PERSPECTIVES IN MARICULTURE

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Post Box No. 1604, Tatapuram P.O.,
Cochin - 682014

2001

The role of the pineal gland and photoperiodicity on growth, metabolism, reproduction in fishes and its application in aquaculture-a review

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ABSTRACT

The pineal gland, situated on the roof of the diencephalon of the brain in fishes, acts as a photoneuroendocrine gland which secretes the hormone melatonin. The secretion of this hormone is controlled mainly by photoperiodicity. This paper is a review of the numerous works showing the role of this gland and its hormone, on growth and metabolism of the body by inhibition of secretion of thyroxin, MSH and other opioid peptides; in the control of behavioural thermoregulation; and on reproduction through gonadal development and secretion of GtH-II with other steroids. The possible use of this knowledge as a modern tool in manipulating aquaculture production is also evaluated.

Introduction

Aquaculture is a viable means of diversification of fisheries to increase fish production both for domestic consumption and export, rural upliftment, employment and income generation to a large section of people (Krishnan, 1998). To meet the growing demand for aquaculture products, modern techniques must come up, which should be cheaper and convenient. This calls for basic research in functional physiology of the organisms, the results of which may ultimately help to modernize both the hatchery as well as culture techniques. The best example is that of the basic research on pituitary gland which revolutionized the induced breeding techniques in aquaculture industry and augmented the aquaculture production.

The pineal gland in fishes arises as a mid-dorsal neuroendodermal evagination from the roof of the diencephalon (Rasquin, 1958; Kavalier, 1980). It is basically a club-shaped or slightly elongated gland. The important contributions related to its morphology and histochemistry in fishes date back to 1905. The ultrastructure studies by electron microscope are contributed by McNulty (1978a, b, c;1979), Ueck *et al.* (1978), Falcon (1979a, b), Omura (1979, 1980), Omura and Ali (1980), McNulty *et al.* (1988), Gonzalez *et al.* (1990), Vigh *et al.* (1991), Wang (1994), Deng and Daren (1996). Basically the pineal gland consists of three parts called pineal sac, pineal thalamus and pineal stalk. Some of the workers (Yadav, 1995) have described it in two parts called pineal sac or end vesicle which is broad (anterior part) and pineal stalk which is elongated and narrow (posterior).

The pineal gland is a photoneuroendocrine gland which secretes the hormone melatonin (Gern *et al.*, 1988) and conveys information to the brain via neural pathway. Melatonin is an indole amine whose chemical composition is 5 - methoxy-N-acetyltryptamine described by several workers, and its precursor is serotonin. The pathway of biosynthesis and metabolism of melatonin in mammals has been described by Wesemann (1974) and Harper *et al.* (1979). In fishes the full pathway is yet to be studied. It is reported that serotonin- N-acetyltransferase (acrylalkylamine-N-acetyltransferase, AANAT) may be the first enzyme in the conversion of serotonin to melatonin which is found in fishes like trout and pike (Coon *et al.*, 1999), whereas, Hydroxyindole-O-methyltransferase (HIOMT) may be catalyzed during the last step in the melatonin biosynthetic pathway (Falcon *et al.*, 1994).

Melatonin is produced rhythmically and its synthesis is regulated either directly by ambient photoperiod in fishes as reported by Falcon (1984), Gern and Greenhouse (1988), Falcon *et al.* (1989). Takabatake and Iga (1991), May and Menaker (1992), Zachmann *et al.* (1992), Thibault *et al.* (1993), Yanez and Meissel (1995), Okimoto and Stetson (1995), Balliet *et al* (1996), Messel and Yanez (1996), Molina *et al.* (1996), Popek *et al.* (1997), Iigo *et al.* (1998), Simonneauk and Pevet (1998), or by an endogeneous circadian oscillator that is entrained by the photoperiod which is reported by Kavaliers (1979), McNulty (1981), Kikuchi and Aoki (1985), Mohapatra *et al.* (1988), Iigo *et al.* (1991), Radchenko (1993), Randall *et al.* (1995) and Okimoto (1998). Temperature is also involved with the photoperiod which is described by many of the above researchers. During natural conditions, melatonin is produced at the highest level during night and the lowest during day.

Portar with his associates in 1995 and 1996 reported that melatonin levels decrease in pinealectomized fish. It was demonstrated that the pineal gland was the only organ in fish, responsible for the presence of melatonin in the blood and the level oscillated regularly over 24 hours showing low values during day and high over night (Popek *et al.*, 1997).

It will be noticed at the end that in spite of the fact that, good amounts of research work has been directed to pineal gland and its secretion in other countries, very few works are observed in India and these also are restricted to a few fresh water fishes.

This review paper reveals the role of the pineal gland and its hormone melatonin on growth, metabolism and reproduction in fishes. The possible use of this knowledge as a modern tool in manipulating aquaculture production is also evaluated.

Function of pineal gland and melatonin

The pineal gland or epiphysis secretes the hormone melatonin according to photoperiodicity. The receptor cells of melatonin are found in brain in fishes (Martinoli *et al.*, 1991; Ekstroem and Vanecek, 1992; Falcon *et al.*, 1996), in heart as in salmonids (Pang *et al.*, 1994), in retina as in gold fish (Iigo *et al.*, 1997) and controls the growth, metabolic activities and reproduction. Among them, the reproduction and growth are the two main aspects in aquaculture production point of view.

Role of pineal gland and melatonin

On reproduction

A pineal control of gonadal maturation has been shown in fishes either by pinealectomy (Devlaming, 1975; Devlaming and Vodicnic, 1978; Vodicnic *et al.* 1978; Vodicnic *et al.*, 1979; Sagi *et al.*, 1983; Garg *et al.*, 1987, 1989; Kezuka *et al.*, 1989; Popek *et al.*, 1997) or by melatonin administration (Sakena and Anand, 1977; Reiter, 1977; Keshavanath, 1981; Joy and Agha, 1991; Bromage *et al.*, 1994; Senthilkumaran and Joy, 1995; Khan and Thomas, 1996) or by both (Joy and Khan, 1991). All the above authors have reported the relation between pineal gland and melatonin with reproduction. The pineal gland controls reproduction through secretion of its hormone melatonin through pineal-hypophysis-pituitary- gonadal axis. Administration of melatonin inhibits the stimulatory effect of a long photoperiod and high temperature on the ovary in early preparatory phase. Treatment with melatonin during preparatory phase resulted in decreased ovarian weight and arrested ovarian recrudescence (Sakena and Anand, 1977). When the gold fishes were pinealectomized in spring and exposed to long photoperiod conditions, the ovaries regressed and plasma gonadotropin levels were significantely depressed compared to sham operated animals. Sham operated gold fish exposed to short photoperiod conditions in spring had regressing ovaries whereas pinealectomized animals under this regime either spawned or had ovaries in the late vitellogenic phase (Vodicnic *et al.*, 1978). The pinealectomized mullet (*Liza ramada*) exposed to long photoperiod (16L/8D) for 14 weeks, showed undeveloped ovaries with maximum oocyte diameter of 100μm, whereas to short photoperiod (8L/16D) for 6 weeks, the mean diameter of oocyte was 270μm (Sagi *et al.*, 1983). In catfish like *Heteropneustes fossilis*, pinealectomy had no effect on gonadal activity during the preparatory, pre-spawning and spawning periods of the reproductive cycle. However, during the post-spawning period, under long or short photoperiod at 25° C or at gradually increasing ambient temperature, pinealectomy accelerated testicular recrudescence and secretory activity of the seminal vesicle (Garg, 1987). In *Channa punctatus*, pinealectomy results in an accelerated growth on the ovary in preparatory phase, but had no significant effect in pre-spawning or post-spawning phase (Joy and Khan, 1991). In fish like *Heteropneustes fossilis*, the gonadosomatic index (GSI) had decreased significantly by melatonin during preparatory and pre-spawning seasons, and also the melatonin administrations arrested vitellogenesis during the gonadal recrudescence (Joy and Agha, 1991). Khan and Thomas (1996) reported the role of melatonin in the control of gonadotropin-II (GtH-II) secretion in Atlantic croaker (*Micropogonias undulatus*) during different phases of day night cycle and seasonal reproductive cycle. Intraperitonial injection of melatonin during the late-night phase on the day night cycle elicited a significant elevation of plasma GtH-II levels in croaker with fully developed gonads. They reported that the stimulatory effect of melatonin was dose dependent. Melatonin inhibited LHRHa-induced GtH-II released during mid-dark phase of the day night cycle in a dose dependent manner. These authors concluded that melatonin can directly influence the pituitary to stimulate GtH-II release. The pineal gland can affect one of the phase of gonad maturation cycles in carp, probably through a stimulating influence of melatonin on estradiol-level in the final phase of vitellogenesis (Popek *et al.*, 1997).

By taking all the knowledge from different research groups, it is reported that pineal gland and melatonin are having either stimulatory or inhibitory effect on the gonadal development and the secretion of GtH-II with other steroids according to photoperiodicity.

Melatonin is also having the inhibitory effect on PGE (Prostaglandin E) and PGF (Prostaglandin F) and ovulation in fish like yellow perch (Stacey and Goetz, 1982). This hormone inhibits gonadal development by reducing the sex- steroid production in certain cases (Nayak and Singh, 1987). Again in 1988 these authors reported that this gland (through pinealectomy) inhibits these sex- steroids at certain stages in same species. This is in close conformity with the earlier findings of Fenwick (1970), DeVlaming *et al.* (1975), Sunderaraj and Keshavanath (1976), Sakena and Anand (1977), Borg and Ekstroem (1981), who reported that gonadal function (wt.and histology) are inhibited with the administration of melatonin. It appears that pineal gland and melatonin are having inhibitory effect to thyroid hormone in fishes during gonadal development and maturation (Nayak and Singh, 1987a, b), which is specially required for the sex steroidogenesis in the process of reproduction.

A review of the above will reveal the fact that reducing the natural melatonin production through using of long photoperiod will augment the gonadal development, thus helping in controlled breeding of fishes.

On metabolic activity and growth

Growth is the main criteria for aquaculture production ultimately, which mainly rely on metabolic activities. The pineal gland and its hormone play the role as an intrinsic controller according to environmental stimuli (photoperiodicity). Metabolism and growth processes are mainly controlled by the endocrine glands by their hormonal secretion and some of these hormones are controlled by the pineal gland. Melatonin has an inhibitory role to the thyroid hormone (Nayak and Singh, 1987a,b) which acts as one of the main growth inducing hormone in fishes. Nayak and Singh (1987b) reported from their experiment in fish *Clarias batrachus* that melatonin is having the inhibitory role to the sex steroid in certain doses.

The pineal gland regulates carbohydrate metabolism by altering insulin responsiveness in the animal like gold fish (Delahunty and Tomlinson, 1984a). Pinealectomy in this species causes a decrease in liver glycogen stores and disappearance in plasma glucose. These effects occur independently of photoperiod acclimation and are seasonal in nature. The hormone from this gland was observed having a hypoglycemic effect in the above species (Delahunty and Tomlinson, 1984b). According to Soengas *et al.* (1998), melatonin plays an indirect role, possibly through alterations in insulin physiology, in the regulation of carbohydrate and ketone body metabolism in brain of fish like rainbow trout. For the first time in the teleost like rainbow trout, the above authors reported the existence of changes in brain carbohydrate and ketone body metabolism due to melatonin treatment.

Removal of pituitary and epiphysis in young sturgeon, *Acipenser baeri*, significantly affects the total lipid content of the liver (Semenkova, 1984). Injection with melatonin changes lipid content in the liver of epiphysectomised fish. The nature of this change differs depending on the time of the treatment and duration of the photoperiod. Semenkova and Sautin (1990) suggested complicated interactions in the system of epiphysis-hypothalamus-hypophysis-lipid metabolism in liver of cartilaginous ganoids. Portar *et al.* (1998) investigated the role of melatonin and pineal gland as intermediaries in the transfer of photic information on daily and calender time in the control of the timing of the par-smolt transformation in the Atlantic salmon (*Salmo salar*). This is suggested by Rourke (1994) and Randall *et al.* (1994). However, the mechanism of this process is unclear.

Withyachumnarnkul (1992) suggested that the optic lobe of certain crustacea like *Macrobrachium rosenbergii* is the source of melatonin and increased the rate of limb regeneration in both eye stalk-intact and eye stalk removed groups like in fiddler crab, *Uca pugilator* (Tilden *et al.*, 1997). This is contrary to results of regeneration studies in other phyla, in which similar melatonin concentrations inhibited regeneration. Tilden *et al.* (1998) sugested that the crustaceans, however, are an exception in that melatonin production increased during the day and long photoperiods also increased the rate of limb regeneration. Therefore, melatonin may be mediating long-day effects on regeneration and other physiological process in crustaceans.

Other roles of pineal gland and melatonin

Several authors have reported that this gland and its hormone have the role to play in the colour change mechanism in fishes (Bhargava and Jain, 1978; Fujii and Miyashita, 1978; Nayudu and Hunter, 1979; Kavaliers 1980; Matsumoto *et al.*, 1982; Iwakiri, 1983;Ohta and Ono, 1983; Kasukawa and Fujii, 1984; Sugimoto *et al.*, 1985; Nishi *et al.*, 1991; Fujii *et al.*, 1992; Takabatake *et al.*, 1992; Nishi and Fujii, 1992; Visconti and Castrucci, 1993; Filadelfi and Castrucci, 1994; Maartensson and Andersson, 1997; Goda and Fujii,1998).There is substantial evidence that the pineal is involved in determining circadian and seasonal organisation in teleosts (Kavaliers, 1979a,b,c; 1980a,b,1981a,b; Tabata *et al.*, 1991). These effects may arise from the pineal photoreceptive functions, the role in circadian integration, and temporal organisation of hormonal physiological and behavioural events through CNS modulation. The pineal gland is involved in the control of behavioral thermoregulation in fishes (Kavaliers and Ralph, 1980; Kavalier, 1982a,b; Varghese and Pati, 1997). and Pati, 1997)

The pineal gland in anadromous fish like salmonids may play a role in the migratory behaviour (Weber and Smith, 1980), and schooling activity in fish like *Chromis viridis* (Sparwasser, 1987) .The influence of the eye and pineal gland on locomotor activity rhythm of channel cat fish, *Ictalurus punctatus, and* the extent to which varying light intensity altered these activity rhythms were evaluated by Goudie *et al.* (1983). Pinealectomized fish exhibited nocturnal activity patterns, which corresponded with the exogenous photoperiod.

Photoperiodicity, control of melatonin production and their role in aquaculture

The production of melatonin is mainly controlled by the photoperiodicity of the environment suggesting that the secretion will be only in scotophase in fishes. This secretion is having mainly inhibitory role to the other hormones in certain stages and periods, which are required for somatic as well as gametic growth of the fishes. By increasing the photoperiodicity at certain stages, the secretion of melatonin can be reduced which leads to the secretion of other required hormones for both gametic as well as somatic growth enhancement, which is the main objective in scientific aquaculture.

Several workers reported that, in fishes, photoperiodicity along with temperature play the major role in reproduction (Razani *et al.*, 1987; Richter *et al.*, 1987; Nakari *et al.*, 1987; Walsh, 1987; Fores *et al.*, 1988; Cantin, 1988; Pavlidis *et al.*, 1989; Jafri, 1989; Adams and Thorpe, 1989; Micale and Perdichizzi, 1990; Agarwal *et al.*, 1990; Grier, 1991; Srivastava and Singh, 1991; Aida, 1992; Kumari and Dutt, 1995; Taranger, *et al.*, 1998), growth (Stefansson *et al.*, 1989; Thorensen and Clarke,1989; Wright *et al.*, 1991; Parma-De-Crouk,1996) and metabolism (Boujard and Leatherland,1993).Therefore through artificial manipulation of photoperiod, we can quicken the metabolic activity, somatic as well as gametic growth in fishes and crustaceans. By using artificial illumination, in combination with temperature regulation, it is now possible to advance or delay the internal clock of fishes and thereby manipulate the timing of smolt transfer in case of salmon. By using this technique at Stirling in conjunction with a series of commercial smolt producers, Portar *et al.* (1999) have produced smolts at regular intervals through the summer, autumn and winter (Fig-1). With such smolt transfers, sectors of the industries are now producing 3-4 Kg salmon through out the year. Fig-2 shows the growth profiles achieved from a series of such 0+smolt transfer. They indicate that the plasma melatonin must be reduced below the threshold level by artificial lighting before the modified photoperiod is capable of altering the timing of smoltification. It is important that, fish in open environments are exposed to ambient light, if the additional artificial illumination is of lower intensity than natural day-time light level. If this is not done, then plasma melatonin may remain above critical threshold levels and so the fish will not respond to the light. Rimmer in Australia achieved reliable spawning in grouper using environmental control like light with temperature.

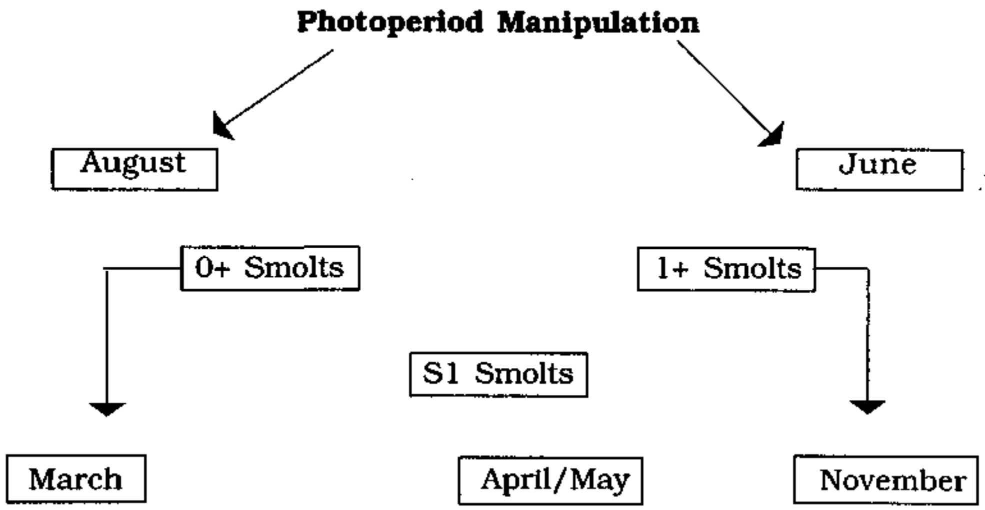

Fig. 1: All- year round smolt production using photoperiod manipulation.

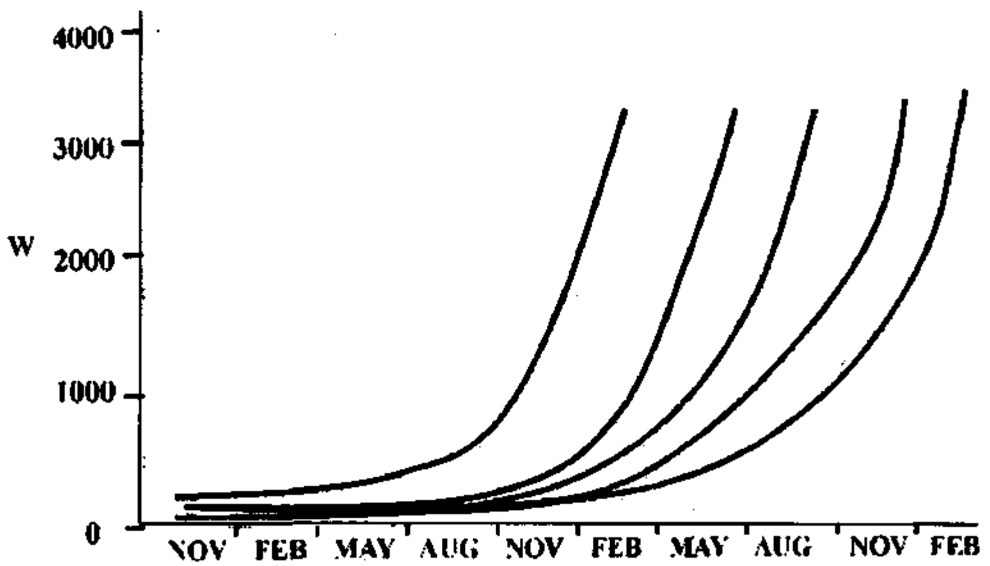

Fig. 2: Growth of 0+ and S1 smolts from seawater transfers in November, December, March, May and October upto harvest weight (3-4 Kg) Source: Figure 1 and 2, Porter *et al.*, Light manipulation, Melatonin and the All - Year - Round Supplies of 3 - 4 Kg Salmon. *Aquaculture News*, July 1999, pp.31-32.

Conclusion

A good deal of evidence has been collected suggesting that the pineal gland, upon receiving light information, directly or indirectly, produces melatonin, which controls many body functions. So, by using this technique described above i.e. by the manipulation of photoperiodicity in certain stages and seasons we can control the secretion of melatonin and ultimately increase the gametic as well as somatic growth. This is a simple technique, which may be used to induce maturation and growth thereby augmenting aquaculture production. For this, intensity of light and duration is very important. So attention must be given to standardize the light intensity along with duration. The melatonin secretion may be reduced chemically in certain stages that will increase the production of other induced hormones required for growth and reproduction. This is possible only after understanding the exact metabolic pathway of melatonin in fishes. So emphasis must be given towards research in this direction.

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