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A Review on the Reproductive Dysfunction in Farmed Finfish

S. Selvaraj[1*], P. Chidambaram[1], V. Ezhilarasi[1], P. Pavin Kumar[2], T. L. S. Samuel Moses[1], Cheryl Antony[1] and B. Ahilan[1]

[1]Department of Aquaculture, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Dr. M.G.R. Fisheries College and Research Institute, Ponneri, Tamil Nadu 601 204, India.
[2]Department of Fisheries Resource Management, Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Dr. M.G.R. Fisheries College and Research Institute, Ponneri, Tamil Nadu 601 204, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Globally, fish production in the wild is decreasing, and different aquaculture systems are presently being used for broodstock development in the captivity. Seasonally, broodstock raised in captivity exhibit different form of reproductive dysfunction at the level of the brain-pituitary-gonad (BPG) axis. Primarily, vitellogenic completion and final oocyte maturation are inhibited in females, and males fail to spermiate spontaneously in the captivity. Reproductive dysfunctions are also observed during sexual differentiation, pubertal onset and sex conversion periods in teleosts. To overcome these problems, different hormonal preparations, primarily gonadotropin-releasing hormones (GnRH) are used. In recent years, kisspeptins have been shown to be potent in inducing gonadal growth and maturation in teleost fish. Understanding the form of reproductive dysfunction is important in formulating suitable hormonal preparations for inducing gametogenesis. The paper reviews the problem of reproductive dysfunction and their possible reason for formulating different hormonal preparations.

**Corresponding author: E-mail: selvaraj@tnfu.ac.in;*

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1. INTRODUCTION

Fish maintained in different aquaculture system fail to experience natural environmental conditions, and result in the failure of reproductive system to complete normal gametogenic cycle in the captivity. Cultured adult fish exhibit different form of reproductive dysfunction, observed during seasonal reproductive cycle [1–9]. In gonochortistic female teleost fish, the two major problems encountered are failure to initiate and complete the vitellogenesis, and the other is failure to undergo final oocyte maturation and ovulation, after completion of vitellogenesis in the captivity. In cultured males, spermiation is the major problem encountered; however, problem in the completion of spermatogenesis have been reported in few cultured freshwater and marine species [4,6]. A shift in the sexual differentiation and pubertal onset timing periods has been reported in few farmed finfish [10]. Particularly, pubertal onset is delayed in number of large teleost species including marine scombrids which take several years to initiate first reproductive cycle in the captivity [11–14]. Primarily, low activities of different elements of reproductive brain-pituitary-gonad (BPG) axis including kisspeptin, gonadotropin-releasing homone and sex steroid have been attributed primarily to the reproductive dysfunction in captivity.

2. REPRODUCTIVE BRAIN-PITUITARY-GONAD (BPG) AXIS

BPG axis is a reproductive axis involved in the regulation of fish gametogenesis [3,15,16,17–21]. It is well known that brain gonadotropin-releasing hormone (GnRH) play a major role in the control of pituitary gonadotropins, follicle stimulating hormone (FSH) and luteinizing hormone (LH). These pituitary GtHs in turn regulate the production of sex steroids driving different stages of gametogensis [22]. As teleost fish express multiple GnRH forms in the brain, more than one form suggested to be involved in the stimulation of pituitary gonadotropins suggesting their complexity in modulating gametogenesis [3].

Particularly, in late evolved fish, such as Perciformes, Atheriniformes and Pleuronectiformes expressing three GnRh forms, GnRh1 form has been shown to be predominantly involved in the control of pituitary Fsh and Lh release [3,23]. In cyprinids and salmonids expressing two GnRh forms, GnRh3 form was found to be controlling the pituitary Fsh and Lh release [8,24]. GnRH acts at a highest level of the BPG axis and has advantage than the use of pituitary gonadotropin preparations including crude pituitary extract and HCG. Chemically synthesized GnRH eliminates the risk of the transmission of disease, and high degree of interspecies similarity of GnRH decapeptides allow single preparation to be used for more than one fish species [25]. The differences in multiple GnRH forms need to be considered while selecting inducing agents based on GnRH in finfish breeding. In recent years, several upstream regulators have been demonstrated to influence GnRH systems in fish [9,26–28].

3. REPRODUCTIVE DYSFUNCTION IN FARMED FINFISH

Cultured eel, mullet and jack mackerel fail to complete vitellogenesis in the captivity, based on the observation of repeated injection of inducing agents like human chorionic gonadotropin (hCG) and GnRH failing to induce positive influence [8,29]. Interestingly, few studies have indicated low expression of brain *gnrh1*, and pituitary *fsh* and *lh* in cultured fish, in comparison to wild fish of similar reproductive stages [30–33]. Also, studies have confirmed low level of circulating Estradiol-17β in the peripheral circulation and low expression of aromatase [3,34]. These low expressions of different elements of BPG axis result in higher rate of ovarian atresia.

In marine scombrids including chub mackerel, female fish fail to complete final oocyte maturation in captivity. In these species, studies have confirmed low level of pituitary GnRH and LH [32,33,35,36]. Also, circulating levels of maturation inducing hormone, 17α,20β-dihydroxypregn-4-en-3-one (17α,20β-DP) have been low in captive fish when compared to wild fish of the same reproductive stage. Similar reasons have been attributed to male fish failing to spermiate in captivity. Overall, it is clear that captive stress and absence of natural environment results in the reduced activity of BPG axis [3,5,6,37–39].

In gonochoristic male fish, spermiation is the major problem encountered. However, problem at the level of spermatogenesis have been reported, and few freshwater species fail to

undergo spermatogenesis in captivity. In addition, few species of captive females and males take longer duration to undergo gonadal growth and maturation. To overcome these problems, several hormonal preparations have been used and found to show prominent results [3,8]. Gonadal steroids play major roles in controlling the synthesis and release of FSH and LH, and both positive and negative feedback effects of androgen and estrogen have been demonstrated in teleosts [11,22,40–44]. In captivity, operation of positive and negative back loop affected due to onset of ovarian follicular atresia and apoptosis, resulting in low level of sex steroids.

Due to lack of suitable environmental conditions and limited breeding tank space, significant rise in the hormonal levels of brain GnRH, pituitary GtHs and sex steroids are not observed [5,6,45]. This is observed in several species including Indian major carps, Chinese carps and Indian catfish which fail to exhibit spawning in the captivity [46-51]. Crude pituitary extracts containing gonadotropins and purified fish gonadotropins were used for induced breeding in salmonids, cyprinids, cichlids and later attempted in several finfish [1,2,52–60]. In recent years, slow releasing devices like osmotic pumps are used for administering pituitary extract particularly in species which fail to initiate vitellogenesis in captivity. Japanese eel (*Anguilla japonica*), which fail to initiate vitellogenesis in captivity, implantation of a single salmon pituitary extract loaded osmotic pump (1.5–4 mg/day/fish) significantly stimulates vitellogenesis, and subsequent implantation of the same osmotic pump yield fully-grown female eels [29]. Similar strategy can be applied for species exhibiting severe reproductive dysfunction in captivity [24].

Difficulty in obtaining the purified and concentrated form of fish gonadotropins, other inducing agents like GnRH analogues are presently used widely in the aquaculture. Particularly, synthetic GnRH based analogues like Ovaprim, Ovatide and WOVA-FH and several other products designed based on GnRH based analogue are presently used for induced breeding of finfish in India [50, 61]. Particularly, in cyprinids showing strong dopaminergic inhibition, dopamine receptor antagonists like domperidone and pimozide are incorporated along with LHRH or GnRH preparations [54,62]. Like pituitary extract, few studies have indicated the potency of brain extract to induce pituitary gonadotropins under in-vitro and in-vivo conditions [23,63].

Multiple spawning in Chinese carps has been achieved through administration of multiple hormones. Two injections of luteinizing hormone releasing hormone analogue (LHRH-a), human chorionic gonadotropin (HCG), carp pituitary (PG) or a combination of two of these induces multiple spawning in Chinese carps [48]. Additionally, multiple spawning is affected in captive maintained females and males. This is mainly due to the sustained release of brain GnRH and pituitary LH in subsequent progression of different stages of gametogenesis. In few species, decrease in the circulating sex steroids has been demonstrated, resulting in ovarian follicular atresia and failing to spermiate in females and males, respectively. In Indian catfishes, administration of oxytocin after GnRHa injection induces voluntary captive spawning, suggesting possibility in application of similar methods for obtaining higher quality eggs in Indian major carps and Chinese carps [63,64]. In recent years, development of ELISA based systems for quantifying the circulating FSH and LH level in fish blood have improved our understating on their involvement in different stages of gametogenesis, and hormone dose requirement for induced breeding in aquaculture.

4. GnRH ANALOGUES IN INDUCED BREEDING

The functional part of GnRH protein is decapeptide that is processed from the precursor by removal of the signal peptide and cleavage at the dibasic amine acid to separate GnRH associated peptide (GAP) region [3,24]. NCBI GenBank accession nos. of finfish expressing three and two GnRH forms in the brain are shown in Table 1 and Table 2, respectively. Amino acid sequences of multiple GnRH forms in finfish are presented in Table 3. Teleosts share the mammalian GnRH (mGnRH) form in the GnRH1 group with other vertebrates [65,66]. However, different variant of GnRH1 form has been reported in seabream (*Sparus* aurata), medaka (*Oryzias latipes*), pejerrey (*Odontesthes bonariensis*), African catfish (*Clarias gariepinus*), herring (*Clupea harengus pallasi*), whitefish, (*Coregonus clupeaformis*), spotted catshark (*Scyliorhinus canicula*), dogfish (*Squalus acanthias*) and Sea lamprey, *Petromyzon marinus* [3,67] (Table 1).

Decapeptide GnRH analogues commonly used in finfish breeding are an analogue of mammalian GnRH, called LHRHa and an analogue of salmon GnRH, called sGnRHa

[7,102]. GnRH analogues are primarily designed from the functional decapeptide region. Amino acid at position 6 (Glycine) is highly conserved in different fish species but suggested to be a target site for proteolytic digestion and thus, reducing the half-life of the peptide in circulation [103]. In these analogues, two modifications are performed. D-Amino acid that are mirror image forms of naturally occurring L-form, are substituted at 6^{th} position, making GnRH analogue more resistant to degradation and increased half life in the peripheral circulation [104]. Also, both analogues lack 10^{th} amino acid, and instead end with an ethylamide (NH-CH_2-CH_3; abbreviated as NEt). This modification at 10^{th} position increases binding affinity towards its cognate receptor. The primary structure for mammalian GnRH is Glu-His-Trp-Ser-Tyr-Gly-Leu-Arg-Pro-Gly-NH_2 and the corresponding analogue is Glu-His-Trp-Ser-Tyr-D-Ala-Leu-Arg-Pro-NH-CH_2-CH_3. Likewise for salmon GnRH is Glu-His-Trp-Ser-Tyr-Gly-Trp-Leu-Pro-Gly-NH_2 and the corresponding analogue is Glu-His-Trp-Ser-Tyr-D-Arg-Trp-Leu-Pro-NH-CH_2 -CH_3 [53,102]. Amino acid sequences of GnRH analogues used in induced breeding of finfish are presented in Table 4. GnRH decapeptide and its synthetic analogues are shown to stimulate gonadotropin secretion in teleosts. However, in many cyprinids gonadotropin releasing inhibiting factor (GRIF's) inhibits the effect of GnRH decapeptide on gonadotropin (GtH) release. This inhibitory effect is prevented by inclusion of dopamine receptor antagonists such as domperidone, pimozide, metoclopramide, or reserpine in the GnRH decapeptide [53,54]. GnRH analogues are sold in many brand names in different countries, with modifications in 6^{th} and 10^{th} amino acid positions. These analogues are administered using different ways: intramuscular, intravenous, intraperitoneal and intracranial.

Several studies have indicated use of different forms of GnRH decapeptide in inducing GtH mRNAs under in-vitro conditions including differential response of administered GnRH at different stages of gametogenesis [30,103]. Lumayno et al. [39] demonstrated that all three native forms of GnRH including a mammalian GnRH analogue stimulate luteinizing hormone from cultured pituitary cells of chub mackerel under invitro condition, suggesting the potency of native multiple GnRH forms in induced breeding. Several studies have demonstrated that GnRH2 (cGnRH-II form) has a higher binding affinity compared to other GnRH forms mainly due to the preconfigured β-II' conformation [104].

GnRHa releasing-systems are successfully used to stimulate gonadal development, maturation and spawning of the gametes in several finfish species [4,61,105,106]. During the last two decades, various GnRHa administration methods were evaluated in aquacultured finfish [4,24]. For sustained release of pituitary gonadotropin in stimulating gametogenesis in multiple spawning finfish, recent developments resulted in the GnRHa incorporation in a polymeric controlled releasing system, which allow releasing of hormone from controlled devices like osmotic pumps for a period or days or weeks or months [4,26,106,107]. The compounds commonly used as slow releasing medium are cholesterol and cellulose, lactic acid and glycolic acid, or co-polymers of dimer fatty acid and sebasic acid, or acetate of ethylene and vinyl (EVAc). Depending on the type of reproductive dysfunction and species size, body shape and other biological features of the species, slow-releasing medium and -devices can be selected for induced breeding.

5. PUBERTAL ONSET IN FARMED FINFISH

Puberty in fish is the developmental period during which an individual becomes capable of reproducing sexually for the first time, and associated with an appearance of meiotic germ cells in the testis and ovary [108–110]. Several reasons have been hypothesized for delay in the onset of puberty in fish [10]. One major reason is the delay in the complete maturation of immune-euroendocrine circuits and networks. Unlike mammals, fish lack bone marrow and lymph nodes; instead, the spleen and head kidney are sites for the interaction of immune system with antigens and harbor the antibody producing lymphocytes. The thymus is a primary lymphoid organ acting as a centre of T-lymphocyte maturation and it is possible that delay in the complete maturation of this centre can result in delay in pubertal onset in fish [111]. Members of the activin/inhibin subfamily have been found to play a major role in T cell homeostasis. Follistatin is a single chain protein with biological activities similar to those of inhibin, but it structurally unrelated to activin and inhibin. All the above three proteins are shown to regulate pituitary FSH secretion without significant effects on luteinizing hormone. Activin stimulates, whereas inhibin and follistatin suppress FSH secretion. It is possible that delay in the activation of the above system may result in the delayed progression of gametogenesis due to low activity

of FSH. It is well demonstrated that an increase in FSH level is necessary for progression of early gametogenesis [112]. In recent years, kisspeptin has been shown to be involved in the activation of reproductive BPG axis with evidences in few fish indicating that GnRH neurons express kisspeptin receptors to influence other downstream regulators [13,17,113]. Interestingly, in fish showing positive influence of kisspeptin on pubertal onset, emerging studies indicate that leptin directly influences gonadotropin secretion as leptin transmits information about energy stored in the peripheral tissues like adipose tissue and liver to the reproductive axis [114-115]. Additionally, in-vivo administration of functional kisspeptin peptides induces spermatogenesis and oogenesis in immature fish [24]. Maintenance of constant temperature in different aquaculture systems induce early pubertal onset in farmed finfish [116,117]. Recent studies also indicate peripheral signals like leptin produced in liver and adipose tissues are involved in the control of pubertal onset in fish [13,28,115]. In migratory salmonids, salinity and photoperiod modulate pubertal onset [118]. In recent years, surrogate broodstock technology has been used to produce donor-derived gametes in surrogates [119,120].

Table 1. GenBank accession nos. of finfish expressing three GnRH forms

Fish	GenBank Accession Nos.			References
	gnrh1	***gnrh2***	***gnrh3***	
Gilthead seabream, *Sparus aurata*	U30320	U30325	U30311	[68]
African cichlid fish, *Haplochromis burtoni*	AF076963	AF076962	AF076961	[69]
Medaka, *Oryzias latipes*	NP_001098169	NC_019863	AB041335	[70,71]
Sea lamprey, *Petromyzon marinus*	AF14448.1	AF144481, DQ457017	AY052628	[72,73]
European sea bass, *Dicentrarchus labrax*	AF224279	AF224281	AF224280	[74,75]
Barfin flounder, *Verasper moseri*	AB066360	AB066359	AB066358	[76]
Atlantic croaker, *Micropogonias undulatus*	AY324668	AY324669	AY3246670	[77]
Spotted green pufferfish, *Tetraodon nigroviridis*	AB212811	AB212812	AB212814	[78]
Nile tilapia, *Oreochromis niloticus*	AB104861	AB104862	AB104863	[79]
Cobia, *Rachycentron canadum*	AY677175	AY677174	AY677173	[80]
Pejerrey, *Odontesthes bonariensis*	AY744689	AY744687	AY744688	[81]
Black porgy, *Acanthopagrus schlegelii*	EU099997	EU099996	EU117212	[82]
Grey mullet, *Mugil cephalus*	AY373450	AY373451	AY373449	[83]
Goldlined seabream, *Rhabdosargus sarba*	EF433770	EF433771	EF433772	[84]
Grass puffer, *Takifugu niphobles*	AB531127	AB531128	AB531129	[85]
Bambooleaf wrasse, *Pseudolabrus sieboldi*	KC896411	KC896412	KC896413	[86,87]
Chub mackerel, *Scomber japonicus*	HQ108193	HQ108194	HQ108195	[35]
Japanese anchovy, *Engraulis japaonicus*	JX406273	JX406274	JX406275	[66]
Spotted catshark, *Scyliorhinus canicula*	MH468810	MH468811	MH468812	[87]

Table 2. GenBank accession nos. of finfish expressing two GnRH forms

Fish	GenBank Accession Nos.			References
	gnrh1	*gnrh2*	*gnrh3*	
Goldfish, *Carassius auratus*	–	U30386	U30301	[88–90]
Rainbow trout, *Oncorhynchus mykiss*	–	AF125973	X79710	[91,92]
North African catfish, *Clarias gariepinus*	X78049	X78047	–	[93]
Japanese Eel, *Anguilla japonica*	AB026989	AB026990	–	[94]
Arowana, *Scleropages jardinii*	–	AB047326	AB047325	[95]
Zebrafish, *Danio rerio*	–	NM_181439	AJ304429	[96,97]
Common carp, *Cyprinus carpio*	–	AY246698	AY189960	[98,99]
chum salmon, *Oncorhynchus keta*	–	AB365004	JX183101	[100]
Beluga, *Huso huso*	EF534707 mGnRH	EF534706	–	[101]

Table 3. Amino acid sequences of naturally occurring multiple GnRH forms in finfish

Position	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
GnRH I forms										
sbGnRH	**pGlu**	**His**	**Trp**	**Ser**	**Tyr**	**Gly**	**Leu**	**Ser**	**Pro**	**Gly-NH_2**
mGnRH	—	—	—	—	—	—	—	Arg	—	—
pjGnRH	—	—	—	—	Phe	—	—	Ser	—	—
cfGnRH	—	—	—	—	His	—	—	Asn	—	—
hrGnRH	—	—	—	—	His	—	—	Ser	—	—
wfGnRH	—	—	—	—	—	—	Met	Asn	—	—
scGnRH	—	—	—	—	His	—	Trp	Arg	—	—
dfGnRH	—	—	—	—	His	—	—	Leu	—	—
lGnRH	—	—	Tyr	—	Leu	Glu	Trp	Lys	Pro	Gly-NH_2
GnRH II forms										
cGnRH-II (teleost)	**pGlu**	**His**	**Trp**	**Ser**	**His**	**Gly**	**Trp**	**Tyr**	**Pro**	**Gly-NH_2**
cGnRH-II (elasmobranch)	—	—	—	—	Phe	Asp	Tyr	Arg	—	—
lGnRH-II (lamprey)	—	—	—	—	—	—	—	Phe	—	—
GnRH III forms										
sGnRH (teleost)	**pGlu**	**His**	**Trp**	**Ser**	**Tyr**	**Gly**	**Trp**	**Leu**	**Pro**	**Gly-NH_2**
sGnRH (elasmobranch)	—	—	—	—	Phe	Asp	—	—	—	—
lGnRH-III (lamprey)	—	—	—	—	His	Asp	—	—	—	—

(sbGnRH, Seabream GnRH1; mGnRH, Mammalian GnRH1; pjGnRH or mdGnRH, Pejerrey or Medaka GnRH1; cfGnRH, catfish GnRH1; hrGnRH, Herring GnRH1; wfGnRH, Whitefish GnRH1; scGnRH, Spotted catshark GnRH1; dogfish GnRH1; lGnRH, Lamprey GnRH1)

Table 4. Amino acid sequences of GnRH I and GnRH III analogues used in induced breeding of finfish

Position	1	2	3	4	5	6	7	8	9	10
GnRH I analogues										
Mammalian GnRH	pGlu	His	Trp	Ser	Tyr	D-Ala	Leu	Arg	Pro	Net
	—	—	—	—	—	D-Arg	Trp	Leu	—	Net
	—	—	—	—	—	D-Tle	—	—	—	Net
	—	—	—	—	—	D-Trp	—	—	—	Net
	—	—	—	—	—	D-Nal (2)	—	—	—	aza-Gly
	—	—	—	—	—	D-Ser(t-Bu)	—	—	—	Net
GnRH III analogues										
salmon GnRH	pGlu	His	Trp	Ser	Tyr	D-Arg	Trp	Leu	Pro	Net
	—	—	—	—	—	D-Lys	—	—	Pro	Net
	—	—	—	—	—	Gly	—	—	Pro	Net
	—	—	—	—	—	D-Lys	—	—	Pro	Gly-NH_2

(D-Amino acid that are mirror image forms of naturally occurring L-form, are substituted at 6th position and analogues lacking 10th amino acid is replaced with an ethylamide (NH-CH_2-CH_3), abbreviated as Net; the table information)

6. SEX CHANGE CONVERSION IN CAPTIVE MAINTAINED FINFISH

Sex change is widespread in teleosts and it is an ontogenetic event in some species; however, in others, it can be triggered by stimuli such as interaction with conspecifics [121,122]. Groupers and Asian seabass are naturally distributed in tropical and subtropical regions and they are aquacultued in many Asian countries including India [123–128]. Physiologically, they are known as protogynous and protandrous hermaphrodites with sex change from female to male and male to female, respectively. This kind of sexuality raises several problems in the broodstock management in fish hatchery and necessitates hormonal treatments for sex change in the hatchery [129–131].

In several species, rise in the 11-ketotestosetrone (11-KT) and 17β-estradiol (E2) coincides with sex change to male and female, respectively [125–128]. Elevation in the serum glucocorticoid, cortisol has been demonstrated in gonochoristic fish species, including medaka, pejerrey, Japanese flounder that exhibit temperature induced masculinization. Also, cortisol is shown to be involved in the initiation of sex change in protogynous hermaphroditic fish. Sex change strategy in the groupers of the genus *Epinephelus* involves the size-advantage model with larger individuals undergoing a sex change after attaining a certain age and body size [122]. In blue spotted grouper, *Epinephelus fario* mature males through sex reversal by the oral administration of methyltestosterone at daily feeding doses of 0.5 mg and 1.0 mg MT/kg body weight for 5 months [129].

Physiologically, female to male sex change in the honeycomb grouper (*Epinephelus merra*) is associated with a drop in E2 levels followed by an increase in 11-KT levels [122,125,126]. Also, naturally occurring sex change is accompanied by significant increase in the size of androgen producing cells and androgen production by the gonads [123,124]. In several sex changing fish, levels of circulating 11-KT have been reported to increase with the progression of sex change. In captivity, steroidogenic pathways favoring production of androgen and estrogen in male (protogynous) and female (protandrous), respectively do not function effectively and result in delay in the sex change. Under aquaculture conditions, slow releasing 11-KT implants (10 ppm/kg body weight) were implanted into the body cavity; 100% masculinization was achieved on 75th day [122]. In recent years, kisspeptin systems are shown to be involved during 17α-methyltestosterone-induced sex reversal in the grouper, likely to be through BPG axis [110,130]. Recent studies suggest that gonochorist teleost species are amenable to chemical-induced gonadal sex reversal even after sexual maturity [131].

7. CONTROL OF SEXUAL DIFFERENTIATION IN CULTURED FISH

Sexual differentiation of farmed finfish can be controlled using hormonal treatments, control in

water quality parameters, and genetic manipulation [34,130–137]. Feminization in blue gill (*Lepomis macrochirus*) and blue crappie (*Pomoxis nigromaculatus*) are achieved by periodic immersions of fry in a 1 mg/l estradiol-17β solution [138]. Also, feminized female tilapia are obtained by feeding fish diethylatilbesterol at 150 mg/kg feed. Similarly, feminization has been achieved in fish showing superior trait in females compared to males [139–141]. Several studies have demonstrated successful all male production of teleost fish using androgens [134,136,137]. In addition to androgens, enzyme inhibitors targeting steroidogenic pathways have been used. Rashid et al. (2007)[138] indicated use of aromatase inhibitor, Fardrazole in the diet at a concentration between 500 and 1000 µg/g diet, which induces testicular development in fugu (*Takifugu rubripes*). Similar method has been used in variety of teleost fish [139,140].

There is strong evidence that water temperature induces sex reversal in teleost fish. In Pejerrey (*Odontesthes bonariensis*), low temperature (15-19°C) favours feminization [141,142]. Mozambique tilapia (*Oreochromis mossambicus*) reared at a high temperature (37±0.5°C) for 50 days result in the sterilization of testes lacking spermatogenic germ cells. Nile tilapia (*Oreochromis niloticus*) juveniles prefer a masculinizing temperature of 36.5°C for inducing sex reversal to males [143]. Recently, it was demonstrated in yellow catfish (*Tachysurus fulvidraco*) that high temperature (33.5°C) induces masculinization. Similar stratagies can be applied for manipulating sex and stimulating growth under aquacultured condition.

8. CONCLUSION

It is well demonstrated that different elements of BPG axis can be used as inducing agents in finfish aquaculture. In recent years, biotechnological tools have been used for production of recombinant proteins. Emerging studies indicate the possibility of using recombinant FSH and LH in inducing spermatogenesis in male eels, suggesting development of similar methods for other finfish. Also, it was demonstrated that recombinant gonadotropin-releasing hormone associated peptide can be used as an inducing agent for breeding in finfish. This strategy would work effectively in a number of fish species, in which repeated injection of GnRH fail to induce final oocyte maturation and spawning in captivity, including its application in manipulating the timing of pubertal onset and sex conversion. Interestingly, recent studies indicate the possibility of using kisspeptin peptide along with dopamine antagonists for inducing LH release in cyprinid fish and the response is dependent on the maturity stage of gonad. There is possibility that kisspeptin effect would be superior atleast in cyprinids and scombrids when compared to GnRH as it acts at higher level in the BPG axis and its effect on circulating steroid level would mediate positive feedback in the brain for sustained release of gonadotropins in fish exhibiting asynchronous ovarian development. Further studies in other freshwater and marine finfish are required to confirm the superior effect of kisspeptin peptides on induced spawning.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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