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Review on Growth and Muscle Quality of Sturgeons

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Abstract The meat and eggs of sturgeon are of great nutritional value, the scale of sturgeon breeding has been steadily expanded, and China has become the largest sturgeon breeding country in the world. Although a series of scientific achievements have been made in the field of conservation biology and applied technology of Sturgeon at home and abroad, little is known about the growth and muscle quality of cultured sturgeon. The present situation of the research on the allometric growth pattern and muscle quality analysis of cultured sturgeon at home and abroad is reviewed. It is found that the present research on the muscle quality of sturgeon is mainly focused on juvenile sturgeon or a certain growth period, lacking in systematicness and integrality. Therefore, it is suggested that the growth and muscle quality of cultured sturgeon should be studied from juvenile to adult in order to reveal the growth and development of sturgeon muscle quality.

Keywords Sturgeon; Growth; Muscle quality

Background

Sturgeon belongs to Osteichthyesus, Atinopterygiiformidae, Chondrosteiformia, Acip Enseriformesus, exists 2 families (Polyodontida, Acipenseridaeae), 6 genera, and 27 species. Convention on International Trade in Endangered species of Animals and plants (CTTES) in Zimbabwe in 1997, all species of sturgeon were included in the convention's protected species (Chen, 2007). There are 8 species distributed in China, mainly in the Yangtze River Basin, Heilongjiang River Basin and three regions of Xinjiang. Acipenser sinensis, Psephurus gladius and Acipenser dabryanus inhabit the Yangtze River Basin. Acipenser Schrenckii and Huso dauricus locate in the Heilongjiang River. Acipenser nudiventrisus, Acipenser ruthenus and Acipenser baerii locate in Xinjiang Yili Rive. All three kinds of sturgeon in the Yangtze River Basin are listed as national first class protected animals, except artificial multiplication and release, all commercial fishing activities are prohibited.

Sturgeon has the characteristics of large individuals, fast growth, strong adaptability and few diseases. Sturgeon is rich in meat and bone, delicious in taste and high in protein in meat and eggs, is a high-grade nutrition. Caviar is made of sturgeon eggs and is rich in essential amino acids and unsaturated fatty acids, inorganic salts, vitamin A, B and D, and trace elements such as calcium, copper, magnesium, iron and selenium, as well as goose liver and truffles, which being called “the three great delicacies in the world”. Known as “Black Gold”, which is a valuable and expensive food in the world.

The contradiction between the shortage of sturgeon in domestic and foreign markets and the decreasing of wild sturgeon resources makes it an inevitable choice to obtain sturgeon products through breeding. In the 1980s, sturgeon culture began to develop in Europe. Sturgeon culture in China began in the 1990s. Through the systematic research on the techniques of total artificial propagation of sturgeon, breeding techniques of seedling species and different models of breeding, a complete system of sturgeon culture techniques has been formed. Factory culture, cage culture, pond culture can achieve better economic benefits. In recent years, sturgeon farming has been concentrated in Italy, France, Germany, the United States, Uruguay and China (Bronzi et al., 2011). By 2008, the production of sturgeon in China reached 21,400 tons, accounting for 83.3% of the total output of sturgeon culture in the world, and became

the largest Sturgeon country in the world. Although a series of achievements have been made in the basic research and applied technology of sturgeon at home and abroad, there is a lack of systematic study on the growth and meat quality of sturgeon and little is known about it. In this article, the current situation, development trend and problems of Sturgeon growth and muscle quality were reviewed.

1 Growth Pattern of Cultured Sturgeon

The relationship between body weight and body length of fish is one of the main contents in the study of fish growth biology. Describing weight by W = aLb, the correlativity between body length and body length, in which the growth power exponent b represents the ratio of the weight increase coefficient to the body length increase coefficient, and represents the heterogeneity of fish development. This heterogeneity is due to the uneven growth of body weight and body length, so parameter b can be used to determine whether the fish are growing at different speeds. Zhuang et al. (2002) studied the abnormal growth and organ development of the juvenile fish of the Siberian sturgeon at the age of 0-53 days. The results showed that the juvenile of the Siberian sturgeon had full-length inflection points at the ages of 9, 28 and 37 days, respectively. The full-length growth was divided into 4 stages, which was allometric growth and showed that the full-length growth was faster than weight gain. During the development of larvae and juveniles of Siberia sturgeon, the size of many key organs has allometric growth. At the age of 3~4 days, the first growth inflection point was reached in the eye diameter, which means that the eye was preferentially developed, so that it could effectively avoid the enemy after the membrane was removed. At the age of 17~18 days, the inflection point appeared in the width of the mouth, and the active feeding ability was strengthened with the improvement of the sensory organs and fins. At 13~14 and 16~17, 21~22 days of age, the dorsal fin, pectoral fin, the length of the anal fin also appeared respectively growth inflection point, marks their swimming ability had more perfect, could effectively avoid enemy and access to food, provided the guarantee for the survival of its early. A study on the isokinetic growth of Acipenser schrenckii larvae at the age of 38 days has obtained similar results (Ma et al., 2007).

The early ontogeny of fish from endogenous nutrition to exogenous nutrition is a very critical period, especially the development of digestive tract. Different from the successive development of other organs, the digestive tract will undergo sharp changes in this period, from a straight tubular simple structure to a complex structure with functional zoning. In the early stage of individual development of Polyodon spathula, the growth rate of body length was faster than that of body weight. This was because the early sturgeon was in yolk stage, which depended on yolk nutrition for development, and did not take in exogenous nutrients, so the weight increased slowly. According to this phenomenon, it could be used to judge the transformation from endogenous nutrients to exogenous nutrients at 6~9 days after hatching (Ji et al., 2012).

The researchers found that allometric growth is common in juvenile sturgeon, but the allometric growth patterns of juvenile sturgeon of different species are different. Polyodon spathula (Yuan et al., 2012), the Siberian sturgeon (Zhuang et al., 2009), the juveniles of Acipenser schrenckii larvae (Zhuang et al., 2002; Ji et al., 2012) and the wild juvenile Acipenser sinensis between 26 and 108 g (Wu, 2007) showed an allometric growth. The growth power index was b < 3, and the body length increased faster than that of body weight. While the juvenile of dagestan sturgeon is between 99.23~383.87 g (Lu et al., 2011) and 617.27~1,379.32 g (He Bin et al., 2011), the juvenile of Huso dauricus is between 53.70~247.13 g (Wang et al., 2011a) and 186.29~1,245.43 g (Wang et al., 2011b), Siberian sturgeon in 0~1 + age (Keszka et al., 2009) and between 25~649 g (Huang et al., 2005), hybrid larvae (Huso dauricus ♀ × Acipenser schrenckii ♂) between 178.9~533.1 g (Liu, 2008) and Acipenser naccarii and Siberian sturgeon larvae between 45.5~820.8 g (Vaccaro et al., 2004) the growth of both show the allometric growth, growth power > 3b, weight growth faster than length. Only in the artificial breeding environment did the young fish of the beluga hybrids (Huso dauricus ♂ × natural hybrid (Huso dauricus ♀ × Acipenser schrenckii ♂)) grow at an equal speed between 145.83~437.36 g (Shi et al., 2008).

Condition factor (K=100×W/L3) is often used to measure fish body fullness, nutritional status and environmental conditions. Most studies have found that at different stages of early development of sturgeon, its condition factor varied from 0.300 to 0.500 (Koksal et al., 2000; Vaccaro et al., 2004; Liu et al., 2008; Shi et al., 2008; Lu et al., 2011; Ta'ati et al., 2011; Wang et al., 2011a; Wang et al., 2011b). The degree of condition factor of the 1st instar of Huso

dauricus changed from 0.350 to 0.434 (Lu et al., 2011), and to the 1st instar (0.289,4~0.372,9) (Wang et al., 2011a) and the 2nd Acipenser schrenckii (0.283,4~0.392,7) (Wang et al., 2011b), the Siberian sturgeon (0.350~0.358) (Koksal et al., 2000), Acipenser sturio (0.380~0.410) (Ta'ati et al., 2011), hybrid juvenile (Huso dauricus × Acipenser schrenckii) (0.341~0.387) (Liu Jiangui et al., 2008), Huso dauricus × natural hybrid (Huso dauricus ♀ × Siberian sturgeon ♂), juvenile fish (0.365,6~0.394,2) (Shi et al., 2008) and juvenile fish (0.32~0.54) (Vaccaro et al., 2004) were similar in condition factor between Acipenser nana and Acipenser sibirica. However, it was lower than that of wild juvenile Acipenser sinensis (Wu, 2007), 0.44~0.603 (Gisbert et al., 1997) of juvenile Acipenser sinensis and 0.72 (Zhuang et al., 1998) of juvenile Acipenser sinensis and juvenile Acipenser sinensis (Gisbert et al., 1997). It was found that the growth dispersion of Acipenser Schrenckii at the first instar was gradually intensified under the condition of pond culture with sufficient water space and food (Wang et al., 2011a). However, the discrete growth of the 2nd instar sturgeon (Wang et al., 2011b) might be due to the fact that the first instar was sensitive to the diurnal changes of weather, temperature and dissolved oxygen, and had poor resistance to stress, while the 2nd instar sturgeon had stronger resistance to stress. Therefore, environmental factors had little effect on growth dispersion.

The growth of sturgeon varies with their growth stage and environmental factors. Due to the long life span of sturgeon, the late sexual maturity, the large size of adult fish, the difficulty and high cost of raising sturgeon, the current studies mainly focus on the study of the growth characteristics of juvenile sturgeon. Studies have shown that there were differences in growth patterns of different sturgeon species in different growth stages, breeding methods, stocking density, water temperature and bait. Compared with the life cycle of sturgeon, most of the experiments were short, the research objects were different, and the culture environment was different, so the growth stage of sturgeon was not obvious, the results were not consistent, and the Sturgeon was lack of systematicness and integrality. It is worth mentioning that Zhang et al. (2013) studied the growth characteristics of hybrid sturgeon (Acipenser schrenckii ♀ × Huso dauricus ♂) (1~7). It was found that hybrid sturgeon (Acipenser schrenckii ♀ × Huso dauricus ♂) showed a trend of "allometry growth-isokinetic growth-allometry growth" from the 1st to 7th instar. Growth power of hybrid sturgeon (Acipenser schrenckii ♀× Huso dauricus) of 1st~3rd instar was b>3, which showed a strong allometric growth. After that, with the increase of age, the heterokinetic growth weakened and the development tended to be even. At the age of 5, the growth power index b=2.94, which is close to 3. At the age of 7, the growth power index b is 2.63 < 3. The condition factor of hybrid sturgeon (Acipenser schrenckii ♀ × Huso dauricus ♂) increased with age, and its correlation with body weight (R2=0.94) was higher than that with body length. The cubic growth equation had the best fitting effect on the growth of hybrid sturgeon (Acipenser schrenckii ♀ × Huso dauricus ♂) at different ages. The inflexion weight, body length and age were 28.53 kg, 82.11 cm and 4.22 ages respectively.

2 Analysis of Muscle Quality of Bred Sturgeon

Muscle quality mainly contains two aspects, muscle mass and muscle flavor. The muscle mass mainly includes the nature, quantity and proportion of nutrients that are beneficial to the human body. The traits of muscle mass are mainly physical and chemical. The physical traits mainly contain fleshcolor, marbling, whiteness, color difference, brightness, water loss rate, water percentage, drip loss, shear value, pH value and so on. The chemical traits mainly contain water, crude protein, crude fat, dry matter, ash content, collagen, iron, manganese, calcium and other substances. The muscle quality is determined by the nature, content and proportion of protein, muscle fat, ash and dry matter. The muscle flavor is the comprehensive feeling of muscle smell, taste and palatability, which depends on the nature, quantity of flavor substance and the interaction of each substance. The texture, tenderness and juicy properties of muscle play a certain helpful role in meat flavor perception. The formation of muscle flavor was determined by the chemical changes between the precursor substance of flavor component in muscle and the precursor substance of meat flavor during heating (Liu, 2007).

There are many studies on muscle quality of fish, focusing more on common cultured fish and some special breed varieties, but less on sturgeon muscle quality. The existing studies on the muscle quality of sturgeon mainly focused on the analysis of muscle nutritional components of juvenile fish in Polyodon spathula (Dong et al., 2007; Chen et al., 2008; Shen et al., 2009; Ji et al., 2011; Yang et al., 2012), Acipenser schrenckii (Hu et al., 2003; Hu et al., 2004; Hu et al., 2006; Yuan, 2006), Acipenser sinensis (Song et al., 2007; Chai et al., 2010) and Huso huso (Ghomi et al., 2012a; Ghomi et al., 2012b; Ghomi et al., 2013).

Different researchers (Dong et al., 2007; Chen et al., 2008; Shen et al., 2009; Ji et al., 2011; Yang et al., 2012) had analyzed muscle nutritional components in Polyodon spathula of 50~1,500 g standard (50 g, 150 g, 300 g, 386.3~428.8 g, 456.4~585.4 g, 600 g, 722~989 g, 1,500 g) with the maximum of 2 years old. The results of normal nutrition analysis of muscle showed that the water content in the muscle of Polyodon spathula decreased, but the protein and fat contents increased gradually with age. The nutritional value of protein depended on the content and composition of amino acids, and 8 essential amino-acids (threonine, valine, isoleucine, eucine, methionine, phenylalanine, lysine, and tryptophan) in the human body played an important role in determining the nutritional value of protein. The tasty degree of fish meat was determined by the contents of 4 flavor amino acids (aspartate, glycine, glutamate, and alanine). The analysis of amino acid contents in the muscle of 50~1,500 g Polyodon spathula indicated that the contents of amino acid and protein in the muscle of Polyodon spathula were the same, and both of them increased with weight gain; the change trend of necessary and delicious amino acid contents was the same as that of total content of amino acids, glutamic acid was the most, and followed by lysine, leucine, aspartate, glycine and alanine. The essential amino-acids in the muscle of 2-year-old Polyodon spathula have a variety of species, especially the composition was suitable; the content of lysine in essential amino-acids was obviously higher than the FAO/WHO mode (Yang et al., 2012). Chinese eat cereal foods most, the muscle of Polyodon spathula could make up for the deficiency of lysine in grain food, thus to improve the utilization rate of protein in human body. It was worth noting that tryptophan (Dong et al., 2007; Chen et al., 2008; Shen et al., 2009; Ji et al., 2011) was not detected in the muscle of Polyodon spathula (all sizes of 50 g, 150 g, 300 g, 386.3~428.8 g, 456.4~585.4 g, 600 g), but detected in the sizes of 722~989 g and 1,500 g and the contents were the lowest, as the the first limiting amino acid (Shen et al., 2009; Yang et al., 2012). The reason for such difference was speculated that tryptophan was resolved in acid hydrolysis.

In the analysis of muscle nutritional components in Acipenser schrenckii of 122.95±24.69 g, 630~770 g, 1.53±0.3 kg and 50~65 kg (Hu et al., 2003; Hu et al., 2004; Hu et al., 2006; Yuan, 2006), it was found that the change of water, protein and fat in the muscle of Acipenser schrenckii was similar to those of Polyodon spathula. It was not found that the content of amino acids changed with age, but the content of glutamic acid was the highest, follwed by lysine, leucine, aspartate, glycine and alanine, the content of tryptophan was the lowest. The results were consistent with those of Polyodon spathula.

Song et al. (2007) had carried out the analysis and comparison of muscle nutritional components and quality of juvenile Acipenser sinensis in the wild and farm. The results showed that the content of water, crude protein and crude ash in the muscle of juvenile Acipenser sinensis in the wild were significantly higher than those in artificial bred Acipenser sinensis ($p<0.05$), but the content of crude fat was significantly lower than that in cultured Acipenser sinensis ($p<0.05$). The wild and bred juvenile Acipenser sinensis basically shared the same amino acid composition, both containing 18 kinds of amino acids. Wherein the content of glutamic acid was the highest, followed by lysine, aspartic acid, leucine and the content of cysteine was the lowest. According to amino acid score (AAS) and chemical score (CS), the first restricted amino acid of wild and bred juvenile Acipenser sinensis was methionine + cysteine, the second restricted amino acid was tryptophan. 6 kinds of saturated fatty acid (SFA), 6 kinds of monounsaturated fatty acid (MUFA) and 9 kinds of polyunsaturated fatty acid (PUFA) were detected in the muscle of wild juvenile Acipenser sinensis. 9 kinds of SFA, 5 kinds of MUFA and 7 kinds of PUFA were detected in the muscle of bred juvenile Acipenser sinensis. Except C14:0, C23:0 and C20:3ω6 ($p>0.05$), the other fatty acids had significantly difference in the muscle of wild and bred juvenile Acipenser sinensis ($p<0.05$). The content of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in the wild Acipenser sinensis were significantly higher than those in the cultured Acipenser sinensis ($p<0.05$), which were 22.99% and 7.15% respectively. 18 kinds of amino acids were detected in the analysis of muscle composition of 1-year-old cultured Acipenser sinensis, in which the contents of tryptophan and cysteine were the lowest (Chai et al., 2010).

The researches on the muscle quality of Huso huso mainly focused on the analysis of the composition and content of fatty acids in the muscle (Ghomi et al., 2012a; Ghomi et al., 2012b; Ghomi et al., 2013). n-6/n-3 fatty acid plays an important role in the human body (Simopoulos, 2002). In the analysis of fatty acids in the muscle of cultured European Huso huso of 5 kg or so (Ghomi et al., 2012a), it was found that monounsaturated fatty acid (MUFA) was

the principal fatty acid, follwed by polyunsaturated fatty acid (PUFA) and saturated fatty acid (SFA). The contents of EPA and DNA in the muscle of cultured Huso huso were lower than those in other cultured sturgeons (Badiani et al., 1997; Paleari et al., 1997; Jankowska et al., 2005; Vaccaro et al., 2005; Hedayatifard and Moeini, 2006). The content of n-6 fatty acid was higher than n-3, thus the rate of n-6/n-3 fatty acids was 3:0. Ghomi et al. (2012b) had also confirmed the analysis results of fatty acids in the muscle of cultured Huso huso of 5 kg or so. It is worth mentioning that Ghomi et al. (2013) firstly and systematically analyzed the relationship between the live weight and muscle composition with fatty acid content in the cultured Huso huso of 1~89 kg. There was obvious change in the normal nutritional composition of muscle in the cultured Huso huso of 1~89 kg, like 11.2%~18.63% crude protein, 1.40%~6.0% fat, 65.77%~80.4% water and 0.54%~1.4% ash. MUFA (43.11%) was the most important fatty acid, followed by PUFA (28.02%) and SFA (20.72%). Protein, SFA (C16:0, C18:0, C20:0), PUFA (C18:2n-6, C18:3n-3, EPA, DHA) and n-3/n-6 rate were significantly related to the weight ($p<0.01$). The contents of n-3, n-6, EPA and DHA as well as n-3/n-6 rate increased significantly with the weight gain of Huso huso ($p<0.01$); MUFA and DHA/EPA rate were not related to the weight. Some researchers also made a preliminary analysis of the muscle quality of juvenile hybrid sturgeon, and the results were similar to those of other researches on juvenile sturgeon (Hu et al., 2004; Jankowska et al., 2005; Vaccaro et al., 2005).

3 Expectation

Sturgeon has become more and more popular for its nutritive and economic values. China has achieved that edible sturgeons and sturgeons used to make caviar are all bred artificially, which accounts for more than 80% of the world's total, and the breeding scale is steadily expanding every year. China has become a truly super country of sturgeon breeding. However, the existing researches mainly focus on the conservation biology of sturgeon species, which is extrememly inappropriate to the increasing tendency of sturgeon breeding scale. The less research on the growth and meat quality of bred sturgeon would become a main factor restricting the development of sturgeon breeding and processing industries. Even if most of existing researches focus on the growth and muscle quality of young sturgeons, each of them is only confined to one or a limited number of age group. The growth and muscle quality are easily affected by many kinds of factors, like species, size, age, feeds, breeding environment and so on, additionally, short experimental time, different breeding environment and long life cycle of sturgeon, which would cause that the results are not comparable, lack of systematicness and completeness, the guiding significance of production practice is limited. Therefore, it would be important to systematically design and completely start the research on the change law of the growth and muscle quality of bred sturgeons in the whole growing period from juvenile to adult. This research would reveal the growth and development law of sturgeon muscle quality, determine the optimum time of sturgeon muscle quality, figure out the optimum point between sturgeon breeding & processing and muscle quality, which might provide the theoretical basis for maximizing the benefits of sturgeon breeding and processing, as well as have important practical significance of the deep processing of sturgeon products. Meanwhile, it would also provide the basic information and scientific basis for Chinese sturgeon species production for the establishment of seed production and germplasm standard of sturgeon in China, and play a guiding role in the development of sturgeon mixed feed.

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