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Slaughter yield and morpho-physiological traits of Russian Sturgeon (*Acipenser Gueldenstaedtii*) with different live weight cultivated in industrial aquaculture

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Abstract

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The study was carried out with six-summer-old male Russian sturgeon raised in an industrial cage farm. At the end of the vegetation season, two groups of fish were formed: with lower (3010.80 ± 72.96 g) and higher (4910.0 ± 100.30 g) live weight. It was found that fish of both weight groups were characterized by high slaughter yield and a small proportion of non-edible parts. As the total weight of fish increased, the relative share of the head, gills, pyloric gland and bone plates decreased significantly. Fish with lower live weight had significantly higher slaughter and edible yields and no significant difference was found between the groups concerning the yield for the processing industry. With the increase in live weight, the relative share of meat in the whole body and in the carcass decreased, but the differences between the groups were insignificant. According to all the exterior characteristics, a significant difference was found between the groups in favour of fish with higher total weight. However, in the case of exterior indices, a significant difference was found only in the high-backed index in favour of the smaller fish. In the interior indices, a significant difference in favour of the larger fish was found for viscerosomatic index (38.4%) and gonadosomatic index (91.2%). For other interior indices, with the exception of heartsomatic index, higher values were also reported in fish of higher live weight, but the differences were insignificant.

Keywords: sturgeon; slaughter analysis; fillet yield; morphometrics; condition indices
Abbreviations: Total body weight, g – TW; Standard length – SL; Maximum body height – BH; Maximum body width – BT; Maximum body girth – BG; Eviscerated weight (total weight without total iviscera) – EW; Carcass weight (TW without intestines, whole head, fins and tail) – CW; Total viscera – TV; Gonads – GO; Heart – Ht; Liver – LW; Spleen – SW.

Introduction

Fish of Acipenseridae family are highly valued for the delicacies produced from them. Natural sturgeon populations are greatly endangered (Vasileva, 2015). Jahrl (2013) pointed out that the Black Sea and the Danube River are the last regions with viable populations of sturgeons.

A number of measures have been taken to protect those endangered species. All sturgeon species have been regulated under CITES (*https://cites.org/eng/prog/sturgeon/index.shtml*). Sturgeon fishing has been banned throughout Europe, but regardless of the actions taken, the conservation status of all sturgeon species has become highly critical (WSCS & WWF, 2018).

In this regard, meeting the market demand for sturgeon products is possible only with aquaculture production (Matishov et al., 2021). Vasileva (2015) emphasized that the development of sturgeon farming by providing valuable products will help reduce the pressure on natural populations.

Sturgeon aquaculture has been developing rapidly, with different species and hybrids being cultivated in different countries (Bronzi et al., 2019).

Due to the exceptionally good qualities of the obtained products, meat and caviar, one of the first species reared in fish farms was the Russian sturgeon (Labenets & Chagay, 2009). The authors noted that Russian sturgeon has been attractive for world aquaculture, and some experts consider the caviar of the species to be the best.

The Russian sturgeon has been the dominant species ever since the establishment of the Bulgarian sturgeon aquaculture (Nikolova, 2019). Despite the fact that in recent years other sturgeon species and hybrids have started to be reared in our country, the Russian sturgeon continues to be the dominant species. According to the latest data, about 240 t of the species were produced annually in Bulgaria (**MAFF**, 2021).

A number of scientific studies of Russian sturgeon, raised in real production conditions, have been conducted in Bulgaria. Studies were carried out on the development of gonads (Bonev & Nikolova, 2019, 2021) and the morphometric characteristics of male and female fish (Nikolova & Bonev, 2021), the morphophysiological characteristics of male fish of different ages (Nikolova et al., 2018), the effect of the age on the technological properties of meat (Vlahova-Vangelova et al., 2019). Some aspects of Russian sturgeon growth cultivated in an industrial farm were also investigated (Nikolova & Bonev, 2020).

Fish growth and development depend on a number of genetic and paratypical factors. The method of morphophysiological traits has been successfully applied to assess the response of fish populations to habitat conditions, as the interior indicators make it possible to assess the physiological condition of fish and the habitat conditions (Nguyen, 2014). In Russian sturgeon, morphophysiological indices were studied for evaluating the physiological status of cultivated and wild fish (Raspopov & Sergeeva, 2016); of individuals from various natural populations during different periods of their lifecycle (Nguyen, 2014).

Fish growth and development determine their meat-producing qualities. Live weight influenced slaughter performance and meat quality (Ghomi et al., 2018; Souza et al., 2015). Growing technology was also important (Prokeš et al., 2011; Akbulut et al., 2013; Nikolova, 2013; Barulin, 2015). A variety of production systems and technologies are used in sturgeon farming. Bronzi et al. (2019) indicated that about 18% of all the sturgeon farming technologies in the world were cage-based farming.

In this regard, the morpho-physiological and slaughter characteristics of Russian sturgeon of different live weight are of great interest when grown in industrial cages.

Materials and Methods

The study was carried out with 6-summer-old male of Russian sturgeon (*Acipenser gueldenstaedtii*), (n = 5).

The fish were reared on an industrial farm located in a warm water dam. The pond refers to large, deep dams by its type – the area is 16.07 km^2, the volume 532.9 × 10^6 m^3. The dam is located in South-Eastern Bulgaria at 41° 37' N latitude and 25° 20' E longitude. This belongs to the Southern Bulgarian climatic zone, Eastern Rhodope climatic region. The average altitude is about 280 m. Fish of different specific and age groups and categories were reared in separate cages on the farm.

The cages were 8 × 8 m in size with a depth of 6 m below the water surface. Each cage was equipped with double polyamide nets.

The average stocking density during the growing season was 20 $kg.m^{-2}$. During the vegetation period, fish growth was monitored by dividing them according to their live weight. Feeding was performed with commercial specialized sturgeon granular extruded mixtures (Table 1).

Table 1. Composition of the commercial feed

Indices	Value	Indices	Value
Protein, %	46	Vitamin A, $IU.kg^{-1}$	10 000
Fat, %	15	Vitamin C, $mg.kg^{-1}$	520
Crude fibre, %	1.4	Vitamin E, $mg.kg^{-1}$	200
Ash, %	6.5	Vitamin D3, $IU.kg^{-1}$	2 303
Total P, %	1.03	Gross energy, $MJ.kg^{-1}$	21.0
Ca, %	1.4	Digestible energy, $MJ.kg^{-1}$	19.2
Na, %	0.3%		

At the end of the vegetation period, five individuals were taken from each cage with smaller (first weight group – Ag-1) and higher (second weight group – Ag-2) total weight for the morphophysiological analysis.

Conventional methods for exterior measurements (Pravdin, 1966) and slaughter analysis of fish (Todorov & Ivancheva, 1992; Pokorni, 1988; Prikryl & Janecek, 1991) were used. Based on the analyses performed, indices related to fish growth and condition, as well as morphophysiological and morphometric indices were considered.

The following indices were calculated: IHB – High-backed index (SL/BH); IBB – Broad-backed index (BT/SL) × 100; IH – Hardness index (BG/SL) × 100; CFF – Fulton's coefficient (TW/ SL^3) × 100; CFC – Clarc's coefficient (EW/ SL^3) × 100; IC – Condition index (TW/(SL ×BH * BG) × 100; ICR – Modified Fulton's coefficient by Jones et al., 1999 (according to Richter et al., 2000), (TW/(SL^2BH)) × 100; VSI – Viscerosomatic index (TV/TW) × 100; HSI – Hepatosomatic index (LW/TW) × 100; GSI – Gonadosomatic index (GO/TW) × 100; SSI – Spleensomatic index (SW/TW) × 100; HtSI – Heartsomatic index (Ht/TW) × 100; Sv1 – Slaughter value 1 (EW/TW) × 100; Sv2 – Slaughter value 2 (TW without intestines and gills/TW) × 100; Sv3 – Slaughter value 3 (CW/TW) × 100.

Data were analyzed by one-way analysis of variance (ANOVA) using SPSS Statistics 21. Mean differences were established by Fisher's least significant difference test for paired comparison with a significance level $p < 0.05$.

Results and Discussion

Table 2 presents the live weight and exterior characteristics of the separate fish groups.

The study on all the exterior traits show a significant difference between the groups in favour of the fish with higher total weight. With a difference of 63.1% in total weight, the fish of the second group had 12.4% higher SL, 25.4% higher BH, 22.4% higher BT and 24.9% higher BG. In general, fish are characterized by isometric growth, meaning that a small change in body length could result in a significant change in body weight. Mousavi & Ghafor (2014) found out a close relationship between body length and weight in several sturgeon species: for *A. persicus. H. huso, A. gueldenstaedti, A. nudiventris* the growth being negative allometric, and for *A. stellatus* – isometric.

In the study on age dynamics of morphophysiological traits and slaughter characteristics in Russian sturgeon, Nikolova et al. (2018) established significant differences between fish of different ages in terms of exterior indices (SL, BH, BT, BG). The present study shows that fish of the same age, reared under the same conditions, but significantly different in total weight, also had significant differences in basic exterior indices.

Table 3 presents slaughter characteristics of fish of both body weight groups. The results show that the Russian sturgeon had a good slaughter performance.

One of the main indicators in determining the meat-producing qualities of animals is the slaughter value. Three values are calculated in fish, depending on the method of use (Todorov & Ivancheva, 1992). In the present study, fish with lower total weight (Ag-1) had significantly higher Sv1 and Sv2 – 4% and 3.4%, respectively. No significant difference in Sv3 was found between the groups. A significant difference between the groups in the first two values was formed at the expense of the head. The share of head and gills was significantly higher in fish with lower total weight – 13.8% and 23.2%, respectively. Considering that in sturgeon species the head conditionally refers to the consumable parts (Levkin, 2016), the first two values show that in consumable Russian sturgeon the proportion of the non-consumable parts is small. For fish in the first weight group it was 9.61% (for Sv1) and 12.76% (for Sv2) and in the second – 13.3% and 15.7%, respectively. The relative share of pyloric appendage (38.9%) and bone plates (35.3%) significantly decreased with the increase of the total fish weight. The differences in the relative share of fins and tail and swim bladder were insignificant. No significant difference was found between the groups in the relative share of the fillet in the whole body and in the carcass. However, it should be noted that in the fish with lower total weight, the share of the whole fillet in the body and in the cleaned carcass was higher (over 3%) and the fillets without belly (over 9%).

Table 2. Characteristics of fish from different weight groups

Indices	Ag-1 (n=5)			Ag-2 (n=5)		
	X	±SE	SD	X	±SE	SD
TW, g Total weight, g	3010.80a	72.96	163.14	4910.0a	100.30	224.28
SL, cm Standard length, cm	67.70b	0.96	2.16	76.12b	1.72	3.84
BH, cm Max. body height, cm	10.64a	0.16	0.35	13.34a	0.19	0.42
BT, cm Max. body width, c	10.18a	0.09	0.22	12.46a	0.38	0.84
BG, cm Max. body girth, cm	30.88b	0.46	1.04	38.58b	1.36	3.05

Values with the same letters in the rows are significantly different: a – $p<0.001$; b – $p<0.01$

Table 3. Slaughter characteristics of Russian sturgeon, %

Indices	Ag-1			Ag-2		
	ΔX	±SE	SD	ΔX	±SE	SD
Slaughter value 1	90.39b	0.49	1.10	86.70b	0.85	1.91
Slaughter value 2	87.24c	0.54	1.21	84.27c	0.78	1.74
Slaughter value 3	64.11	1.24	2.78	64.21	0.60	1.34
Relative share of the total body weight						
Head without gills	18.44c	0.79	1.76	15.89c	0.83	1.8
Gills	3.15b	0.17	0.37	2.42b	0.09	0.20
Fins and tail	4.68	0.35	0.79	4.16	0.26	0.58
Swim bladder	0.68	0.06	0.13	0.70	0.06	0.14
Pyloric appendage	0.18c	0.02	0.06	0.11c	0.02	0.04
Bone plates	4.81c	0.44	0.98	3.11c	0.59	1.38
Fillet with skin	49.92	1.38	3.09	48.34	3.06	6.83
Fillet with skin without belly flap	42.99	2.29	5.12	38.99	1.68	3.75
Relative share of the carcass weight						
Fillet with skin	77.83	1.11	2.47	75.25	4.66	10.41
Fillet with skin without belly flap	66.94	2.61	5.82	60.71	2.51	5.69

Values with the same letters in the rows are significantly different: b – $p<0.01$; c – $p<0.05$

Souza et al. (2015) studied the effect of the body weight in rainbow trout and also found a better yield for entire eviscerated fish and a higher relative share of the head in fish with lower live weight. The authors did not establish an effect of body weight on abdominal muscle yield and the amount of fillet with and without skin.

The effect of the body weight on the slaughter characteristics is not unidirectional and probably depends on a complex of factors.

Thus, Badiani et al. (1999) found that the species significantly affected eviscerated yield, white flesh yield, viscera index, gonado-somatic index in sturgeon fishes, but did not affect dressed yield. Chapman et al. (2005) also established an effect of the species on dressed fillet yields in a study of Russian and Siberian sturgeon.

In their study Punga Fish, Intarak et al. (2015) found that body weight did not have a significant effect on carcass quality (dressing and fillet percentage).

In a study of slaughter characteristics in Siberian sturgeon with lower and higher live weight (Nikolova & Georgiev, 2021), it was found that in larger fish all the carcass parameters were better, but the difference was significant only for the relative share of the fillet in the cleaned carcass.

In a study of Russian sturgeon, Nikolova et al. (2018) established that fish of different ages and with different live weight, respectively, did not differ significantly in slaughter yields.

In a study of morphophysiological and slaughter characteristics of the hybrid of Siberian and Russian sturgeon with three different body weight, Nikolova et al. (2021) established that the slaughter rates depended less on the live weight of fish and more on fish condition, the best slaughter value and amount of meat in the body and in the cleaned carcass being the fish from the intermediate weight group, but best fattened.

In Table 4, morphometric and morphophysiological indices are presented. Exterior indices characterize body shape. High-backed index is important in fish breeding, as the aim is to improve the amount of meat in the carcass by increasing the back height. In the present study, the high-backed index significantly decreased (by 0.66 units) with the increase in body weight. Broad-backed index, on the contrary, increased in fish with higher weight, but the difference was insignificant. The same was valud for the hardness index.

With the exception of IC, the values of the condition indices (CFF, CFC, IC and ICR) were higher in fish with higher weight, but the differences were insignificant. In a study of Siberian sturgeon, all of the above condition indices had higher values in fish with higher weight (Nikolova & Georgiev, 2021).

Condition indices show the physical condition of fish. Under natural conditions, the Fulton's coefficient in sturgeon species can vary greatly (Mousavi & Ghafor, 2014).

In male reproductive sturgeon from natural populations in the Caspian Sea with a body weight of 7.2 ± 0.7 (from 2.3 to 14.9 kg), Raspopov and Sergeeva (2016) calculated Fulton's coefficient of 0.54 ± 0.02 (from 0.43 to 0.74). Similar results were reported for the Caspian wild Russian sturgeon by Gusejnova (2017).

Table 4. Morphometric and morphophysiological indices of Russian sturgeons from different groups

Indices	Ag-1			Ag-2		
	ΔX	±SE	SD	ΔX	±SE	SD
IHB	6.37b	0.14	0.31	5.71b	0.09	0.22
IBB	15.05	0.33	0.74	16.42	0.77	1.72
IH	45.65	0.99	2.21	50.89	2.70	6.04
CFF	0.97	0.04	0.09	1.13	0.09	1.99
CFC	0.88	0.04	0.08	0.98	0.08	0.18
IC	13.55	0.29	0.64	12.60	0.43	0.97
ICR	6.19	0.21	0.46	6.42	0.43	0.97
VSI	9.61b	0.49	1.10	13.30b	0.85	1.91
HSI	1.67	0.17	0.37	2.01	0.17	0.39
GSI	2.92b	0.58	1.29	5.58b	0.37	0.84
SSI	0.18	0.02	0.04	0.21	0.04	0.08
HtSI	0.17	0.02	0.05	0.15	0.02	0.04

Values with the same letters in the rows are significantly different: b – $p < 0.01$

In aquaculture farms, fish condition is directly related to the feeding diet and the technology of rearing. The present experiment shows that under the conditions of the studied technology, the Russian sturgeon was well-fattened at the end of the growing season and the maximum CFF value reported in larger fish exceeded one.

In a study of Russian sturgeon of different ages and with different live weight, Nikolova et al. (2018) did not find significant differences in morphometric and morphophysiological indices in fish from the different age groups.

In a study of cultured Russian sturgeon juveniles, Raspopov and Sergeeva (2016) found that the indices of some of the most important internal organs (heart, liver and spleen) changed with age and the intensity and direction of variability was different in each of those organs.

In the present study, a significant difference was found in favour of the larger fish for VSI (38.4%) and GSI (91.2%). For other interior indices, with the exception of HtSI, higher values were also reported for the fish with higher body weight, but the differences were insignificant.

In the Siberian and Russian sturgeon hybrid, VSI was also found to increase with the increase in live weight and the cardiosomatic index (HtSI) decreased, the difference between the separate weight groups for the latter index being significant (Nikolova et al., 2021). On the contrary, in Siberian sturgeon Nikolova and Georgiev (2021) obtained higher VSI values in smaller fish and concerning HtSI, as in the current study, the relative share of heart decreased with the increase of total weight.

Reduction of the relative share of heart and spleen with the increase of live weight in Siberian sturgeon cultured in tanks was established by Yazdani Sadati (2006). Regarding the spleen, SSI was higher in fish with higher live weight in the present study, but the difference was not significant.

Comparing the values of the interior indices in cultured male Russian sturgeon, obtained in the present study, with those established by Raspopov and Sergeeva (2016) in adult males of the Caspian Sea species, shows that the cardiosomatic and dallacosomatic indices in fish in the natural habitats were higher – 0.19 ± 0.01 and 0.33 ± 0.0%, respectively, while the hepatosomatic index was lower (0.98 ± 0.1%).

The values for HtSI, SSI and HSI established by Gusejnova (2017) in male Russian sturgeon from the Caspian Sea, were higher than those reported by Raspopov and Sergeeva (2016) – 0.32 ± 0.07, 0.47 ± 0.18 and 2.37 ± 0.85 %, respectively. The latter index had higher values than those established in the present study for cultured Russian sturgeon. In terms of GSI, the values found in the study were many times higher than those reported for male Russian sturgeon from natural populations – 0.94 ± 0.20% (Raspopov & Sergeeva, 2016); 0.63 ± 0.11% (Gusejnova, 2017).

The differences in the development of the separate internal organs in wild and cultivated fish are probably due to the specificity of fish farming under the conditions of industrial cage technology (limited space for movement, intensive feeding with balanced industrial mixtures, etc.). Thus, in a study of female Beluga sturgeon, Tyapugin (2017) found that the reproductive performance in fish reared in net cages, was better than in fish from natural habitats. The author explained the results obtained with the more abundant feeding diet with mixtures of high nutritional value and the lack of intense movement in cultured fish.

Conclusions

The male Russian sturgeon of consumable size, reared on an industrial cage farm, is characterized by high slaughter yield and a small proportion of non-consumable parts. In fish of the same age, the relative share of the head, gills, pyloric gland and bone plates decreased significantly with the increase in body weight. Fish with lower total weight had significantly higher slaughter (Sv1) and consumable (Sv2) yields and no significant difference was found between the groups referring to the yield for the processing industry (Sv3). A significant difference between the groups in the first two yields was formed at the expense of the head. No significant difference was found between the groups in the relative share of the fillet in the whole body and in the carcass. The relative share of meat in the whole body and in the carcass decreased with the increase in live weight, but the differences between the weight groups were insignificant. Referring

all the exterior characteristics, a significant difference was found between the groups in favour of fish with higher total weight. However, concerning exterior characteristics, a significant difference in favour of the smaller fish was found only in the high-backed index. In the interior indices, a significant difference in favour of the larger fish was found for VSI (38.4%) and GSI (91.2%). For other interior indices, with the exception of HtSI, higher values were also reported in the fish with higher body weight, but the differences were insignificant.

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