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Advances in Yellow Catfish Reproductive Biology: Implications for Aquaculture

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Abstract Yellow catfish is a freshwater fish with significant aquaculture value. The study of its reproductive biology is of great significance for improving the efficiency of artificial breeding and achieving sustainable aquaculture. This study reviews the latest research progress in reproductive biology of yellow catfish, including reproductive system anatomy and development, endocrine regulation, gametogenesis and oocyte maturation, artificial induction reproduction and seedling breeding, reproductive behavior and environmental adaptation, as well as genetic improvement and molecular breeding. The role of the HPG axis and sex hormones in reproduction was emphasized and expounded. The molecular mechanism of oocyte maturation and the influence of gamete quality on fertilization rate were analyzed. Technical breakthroughs such as induction of labor and hatching were summarized. Meanwhile, the influences of environmental factors such as temperature, light and water quality on reproductive efficiency were discussed, and the potential of genetic breeding technology to improve reproductive traits was explored. Finally, the application prospects of these advancements in aquaculture are prospected, and it is pointed out that these studies provide important scientific basis for efficient artificial breeding and sustainable aquaculture of yellow catfish.

Keywords Yellow catfish; Reproductive biology; Endocrine regulation; Artificial breeding; Molecular breeding

1 Introduction

The yellow catfish (*Pelteobagrus fulvidraco*, also known as *Tachysurus fulvidraco*) is a common freshwater bony fish that can be found in rivers and lakes in East and Southeast Asia, especially widely distributed in China and South Korea. Its meat is tender, grows fast and has strong adaptability. Therefore, it has always been a "star breed" in the aquaculture industry and has considerable economic value (Gong et al., 2018; Kim et al., 2024). However, compared with these obvious advantages, what is more remarkable is its gender difference. Male fish are often two or three times larger than female fish. This dimorphism in body size has attracted a lot of attention from researchers in both basic biology and breeding practice. yellow catfish can live in different types of water bodies, ranging from still water to flowing water. Its reproductive capacity, egg size and even spawning season will vary with the environment (Liao et al., 2018). In recent years, with the establishment of high-quality reference genomes, people finally have powerful tools to study its economic traits, sex determination and reproductive regulatory mechanisms, and also lay the foundation for subsequent selective breeding and functional genomics research (Huang et al., 2022).

If we extend the timeline a bit, the development speed of the entire aquaculture industry over the past few decades has been almost explosive. Freshwater fish farming has become one of the important ways for humans to obtain animal protein. In China, the output of yellow catfish has been increasing almost every year and has exceeded 500 000 tons in recent years (Kim et al., 2024). On the other hand, intensive farming also brings troubles. Genetic degradation, frequent diseases, coupled with environmental problems such as high temperature and water pollution, put pressure on the farming benefits (Chen et al., 2022). Especially in terms of disease resistance and reproductive capacity, the problems are more prominent. Bacterial infections such as Aeromonas and Edwardsiella escherichia can often cause serious losses in a short period of time (Ning et al., 2022; You et al., 2023). In addition, the changes in river ecology caused by large-scale hydropower projects have also disrupted the reproductive rhythm and spawning environment of wild yellow catfish, which reminds people that habitat protection and ecological management of species-specific responses must be considered (Liao et al., 2018). However, innovations in breeding technology are opening up a new situation. Whether it is gene editing, marker-assisted selection, or the breeding of YY super male lines, they all provide new ideas for improving growth performance, disease resistance and reproductive efficiency.

Therefore, a thorough understanding of the reproductive biology of yellow catfish is not merely a matter of academic interest, but also concerns the sustainable development of the industry. This article compiles the major progress in the research on the breeding and ecology of yellow catfish in recent years, explores how these achievements can feed back to aquaculture practice, and points out the research directions worthy of attention in the future. From multiple perspectives including molecular genetics, physiology and ecology, we attempt to explain how this knowledge can help improve breeding, disease prevention and control, and production strategies. Ultimately, the continuous exploration of this field can not only enhance the efficiency and stability of breeding, but also provide scientific support for the protection and restoration of wild populations under environmental changes.

2 Anatomy and Developmental Patterns of the Reproductive System in Yellow Catfish

2.1 Structural differences between male and female reproductive systems

The internal structural differences between male and female *Pelteobagrus fulvidraco* are quite obvious, which is also an unavoidable point when studying its reproductive strategies and breeding management. The ovaries in female fish are mostly cylindrical, while the testicles in male fish are like forked branches. The gender can be identified at a glance during dissection (Liao et al., 2018). Female ovaries are distributed in pairs. From immature to fully mature, they roughly go through six stages. The size and appearance of oocytes can directly reflect the development process. On the male side, the paired testicles gradually become active before reproduction. The spermatogenic cells inside start to divide in large numbers, and spermatogenic cysts increase and mature sperm are produced (Jing et al., 2014). Later, with the breakthrough of molecular genetics technology, people successfully cultivated YY super males, providing new materials for the study of gonadal development. Tissue sections showed that these YY males had a more developed testicular structure, larger spermatogenic cysts, and a higher sperm count, indicating that genetic background does influence the maturity and functional performance of the gonads (Gong et al., 2018).

2.2 Temporal changes in the reproductive cycle

When the yellow catfish reproduces is not a fixed death but varies with environmental changes. In flowing water, they generally lay eggs earlier than the populations in still water, seemingly an adaptation to local conditions such as water flow and temperature. Factors such as temperature, duration of light exposure and water quality can also unconsciously affect the development process of the gonads. The maturity of female fish ovaries, the number of eggs laid and the size of the eggs fluctuate with different environments and habitats. Before the spawning season of male fish, spermatocytes in the testis begin to multiply in large numbers, and mature sperm gradually accumulate (Jing et al., 2014; Liao et al., 2018). However, there are exceptions. During the critical stage of sex differentiation, if high-temperature stress is encountered, gonadal development will be disrupted, the sex ratio will shift, and reproductive capacity will decline. This is particularly worthy of attention in the context of increasingly intensified climate change (Chen et al., 2022). These periodic changes remind us that both environmental and genetic factors jointly determine the breeding rhythm of the yellow catfish, and mastering this rhythm is a crucial part of aquaculture management.

2.3 Relationship between sex ratio and reproductive success rate

Whether the population of yellow catfish can reproduce smoothly depends on the sex ratio. The gender ratio varies in different regions and water bodies, and is often affected by environmental conditions such as temperature and water flow. In fish farms, people tend to favor male fish because they grow fast and are large in size. Therefore, all-male or male-biased populations are often obtained through sex reversal or by breeding YY super males (Jing et al., 2014; Gong et al., 2018). But this is not an absolute good thing either. Environmental stress such as excessively high temperature sometimes causes genetic female fish to become "pseudo-males", thereby disrupting the normal sex ratio. Moreover, the reproductive capacity of these XX pseudo-males is usually inferior to that of true XY male fish. Model analysis also suggests that once the degree of masculinization exceeds a certain limit, the stability of the entire population will be threatened (Chen et al., 2022).

3 Endocrine Regulation Mechanisms and the Role of Reproductive Hormones

3.1 The key role of the HPG axis in yellow catfish reproduction

During the breeding process of the yellow catfish (*Pelteobagrus fulvidraco*), the endocrine system acts like an invisible "command center", and the hypothalamic-pituitary-gonadal (HPG) axis is the main thread of the entire system. It is not merely a chain of command transmission, but more like an information integration hub. After summarizing environmental signals and an individual's physiological state, it regulates the secretion of various reproductive hormones. Like other bony fish, the hypothalamus of the yellow catfish secretes gonadotropin-releasing hormone (GnRH), which prompts the pituitary gland to release follicle-stimulating hormone (FSH) and luteinizing hormone (LH). These hormones further stimulate the gonads, promoting the synthesis of sex steroids and the development of gametes (Chen et al., 2021). However, this set is not a simple linear reaction. The latest molecular-level research has found that some steroid-related genes (such as *TSPO* and *SMAD*4) play the role of "fine regulation" in the response of gonadal tissue. Their specific expression indicates that the HPG axis has undergone long-term evolutionary optimization and differentiation in yellow catfish, enabling reproductive activities to respond more accurately to seasonal and internal and external environmental changes.

3.2 Dynamic changes of major sex hormones

The several major sex hormones in the yellow catfish, namely estrogen, androgen and progesterone, are not stable. They fluctuate with the stage of gonadal development and the external environment. When the ovaries are developing, estrogen levels rise, promoting the growth of oocytes. Male fish rely on androgens to maintain sperm production (Chen et al., 2021). But the situation can also be artificially disrupted. For instance, 17α -estradiol (EE2) used in the experiment interfered with the normal development of the testicles of male fish, causing disorders in cell division. This also indicates that the reproductive system of the yellow catfish is highly sensitive to hormone balance. On the other hand, the involvement of microRNAs (miRNAs) makes things more complicated. These small molecules do not directly "produce" hormones, but can regulate related genes at the post-transcriptional level and even show gender-specific expression (Jing et al., 2014). In other words, the reproduction of yellow catfish is not driven by a single hormone, but is a dynamic result of the combined effects of genes, epigenetics and hormones.

3.3 Hormonal feedback and environmental adaptation regulation

The ability of the yellow catfish to reproduce rhythmically seems natural, but in fact, it is all thanks to the hormone feedback system within its body that maintains stability. The positive and negative feedback mechanism in the HPG axis enables sex steroids to control the release of GnRH and gonadotropins in turn, ensuring that reproduction does not disrupt the rhythm. Unfortunately, this balance is not always maintained. A slight deviation in the environment, such as an increase in water temperature, may cause the entire system to be out of balance. The sex ratio begins to be skewed and reproductive capacity is also affected accordingly. Especially during the critical period of sex differentiation, if high temperatures persist, so-called "pseudo-males" will emerge, fish that should originally be female are forced to grow into males, but their reproductive capacity is often very poor (Chen et al., 2022). Such a situation becomes even more intractable against the backdrop of global warming. Although the yellow catfish has some ability to adapt to the environment, its endocrine system is overly dependent on external signals. Once the ecological conditions change too rapidly, this coupling becomes a weakness instead. Understanding the details of this feedback and adaptation is not only a scientific research issue, but also related to how future aquaculture should be adjusted and how to keep the reproduction of this species stable and sustainable (Chen et al., 2022).

4 Molecular Mechanisms of Gametogenesis and Oocyte Maturation

4.1 Morphological characteristics of follicular development

During the breeding process of yellow catfish, the growth of oocytes seems to be a gradual process, but in fact, there is a series of delicate structural changes behind it. Follicular development begins with the active division of granulosa cells, and at the same time, the matrix of cumulus cells gradually forms, which provide necessary support for the growth of oocytes. At the primary stage, the oocyte is surrounded by the granulosa layer and the follicular membrane. The microvilli structure between the cells enables efficient exchange of nutrients and signals back and forth. When the yolk material and organelles continuously accumulate and increase in volume, the germinative vesicles will slowly move to the outside of the oocyte, which often indicates that meiosis is about to resume and ovulation is about to begin. This process consumes a great deal of energy, is highly dependent on ATP generation, and is simultaneously influenced by both intrinsic genetic regulation and external conditions (such as nutrition and hormonal changes) (Martyniuk et al., 2013; Song et al., 2018). If the follicular structure is imbalanced or the coordination between cells is blocked, the probability of generating oocytes with high developmental capacity will significantly decrease.

4.2 Signal transduction pathways in oocyte maturation

It is not just a single hormone or gene that controls the maturation of yellow catfish oocytes, but a complete set of interwoven signaling pathway systems. Metabolic status, environmental stimuli, and hormone levels all converge at the molecular level. In the research, leptin was found to be a key "connection point", which can link fatty acid β -oxidation with the process of oocyte maturation. The experimental results show that leptin can up-regulate genes related to β -oxidation such as *CPT1*, *Acsl* and *ACOX1*, and also promote the expression of mature-related genes such as *MAPK*, *Cdc*2 and *IGF-1R*, and activate the JAK-STAT pathway. This signaling system is particularly important for meiosis recovery and germinal vesicle rupture (Song et al., 2018). If β -oxidation is inhibited, the promoting effect of leptin will almost disappear, which shows the core position of metabolic signals in this link. In addition, pathways such as PI3K-AKT and GPCR have also been proven to be involved in regulating follicular development and gametes production (Xiong et al., 2015). The interlaced operation of these signals ultimately affects chromatin remodeling, cytoplasmic reorganization, and whether the oocyte can smoothly enter the fertilization stage.

4.3 Relationship between gamete quality and fertilization rate

Whether the yellow catfish can successfully reproduce often does not depend on the quantity but on the "quality" of the oocytes. A high-quality oocyte usually indicates that both the nucleus and cytoplasm are fully mature, with sufficient energy and normal expression of related genes. Studies have found that enhancing fatty acid β -oxidation can significantly increase the maturation rate and diameter of oocytes, and simultaneously activate key genes affecting oocyte ability (Song et al., 2018). Conversely, if metabolism or signal transduction is disrupted, the quality of oocytes will decline, and the fertilization rate and embryo survival rate will also deteriorate accordingly. It is not only the internal metabolism that affects quality, but also the microenvironment around the follicle. The balance of growth factors, antioxidant substances and hormone signals all play a key role (Martyniuk et al., 2013). Therefore, understanding these molecular mechanisms is not only for academic discussion but also can provide practical ideas for aquaculture, such as improving the reproductive efficiency of yellow catfish through nutritional supplementation, hormone regulation or genetic improvement.

5 Artificial Induced Breeding Techniques and Seedling Cultivation

5.1 Hormone-induced and reproduction synchronization techniques

Hormone induction is the key technology to achieve synchronous reproduction of yellow catfish. During the breeding season, broodstock with high maturity are selectively induced to undergo labor induction treatment, usually by injecting carp pituitary gland extract or synthetic gonadotropin analogs (such as LRH-A, etc.). By scientifically controlling the injection dose and timing, female fish can be induced to ovulate and male fish can ejaculate, allowing multiple broodstock to spawn and be fertilized at the same time, achieving synchronized reproduction (Kim et al., 2024). Generally, female fish are injected with an appropriate amount of hormones according to their body weight, and the dose of male fish is about half of that of female fish. The male and female ratio is 1:1 to ensure that they enter the breeding state at the same time. Oxygen injection is often performed in the evening, and the broodstock group can be seen spawning at dawn the next day. At the same time, combined with water temperature adjustment and a small amount of micro-flow water stimulation, simulating natural reproduction signals can improve the labor-inducing effect. Standardized hormone induction significantly improves the efficiency of artificial reproduction (Hettiarachchi et al., 2024), especially for fish groups that are difficult to spawn at the same time under natural conditions, ensuring the stability of seed production and the safety of broodstock.

5.2 Artificial insemination and embryo incubation management

Artificial insemination is usually performed after induction of labor when the female is about to ovulate. Technicians gently press the abdomen of the female fish to collect the eggs, and squeeze out the semen of the male fish and mix them well to achieve in vitro fertilization. Since yellow bream eggs are sticky, it is necessary to add an appropriate amount of clay suspension or tannic acid solution and stir gently after fertilization to remove the egg stickiness (deadhesiveness) and prevent the eggs from adhering to each other and affecting water flow and development. The fertilized eggs after debonding are placed in incubation equipment for running water incubation management. During the incubation process, maintain appropriate water temperature (such as 18 C~25 °C, the embryo hatches in about 7 days at around 20 °C), sufficient dissolved oxygen and micro-flowing water to ensure normal development of the embryo. White necrotic eggs should be removed regularly and fungal infections such as saprolegnia should be prevented (the eggs can be soaked with light salt water or safe antifungal agents). When the embryo develops to the point where the yolk sac has been absorbed and the fry begin to swim for food, they need to be transferred to the seed breeding tank for feeding and management in time (Hettiarachchi et al., 2024). Perfect artificial insemination and hatching management can significantly improve the fertilization rate and seedling survival rate.

5.3 Case study: commercial practice of artificial breeding in yellow catfish

The artificial breeding of yellow catfish is not a recent development, but it is only in recent years that there have been more and more cases that have become large-scale and profitable. A typical example is the catfish breeding farm in hunan. The technical team there did not have a smooth start. They repeatedly explored in the processes of broodstock breeding, spawning and hatching, and gradually developed a more efficient management approach. Over the course of a breeding season, through hormone induction and meticulous operation, they produced four batches of yellow catfish parent fish in just one week, hatching nearly 40 million healthy fry. It seems to be just a number, but behind it is the support of a full-process system, from the overwintering management of broodstock, to simultaneous induction of labor and flow hatching during the breeding season, and then to the grading and cultivation of seedlings, each link is interlinked. This approach ensures a high survival rate of the fish fry and their rapid growth. The result is that artificial breeding not only makes up for the shortage of wild seedlings but also makes the supply of seedlings more stable, and the income of farmers has also increased in a tangible way (Figure 1). Now, the promotion of artificial breeding of yellow catfish is driving the entire industry towards a larger scale and more sustainable direction (Hettiarachchi et al., 2024).

6 Reproductive Behavior and Environmental Adaptation Mechanisms

6.1 Spawning behavior characteristics in natural environments

The breeding behavior of yellow catfish in natural waters is obviously seasonal and gregarious. Generally, wild yellow catfish reaches sexual maturity at the age of 2 winter, and enters the breeding period in late spring and early summer every year when the water temperature rises to about 20 °C. They often choose the time after rain when the water level rises and the environment is fresh to swim in groups to shallow areas with aquatic plants and gravel along the rivers and lakes. During the breeding process, several male fish chase and surround the female, stimulating the female to release eggs and at the same time expel sperm to complete in vitro fertilization. yellow catfish eggs are sticky and adhere to the surface of aquatic plants and rocks after they are laid to obtain good oxygen supply (Liao et al., 2018). After spawning, the broodstock does not protect the eggs, and the eggs develop and hatch on their own in the natural environment. The whole spawning behavior is usually carried out in the early morning or evening when the light is softer. It does not last long but is quite intense. Under natural conditions, yellow catfish can lay tens of thousands of eggs at one time, and the fry can hatch after about a week of embryonic development.

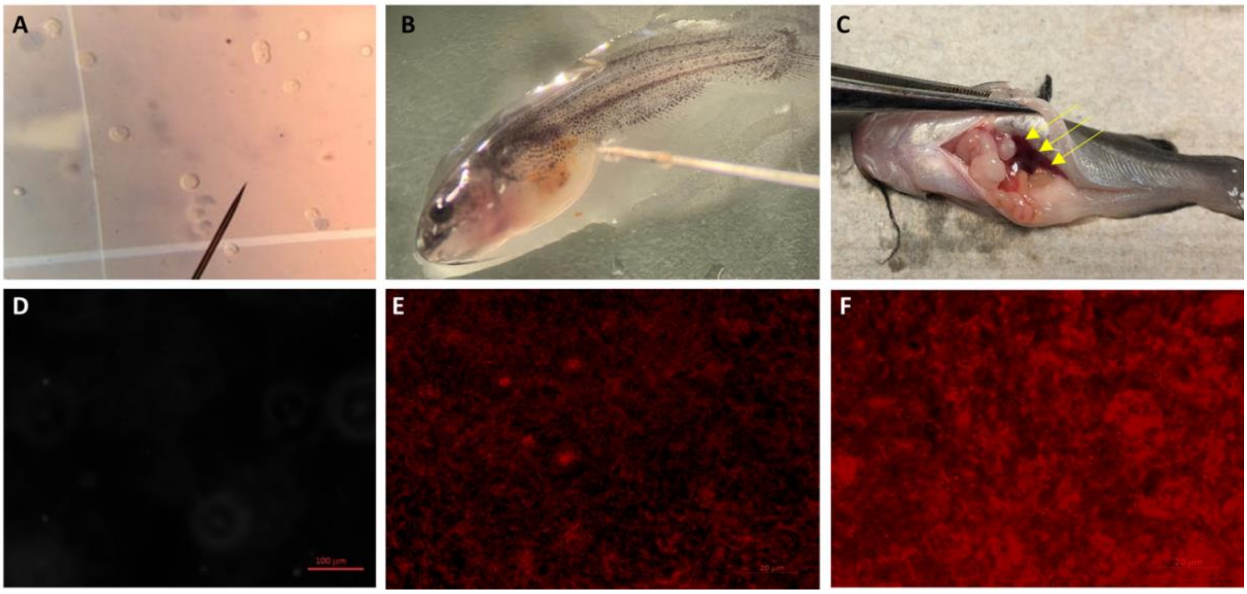

Figure 1 Stem cell (A) transplantation (intraperitoneally) (B) of donor derived stem cells into triploid white catfish (*Ameiurus catus*). Transplanted stem cells migrate to the genital ridge of the recipient, are incorporated, and initiate oogenesis or spermatogenesis. Gonadal growth of the xenogeny (C). The non-injected control treatment (D) showed no fluorescence, while those injected with channel catfish (*Ictalurus punctatus*) stem cells were fluorescing in fry sampled at 45 (E) and 90 DPH (F) (Adopted from Hettiarachchi et al., 2024)

6.2 Effects of temperature and light on reproductive efficiency

Temperature and light are key environmental factors affecting the reproductive efficiency of yellow catfish. Temperature directly determines the breeding time and embryonic development speed of yellow catfish: usually the water temperature must reach above about 18 ℃~20 ℃ before the fish gonads can fully mature and spawning activity can start. Within the appropriate temperature range (about 18 ℃~25℃), the hatching rate of fertilized eggs and the survival rate of larvae are higher; too low a temperature will delay or inhibit reproduction, while too high a water temperature may lead to abnormal embryo development or a decrease in survival rate (Chen et al., 2022). In addition, the length of light (photoperiod) affects the breeding season of yellow catfish by regulating hormone secretion in the body. As the daylight hours lengthen in spring, the gonad development of broodstock fish accelerates, and reproduction tends to be active. If the lighting time is artificially extended, the breeding period of yellow catfish can be advanced or extended to a certain extent and the frequency of spawning can be increased. However, excessive light intensity may cause stress to the broodstock, so the breeding environment should be kept with soft light (Farmer et al., 2015).

6.3 Synergistic effects of water quality and nutritional factors

The quality of water and nutritional conditions will synergistically affect the reproductive success rate of yellow catfish. Excellent water quality provides a healthy environment for broodstock and embryos: high dissolved oxygen, suitable pH, low ammonia nitrogen, etc. help reduce broodstock stress, improve sperm and egg quality, and reduce embryonic mortality (Guo et al., 2021). If the water quality deteriorates (such as increased ammonia nitrogen or insufficient dissolved oxygen), even if the nutrition is sufficient, the broodstock may suffer from reduced fecundity and reduced survival rate of fertilized eggs due to stress. Likewise, adequate and balanced nutrition is crucial to gonadal development and reproductive performance of yellow catfish. Feed rich in protein, essential fatty acids and vitamins can promote female fish to produce high-quality eggs and improve fertilization and hatching rates; malnutrition will lead to a decrease in egg quality and affect reproductive efficiency. Water quality and nutrition often influence each other: good water quality allows broodstock to feed and metabolize smoothly, and nutrients can be fully utilized; while adequate nutrition enhances the stress resistance of broodstock and improves their reproductive adaptability under sub-ideal water quality conditions (Li et al., 2021). Therefore, in breeding management, it is necessary to simultaneously improve the water environment and strengthen the nutrition of broodstock. The coordinated optimization of the two can maximize the reproductive efficiency of yellow catfish.

7 Genetic Improvement and Prospects for Molecular Breeding

7.1 Genetic analysis and marker development of reproductive traits

Genetic analysis and molecular marker development of reproductive traits of yellow catfish are the basis for To improve the genetic properties of the yellow catfish, one must first understand its reproductive characteristics. Researchers usually conduct reproductive experiments first to collect some specific data, such as the number of eggs laid, hatching rate, age of sexual maturity, etc. (Huang et al., 2022; Kim et al., 2024). These data may seem disorganized, but through family analysis and quantitative genetics methods, it is possible to calculate which traits are genetically controlled and how much they change. On this basis, they will further use molecular biological methods to look for genetic markers associated with these traits. For instance, screen microsatellite or SNP loci from the genome of yellow catfish to see which ones are associated with reproductive rate or early maturity. Then, construct a genetic linkage map and conduct QTL mapping to identify the key gene regions that control these traits. Once these markers are proven reliable, breeders can directly use them to screen juvenile fish. By simply testing the markers, they can roughly determine their reproductive potential and keep those individuals carrying superior genes as parents. In this way, the entire breeding process becomes faster and more accurate.

7.2 Molecular breeding and gene editing strategies

Nowadays, yellow catfish breeding is increasingly advanced by molecular breeding and gene editing. Methods such as marker-assisted selection (MAS) or genome-wide selection have enabled breeders to identify potential fish in advance through DNA testing when they are still young. Compared with the traditional method that only relied on body shape and output in the past, this approach is more accurate in selection and can also significantly shorten the generation gap. Meanwhile, gene editing technologies (such as CRISPR/Cas9) are opening up new possibilities. Researchers envision that it is possible to make targeted modifications to key genes that affect growth and reproduction, such as knocking out genes that inhibit growth, to make individuals grow faster. Or adjust the genes related to gonadal development to make yellow catfish mature earlier (Huang et al., 2022). These ideas sound very attractive. After all, who wouldn't want to cultivate new strains that grow fast and are resistant to diseases. However, it should be noted that gene editing in aquaculture has not yet reached a mature stage. Safety and ethical issues remain unavoidable topics that require time and careful research to verify.

7.3 Case study: genomic selection for early-maturing yellow catfish strains

An aquaculture breeding team successfully used genomic selection technology to breed a new strain of early-maturing yellow catfish. First, they screened out some precocious individuals from numerous broodstock families that would become sexually mature and spawn that year, and recorded the reproductive trait data of each broodstock in detail. Subsequently, genomic DNA sampling and high-density molecular marker detection were performed on these broodstock and their offspring to construct a genomic selection prediction model for yellow catfish (Figure 2) (Gong et al., 2018; Huang et al., 2022). By calculating the genomic breeding values carried by each juvenile fish (for traits such as age at sexual maturity), the researchers selected the fish with the highest predicted values as the next generation's parents. After several generations of genome-assisted breeding, the team finally obtained an early-maturing yellow catfish strain with stable genetics. This strain of yellow catfish can reach sexual maturity one breeding season earlier than the ordinary strain, shortening the seed production cycle and greatly improving reproductive efficiency. This case shows that genomic selection has significant results in improving the reproductive traits of yellow catfish, and provides an effective way to breed strains with special traits (Dong et al., 2011).

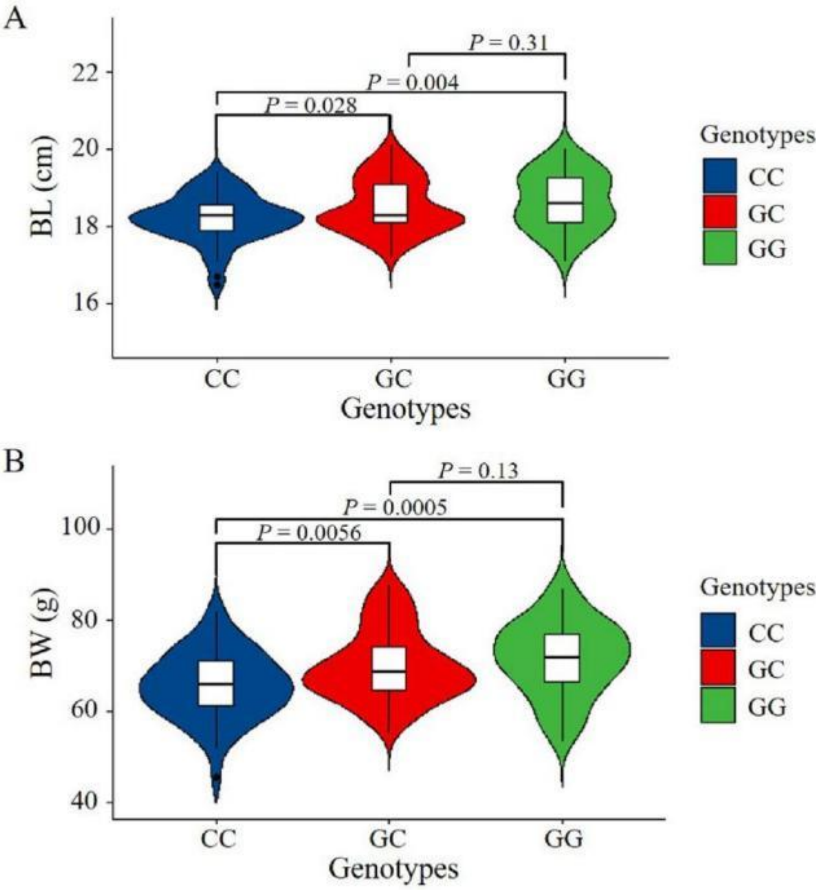

Figure 2 Statistical comparison between grow traits and three genotypes of the SNP Chr15:19195072 (G/C) in male yellow catfish (Adopted from Huang et al., 2022)

8 Future Prospects and Sustainable Aquaculture Strategies

8.1 Intelligent reproduction monitoring and control systems

In the future, yellow catfish farming may no longer require farmers to stand by the pond to observe. The existing intelligent systems can, through sensor networks and automatic devices, monitor in real time various parameters in the breeding ponds, such as water temperature, dissolved oxygen, pH value, and even the activity status of the broodstock. Once the underwater camera captures signs of reproduction such as chasing and gathering, the system immediately issues a reminder. In fact, such systems not only remind but also can adjust by themselves: the heating or cooling equipment will be automatically started or stopped when the water temperature is not suitable, and the light intensity will also change according to the set program, trying to imitate the natural rhythm as much as possible (Chen et al., 2022). Some more advanced equipment can even automatically feed and add trace elements, keeping the broodstock in the best condition before and after the breeding period. In the laboratory, there are also people developing intelligent devices that can assist in inducing labor and controlling hatching, with almost no human intervention required. Even better, artificial intelligence algorithms can analyze historical data, summarize experiences, predict the peak of egg-laying, and constantly adjust strategies to make reproduction more stable and accurate.

8.2 Construction of eco-friendly breeding models

The eco-friendly breeding model emphasizes taking into account environmental protection and the ecological needs of the species when artificially intervening in yellow catfish breeding. Specifically, artificial reproduction in this mode simulates natural conditions as much as possible and reduces excessive dependence on chemicals and hormones. For example, arranging aquatic plants, stones, etc. in the broodstock breeding tank creates a natural spawning scene, guiding the broodstock to naturally spawn and fertilize, and reducing the dosage of oxytocin hormones from the source. In terms of water quality management, biological filtration and circulating water technology are used to keep the water environment clean and stable. During the incubation process, natural antibacterial means (such as plant extracts) are used as much as possible to prevent oomycete and avoid the use of drugs that may pollute the environment. Eco-friendliness is also reflected in maintaining biodiversity during the breeding process, such as avoiding disordered hybridization between different strains or species, and protecting wild yellow catfish germplasm resources. By constructing a low-emission, low-energy-consumption breeding system, the pollution pressure of wastewater and residual bait on surrounding waters is reduced (Kim et al., 2024).

8.3 Frontiers in reproductive biology research of yellow catfish

Looking to the future, research on the reproductive biology of yellow catfish will focus on multiple frontier directions. On the one hand, it is necessary to deeply analyze the internal mechanism of yellow catfish reproduction, such as neuroendocrine regulation, gametogenesis mechanism and other basic issues. Studying the role of key hormones and genes on the pituitary-gonadal axis of yellow catfish through molecular biology and omics technology can reveal the regulatory network that affects ovarian maturation, ovulation and spermatogenesis. At the same time, the process of egg fertilization and early embryo development is carefully observed with the help of microscopic imaging and other means to find ways to improve the fertilization rate and embryo survival rate (Gong et al., 2018; Huang et al., 2022). On the other hand, cutting-edge research also focuses on innovations in reproductive technology and environmental conditions. The development of more efficient and environmentally friendly methods of artificial induction of labor (such as new ovulation induction drugs or physical stimulation technology) is one of the hot topics, and improving hatchery equipment and processes to increase the survival rate of fry has also attracted much attention. In addition, it is also important to explore the reproductive adaptation mechanism of yellow catfish to environmental changes such as water temperature and hydrology in the context of climate change, in order to adjust breeding strategies to cope with the uncertain environment in the future (Liao et al., 2018; Chen et al., 2022).

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Conflict of Interest Disclosure

The authors confirm that the study was conducted without any commercial or financial relationships and could be interpreted as a potential conflict of interest.

References

Chen F., Zhong C., Song C., Chen S., He Y., and Tan X., 2021, Molecular characterization and functional analysis of two steroidogenic genes *TSPO* and *SMAD4* in yellow catfish, International Journal of Molecular Sciences, 22(9): 4505.
https://doi.org/10.3390/ijms22094505

Chen M., Lu Z., Liu Y., Li B., Gao Z., and Shen Z., 2022, High-temperature stress will put the thermo-sensitive teleost yellow catfish (*Tachysurus fulvidraco*) in danger through reducing reproductivity, Ecotoxicology and Environmental Safety, 239: 113638.
https://doi.org/10.1016/j.ecoenv.2022.113638

Dong Z., Ge J., Li K., Xu Z., Liang D., Li J., Li J., Jia W., Li Y., Dong X., Cao S., Wang X., Pan J., and Zhao Q., 2011, Heritable targeted inactivation of myostatin gene in yellow catfish (*Pelteobagrus fulvidraco*) using engineered zinc finger nucleases, PLoS ONE, 6(12): e28897.
https://doi.org/10.1371/journal.pone.0028897

Farmer T., Marschall E., Dąbrowski K., and Ludsin S., 2015, Short winters threaten temperate fish populations, Nature Communications, 6: 7724.
https://doi.org/10.1038/ncomms8724

Gong G., Dan C., Xiao S., Guo W., Huang P., Xiong Y., Wu J., He Y., Zhang J., Li X., Chen N., Gui J., and Mei J., 2018, Chromosomal-level assembly of yellow catfish genome using third-generation DNA sequencing and Hi-C analysis, GigaScience, 7(11): 1-9.
https://doi.org/10.1093/gigascience/giy120

Guo J., Pu Y., Zhong L., Wang K., Duan X., and Chen D., 2021, Lead impaired immune function and tissue integrity in yellow catfish (*Peltobargus fulvidraco*) by mediating oxidative stress inflammatory response and apoptosis, Ecotoxicology and Environmental Safety, 226: 112857.
https://doi.org/10.1016/j.ecoenv.2021.112857

Hettiarachchi D., Alston V., Bern L., Al-Armanazi J., Su B., Shang M., Wang J., Xing D., Li S., Litvak M., Dunham R., and Butts I., 2024, Advancing aquaculture: production of xenogenic catfish by transplanting blue catfish (*Ictalurus furcatus*) and channel catfish (*I.punctatus*) stem cells into white catfish (*Ameiurus catus*) triploid fry, PLoS ONE, 19(6): e0302687.
https://doi.org/10.1371/journal.pone.0302687

Huang P., Guo W., Wang Y., Xiong Y., Ge S., Gong G., Lin Q., Xu Z., Gui J., and Mei J., 2022, Genome-wide association study reveals the genetic basis of growth trait in yellow catfish with sexual size dimorphism, Genomics, 2022: 110380.
https://doi.org/10.1016/j.ygeno.2022.110380

Jing J., Liu W., Xiong S., W., Zhang J., Wang W., Gui J., and Mei J., 2014, Sex-biased miRNAs in gonad and their potential roles for testis development in yellow catfish, PLoS ONE, 9(9): e107946.
https://doi.org/10.1371/journal.pone.0107946

Kim K., Kim K., and Song H., 2024, Genetic structure and diversity of hatchery and wild populations of yellow catfish *Tachysurus fulvidraco* (Siluriformes: Bagridae) from Korea, International Journal of Molecular Sciences, 25(7): 3923.
https://doi.org/10.3390/ijms25073923

Li M., Qiang J., Bao J., Tao Y., Zhu H., and Xu P., 2021, Growth performance physiological parameters and transcript levels of lipid metabolism-related genes in hybrid yellow catfish (*Tachysurus fulvidraco* ♀ × *Pseudobagrus vachellii* ♂) fed diets containing Siberian ginseng, PLoS ONE, 16(2): e0246417.
https://doi.org/10.1371/journal.pone.0246417

Liao C., Chen S., Guo Z., Ye S., Zhang T., Li Z., Murphy B., and Liu J., 2018, Species-specific variations in reproductive traits of three yellow catfish species (*Pelteobagrus* spp.) in relation to habitats in the Three Gorges Reservoir China, PLoS ONE, 13(7): e0199990.
https://doi.org/10.1371/journal.pone.0199990

Martyniuk C., Prucha M., Doperalski N., Antczak P., Kroll K., Falciani F., Barber D., and Denslow N., 2013, Gene expression networks underlying ovarian development in wild Largemouth Bass (*Micropterus salmoides*), PLoS ONE, 8(3): e59093.
https://doi.org/10.1371/journal.pone.0059093

Ning X., Peng Y., Tang P., Zhang Y., Wang L., Zhang W., Zhang K., Ji J., and Yin S., 2022, Integrated analysis of transcriptome and metabolome reveals distinct responses of *Pelteobagrus fulvidraco* against *Aeromonas veronii* infection at invaded and recovering stage, International Journal of Molecular Sciences, 23(17): 10121.
https://doi.org/10.3390/ijms231710121

Song Y., Tan X., Pan Y., Zhang L., and Chen Q., 2018, Fatty acid β-oxidation is essential in leptin-mediated oocytes maturation of yellow catfish *Pelteobagrus fulvidraco*, International Journal of Molecular Sciences, 19(5): 1457.
https://doi.org/10.3390/ijms19051457

Wang S., Li X., Zhang M., Jiang H., Wang R., Qian Y., and Li M., 2021, Ammonia stress disrupts intestinal microbial community and amino acid metabolism of juvenile yellow catfish (*Pelteobagrus fulvidraco*), Ecotoxicology and Environmental Safety, 212: 112932.
https://doi.org/10.1016/j.ecoenv.2021.112932

Xiong S., Jing J., Chen X., Wang W., Gui J., and Mei J., 2015, Comparative transcriptome analysis of differentially expressed genes and signaling pathways between XY and YY testis in yellow catfish, PLoS ONE, 10(8): e0134626.
https://doi.org/10.1371/journal.pone.0134626

Xu P.M., and Jin L.F., 2025, Genomic evolution of growth and reproduction related genes in shrimp, International Journal of Marine Science, 15(3): 154-166.
https://doi.org/10.5376/ijms.2025.15.0014

You S., Jiang X., Zhang G., Ji W., Ma X., Zhou X., and Wei K., 2023, Molecular characterization of nine TRAF genes in yellow catfish (*Pelteobagrus fulvidraco*) and their expression profiling in response to *Edwardsiella ictaluri* Infection, International Journal of Molecular Sciences, 24(9): 8363.
https://doi.org/10.3390/ijms24098363

Zheng H., Ji W., Zhang G., Zhang X., Shi Z., Wei K., Yang R., and Gardner J., 2016, Molecular characterization and expression analyses of the complement component *C8α C8β* and *C9* genes in yellow catfish (*Pelteobagrus fulvidraco*) after the *Aeromonas hydrophila* challenge, International Journal of Molecular Sciences, 17(3): 345.
https://doi.org/10.3390/ijms17030345