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Aquaculture Development and Nutrition Management of Large Yellow Croaker (*Pseudosciaena crocea*) in China: An Overview

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Abstract

Aquaculture production in China has made large contributions to the global total volume of fish for human consumption. The developed mariculture fish species large yellow croaker (*Pseudosciaena crocea*) is the highest economic marine fish of China. As a schooling fish, large yellow croaker (LYC) usually migrates from northeast China to the southeast seacoast to over-winter. Indeed, there are several culture systems that can be applied for large yellow croaker, which should simulate the natural habitat for this fish species. The nutrition management of LYC has attracted researchers to study their nutrient requirements, growth, and other physiological characteristics. Here, we review the general biology (geographic distribution and habitat), hatchery development, aquaculture systems, and nutrition management of LYC. The paper aims to underpin the most significant investigations and highlight the future prospects for the LYC aquaculture industry in China.

Keywords

Geographic distribution, habitat, hatchery, aquaculture system, dietary nutrients

Introduction

Aquaculture continues to grow faster than other major food production sectors (FAO, 2018). Global fish production peaked at about 171 million tons in 2016, with aquaculture representing 47 percent of the total (FAO). In China, by far the major producer of farmed fish in 2016, contributed 62 percent of the total volume of global aquaculture production in 2016 (FAO, 2018).

As an economically important marine fish, large yellow croaker (*Pseudosciaena crocea*) (Figure 1) has been cultured for more than three decades in China due to its delicious taste, and nutritional and

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Figure 1. Large yellow croaker (*Pseudosciaena crocea*). The photo was taken on January 31, 2018 in a laboratory of the University of Shanghai for Science and Technology, Shanghai-China

economic values (Duan *et al.*, 2001; Wang *et al.*, 2019). They can be grouped into three geographical populations, i.e. Daiquyang, Min-yuedong, and Naozhou stocks (Huang & Walters, 1983; Wang *et al.*, 2013). The majority of large yellow croaker (LYC) are cultured along China's east seacoast in such provinces as Guangdong, Fujian, and Zhejiang (Liu *et al.*, 2008; Chen *et al.*, 2020). According to the China Fishery Bureau, the aquaculture production of LYC reached 177,600 tons in 2017, making LYC the largest contributor to marine aquaculture fish in China (Fishery Bureau, 2018). Since there are huge demands from nation-wide and foreign markets for LYC, the demand for LYC nutrition supplies has also increased. LYC diets and nutritional requirements have been studied since the beginning of the 21st century (Duan *et al.*, 2001). They have included the ideal levels of lipids (Ai *et al.*, 2008), protein (Ai *et al.*, 2006; Duan *et al.*, 2001), amino acids (Mai, *et al.*, 2006; Xie *et al.*, 2012; Zhang, Ai, *et al.*, 2008), fatty acids (Zuo *et al.*, 2012a; 2012b), color pigments (Li *et al.*, 2014; Yi *et al.*, 2014), and other nutrients. The fish growth performance, survival rate, specific growth rate, and proximate compositions have been used as the parameters to evaluate the effectiveness of the experimental diets (Duan *et al.*, 2001; Zhang *et al.*, 2008; Li *et al.*, 2010). Recently, research has focused on physiological studies, such as the antioxidant capacity (Yi *et al.*, 2018), intestinal digestive enzymes (Zhang *et al.*, 2016), and immune responses (Li *et al.*, 2014) of large yellow croaker.

In this paper, we summarize the general biology (geographic distribution, habitat and migration), fisheries and aquaculture developments (hatchery history and culture systems), and nutritional management of large yellow croaker, which is one of the principal marine aquaculture fish species in China.

General biology

Geographic distribution

Pseudosciaena crocea has an endemic distribution in the coastal waters of continental East Asia, including East China, northern South China, Southern Yellow Seas, Taiwan, and South Korea (Huang & Walters, 1983; Chen *et al.*, 2018). Based on the morphological characteristics, geographical habitats, and the structure of the populations, LYC in the China Sea (Figure 2) can be grouped into three geographical stocks, as Daiquyang, Min-yuedong, and Naozhou (Huang & Walters, 1983; Liu *et al.*, 2008; Wang *et al.*, 2013). These stocks are distributed from the southern Yellow Sea to the central East China Sea, the southern East China Sea to the eastern Pearl River, and the western Pearl River to the Leizhou Peninsula, respectively (Liu *et al.*, 2008; Wang *et al.*, 2013). The Daiquyang stock typically has a slow growth rate and late sexual maturation, but also cold tolerance and a long life; the Min-Yuedong stock has an intermediate growth rate with intermediate longevity and sexual maturation; and the Naozhou stock has a fast growth rate, early sexual maturation, and relatively short life (Liu *et al.*, 2008).

Figure 2. Three putative geographical stocks along the coastal waters of China, the Daiquyang (a), Min-Yuedong (b) and Naozhou (c) stocks. Image is from Google Maps (maps.google.com) and Liu *et al.* (2008).

Habitat and migration

The temperature range of LYC is about 8-32°C, while the most suitable temperature is 18-25°C. If the temperature is above 30°C or below 14°C, fish will usually reduce their food intake (Zhang, 2003). Large yellow croaker is a broad-eating fish, and they can bait hundreds of species of other small fish in the natural environment, e.g. copepods, bran shrimp, krill, and other zooplankton (Zhang, 2003).

LYC is a temperate seawater schooling fish species (Lü *et al.*, 2008). In the central East China Sea area, the large schools of LYC mature in late March and migrate inshore to spawn in shallow coastal waters (<30m) during April to June (Huang & Walters, 1983; Lin, 1987). In the southern East China Sea area, fish mainly spawn from November to January (Lin, 1987). There are about 13 spawning grounds along the China Sea from north to south, namely the South Korea-inshore, Lusiyang, Daiquyang, Damuyang, Maotouyang, Dongtouyang, Guanjingyang, Xiamen-offshore, Nanao-inshore, Shanwei-offshore, Hongkong, Naozhou, and Xuwen sites (Huang & Walters, 1983; Liu *et al.*, 2008). The three most important spawning grounds are Daiquyang and Lusiyang in the northern Zhejiang coastal waters, and Mao-touyang in the middle of Zhejiang coastal waters (Lü *et al.*, 2008). Spawning season coincides with the fishing season. The fishing season begins annually in early April and ends in late June (Huang & Walters, 1983). As temperatures decrease, LYC moves further east from October to December and over-winter offshore in deeper waters (50-80m) from January to March (Lü *et al.*, 2008). The over-wintering grounds consist of the southern Yellow Sea, the offshore northern Zhejiang province, and between the southern Zhejiang to southern Fujian Provinces (Liu *et al.*, 2008).

Fisheries and aquaculture

Fishery activities

The number of LYC fisheries declined in the 1970s due to overfishing, and the fish was extremely overexploited by the mid-1980s to 1990s; for example, the harvest dropped from 155,000 tons in 1970 to only 1,700 tons in 1990 (Lü *et al.*, 2008). From April to July of 1981, bottom trawling was stifled along the coast of China to protect LYC during the spawning period (Lü *et al.*, 2008). In 1998, the Chinese government initiated a policy to release and restock LYC in Zhejiang province (Lü *et al.*, 2008). Although no statistics were recorded from 1998 to 2002, there has been an increase in the number of LYC harvested since 2003 (Lü *et al.*, 2008). In 2006, there were 55.2 tons of LYC harvested near the releasing area of the Daiquyang Sea (Lü *et al.*, 2008). To date, the contribution of wild catches is still limited despite the enforced management measures (Liu *et al.*, 2008; Wang *et al.*, 2013; Wang, *et al.*, 2014).

Hatchery development

Due to the decline of wild stocks, the Chinese government began investing in hatcheries to restore the LYC resources. In 1985, wild stocks of 30 mature female LYC were captured in the Guanjingyang spawning ground, and a total of 1,115,000 fertilized eggs were obtained (Su *et al.*, 2004). In May of 1987, domesticated broodstocks of 20 pairs were selected for artificial spawning and 100 fry were successfully nursed, which was a milestone for artificial propagation (Chen *et al.*, 2018). In 1990, the second generation consisting of a million fry were artificially hatched successfully without relying on wild-caught broodstock (Su *et al.*, 2004). During the 1990s, with strong support from the Ministry of Agriculture and the Fujian Province government, several projects were approved, including the "Development and research on cultivation techniques of large yellow croaker", "Development and research of artificial breeding technology of large yellow croaker", and "Technical research on the large yellow croaker breeding industry", among others (Chen *et al.*, 2018). These efforts contributed to the development of the LYC aquaculture industry, which made it the largest culture industry of any marine fish in China (Chen *et al.*, 2018). The number of hatcheries in Fujian Province increased nearly 22 times in only 4 years, from 20 hatcheries in 1996 to 432 hatcheries in 2000 (Zhang *et al.*, 2002). In 1999, a hatchery attempt for the Daiquyang stock was launched in Zhejiang Province and 300,000 fry were successfully cultivated in 2000 at the Zhoushan Fisheries Research Institute (Ni & Lu, 2003).

At the beginning of 21st century, more projects were established to contribute to the LYC aquaculture, e.g. original stock management, disease control, environmental monitoring, technical training, and information network development (Chen *et al.*, 2018). In November of 2011, the "Industrialization of the Daiquyang stock of large yellow croaker aquaculture" was launched in Zhejiang province (Chen *et al.*, 2018). In 2014, the research team of Ming-Yun Li documented the development of a new variety of LYC named Donghai No. 1, the fifth generation of wild stock from Daiquyang in 2000 (Miao *et al.*, 2014). According to the report, in 2012, Donghai No. 1 contributed a higher yield of hatchery-produced fry than that of the local commercial fry in Xiangshan and Fenghua cites, Zhejiang Province (Miao *et al.*, 2014). In October 2015, the State Key Laboratory of Large Yellow Croaker Breeding was launched by Ningde Fufa Fisheries Co., Ltd., which was the first State Key Laboratory of aquaculture enterprises in China (Chen *et al.*, 2018).

To date, the annual national production of China has the potential to increase each year (Yin *et al.*, 2017). The aquaculture production of China has nearly doubled from 85,800 tons in 2010 to 165,496 tons in 2016 (Fishery Bureau, 2011; 2017).

Culture systems

Aquaculture systems are believed to have an impact on the flesh quality, such as the proximate composition, color, texture, and fatty acid and amino acid profiles of cultured LYC (Zhong *et al.*, 2014; Zhou *et al.*, 2014). To date, the marine aquaculture systems of LYC have developed rapidly (Chen *et al.*, 2020). There are several kinds of culture systems in LYC aquaculture, e.g.

Figure 3. Floating sea cage culture of large yellow croaker
(The photo was taken on January 28, 2018 in Xiapu City-Fujian Province-China)

floating sea cage, earthen pond, enclosure/seine net, storm-resistance deep-sea cage, indoor recirculation system, and the north-south connected farming model. Selecting the best system depends on the local geographic conditions, the economic resources of the anglers, and the scale of the project (Liu, 2013).

The most prevalent system is the floating sea cage, which has developed since the 1980s (Miao *et al.*, 2007) and accounts for 95% of the yield of LYC species (Hong *et al.*, 2018). Traditional cage culture is generally selected in clear-water harbors where water currents are relatively slow (Figure 3). In the 1990s, floating sea cages, sized 3×3×3 m, usually had a high density of fish, and poor-water exchange capacity and quality, which could easily have changed the migration and habitats of LYC (Miao *et al.*, 2007; Ni & Wang, 2009). Hence, in 2006, the government launched the "Large yellow croaker standardized cage culture technology" project, which was carried out by fishery science and technology researchers; it began the practice of using new, larger-ranged cages to replace the former small, shallow cages (Hong *et al.*, 2018). To date, each cage is about 4×4m standards with the depth ranging from 8-10m, and an area of 2000m^2 of connected cages forms a cage unit, commonly known as a fish platoon (Hong *et al.*, 2018).

Earthen pond farming is a kind of simulated ecological pattern (Jiang, 2014; Chen *et al.*, 2018). The size of the pond depends on the target population of fish produced but is usually about 3 hectares as the pond needs to have an inflow and draining capacity every day of the year (Jiang, 2014). The south of China, especially Fujian Province, is famous for its abundant marine resources and excellent seawater quality; therefore, it is of practical significance to investigate earthen pond farming and improve the quality of LYC, which can supply market demands and promote the increase of anglers' income (Jiang, 2014).

Enclosure/seine net farming is another kind of simulated ecological pattern that is an ideal system for fish farming. The enclosure net sizes are either 0.2-0.27hm^2, 1.00-1.33hm^2, or bigger than 10hm^2, and should be placed in areas with a water depth of more than 5m (Chen *et al.*, 2018; Hong *et al.*, 2018). The seine net has larger space for fish activity, more water exchange, less residual bait, less disease, and high survival rate, and at the same time, there is a certain amount of natural biological bait supplement (Miao & Li, 2006). It has been approved to contribute to the flesh quality of LYC more than that of the traditional floating sea cages and earthen ponds (Miao *et al.*, 2007; Han *et al.*, 2011; Yan *et al.*, 2015).

Storm-resistance deep-sea cage/deep-water sea cage farming is a potential solution for LYC aquaculture. The cultured sea area must have the conditions for avoiding strong winds, a suitable temperature for species over-wintering, a water depth more than 10m, and a water flow below 0.7 m s^{-1} (Zhang, 2003). A semi-open bay facing south is generally optimal, as it is relatively less affected by typhoons (Zhang, 2003). In order to avoid typhoons, fish are stocked in October and harvested in June of the following year (Hong *et al.*, 2018). The quality of LYC cultured in deep-water sea cages is more preferable with better nutritive quality and flavor than that of traditional sea cages (Zhong *et al.*, 2014 Guo *et al.*, 2016; Xiao *et al.*, 2017).

Studies utilizing indoor recirculation systems have been recently conducted to test the low salinities of the cultured water (Huang, 2015; Wang *et al.*, 2016). The natural salinity of seawater (28%) was reduced to 8, 4, 2 or 0.5%; the fish (initial weight of 0.1g) survival rate remained 59% after 4 months (Huang, 2015). In another study, the salinities of 5% and 10% did not have negative effects on the physiological functions of juvenile LYC (initial weight of 0.12g) after 10 weeks (Wang *et al.*, 2016). If the model is successful in the future, it will be applied to indoor recirculation systems with freshwater (Huang, 2015) or saline ponds (salinities from 5% to 10%) (Wang *et al.*, 2016).

North-south connected farming is a new model for sustainable development in recent years (Li *et al.*, 2017). Fish would be moved to a suitable temperature area to escape the cold weather in the north and the hot weather in the south. In 2017, Ming-Yun Li and his team investigated the north-south connected farming model (Li *et al.*, 2017). The fish hatched in Fujian Province would be shifted to Shandong Province to culture in the summer and autumn. As the winter arrived, the fish would be transferred to Fujian for cultivation. The transaction would be continued until the fish reached the market size and could be sold out. The model is believed to contribute to a higher fish growth rate, disease resistance, and better fish quality and flavor (Li *et al.*, 2017).

Nutrition management

It is crucial to study nutritional management since juvenile nutrition investments are about 70-80% of the LYC aquaculture total investment (Liao *et al.*, 2011). The nutrition sources of LYC in commercial hatcheries are based on two main sources: the fresh/frozen trash fish diet and commercial compound diet (Liu, 2014; Liu & Li, 2001).

Fresh/frozen trash fish have basically occupied 80% of the LYC diets in the markets of Ningde, Fujian Province (Liu, 2014). However, trash fish have some disadvantages to the aquaculture of LYC. Trash fish have limited resources, an unstable supply chain (Liu & Li, 2001; Liu, 2014), spoil easily, and have nutritional inconsistencies (Liu, 2014). Trash fish residue also pollutes the environment (Wang, 2014). The bacterial communities of fresh/ frozen trash fish for LYC have been studied, and there are several bacteria that could lead to diseases (Wang *et al.*, 2014). Therefore, with the goal of sustainable development, hatcheries should shift to the compound diet.

Compound diets have been increasingly been used since the beginning of the 21st century (Liu & Li, 2001; Liu, 2014). Since then, studies about LYC nutrition have been multiple and abundant. Studies about the nutritional requirements of LYC larvae and juveniles are summarized as follows.

Larvae diets

Nutritional information for LYC larvae has been studied from the late 2000s (Ai *et al.*, 2008). Since dietary lipid levels significantly affect the growth and survival rate of LYC larvae, the optimal dietary lipid level was found to be in the range of 172 to 177 g kg^{-1} of diet (Ai *et al.*, 2008). Consequently, Yu *et al.* (2012) reported that the level of 57.1% protein with 13.6% dietary carbohydrates was suitable for LYC larvae with an energetic 16.65 MJ kg^{-1} diet. Moreover, larvae usually have higher protein requirements in order to break the proteins down into amino acids for rapid growth in early life (Rønnestad *et al.*, 2003). The optimum dietary amino acids pattern contributes to the balance of amino acids required, decreases amino acid oxidation, and increases the efficiency of food conversion (Conceição *et al.*, 2003). The effects of dietary amino acids on the growth and protein metabolism of LYC larvae were studied by Li *et al.* (2013). The amino acid patterns with crystalline-amino acids replacing approximately 40% of fishmeal protein-bound nitrogen were tested with large yellow croaker egg protein, large yellow croaker larvae whole-body protein, large yellow croaker muscle protein, and white fishmeal protein, respectively. The results showed that the specific growth rate and whole-body protein content obtained were highest in white fishmeal protein (11.3%) compared to egg protein, whole-body protein, and muscle protein diets (9.9, 10.3, and 10.6 % day^{-1}, respectively). The specific activities of the digestive enzymes and the ratio of "pancreatic enzymes in intestinal segments/pancreatic enzymes in pancreatic segments" were also significantly higher in larvae fed with white fishmeal protein. In addition, the requirement of dietary lysine, an essential amino acid that can promote larvae growth rate, was singly studied by Xie *et al.* (2012). The optimum lysine level for LYC larvae was estimated to be 33.7 g kg^{-1} (65.5 g kg^{-1} dietary protein) or 33.4 g kg^{-1} (64.9 g kg^{-1} dietary protein) based on the maximum growth and survival rate, respectively. Furthermore, the dietary phosphorus requirement level was found to be 57.2 g kg^{-1} dry diet, which can boost the survival rate, growth performance, and stress tolerance for LYC larvae (Zhao *et al.*, 2013).

Juvenile diets

The evolution of the compound diet began with research on the dietary protein: lipid ratio of LYC (Duan *et al.*, 2001). The authors tested four dietary protein levels (34, 37, 42, and 47%) and three dietary lipid levels (7.5, 10.5, and 14.0%) for juvenile LYC (0.57g initial weight) for 60 days. White fishmeal, α-starch, and wheat flour were used as the main dietary ingredients. Their data suggested that the dietary protein: lipid ratio of 47:10.5 obtained the maximum weight gain, survival rate, feed conversion, and protein efficiency ratio.

Increasing demand, limited availability, and the high price of fishmeal (FM) have resulted in the quest for alternative protein from animal and vegetable resources (Ai *et al.*, 2006; Li *et al.*, 2010). Table 1 shows studies that included different protein sources for juvenile and market-sized LYC. Ai *et al.* (2006) assessed six isonitrogenous (43% crude protein) and isoenergetic (20 kJ g^{-1}) diets replacing 0, 15, 30, 45, 60, and 75% FM protein with meat and bone meal protein for LYC (1.88g initial weight) to apparent satiation for 8 weeks (Table 1). The results indicated that 45% of FM protein could be replaced by meat and bone meal protein without

Table 1. Replacement of fishmeal protein with animal and vegetable resources

Replacement sources	Fish initial weight (g)	Duration	Replacement %	FM % (base diet)	Growth effect	Culture system	References
Meat and bone meal	1.88 ± 0.02	8 weeks	0, 15, 30, 45, 60, 75	55	45% no differences	Floating sea cages (1.0×1.0×1.5m)	(Ai *et al.*, 2006)
Compound protein sources (soybean meal, meat and bone meal, peanut meal, and rapeseed meal; 4:3:2:1)	1.88 ± 0.01	8 weeks	0, 13, 26, 39, 52, 65	48.8	26% no differences	Floating sea cages (1.0×1.0×1.5m)	(Zhang, *et al.*, 2008)
Soybean meal, meat and bone meal, poultry by-product meal, and peanut meal	23.3 ± 0.96	8 weeks	30	42-60	Peanut meal with inferior weight gain, and specific growth rate	Floating sea cages (1.5×1.5×2.0m)	(Li *et al.*, 2010)
Soybean protein concentrate meal	10.50 ± 0.04	56 days	0, 25, 50, 75, 100	40	No differences	Floating sea cages (3.0×3.0×3.0m)	(Wang *et al.*, 2017)

significantly reducing growth.

Zhang *et al.* (2008) conducted feeding trials to evaluate the replacement of compound protein sources (soybean meal, meat and bone meal, peanut meal, and rapeseed meal; 4:3:2:1) for juvenile LYC (1.88g initial weight) for 8 weeks. Six isonitrogenous and isoenergetic diets were formulated to contain 0, 9, 18, 27, 36, and 45% of the compound protein to replace 0, 13, 26, 39, 52, and 65% of the fishmeal protein, respectively. The specific growth rates and feed efficiency ratios of fish fed the 13 and 26% replacement diets were not significantly different from those of fish fed with the fishmeal diet, while those fed the 39-65% replacement diet were significantly lower than the fishmeal diet. The whole-body protein content, and methionine, cysteine and lysine contents significantly decreased with increased dietary compound protein levels (39-65%). It was therefore concluded that the compound protein sources could replace about 26% of the fishmeal protein in the diets of LYC.

In another attempt to find an alternative to fishmeal, Li *et al.* (2010) evaluated the replacement of 30% of fishmeal with soybean meal, meat and bone meal, poultry by-product meal, or peanut meal in the practical diets of juvenile LYC (23.3g initial weight) for 8 weeks (Table 1). The results showed that fish fed with various protein sources had no significant differences in survival, weight gain, and specific growth rates, except for the peanut meal diet, which showed inferior weight gain and specific growth rate, and lower contents of crude protein, lipids, and carcass lysine.

In a study by Wang *et al.* (2017), the level of dietary soy protein replacement was even acclimated to a maximum of 100%. Five isonitrogenous and isolipidic diets (45% protein and 10% lipids) were formulated by replacing of fishmeal protein (0, 25, 50, 75, and 100%, respectively) with soybean protein concentrate meal. Among the dietary treatments, there were no significant differences in weight gain, specific growth rate, feed conversion ratio, and feed intakes;

Table 2. Replacement of fish oil by animal and vegetable resources

Replacement sources	Fish initial weight (g)	Duration	Replacement %	FO % (base diet)	Growth effect	Culture system	References
Soybean oil and beef tallow	243.52 ± 5.40	9 weeks	100	7.4	No differences	Floating sea cages (2.0×2.0×2.0m)	(Wang *et al.*, 2012)
Soybean oil and palm oil	245.29 ± 7.45	12 weeks	0 SO, 50 SO, 100 SO, 100 PO	6.4	50 SO, 100 PO, no differences	Floating sea cages (3.0×3.0×3.0m)	(Duan *et al.*, 2014)
Soybean, linseed, rapeseed, and peanut oil	13.77 ± 0.07	8 weeks	100	3.4	SO, no differences	Floating net cage (1.5×1.5×2.0m)	(Qiu *et al.*, 2017)
Vegetable oil (soybean oil, linseed oil)	8.93 ± 0.21	10 weeks	0, 50, 100	9	Decreased	Floating cages	(Tan *et al.*, 2016)
Soybean oil	36.80 ± 0.39	12 weeks	50, 100	6.5	Decreased	Large sea cages (4.0×4.0×4.0m)	(Mu *et al.*, 2018)
Soybean oil with added dietary chenodeoxycholic acid	10.03 ± 0.02	10 weeks	100 SO added CDCA 300, 900 mg kg^{-1}	6.0	CDCA better	Floating sea cages (1.0×1.0×1.5m)	(Du *et al.*, 2017)
Palm oil	15.87 ± 0.14	70 days	0, 33.3, 66.7, 100	7.5	66.7, 100% suppressed	Triplicate floating cage (1×1×1.8m)	(Li *et al.*, 2019)

Note: FO: fish oil; SO: soybean oil; PO: palm oil; CDCA: chenodeoxycholic acid.

the muscle protein and moisture contents also showed no significant differences. However, the lipid content was significantly lower in the dietary treatment with 100% soy protein replacement. The results also showed that the inclusion of soy protein with balanced dietary amino acids did not promote antioxidant capacities and affected the non-specific immune response of large yellow croaker.

Fish oil is a good source of lipids and has a high content of n-3 polyunsaturated fatty acids for marine fish nutritional requirements (Sargent & Tacon, 1999). However, fish oil faces the challenges of high prices and unstable production due to the increasing demand for fishmeal and fish oil in aquaculture (Wang *et al.*, 2017). To cut down the cost of feeding, some studies have tested different types of oil to replace the dietary fish oil used in aquaculture (Wang *et al.*, 2012). Table 2 shows the studies that tested the replacement of fish oil with animal and vegetable resources in the literature. Some studies have demonstrated that the oil sources do not affect the growth performance of LYC grown-out fish (Wang *et al.*, 2012; Duan *et al.*, 2014) and juvenile LYC (Qiu *et al.*, 2017).

In a 9-week feeding trial conducted by Wang *et al.* (2012), three isonitrogenous and isoenergetic diets containing fish oil, soybean oil, and beef tallow, respectively, were studied to check their effects on the growth performance, tissue fatty acid composition, and peroxisome proliferator-activated receptor γ gene expression in LYC grown-out fish (243.52g initial weight). No significant differences in weight gain, growth rate, and feed conversion rate were found among the different treatments after the trial. The fatty acid profiles of fish fillets and livers were influenced by the dietary fatty acid compositions, where the concentrations of eicosapentaenoic acid and docosahexaenoic acid decreased as the fish oil was replaced with soybean oil and beef tallow, respectively. The consumption of soybean oil displayed an increase of lipid accumulation in the liver and the expression of the peroxisome proliferator-activated receptor γ gene that influences the function of lipid storage and metabolism.

Similarly, Duan *et al.* (2014) documented that replacing fish oil with 50% soybean oil and 100% palm oil resulted in no significant differences of the specific growth rate, condition factor, gutted yield, and colorimetric values of grown-out LYC (245.29g initial weight). Furthermore, five isonitrogenous and isolipidic experimental diets were formulated to check the effects of different lipid sources (fish, soybean, linseed, rapeseed, and peanut oil) on fish growth and the fatty acid compositions of juvenile LYC (13.77g initial weight) for 8 weeks (Qiu *et al.*, 2017). The results suggested that different lipid sources could affect the fatty acid compositions in the muscles and livers of LYC in various metabolic pathways; and that soybean and palm oil can completely replace fish oil in the diets of LYC without suppressing the growth performance.

However, high levels of vegetable oil can suppress the growth and antioxidant capacity of juvenile LYC (Li *et al.*, 2019; Tan *et al.*, 2016; Mu *et al.*, 2018). Three isonitrogenous and isolipid diets with 0, 50, and 100% vegetable oil were fed to juvenile LYC (8.93g initial weight) (Tan *et al.*, 2016). The results showed that dietary vegetable oil could exert anti-immunological effects by altering TLR-NF-κB signaling, and elevating the inflammatory response by increasing the gene expression of pro-inflammatory cytokines (IL1b and TNFa) and decreasing the gene expression of anti-inflammatory cytokines (arginase I and IL10). In addition, the replacement of 50 and 100% fish oil with soybean oil can suppress the growth performance, feed utilization, and anti-oxidation capacity of juvenile LYC (36.80g initial weight) (Mu *et al.*, 2018). Similarly, a high percentage of dietary palm oil (66 and 100%) supplemented to diets can suppress fish growth, antioxidant capacities, and induce the inflammatory response of juvenile LYC (15.87g initial weight) (Li *et al.*, 2019). Fortunately, the imperfection of soybean oil replacement can be conquered with the supplementation of chenodeoxycholic acid (300 and 900 mg kg^{-1}) to the diets of juvenile LYC (10.03g initial weight) (Du *et al.*, 2017). The results of this study showed that chenodeoxycholic acid supplemented diets could improve the growth performance, body composition, and lipid deposition in the livers of LYC.

Some studies have reported the amino acid requirements of juvenile LYC (Table 3). The dietary methionine requirement was examined by Mai *et al.* (2006a) using six diets with graded levels of methionine (0.66, 0.89, 1.13, 1.41, 1.67, and 1.89% diets) for juvenile LYC (1.23 ± 0.02g initial weight). The specific growth rate, feed conversion efficiency, and protein efficiency ratio increased with increasing methionine levels up to the 1.41% diet and then declined. No significant differences in body composition were observed among the dietary treatments. It was therefore concluded that the optimum dietary level of methionine for juvenile LYC was the 1.44% diet. Zhang *et al.* (2008) examined the dietary lysine requirement for juveniles with six isonitrogenous and isoenergetic practical diets formulated with lysine (1.27, 1.83, 2.41, 3.02, 3.60, and 4.22% dry matter). The specific growth rate, feed efficiency ratio, protein efficiency ratio, and protein retention significantly increased with increasing lysine levels from 1.27 to 2.41% of the diet, and then leveled off. The whole-body protein and lysine contents increased significantly with the increasing dietary lysine levels, while the lipid contents showed an opposite trend to that of body protein. No significant differences were observed in moisture, ash, and other essential amino acids of the fish among the dietary treatments. It was concluded the optimum lysine requirements were 2.48, 2.45, and 2.43% of the diet, respectively, based on broken-line analysis of the specific growth rate, feed efficiency ratio, and protein efficiency ratio.

Large yellow croaker is a marine fish that has significant yellowness of skin color (Guo *et al.*, 2018). Dietary natural pigments can enhance the natural skin pigmentation of LYC, such as xanthophylls, astaxanthin, and *Haematococcus pluvialis* (Chlorophyceae, order Volvocales) (Li *et al.*, 2014; Yi *et al.*, 2014) (Table 3). Xinwen Yi and his co-authors have studied the effects of xanthophylls and astaxanthin, compared

Table 3. Amino acid and other dietary nutrient requirements for juvenile large yellow croaker

Dietary nutrients	Experimented amount (% dry diet basic)	Fish initial weight (g)	Duration	Culture system	References
Methionine	0.66, 0.89, 1.13, 1.41, 1.67, 1.89	1.23 ± 0.02	10 weeks	Floating net cages (1.0×1.0×1.5m)	(Mai *et al.*, 2006a)
Lysine	1.27, 1.83, 2.41, 3.02, 3.60, 4.22	1.23 ± 0.02	10 weeks	Floating sea cages (3.0×3.0×3.0m)	(Zhang, *et al.*, 2008)
Astaxanthin and *Haematococcus pluvialis*	Astaxanthin (0.03, 0.05, 0.10), *H. pluvialis* (0.28, 0.56, 1.12)	5.57 ± 0.01	66 days	Net cages (1.5×1.5×2.0m)	(Li *et al.*, 2014)
Astaxanthin and xanthophylls	Astaxanthin (37.5, 75*), xanthophylls (37.5, 75*)	33.33 ± 1.67	9 weeks	Floating sea cages (3.0×3.0×3.0m)	(Yi *et al.*, 2014)
Xanthophylls/astaxanthin ratio	75/0, 50/25, 37.5/37.5, 25/50, 0/75*	13.80 ± 0.03	8 weeks	Floating sea cages (1.0×1.0×1.5m)	(Yi *et al.*, 2015)
Astaxanthin and vitamin E	Astaxanthin (25, 50*), vitamin E (0, 120, 800*)	3.00 ± 0.01	10 weeks	Floating sea cages (1.5×1.5×2.0m)	(Yi *et al.*, 2018)
Phosphorus	0.30, 0.55, 0.69, 0.91	1.88 ± 0.02	8 weeks	Floating sea cages (1.0×1.0×1.5m)	(Mai *et al.*, 2006b)
Copper	2.61, 3.25, 4.65, 7.16, 11.38, 18.45*	9.18 ± 0.06	10 weeks	Floating sea cages (3.0×3.0×3.0m)	(Cao *et al.*, 2014)
Citric acid	0.4, 0.8, 1.6, 3.0	7.71 ± 0.02	9 weeks	Floating sea cages (1.5×1.5×2.0m)	(Zhang *et al.*, 2016)
Tea polyphenols	0, 0.01, 0.02, 0.05	15.88 ± 0.12	70 days	Net cages (1.0×1.0×2.0m)	(Ji *et al.*, 2018)

*Note: *, mg kg^{-1}.*

to a basal diet, on fish growth, skin pigmentation, and carotenoid concentration of LYC (Yi *et al.*, 2014; Yi *et al.*, 2015; Yi *et al.*, 2018). In general, the survival rate, specific growth rate, and protein efficiency ratio were not significantly different among treatments. A higher yellowness (b*) value and carotenoid concentration were observed in both the dorsal and ventral skins of fish with increased xanthophyll levels than those with increased astaxanthin levels, which were both higher than those of the basal diet.

Li *et al.* (2014) studied the effects of dietary astaxanthin (0.03, 0.05, and 0.10 g $100g^{-1}$ diet) and *Haematococcus pluvialis* (*H. pluvialis)* (0.28, 0.56, and 1.12g $100g^{-1}$ diet), compared to a basal diet, on fish growth, antioxidant status, and, especially, the immune response of LYC (initial weight 5.57g) for 66 days. No significant differences were observed in the fish survival rate, food conversion ratio, protein efficiency ratio, and hepatosomatic index among the different treatments. Weight gain and whole-body lipid content were highest in the *H. pluvialis* treatment, compared to the astaxanthin and basal diets. The condition factor of the *H. pluvialis* treatment was significantly higher than that of astaxanthin, which was similar to that of the basal diet. It was found that LYC with astaxanthin and *H. pluvialis* had lower glucose, triglyceride, and cholesterol levels than those of fish fed a basal diet. Serum lysozyme activity, an index of innate immunity, was reported to increase with increased dietary astaxanthin or *H. pluvialis* levels. The complement response, acting as a bactericidal agent in serum and mucus, was also found to improve in large yellow croaker fed with astaxanthin or *H. pluviali*.

Other dietary nutrient requirement studies have also reported the optimal concentrations for juvenile LYC, e.g. dietary phosphorus 0.89-0.91% of diet (Mai *et al.*, 2006b), dietary copper 3.41 mg kg^{-1} (Cao *et al.*, 2014), dietary citric acid 0.8-1.6% diet (Zhang *et al.*, 2016), and dietary tea polyphenols 0.01-0.02% diet (Ji *et al.*, 2018) (Table 3). Recently, dietary requirements have been inter-studied with the biological functions of fish, i.e. antioxidant capacity (Yi *et al.*, 2018), immune response (Zuo *et al.*, 2012a; Li *et al.*, 2014), intestinal digestive enzyme activities (Zhang *et al.*, 2016), lipid metabolism genes expression (Ji *et al.*, 2018), and disease resistance (Zuo *et al.*, 2012a). These studies contribute to the holistic understanding of the physiological mechanisms behind the fish traits and their reactions to certain dietary nutrients.

Conclusions and Future Perspectives

As one of the most financially important marine fish farmed in China, large yellow croaker aquaculture is gaining attention from the Chinese government, culturists, technicians, and scientists. This article presents an overview of large yellow croaker aquaculture in China, providing related information about the general biology, aquaculture development, culture systems, and nutrition management of large yellow croaker. The floating sea cage is the main model of LYC aquaculture; however, novel aquaculture systems such as the storm-resistance deep-sea cage and indoor recirculation system have great potential for large-scale aquaculture production. The ideal marine juvenile diet for LYC is one containing the protein: lipid ratio of 47:10.5; likewise, other nutrient requirements have also been studied recently.

Important research efforts should continue in the field of culture systems for LYC, and should support the sustainable development and environmental safety of marine aquaculture. Currently, the installation and operation of submersible offshore sea-cages are attracting investments from operators and managers, and this system can be utilized for LYC depending on the local circumstances, the resources of each farm business, and the continuous innovation of the culturists, managers, and scientists.

To reduce the price of the diets fed to LYC and triumph over the unstable availability of fishmeal and fish oil, studies about the replacement of protein and lipid sources should continue to be carried out on other protein and lipid sources and vegetable oils. In addition, investigations on dietary supplementations, such as dietary amino acids, phospholipids, and n-3 highly unsaturated fatty acids, are needed to determine the favored sources of metabolic energy for LYC. Moreover, further research about the physiological responses to particular dietary nutrients of LYC will contribute to our understanding of fish metabolism, help protect the fish from disease, and allow increases in large-scale fish production.

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Conflicts of Interest

The authors declare no conflicts of interest.

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