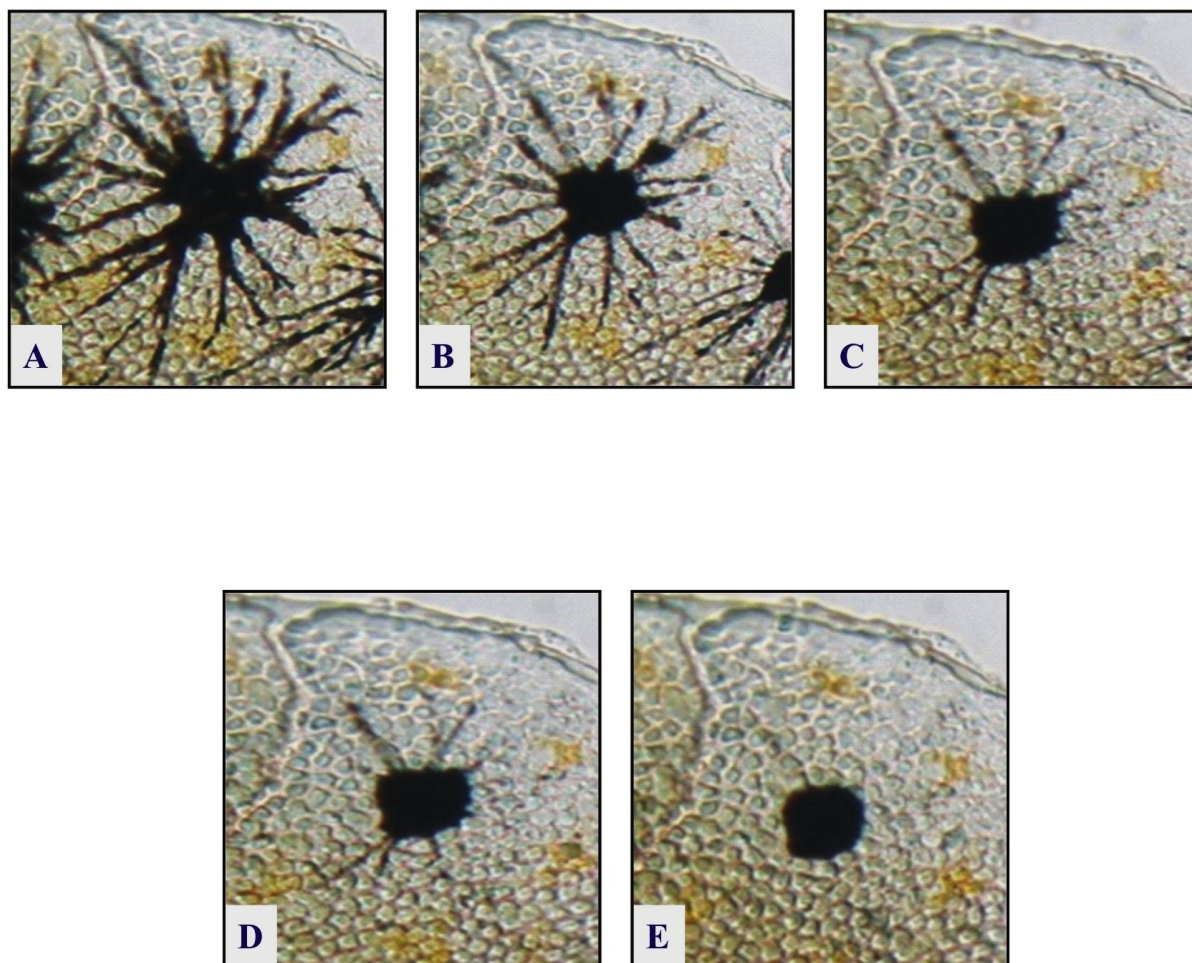   (C) Fish adapted to Black - background

Fig.2: Typical series of photomicrographs of a single melanophore showing Melanophore Index(M.I.) As used for measurement of drug induced *in vitro* melanophore responses in the fish x 100 .

     (A)   M.I.=5   (Fully dispersed state)
     (B)   M.I.=4
     (C)   M.I.=3 (M.I.=4,3 and 2 represent the intermediate state)
     (D)   M.I.=2
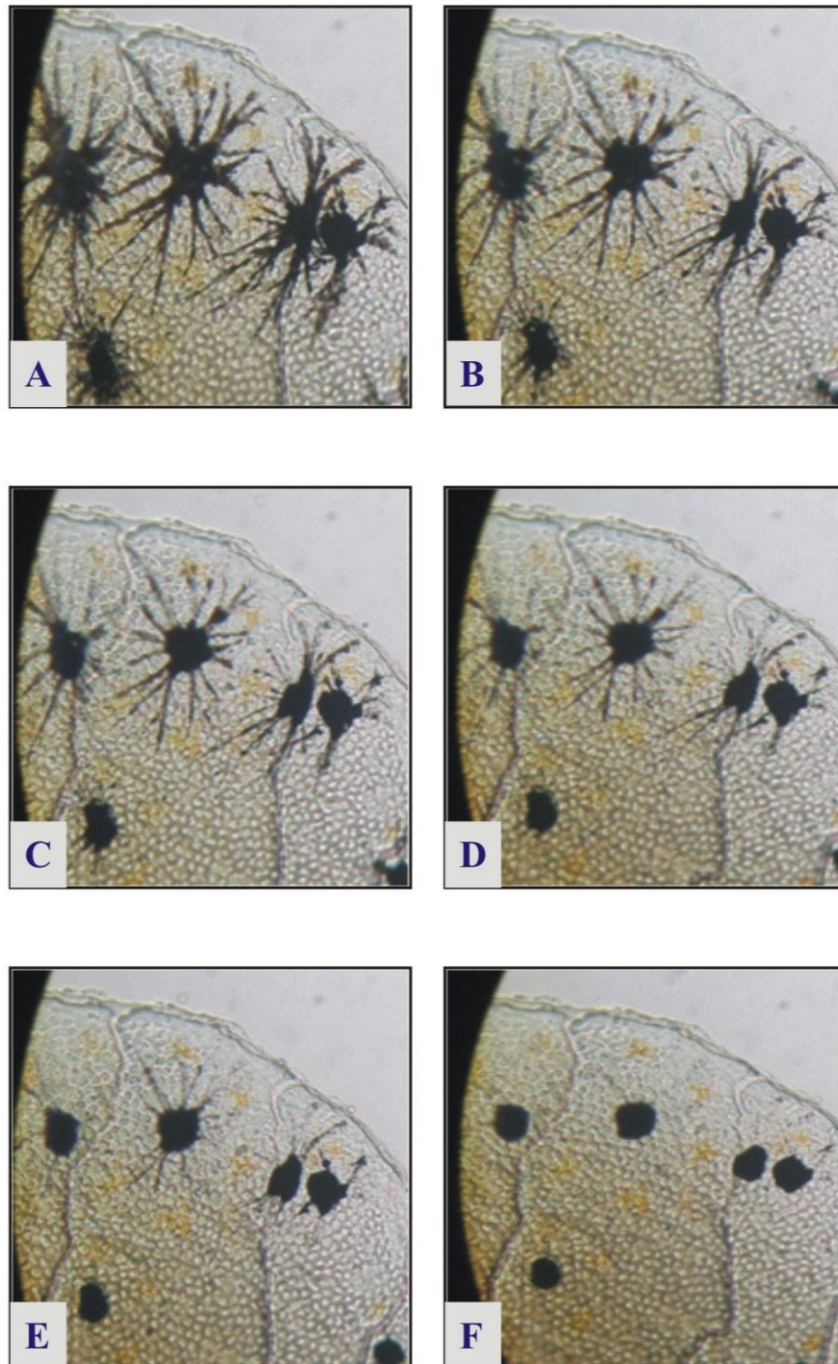   (E)   M.I.=1   (Fully aggregated state)

Fig.5: Typical serial photomicrographs showing effect of K^+-Ringer on melanophores in an isolated scale preparation x 100.
(A) Equillibrated in physiological saline (15 min) melanophores are completely dispersed, (B) 1 (min), (C) 2 (min), (D) 3 (min), (E) 4 (min) and (F) 5 (min) after the application of K^+-Ringer. (Melanophores are completely aggregated).
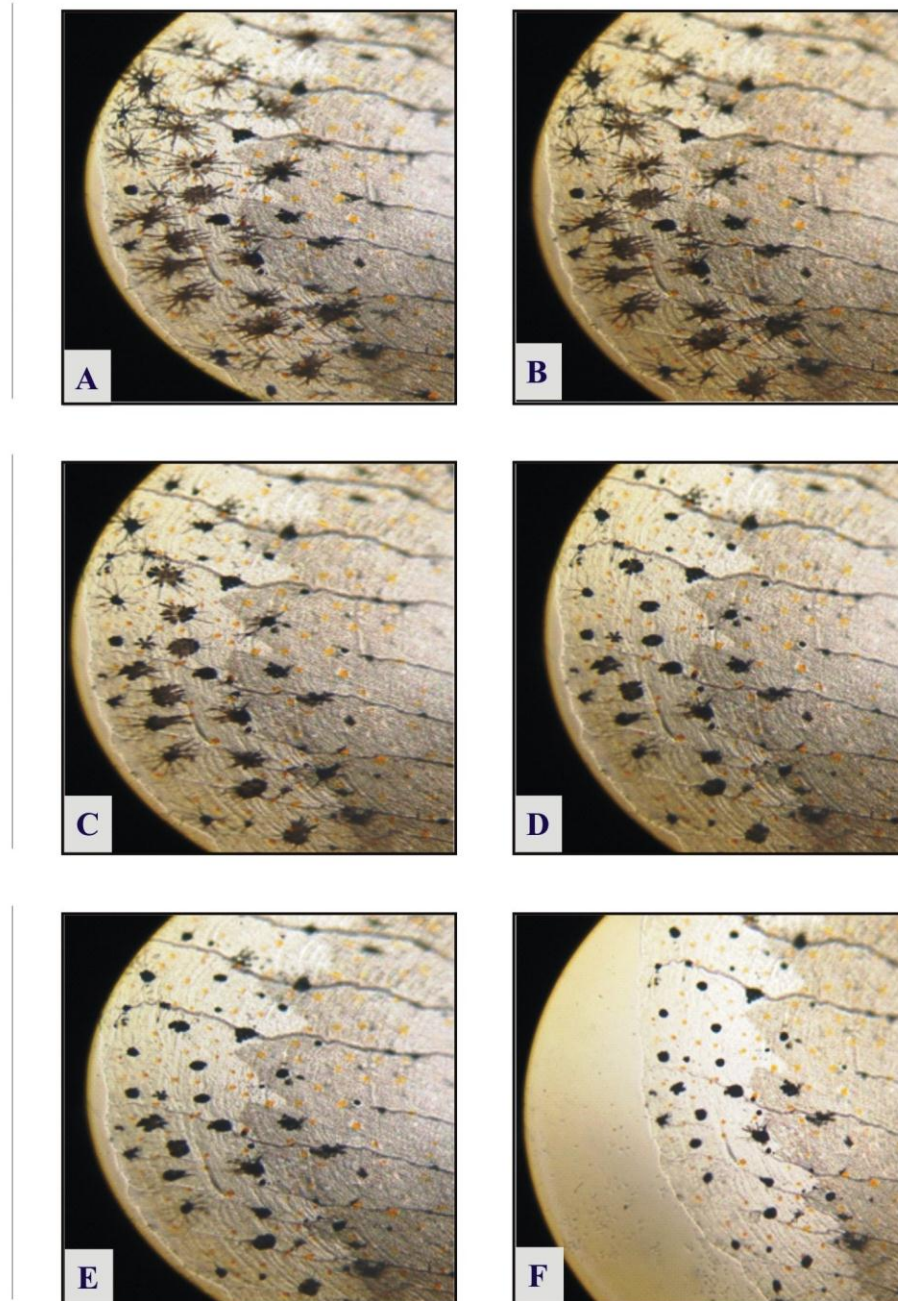
Fig.9: Typical serial photomicrographs showing effect of epinephrine (5×10^{-6} M) on melanophores in an isolated scale preparation of the fish x 100. (A) Equillibrated in physiological saline (15 min) melanosomes are completely dispersed in the melanophores, (B) 1 (min), (C) 2 (min), (D) 3 (min), (E) 4 (min) and (F) 5 (min) after the application of epinephrine (5×10^{-6} M) Melanophores are completely aggregated.

Melanophores display a radial array of microtubules extending from perinuclear area of the cell where microtubule organizing centre is located and projecting into cell extensions. Microtubule with minus end converges at the cell centre and their plus end points towards periphery. Thus in this arrangement, motor protein kinesin moves towards plus end of the microtubule (away from centrosome) causing dispersion and dyneins which move towards centrosome cause aggregation. Regulation of pigment transport involves changes in level of cAMP which regulate activity of microtubule motors (Nascimento *et al.*, 2003). Rapid transport in melanophores and erythrophores appears to occur in association with microtubules.

Adenosine and adenine nucleotides have been considered to take part in the control of effector activities (Sattin and Rall, 1970; Stone, 1981). In particular, the concept that some neuron which are non-cholinergic and non-adrenergic, might release a purine compound as a neurotransmitter, has become a matter of common knowledge (Burnstock, 1972). The presence of such a system has also been suggested in the neural control of chromatophore movements in fish (Fujii and Miyashita, 1976b). It has been shown that some purine compounds disperse pigment in chromatophores in at least some fish species (Fujii and Miyashita, 1976a; Ozato, 1977). Accumulated evidence indicates that adenosine or a related nucleotide is not a hormone but that it is released from neural elements either as a true transmitter or as a co-transmitter which modifies the former's action (Miyashita *et al.*, 1984).

Later work by Kumazawa *et al.*, (1984) has established the dual transmitter theory with a substantial difference, in terms of action, between the true transmitter (norepinephrine) and the co-transmitter (ATP). According to them, the effect of NE disappears very quickly while that of ATP lasts much longer. After the ceassation of neurous excitation, the latter can effectively reverse the action of former.

The melanotropic peptides play a major role in the control of vertebral integumental pigmentation. The two physiologically important melanotropins are α-MSH (α-melanocyte stimulating hormone) and MCH (melanin concentrating hormone).In lower vertebrates like fishes, MSH is released from the intermediate lobe of pituitary gland. The action of MSH on fish melanophores is mediated by receptors that are specific to peptide. (Fujii & Miyashita, 1980; Sharma, 1990). Extracellular Ca^{2+} ions are required for this action of MSH (Fujii, 1993a). MCH–secreted from the posterior lobe of pituitary induces colour changes in fishes, and it was originally isolated from salmon pituitary (Kawauchi *et al.*, 1983).

MCH was shown to elicit pigment aggregation in melanophores of almost all teleostean species when present at low concentrations (Wilkes *et al.*, 1984; Oshima *et al.*, 1985; 1986; Nagai *et al.*, 1986 Jain and Patil, 1990), and was shown to act via MCH receptors on the cell membrane (Oshima *et al.*, 1985). In frog and lizard melanophores, however, this peptide had no melanin-aggregating effect, but instead showed weak melanin-dispersing activity (an α–MSH–like activity), being approximately 600 – fold less potent than α – MSH on these melanophores (Wilkes *et al.*, 1984). On the other hand cyclic melanotropin (Cys4, Cys 10) α–MSH has been reported to be a potent agonist of tetrapod melanophores, leading to skin darkening (Sawyer *et al.*, 1982). Since MCH is also a cyclic peptide, Wilkes *et al. (*1984*)*, thought that melanin dispersion in response to MCH at higher concentration might be caused through the activation of MSH receptors by MCH.

Work done in India with regard to fish chromatophores and colour change includes aspects like integumantary colour pattern (Bhargava and Jain, 1974; Dwivedi, 1978; Dandegoankar, 1980; Dubey and Jain, 1983; Anand, 1985;Dubey 1991), transitory colour change (Bhargava and Jain, 1978; Dandegaonkar, 1980; Prabhakar, 1988), quantitative colour change (Dwivedi, 1976; Sharma, 1990) and circadian colour change (Bhargava and Jain, 1981), effect of pollutant on melanophores and colour change (Anand, 1985; Kulshrestha and Arora, 1988) and effects of other autonomic drugs on various fresh-water fish species that have been investigated from India include *Nandus nandus* (Jain, 1976), *Rasbora daniconius* (Dwivedi, 1978), *Heteropneustes fossilis* (Bhargava and Jain, 1978; Gupta 1988; Rajiv and Bhargava, 1990; Shrivastava, 1991; Gupta, 1992), *Labeo rohita* (Jain and Patil, 1990, 1992), *Puntius conchonius* (Khare, 1990), *Puntius sophore* (Dwivedi, 1995), *Cyprinus carpio* (pigment cell types *i.e.,* melanophores from the fresh water fish, *Balantiocheilos melanopterus*, belonging to family cyprinidae.

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REFERENCES

Acharya LSK, Ovais M. (2007) α_1 and α_2 adrenoceptor mediated melanosome

aggregatory responses *in vitro* in *Oreochromis mossambica* (Peter) melanophores. *Ind. J. Exp. Biol.* **45:** 984-991.

Adelman HB, Butcher EO. (1937) Experiments on the nervous control of the melanophores in *Fundulus heteroclitus. Bull. Ml. Desert I Biol. Lab.* 15-16.

Ahlquist RP. (1948) A study of the adrenotropic receptors. *Am. J. Physiol.* **153:** 586-600.

Amiri MH. (2009) Postsynaptic alpha-2 adrenoceptors mediate melanosome aggregation in melanophores of the white-spotted rabbitfish (*Siganus canaliculatus*). *Pak. J. Bio. Sci.* **12(1):** 1-10.

Anand S. (1985) Influence of the organophosphorus compound DDVP on the melanophores of the Indian major carp, *Cirrhinus mrigala* (Ham.). *M.Phil Dessertation, Jiwaji University, Gwalior (M.P.)*

Andersson RG, Karlsson JO, Grundstrom N. (1984) Adrenergic nerves and the alpha 2-adrenoceptor system regulating melanosome aggregation within fish melanophores. *Acta Physiol Scand.* **121**: 173-179.

Bagnara JT, Hadley ME. (1973) Chromatophores and colour change: The comparative physiology of animal pigmentation. *Prentice Hall, Inc, Englewood Cliffs, New Jersey*. 1-191.

Ballowitz E. (1893a) Die Innervation der chromatophorem. *Verh Anatl. Ger. Jena.* 7: 71-76.

Ballowitz E. (1893b) Nervenendingungen der pigmentzellen ein Beitrag zur Kenntnis des Zusammenhanges der Endverzweigungen der Nerven mit dem Protoplasma der Zellen. *Z. Wiss. Zool.* **56:** 673-706

Bauer DH, Demski LS. (1980) Vertical banding evoked by Electrical stimulation of the brain in anaesthetized green sunfish, *Lepomis cyanellus* and blue gills, *Lepomis macrochirus. J. Exp. Boil.* **84**: 149-60.

Bearends GP, Bearends –Van Roon JM. (1950) An introduction to the study of the ethology of cichlid fishes. *Behaviour.1:Suppl. P.* 1-242.

Bhargava HN, Jain AK. (1974) Studies on the morphological colour pattern of a fresh-water teleost *Nandus nandus* (Ham.) under normal background conditions. *Gegenbaurs morph. Jahrb.* **120:** 503-518.

Bhargava HN, Jain AK. (1978) Some aspect of colour change mechanism in the Indian fresh water siluroid, *Heteropneustes fossilis* (Bloch). *Biochem. Expt. Biol.* **14:** 359-373.

Bhargava HN, Jain AK. (1981) Circadian oscillation in the rate of paling of the Indian freshwater siluroid, *Heteropneustes fossilis* (Bloch). *Biochem. Exptl. Boil*. **14 (4)**: 359-373.

Brucke E. (1852). Denkschr. Akad. Wiss, wien. Mathnat. KI. **4**:179.

Burnstock G. (1972) *Pharmacol. Rev*. **24**: 509-581.

Burton D. (1980) A cellular analysis of chromatophores patterning in winter flounder (*Pseudopleuronectes americanus*, Walbum). *Comp. Biochem. Physiol.* **A67**: 453-457.

Burton D, Vokey JE. (2000a) The relative *in vitro* responsiveness of melanophores of winter flounder to α-MSH and MCH. *J. Fish Biol.* **56:** 1192–1200.

Burton D, Vokey JE. (2000b) α_1 and α_2-adrenoceptor mediation in melanosome aggregation in cryptic patterning of *Pleuronectes americanus. Comp. Biochem. Physiol.* **125A:** 359–365.

Bylund DB, Eikenberg DC, Hieble JP, Langer SZ, Lefkowitz RJ, Minneman KP, Molinoff PB, Ruffolo RR, Trendelenburg U. (1994) International union of pharmacology nomenclature of adrenoceptors. *Pharmacol. Rev*. **46**: 121-136.

Chowdhary M. (2003) Resposnses of fish (*Cyprinus carpio*) melanophores to some adrenoceptor activating and blocking drugs. *M.Phil. Dessertation. Jiwaji Univ. Gwalior.* (M.P.)

Colley AM, Hunt EL. (1974) Cyclic AMP and adrenergic receptors in *Gambusia affinis* melanophore response *in vitro. Gen. Endocrinol.* **23:** 154-163.

Dandegaonkar SD. (1980) Physiology of colour changes in tropical fish *Lepidocephalichthys thermalis, Ph.D. Thesis. Marathwada Univ. Aurangabad.*

De Groot SJ, Norde R, Verheijen FJ. (1969) Retinal stimulation and pattern in the common sole *Soka solea* (L.) (Pisces:soleidae) Netherlands *J. Sea Res.* **4**: 339-349.

Douglas WA, Lanzing WJR. (1981) Colour change and visual cues in the sand flathead, *Platycephalus arenarius* (Ramsay and Ogillay). *J. Fish Biol*. **18**: 619-628.

Dubey PK, jain AK. (1983) Melanophore characteristics in a freshwater teleosts, *Puntius conchonius* (Ham*). Z. Mikrosk. Anat. Forsch. Leipzing.* **97:** 329- 342.

Dubey PK, Maheshwari LD, Jain AK, Dubey PK (1991) The pineal organ and the colour change mechanism in a fresh water fish. *Ph.D Thesis. Jiwaji University, Gwalior.*

Dwivedi DK. (1976) Studies on color change mechanisms in freshwater fish. *Ph.D Thesis. Univ. Saugor, Sagar.*

Dwivedi DK. (1978) The effects of drugs on the melanophores of the teleost, *Rasbora daniconius. Aust. J. Pharm. Sci.* **7:** 29-31.

Dwivedi S. (1995) Neural control of pigment migration in the Puntius melanophore. Pharmacological observations. *M.Phill. Dissertation. Jiwaji University, Gwalior.*

Eberth CJ, Bunge R. (1895) Die Nerven der chromatophoren bei fishen. *Arch. Mika. Anat.* **46**: 370-373.

Falck B, Muntzing J, Rosengren AM. (1969) Adrenergic nerves to the dermal melanophores of the rainbow trout, *Salmo gairdneri. Z. Zelforsch. U. Microskope, Anat.* **99:** 430-434.

Fernando MM, Grove DJ. (1974b) Melanophore aggregation in the plaice *(Pleuronectes platessa L.)* I. Changes in *in vivo* sensitivity to sympathomimetic amines. *Comp. Biochem. Physiol.* **48:** 723-732.

Fernando MM, Grove DJ. (1974a) Melanophore aggregation in the plaice *(Pleuronectes platessa L.)* II. *In vitro* effects of adrenergic drugs. *Comp. Biochem. Physiol.* **48:** 711–721.

Fingerman M. (1963) The control of chromatophores. *Pergamon press. Oxford.*

Finnin BC, Reed BL. (1970) A pharmacological study of the controls existing over teleost melanophores. *Aust. J. Pharm. Sci. Suppl.* **51:** 25-29.

Fox DL. (1979) Biochromy University California Press, Berkeley.

Fujii R. (1961) Demonstration of the adrenergic nature of transmission of the junction between melanophores concentrating nerve and melenophore in bony fish. *J. Fac. Sci. Univ. Tokyo.* **9:** 171-196.

Fujii R. (1969) Chromatophores and pigment, in *Fish Physiology*, Vol. III, Hoar, W.S. and Randall, D.J; Eds. *Acad. Press, New York.***3:** 307-353.

Fujii R. (1993a) Coloration and chromatophores. In: Evans DH. The Physiology of Fish. *Boca Raton, FL: CRC Press*; 535-562.

Fujii R. (1993b) Cytophysiology of fish chromatophores. *Int. Rev. Cytol.* **143:** 191-255.

Fujii R. (2000) The regulation of motile activity in fish chromatophores. *Pigment Cell Biol.* **13:** 300-319.

Fujii R, Wakatabi H, Oshima N. (1991) Inositol 1,4,5–triphosphate signals the motile response of fish chromatophores–I. Aggregation of pigment in the tilapia melanophore *J. Emp. Zool.* **259:** 9-17.

Fujii R, Miyashita Y. (1975) Receptors mechanisms in fish chromatophores I- Alpha nature of adrenoceptors mediating melanosome aggregation in guppy melanophores. *Comp. Biochem. Physiol.* **51C:** 171-178.

Fujii R, Miyashita Y. (1976a) Beta adrenoceptors, cyclic AMP and melanosome dispersion in guppy melanophores. *In: Riley V (ed) Pigment Cell.* **3:** 336–344.

Fujii R, Miyashita Y. (1976b) Receptor mechanism in fish chromatophores–III Neurally controlled melanosomes aggregation in a Siluroid (*Parasilurus asotus*) is strangely mediating by cholinoceptor. *Comp. Biochem. Physiol.* **55 C:** 43-49

Fujii R, Oshima N. (1986) Control of chromatophore movements in teleost fishes. *Zool. Sci*. **3:** 13-47.

Fujii R, Oshima N. (1994) Factors influencing motile activities of fish chromatophores. In: Gilles R. *Advances in Comp. Environ. Physiol.* **20:** *Berlin: Springer-Verlag.* 1-54.

Fujii R, Jain AK, Miyashita Y. (1980) Note on the nervous control of melanophores of the Loach, *Misgurnus anguillicaudatus. J. Lib. Arts. Sci. Sapporo Med. Coll.* **21:** 61-73.

Gray EG. 1956. Control of the melanophores of the minnom, *Phoxinus phoxinus. J. Exp. Biol.* **33:** 448-459.

Grove DJ. (1969a) The effect of adrenergic drugs on melanophores of the minnow, *Phoxinus phoxinus* (L.) *Comp. Biochem. Physiol.* **28:** 37-54.

Grove DJ. (1969b) Melanophore dispersion in the minnow, *Phoxinus phoxinus* (L). *Comp. Biochem. Physiol*. **28:** 55-65.

Gupta PR. (1988) Melanin concentrating hormone (MCH): A potent agonist of melanosome aggregation within fish melanophores. *M.Phil dissertation. Jiwaji University, Gwalior.*

Gupta R. (1992) Neuronal and hormonal factors influencing colour changes in the Indian air-breathing catfish, *Heteropneustes fossilis* (Bloch.). *M. Phil Dissertation. Jiwaji Univ. Gwalior.*

Handa K. (2007) Chromatic behavior and melanophore response to some adrenergic drugs in the fish, *Trichogaster trichopterus* (Pallas) *M. Phil Dissertation. Jiwaji Univ. Gwalior.*

Healey EG. (1948) The colour change of the minnow (*Phoxinus laevis*). *Bulletin of Animal Behaviour.* **6:** 5-15.

Healey EG. (1957) In: The physiology of the fish. (Ed. Brown M.E.) *Academic Press, New York.*

Healey EG. (1967) Experimental evidence for the regeneration of nerve fibres controlling colour changes after anterior spinal section in the minnow, (*Phoxinus phoxinus* L.). *Proc. R. Soc. Lond.* **168:** 57-81.

Hoffmann BB. (1984) Adrenergic receptor activating drugs In: Basic and clinical pharmacology (Ed. Katzung B.G.). *Marizen Asian Edition.* pp. 86-95.

Iwata K S, Fukuda H. (1973) Central control of colour changes in fish: Responses of fish to Environmental Changes.(Ed. Chavn W.). *Spring field, C.C.Thoma.* 316-341.

Jain AK, Patil S. (1990) Evidence for melanin concentrating hormone (MCH) receptors mediating melanosome aggregation in *Labeo* melanophores. *Ind. J. Physiol. Pharmacol.* **34(3):** 187-190.

Jain AK. (1976) Studies on the colour change mechanism in a fresh-water fish. *Ph.D. Thesis. University of Saugar*, Sagar, M.P.

Jain AK, Bhargava HN. (1979). Studies on the colour change mechanism in fresh water teleost *Nandus nandus* (Ham) I Neural control. *J. Neural Transmission.* **44:** 51-63.

Jain AK, Patil S. (1992) α_2-adrenoceptor activation induced melanophore response in a fresh-water telesot, *Labeo rohita*: an *in vitro* and *in vivo* study. *Proc. Nat. Acad. Sci. India*. **62 (B) III**: 323-332.

Karlsson JOG, Andersson RGG, Elwing H, Grundstron N. (1987) Comparative studies on nerve and noradrenaline-induced melanosome aggregation within different species of fish. *Comp. Biochem. Physiol.* **88C:** 287-291.

Kasukawa H, Oshima N. (1987) Divisionistic generation of skin hue and the change in the scaly cheek damselfish, *pomacentrus lepidogenys. Pig. Cell. Res*. **1:** 152- 157.

Kasukawa H, Oshima N, Fujii R. (1986). A comparative survey of type of sympathetic neuromelanophores transmitter in Catfish. *Comp. Biochem. Physiol.* **85C**: 115-120.

Katayama H, Morishita F, Matsushima O, Fujiimoto M. (1999) Adrenergic receptor subtypes in melanophores of the marine gobies *Tridentiger trigocephalus* and *Chasmichthys gulosus. Pigment Cell Res***. 12:** 206-217.

Kawauchi H, Kawazoe I, Tsubokawa M, Kishida M, Baker BI. (1983) Characterization of melanin concentrating hormone in chum salmon pituitary. *Nature*. 305-321.

Khare B. (1990) Responses of integumentary melanophores produced by adrenoceptor agonist, antagonists and melanotropic peptides in a fresh water teleost, *Puntius conchonius* (Ham.). *M.Phil. Dessertation. Jiwaji Univ. Gwalior.* (M.P.).

Khoda Y, Watanabe M. (1982a) Relationship of colour pattern to dominance order in fresh-water serranid fish, *Coreoperca kawamebari. Zool. Mag*. **91:** 140-145.

Khokhar R. (1971) The chromatic physiology of the catfish *Ictalurus melas* (Rafinesque). 1. The melanophore responses of intact and eyeless fish. *Comp. biochem. Physiol*. **39A:** 531-543.

Kinoshita H, Ueda K. (1970) Physiological studies of fish melanophores – I. Concentration and dispersion response, elicited by electric stimulation *J. Fac. Sci, Univ. of Tokyo. Sec. IV*. **12:** 101-116.

Kulshrestha SK, Arora N. (1998) Effect of sublethal D.D.T. and Carbofuran exposure on the trunk melanophores of the fish, *Rasbora daniconius. Environ. Ecol*. **6**: 369-372.

Kumazawa T, Oshima N, Fujii R, Miyashita Y. (1984) Release of ATP from adrenergic nerve controlling pigment aggregation in tilapia melanophores. *Comp. Biochem. Physiol.* **78C:** 1-4.

Kuruvilla M. (1991) Studies on certain aspect of colour change mechanism in some fresh water teleost fish. *Ph.D. Thesis. University of Saugar*, Sagar, M.P.

Langer SZ. (1974). Presynaptic regulation of catecholamine release. Biochem. Pharmac. **23:** 1793-1800.

Lanzing WJR. (1977) Netherlands. *J. Sea Res*., **11**: 213-222.

Lanzing WJR, Bower CC. (1974) Development of colour patterns in relation to behavior in *Tilapia mossambica (Peters). J. Fish Bioil.* **6:** 29-41.

Martenson LGE, Andersson RGG, Karlsson JOG. (1990) A comparison of the α-adrenoceptor system regulating pigment migration in erythrophores and melanophores of *Labrus ossifagus. Comp. Biochem. Physiol*. **96C:** 399-404.

Martinotti E. (1991) α-adrenergic receptor subtypes on vascular smooth musculature. *Pharm. Research.* **24:** 297-306.

Miyashita Y, Kumazawa T, Fujii R. (1984) Receptor mechanisms in fish Chromatophores – VI Adenosine receptors mediate pigment dispersion in Guppy and Catfish melanophores. *Comp. Biochem. Physiol.* **77C**: 205-210.

Miyashita Y, Fujii R. (1975) Receptor mechanisms in fish chromatophores. II. Evidence for beta adrenoceptors mediating melanosome dispersion in guppy melanophores. *Comp. Biochem. Physiol* **88C**: 69-74.

Morishit F, Katayama H, Yamada K. (1985) *Comp. Biochem. Physiol.*, **81C**: 279-285.

Morishita F. (1987) Responses of the melanophores of the medaka, *Oryzias latipes*, to adrenergic drugs: evidence for α_2-adrenergic receptors mediating melanin aggregation. *Comp. Biochem. Physiol.* **88C**: 69–74.

Muske LE, Fernald RD. (1987). Control of a teleost social signal. I. Neural basis for differential expression of a color pattern. *J. Comp. Physiol. A* **160**: 89-97.

Nagai M, Oshima N, Fujii R. (1986) A comparative study of melanin– concentrating hormone (MCH) action on teleost melanophores. *Biol.Bull.* **171:**360-70.

Nagaishi H, Oshima N, Fujii R. (1992) Effects of Atropine on the melanophores and light–reflecting chromataphores of some teleost fishes *Comp. Biochem physiol.* **103C:** 363-368.

Nagiashi H, Oshima N. (1989) Control of the pigment migration in melanophores in the dorsal and ventral skin of the upside-down catfish. *Comp. Biochem. Physiol.* **93C:** 67-71.

Naitoh N, Nakai Y, Kawauchi H, Hayashi Y. (1985) Immunocytochemical identification of melanin-concentrating hormone in the brain and pituitary gland of the teleost fishes *Oncorhynchus keta and Salno gairdneri. Cell. Tissue Res.* **242:** 41-48.

Nascimento AA, Roland JT, Gelfand VI. (2003) Pigment model for the study of organelle transport. *Annu. Rev. Cell. Dev. Biol.* **19:** 469-491.

Needham AE. (1974) The significance of Zoochromes, *J. Springer–verlag, Berlin, Heidelberg, New York.*

Oshima N, Kasukawa H, Fujii R, Wilkes bC, Hruby VJ, Castrucci AML, Hadley ME. (1985) Melanin concentrating hormone (MCH) effects on telesots (*Chrysipters cyanea*) melanophores. *J. Exp. Zool.* **235:** 175-180.

Oshima N, Kasukawa H, Fujii R, Wilkies BC, Hruby VJ, Hadley ME. (1986) Action of melanin concentrating hormone (MCH) on teleost chromatophore *Gen. Comp. Endochrinol.* **64:** 381-388.

Ozato K. 1977. Effects of ACTH adenyl compound and methyl Lanthines on gold fish erthrophores in cultura. Gen. Comp. Endocri. **31:** 335-342.

Parker GH, Welsh JH, Hyde JL. (1945) The amount of acetyl choline in the dark skin and in the pale skin of catfish. *Proc. Natl. Acad. Sci. US.* **31:** 1-8.

Parker GH. (1948) Animal colour changes and their neurohumours. *Cambridge University Press.*

Patil S, Jain AK. (1989) The sympathetic neuromelanophore transmission in a freshwater Indian Major Carp. *Labeo rohita* (Ham) *Ind. J. Physiol Pharma.* **33:** 101-106.

Pouchet G. (1876) Des changements de coloration Sons 1' influence des-nerts. J. *Anat. Physiol.* **12:** 113-165.

Prabhakar RM. (1988) Photopigmentary responses in intact and eyeless fish *Labeo gonius* (Ham.). *M.Phil. Dissertation, Jiwaji University. Gwalior* (M.P.) India.

Rajiv PR, Bhargava HN. (1990) Effects of some adrenergic drugs on spinal sectioned and blinded *Heteropneusts fossilis* (Bloch) with a note on dispersing nerve fibres. *Proc. Nat. Acad. Sci. Ind.* **60:** 253-261.

Reed PL, Finnin BC. (1972) Pigmentation: Its genesis and biologic control. *Appleton-century-crofts, New York.*

Sattin A, Rall TW. (1970) The effect of adenosine and adenine nucleotides on the cyclic adenosine 3'5'–phosphate content of guinea pig cerebral cortex slices. *Mol. Pharmacy.* **6:** 13-23.

Sawyer TK, Hruby VJ, Darman PS, Hadley ME. (1982) [4-Half-cystine, 10-half-cystine]-α-melanocyte stimulating hormone: a cyclic α-melanotropin exhibiting superagonistic biological activity. *Proc. Natl. Acad. Sci. USA.* **79:** 1751-1755.

Scheline RR. (1963) Aderenergic mechanism in fish chromatophores pigment concentration in Cuckoo wrasse*, Labrus ossifagus* L. *Comp. Biochem. Physiol.* **l9:** 215-227.

Scott GT. (1965) Physiology and pharmacology of colour change in the sand flounder, *Scopthalmus aquosus. Limnology and Oceanography.* **10:** R 230-246.

Sharma B. (1990) Chromomotor colour change in *Puntius sophore* (Ham.): Influence of certain autonomic drugs and melanotropic peptides. *M.Phil. Dissertation, Jiwaji University, Gwalior.*

Shrivastava S. (1991) The beta adrenergic receptors and melanosome dispersion (darkening) in the Indian catfish *Heteropneustes fossilis* (Bloch). *M.Phil. Dissertation. Jiwaji University, Gwalior (M.P.).*

Singh A (2008) Photo-pigmentary responses and physiology of colour change in the nocturnal African catfish ,*Clarias geripinus* (Burchell,1822). *M.Phil Dessertation. Jiwaji University.*

Stone TW. (1981). Physiolgical roles for adenosine and adenosine-5-triphosphate in the nervous system, *Neuroscience.* **6:** 523-555.

Sugimoto M, Tuki M, Miyakoshi T, Maruko K. (2002) The influence of long term chromatic adaptation on pigment cells and striped pigment patterns in the skin of the zebrafish, *Danio rario. J. Zool. A Comp. Exp. Biol.* **303:** 430-440.

Vinconsti MA, Castrucci AML. (1981) Evidence of adrenergic and cholinergic

recerptors in teleost melanophores. *Comp. Biochem. Physiol.* **70C:** 293-296.

von Frisch K. (1911) Beitrage zur physiologic der pigmentzellen in der fischhart. *Pfligers Arch-ges. Physiol.* **138:** 319-381.

Voss J. (1970) Contribution a I'Ethologic des poisons Cichlides: *Pelmatochromis homasi* (Boulenger 1916). *Rev. Comp. Animal.* **4**: 17-29.

Waring H. (1963) Colour change mechanism of cold blooded vertebrates. *Acad. Press. New York.*

Wilhelm R. (1969) Vergleichende Untersuchungen Uber den nervous gesteurton farbweschsel der fische. *Z. Vergl. Physiol.* **65**: 153-190.

Wilkes BC, Hruby VJ, Castrucci AML, Sherbrooke WC, Hadley ME. (1984) Synthesis of a cyclic melanotropic peptide exhibiting both melanin concentrating and–dispersing activities. *Science.* **224**: 1111-1113.

Yamada K, Miyata S, Katayama K. (1984) Autoradiographic demonstration for adrenergic innervation to scale melanophores of a teleost fish, *Oryzias latipes. J. Exp. Zool.* **229:** 73-80.

Zhong H, Minneman KP. (1999) α_1- adrenoceptor subtypes, *Eur. J. Pharmacol.* **375:** 261-276.