



EDITORIAL

Progress in Aquaculture Genetics and Breeding in China

China is a leading country in aquaculture, contributing around two thirds of the world's production (FAO 2017). In 2016, the aquaculture production of China reached 51.42 million tons, which was about three times that of its capture production (MOA 2017). Given China's leading position in aquaculture, adopting the breeding technologies of China would be of great benefit for the sustainable development of future aquaculture globally (Gjedrem et al. 2012). In fact, many aquaculture species, including fish, crustaceans, mollusks, and edible algae, are involved in some breeding programs in China, resulting in 182 novel varieties approved by the Ministry of Agriculture of China by 2017. The total value of China's aquaculture seed production was 64.09 billion RMB (1.01 billion USD) in 2016 (MOA 2017). Many traditional and new technologies have been adopted in these breeding programs, including selective breeding, hybridization, gynogenesis, sex control, transgenesis, genome selection, and many others (Chang et al. 2013; Zhang 2015; Gui et al. 2016). This special issue is a timely showcase for recent progress in aquaculture genetics and breeding in China.

Special Issue Summary

Selective Breeding

Selective breeding is a strategy aimed at choosing favorite individuals based on their phenotypes or genotypes. The effect of selective breeding depends on selection intensity, generation interval, and heritability of the target traits. Most aquatic species have high fecundity, short generation intervals, and relatively high heritabilities for economically important traits, allowing high selection intensity and effective genetic gains in a short time in aquaculture breeding programs (Gjedrem et al. 2012). X. Liu et al. (2018) and Y. Liu et al. (2018) estimated the heritabilities of length and weight characters of the Japanese flounder, *Paralichthys olivaceus*, from the Bohai

Sea of China, and found that they ranged from 0.23 to 0.48. They also tested parentage assignments using microsatellites with high exclusion probabilities in full-sib samples, so the heritabilities of growth-related traits could be estimated based on pedigree assignment in full-factorial crosses, an efficient strategy for selective breeding.

The estimated heritabilities of growth traits of the Chinese mitten crab, *Eriocheir sinensis*, such as weight, length, width, and depth, were also moderately high (0.35–0.45) (X. Liu et al. 2018; Y. Liu et al. 2018). Moreover, the heritabilities for allometry scalings were estimated as 0.893, 0.909, and 0.488 of body length, depth, and width to body weight, respectively, suggesting that body shape can be effectively selected for the Chinese mitten crab (X. Liu et al. 2018; Y. Liu et al. 2018).

The Chinese mitten crab is a native species of China, and the most valuable freshwater species of the aquaculture industry in China (Wang et al. 2018). Genetic improvement programs of the Chinese mitten crab were initiated in 2000 and now there are five certificated varieties that have resulted from those breeding programs with growth rate improved by 16.7–26.0%. Four of the five genetically improved varieties were bred under mass selection and only one was bred under a complete set of strategies of selective breeding, which are summarized in detail in this special issue by Wang et al. (2018).

Another endemic Chinese species that has attracted more recent attention is the freshwater sleeper, *Odontobutis potamophila*. H. Zhang, Zhang et al. (2018), H. Zhang, Zhao et al. (2018), and X. Zhang et al. (2018) identified and characterized single nucleotide polymorphisms (SNPs) of insulin-like growth factor 1 receptor (IGF-1R) genes in *O. potamophila*. They found that a SNP site in the intron of IGF-1R was associated with growth performance and suggested that this SNP site could be used in

marker-assisted selection (MAS) (H. Zhang, Zhang et al. 2018; H. Zhang, Zhao et al. 2018; X. Zhang et al. 2018). Likewise, microsatellite loci were examined for potential use in MAS in pearl oyster, *Pinctada fucata martensii*, which is an important commercial bivalve used for the production of marine pearls in China and Japan (Zhan et al. 2018). Five expressed sequence tag–derived microsatellites were found linked to commercially important growth traits of *P. fucata martensii* (Zhan et al. 2018).

Besides growth performance, disease resistance is another most targeted trait for selective breeding. Jia et al. (2018) evaluated resistance to Cyprinid herpesvirus 3 (CyHV-3) of three selected generations of mirror carp, *Cyprinus carpio* L. They found that the survival rate of generations G1, G2, and G3 was 3.7, 31.2, and 35.1%, respectively, higher than the control. G2 and G3 had significantly larger survival rates than G1 ($P=0.000$), but there was no significant difference between G2 and G3. Thus, G3 possesses strong resistance ability to CyHV-3 virus but has little potency for further selection for CyHV-3 virus resistance (Jia et al. 2018).

Hybridization

Hybridization of farmed species is often manipulated for obtaining favorable traits, such as faster growth rate and sterility. Tao et al. (2018) investigated the molecular mechanism of sterility of allotriploid crucian carp, which was produced by crossing female Japanese crucian carp, *Carassius cuvieri*, with male tetraploid hybrids between female red crucian carp, *Carassius auratus* red var. ($2n=100$), and male common carp, *C. carpio* L. ($2n=100$). The sterile allotriploid crucian carp has multiple advantages, such as sterility, faster growth rate, good flesh quality, and higher antidisease ability. The results showed that the allotriploids had significantly higher expression of follistatin messenger RNA in pituitaries during both the prespawning and spawning periods, suggesting that the elevated expression of the follistatin gene in the pituitaries of the allotriploids might lead to sterility of allotriploids by blocking the inhibitory effect of activin on the luteinizing hormone β subunit (Tao et al. 2018).

Li et al. (2018) also explored mechanisms of gonadal masculinization of triploid, but in hybrid groupers *Epinephelus coioides* ♀ × *Epinephelus lanceolatus* ♂. They found that the diploid hybrids showed high serum E2 levels at 10 and 43 mo and high T levels at 43 mo, while the triploid hybrids showed high E2 levels at 18 and 30 mo and high T levels at 18 mo. Furthermore, the expression levels of *fshr*, *lhr*, *dmrt1*, and *sox9* genes were higher in triploid hybrids than in diploid hybrids, suggesting that the hyperactive expression of these genes may be associated with the gonadal masculinization of triploid hybrids.

Gynogenesis

H. Zhang, Zhang et al. (2018), H. Zhang, Zhao et al. (2018), and X. Zhang et al. (2018) reported a strategy for mass production of mitotic gynogenetic doubled haploids (DHs) in the Japanese flounder, *P. olivaceus*. They compared the results of mitotic gynogenetic DHs induced from four females of different genetic backgrounds, including a wild-type female, a meiotic gynogenetic female, a heterozygous mitotic gynogenetic female, and a heterozygous clonal female. The heterozygous clonal female group had the highest hatching rate, lowest abnormality rate, and highest homozygosity rate. They hypothesized that high homozygosity indicated fewer deleterious recessive genes, and therefore, the mortality of the DH progeny from homozygous deleterious mutations might decline, resulting in high survival rate (H. Zhang, Zhang et al. 2018; H. Zhang, Zhao et al. 2018; X. Zhang et al. 2018). This strategy of successful mass production of DHs could help in research and breeding programs in the Japanese flounder.

Sex Control and Manipulation

Many species of fish and shellfish are sexually dimorphic in economically important traits, such as growth rate and body size. Monosex fingerlings are commercially produced in China for many species, such as the yellow catfish, *Pelteobagrus fulvidraco* (all male); tilapia, *Oreochromis* sp. (all male); the Japanese flounder, *P. olivaceus* (all female); and the tongue sole,

Cynoglossus semilaevis (all female) (Gui et al. 2016). Tilapia is the second most farmed fish in the world, and China is the largest producer and exporter of tilapia products (Chen et al. 2018). Raising all-male tilapia not only provides benefits from the higher growth rate of male fish but also alleviates the problem of excessive reproduction during the growout stage. Chen et al. (2018) reviewed different strategies of producing all-male tilapia, emphasizing marker-assisted breeding, cross-breeding, and genetic modification technologies with examples from their research. They have isolated sex-linked DNA markers and used those in MAS for Nile tilapia and blue tilapia and developed all-male tilapia with genotypes of XY, ZZ, ZX, ZY, and WY from crossing combinations of XX females with YY supermales, ZZ pseudofemales with ZZ males, XX females with ZZ males, ZZ pseudofemales with YY supermales, and WW superfemales with YY supermales, respectively. They also have mutated many genes critical to sex determination and differentiation by transcription activator-like effector nuclease and clustered regularly interspaced short palindromic repeats/associated protein 9 and established the gene knockout lines (Chen et al. 2018).

Another potential and interesting application of sex manipulation is eradicating invasive species through altering the sex ratio of a target fish population. The number of females can be reduced using a Trojan Y chromosome (TYC) strategy (Gutierrez and Teem 2006), in which a sex-reversed female fish containing two Y chromosomes (FYY) is released into the target population to increase male progeny (MXY). Over time, it can shift the population strongly toward males. Jiang et al. (2018) optimized experimental parameters to effectively generate male fish containing two Y chromosomes (MYY), which can be used to produce FYY through hormonal treatment. They explored optimal duration of UV irradiation and heat shock treatment needed to inactivate the maternal nuclear genome and duplicate the male genome in the common carp, *C. carpio*. Their study provided a good reference for applying the TYC method to control invasive common carp.

Characterization of Genes Associated with Traits Related to Aquaculture Performance

Other papers in this special issue are focused on the characterization of important genes potentially affecting aquaculture performance in various organisms (Jin et al. 2018; Ping et al. 2018; Shan et al. 2018; H. Zhang, Zhang et al. 2018; H. Zhang, Zhao et al. 2018; X. Zhang et al. 2018). Shan et al. (2018) cloned the crustacean cardioactive peptide (CCAP) gene from eyestalks of the oriental river prawn, *Macrobrachium nipponense*, and studied its expression profile under hypoxic conditions. Their results showed that Mn-CCAP responded strongly to hypoxia-induced oxidative stress, and brain and eyestalk may respond in different ways to hypoxia.

The myogenic enhancer factor 2 (MEF2) gene family is a regulator in the control of muscle repair, regeneration, and development. Ping et al. (2018) showed that MEF2 was highly expressed in skeletal muscle, and it had a central role in muscle repair, regeneration, and development of the ricefield eel, *Monopterus albus*.

Forkhead box protein L2 (Foxl2) has dramatic effects on early differentiation and development of the female gonad in mammals and fish through the repression of SOX9 expression. Jin et al. (2018) characterized the Foxl2 gene of the oriental river prawn, *M. nipponense*. Their results suggested that Mn-Foxl2 may be involved in morphological larval changes, initiation of metamorphosis, and gonadal sex differentiation. Mn-Foxl2 mRNA expression levels were significantly higher in testes than in ovaries, implying that Mn-Foxl2 may promote both the male and female sexual development in *M. nipponense* (Jin et al. 2018).

H. Zhang, Zhang et al. (2018), H. Zhang, Zhao et al. (2018), and X. Zhang et al. (2018) studied the effects of injecting luteinizing hormone-releasing hormone analog (LHRH-A) on intestine of Grass carp, *Ctenopharyngodon idella*. They compared transcriptome profiles of the LHRH-A injection group and the control group and found that protein digestion and absorption pathways as well as fat digestion and absorption pathways were upregulated by LHRH-A injection.

Future Prospects

One of the important steps for increasing the benefit of breeding programs is to engage all participants, including the researchers, seed producers, and farmers who grow the end products, to form a powerful system to create better genetically improved varieties and to increase the acceptability of new varieties to farmers. In terms of adopting new technology, more studies need to be focused on understanding important genes related to aquaculture performance, improving methods using whole genome selection, and applying genome-editing approaches.

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