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Effect of body weight on morphophysiological and slaughter characteristics in Siberian sturgeon (*Acipenser baerii*), Russian sturgeon (*Acipenser gueldenstaedtii*) and their hybrid (F1 *A. baerii x A. gueldenstaedtii*)

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Abstract

The study was carried out with sturgeon fish of different genotypes cultured in a large warm-water reservoir of an industrial cage farm located in southeastern Bulgaria. The study results indicated that the influence of body weight on more than morphological and slaugter characteristics was not unidirectional in fish of different genotypes. In Russian sturgeon with increasing body weight the viscerosomatic index increased, but the relative share of head, pyloric gland, chord, bony shields significantly decreased. In the hybrid, the relative share of head without gills, fins and tail, chord decreased and the viscerosomatic and hepatosomatic indexes increased, respectively. In all studied groups, the relative share of gonads increased significantly with increasing body weight. A significant negative effect of body weight increase on some slaughter yields (Sv1 and Sv2) was found in Russian sturgeon and hybrids. In Siberian sturgeon, the higher body weight significantly increased the relative share of whole fillets in the carcass. In Siberian sturgeon and hybrids, there was no significant effect of body weight on exterior indices. Only in the Russian sturgeon the increasing body weight resulted in improved high back. With regard to fish condition, a significant influence was found only in Siberian sturgeon. The increasing body weight have a positive effect on condition index (IC) and modified Fulton's coefficient (ICR).

Keywords: aquaculture; sturgeon, slaughter analysis, fillet yield, morphometrics, condition indices

Abbreviations: Ab - Siberian sturgeon; Ag – Russian sturgeon; Hy – hybrid.

INTRODUCTION

Sturgeon farming plays a crucial role in both meeting market demand for sought-after delicacies and alleviating anthropogenic pressure on threatened natural sturgeon populations. Different species and hybrids are cultivated on farms (Bronzi et al., 2019; Nikolova, 2019). In this regard, there has been an increased interest in the productive, morphometric and morphophysiological characteristics of parental species and their hybrids. Various studies have focused not only on species differences but also on age-related dynamics (Baranov, 2000; Efimov, 2004; Novokshtenova et al., 2020).

The relationships between body size and the development of internal organs have been studied across various species. Morphophysiological indices, as indicators of growth, development and physiological status of fish are widely applied in aquaculture (Cocan et al., 2013; Khrustalev et al., 2018, Zolotova, 2009), including studies of sturgeon species (Evgrafova et al., 2020; Nguen Din Fung et al., 2013; Nguen Din Fung, 2014). Body weight and size affect the quality characteristics of fish.

Table 1. Characteristics of the studied groups

Species/hybrid	Weight group	n	Average body weight, g X ± SE
Siberian sturgeon	Ab-1	5	2823.00[a] ±126.044
	Ab-2	5	4273.20[a] ±110.288
Russian sturgeon	Ag-1	5	3010.80[b] ±72.950
	Ag-2	5	4910.00[b] ±100.300
Hybrid	Hy-1	5	2796.60[c] ±129.839
	Hy-2	5	4934.80[c] ±192.539

Legend: [a, b, c] *Values with the same letters within each genotype are statistically different: (p<0.001)*

Body weight has been found to influence musculature and skin composition in rainbow trout (*Oncorhynchus mykiss*) (Xie & Liu, 2023a), in Ricefield Eel (*Monopterus albus*) (Xie & Liu, 2023b), as well as some sturgeon hybrids (*Acipenser baerii* × *Acipenser schrenckii*) (Xie & Liu, 2022) and (*Huso dauricus* × *Acipenser schrenckii*) (Xie et al, 2023c). The effect of body length on chemical content and energetics of meat, as well as fatness and hepatosomatic index has been found in juvenile Lake sturgeon (*Acipenser fulvescens*) (Beamish et al., 2011). Raspopov et al. (2017) found that body weight influences the development of internal organs in Beluga (*Huso huso*) and Russian sturgeon (*Acipenser gueldenstaedtii*) of the same age.

The current strudy aimed to investigate the influence of body weight on basic morphophysiological and slaughter characteristics in Siberian sturgeon (*Acipenser baerii*), Russian sturgeon (*Acipenser gueldenstaedtii*), and their hybrid (F_1 *A. baerii x A. gueldenstaedtii*).

MATERIALS AND METHODS

The study was carried out with male Siberian sturgeon (*Acipenser baerii*) Russian sturgeon (*Acipenser gueldenstaedtii*) and their hybrid (F_1 *A. baerii x A. gueldenstaedtii*) cultured in an industrial cage farm. The farm is located in the reservoir near Kardzhali in southeastern Bulgaria. Fish of different origins and categories are cultured in separate cages under identical rearing and feeding conditions. Two weight groups (1 and 2) for each genotype were formed for the analyses at the end of the vegetation period. For each group, five fish, with different average body weight, were randomly sampled from cages. A total of six groups (n=30) were formed (Table 1). Russian sturgeon and hybrids were at age six and Siberian sturgeon at age four.

Morphophysiological and slaughter analyses were performed by standard methods (Prikryl & Janecek, 1991; Todorov & Ivancheva, 1992). Morphophysiological and morphometric indices routinely applied in fish farming were calculated (Nikolova & Stoyanova, 2022). In Table 2 are presented the studied indicators and their abbreviations.

SPSS Stasistics (IBM, ver. 21) was used for statistical processing.

RESULTS AND DISCUSSION

Table 3 shows the body measurements of fish with different body weights. In larger fish, all measurements were significantly greater, althought distinct trends were observed among individual genotypes. Across all measured lengths, the greater differences (p<0.001) were observed in the hybrid. For TL and FL, the smallest difference was noted (p<0.01) in the Russian sturgeon.

Table 2. Investigated characteristics and indices.

Parameters	Abbreviation
Total weight, g	TW
Total length, cm	TL
Fork length, cm	FL
Standard length, cm	SL
Maximum body height, cm	BH
Maximum body width, cm	BT
Maximum body girth, cm	aO
Eviscerated weight, g	EW
Total intestines, g	It
Gonads, g	GO
Liver, g	LW
Spleen, g	SW
Heart, g	Ht
Swim bladder, g	Sb
Pyloric appendage, g	Pa
Fins and tail, g	FT
Head without gills, g	Hw
Gills, g	G
Bone plates, g	Bp
Chord, g	Ch
Fillet with skin, g	FS
Fillet with skin without belly flap, g	FSwB
Carcass weight (Total weight without intestines and whole head), g	CW
Slaughter value 1 (Eviscerated weight/Total weight)*100, %	Sv1
Slaughter value 2 (Total weight without intestines and gills/ Total weight)*100, %	Sv2
Slaughter value 3 (Carcass weight/Total weight)*100, %	Sv3
Fulton's coefficient $(TW/SL^3)*100$, %	CFF
Clarc's coefficient $(EW/SL^3)*100$, %	CFC
Condition index (TW/(SL*BH*aO)*100), %	IC
Modified Fulton's coefficient [a], $(TW/(SL^2BH))*100$) [a] by Jones et al., 1999 (according Richter et al., 2000)	ICR
High-backed index (SL/BH)	IHB
Broad-backed index (BT/SL)*100, %	IBB
Hardness index (aO/SL)*100), %	IH
Viscerosomatic index (EW/TW)*100,%	VSI
Hepatosomatic index (LW/TW)*100, %	HSI
Gonadosomatic index (GO/TW)*100,%	GSI
Spleensomatic index (SW/TW)*100, %	SSI
Heartsomatic index (Ht/TW)*100, %	HtS

Body weight gain had the most significant impact on height ($p<0.001$), width ($p<0.001$), and body girth ($p<0.01$) in Russian sturgeon, with a difference exceeding 25% for body height. In the hybrid, the difference for the parameter was over 15%, but it was not statistically significant ($p=0.222$). Among the studied group, Siberian sturgeon showed the least pronounced effect of body weight on body volume parameters, with body height being the least affected (7.88%; $p<0.05$) (Table 3).

Numerous studies have explored patterns of change in body proportions during fish growth. Zolotova (2009), in research of golden and rainbow trout, found that as body weight increased, relative body height doubled, whereas relative width decreases by half. Evgrafova et al. (2020) reported interspecific and seasonal variations in size-weight charasteristics in Ship sturgeon, Beluga, and their hybrids.

Table 4. demonstrates that with increasing body weight most organs and body parts in fish significantly increase, but there are also differences in development in fish of different genotypes.

The differences in spleen and heart weights in Siberian sturgeon; as well as the chord in Russian sturgeon and hybrid; and the pyloric gland in Siberian and Russian sturgeon are not significant, the difference in the latter being practically negligible. The difference in the bone plates in the two parental groups was also negligible, whereas in the hybrid it was significant (p<0.05). In Siberian sturgeon, the increase in body weight did not significantly affect the relative share of internal organs (Table 4).

The effect of body weight on the relative share of pyloric gland differed among genotypes. Although not statistically significant, in heavier Siberian sturgeon and hybrids the relative share of pyloric gland increased. On the contrary, in heavier Russian sturgeon it significantly decreased (p<0.05). In all studied genotypes, an increase of the relative share of the swimbladder in heavier fish can be noted as a trend.

The effect of body weight on the main carcass characteristics is presented in Table 5. In Siberian sturgeon, body weight positively influenced all traits, with practically negligible differences in SV1 and SV2. Among the other indices, the differences were more pronounced, althought, only the relative share of whole fillets in the carcass showed a significant difference (p<0.05).

Yazdani Sadati & Vlasov (2006), who studied cultured Siberian sturgeon, found a positive correlation between fish weight and carcass yield (Sv1), and the relative share of muscle.

In Russian sturgeon, only at the Sv3 body weight had not significant positive effect (Table 5). For the other studied indices, the influence was negative, with significant differences in the Sv1 (p<0.01) and Sv2 (p<0.05).

In the case of the hybrid, also with increasing body weight, the Sv1 (p<0.01) and Sv2 (p<0.05) decreased significantly, but in contrast to the Russian sturgeon, for all other indicators the influence was positive, but not significant.

Body weight influenced morphophysiological indices to variying degree (Table 6). In the current study were included exterior and interior indices used in fish studies. Some of the indices, e.g. IH and IHB, as directly related to fish productivity, are included in the selection indices in aquaculture (Khabzhokov et al., 2018). The authors point out that the hardness index (IH) gives an accurate and comprehensive assessment of each fish in terms of its development (weight, length, height, width, condition, gonad development rate).

Table 3. Effect of body weight on exterior measurements.

Group / Indices	Ab			Ag			Hy		
	Diff.*	**F**	**Sig.**	**Diff.***	**F**	**Sig.**	**Diff.***	**F**	**Sig**
TL	13.25	25.906	0.001	6.53	13.152	0.007	14.92	44.469	0.000
FL	12.95	21.293	0.002	10.09	19.992	0.002	14.61	84.006	0.000
SL	11.78	22.388	0.001	12.44	18.266	0.003	21.68	59.407	0.000
BH	7.88	11.393	0.010	25.38	121.096	0.000	15.18	1.752	0.222
BT	12.06	20.167	0.002	22.40	34.200	0.000	16.23	4.007	0.080
aO	11.46	26.667	0.001	24.94	28.535	0.001	20.91	23.557	0.001

*Legend: * Difference between weight groups (2 vs 1), %*

Table 4. Influence of body weight in the studied fish on weight characteristics.

Group / Indices	Ab			Ag			Hy		
	Diff.*	**F**	**Sig.**	**Diff.***	**F**	**Sig.**	**Diff.***	**F**	**Sig**
Weight, g									
CW	60.00	30.375	0.001	11.34	194.012	0.000	78.68	144.458	0.000
FS	68.08	31.711	0.000	57.45	27.818	0.001	84.10	95.771	0.000
FSwB	73.74	31.584	0.000	47.43	24.026	0.001	100.35	87.892	0.000
It	47.04	8.341	0.020	126.50	70.948	0.000	124.41	84.252	0.000
GO	190.71	8.196	0.021	211.51	46.701	0.000	290.64	17.751	0.003
LW	65.79	6.234	0.037	97.60	22.668	0.001	127.87	23.841	0.001
SW	58.88	2.724	0.137	84.57	5.669	0.044	42.37	3.878	0.084
Ht	12.58	0.675	0.435	48.13	5.836	0.042	42.82	5.440	0.048
FT	40.07	45.202	0.000	44.74	11.738	0.009	54.34	42.229	0.000
Hw	33.54	28.860	0.001	62.58	15.682	0.004	52.11	61.347	0.000
G	40.53	12.460	0.008	25.66	8.975	0.017	66.48	27.107	0.001
Bp	9.62	0.084	0.780	4.21	0.044	0.840	107.52	8.203	0.021
Sb	63.33	42.471	0.000	67.26	11.069	0.010	86.34	12.383	0.008
Pa	267.62	0.870	0.378	0.19	0.000	0.994	97.66	6.829	0.031
Ch	27.72	10.405	0.012	22.40	2.643	0.143	20.60	1.738	0.224
Relative share, % of body weight									
Hw	-11.91	2.954	0.124	-13.83	4.928	0.057	-14.11	5.265	0.051
G	-7.61	0.380	0.555	-23.17	14.843	0.005	-5.88	0.301	0.598
FT	-7.57	1.314	0.285	-11.11	1.392	0.272	-12.82	3.980	0.081
Sb	6.98	0.624	0.452	2.94	0.032	0.862	5.80	0.134	0.723
Pa	120.91	0.514	0.494	-38.89	5.395	0.049	11.76	0.335	0.579
Ch	-16.00	3.151	0.114	-24.88	4.782	0.060	-31.25	9.045	0.017
Bp	-26.95	0.717	0.422	-35.24	5.361	0.049	18.88	0.504	0.498

Table 5. Influence of body weight on main slaughter parameters, %.

Group / Indices	Ab			Ag			Hy		
	Diff.*	**F**	**Sig.**	**Diff.***	**F**	**Sig.**	**Diff.***	**F**	**Sig**
Sv1	0.53	0.078	0.788	-4.08	14.056	0.006	-3.35	10.516	0.012
Sv2	0.81	0.142	0.717	-3.40	9.815	0.014	-3.26	10.708	0.011
Sv3	5.94	1.266	0.293	0.16	0.005	0.943	1.23	0.255	0.627
***FS to TW**	11.27	3.077	0.118	-3.17	0.222	0.650	4.22	1.071	0.331
***FSwB to TW**	15.71	3.318	0.106	-9.30	1.990	0.196	12.49	2.858	0.129
***FS to CW**	5.31	4.268	0.073	-3.31	0.292	0.604	3.01	1.094	0.326
***FSwB to CW**	10.03	3.043	0.119	-9.31	2.968	0.123	11.15	2.739	0.137

Legend: *FS to TW /Whole fillet to body weight/; FSwB to TW /Fillet without belly to body weight/; FS to CW /Whole fillet to carcass/; FSwB to CW /Fillet without belly to carcass/

Yazdani Sadati & Vlasov (2006) emphasized on the importance of heartsomatic, spleensomatic and hepatosomatic indices in studying the response of sturgeon species to culture conditions. Raspopov et al. (2017) studied the influence of body weight on the development of internal organs in Beluga and Russian sturgeon of the same age. The authors noted that interior indices can be used not only to establish species specificity of development at different stages during ontogeny, but also to assess culture conditions of fish.

Results of the current stidy indicated that parameters such as IBB, IH, VSI and HtSI decreased with increasing fish weight in Siberian sturgeon (Table 6). The differences were insignificant, but the trends showed an anticipatory linear growth of the fish body. In Siberian sturgeon, an increase in body weight resulted in an improvement of all condition indices, with significant influence at IC ($p<0.01$) and ICR ($p<0.05$). Fish with higher body weight had significantly higher relative gonad share ($p<0.05$).

In natural habitat, the Siberian sturgeon matures sexually late, but under culture conditions in warm-water farm, accelerated development of generative organs was observed (Bonev, 2018). The Siberian sturgeon is a potamodromous species possessing a number of adaptations at both species and population levels (Ruban, 2005; 2019). The natural range of the Siberian sturgeon is characterized by significantly harsher thermal and trophic conditions. As a result, compared to the Russian sturgeon, it exhibits higher levels of generative turnover and a greater gonadosomatic index (Ruban, 2019).

In the current study, an increase in the body weight in Russian sturgeon resulted in a decrease in HtSI ($p<0.01$); and an increase in the values of all other indices, with significant ($p<0.01$) differences for VSI and GSI (Table 6).

In the hybrid, body weight gain did not significantly affect body proportions, but positively affected the development of internal organs in general (VSI; $p<0.05$).

In all studied genotypes, a trend has been observed, although not significant, for the relative share of liver with increasing body weight (Table 6). With regard to the spleen, the relative share of the organ decreased with increasing fish weight only in the hybrid, whereas the spleen-somatic index (SSI) increased in both Siberian and Russian sturgeon.

The study of Yazdani Sadati & Vlasov (2006) on cultured Siberian sturgeon, found that the hepatosomatic index increased with increasing fish weight. On the contrary, heartsomatic, spleensomatic indices, and the relative share of swim bladder decreased.

In general, the results about development of internal organs in different fish species are not unidirectional. Raspopov et al. (2017), in a study about age-related dynamics of the heartsomatic index in juvenile Russian sturgeon and Beluga, found that during growth the relative share of the heart was inversely proportional to the weight of the fish, while for the spleensomatic index the opposite regularity was found. Kuritsin et al. (2017), in *Oncorynchus mikiss* and *Coregonus muksun* cultured in cages, found that, apart from the heartsomatic index, all other indices of internal organs, significantly increased with age and body weight growth. Lavrovskiy (1980) in channel catfish have found that the kidney, heart and liver index decrease with age. Khrustalev et al. (2018) in Whitefish cultured in RAS found that the relative share of liver decreased as fish grew older. Conversely, for the spleen, the authors in the same study found an increase in the relative share of the organ as the fish grew. Zolotova (2009) who studied Golden and Rainbow trout found that the relative share of liver increased as fish grew. However, the relative share of spleen, heart and swim bladder decreased. Nguen Din Fung et al. (2013), in a study of Beluga, Russian and Starry sturgeons, found that species influenced the levels of the hepato- and spleen-somatic indexes.

Table 6. Influence of body weight in the studied fish on morphophysiological indexes.

Group / Indices	Ab			Ag			Hy		
	Diff.*	**F**	**Sig.**	**Diff.***	**F**	**Sig.**	**Diff.***	**F**	**Sig**
IHB	3.71	0.916	0.366	-10.36	15.036	0.005	-2.82	0.050	0.829
IBB	-0.07	0.000	0.987	9.10	2.672	0.141	-1.74	0.033	0861
IH	-0.48	0.028	0.872	11.48	3.312	0.106	2.36	0.151	0.708
CFF	7.89	1.507	0.254	16.49	2.515	0.151	6.41	0.497	0.501
CFC	7.90	1.574	0.245	11.36	1.275	0.292	4.35	0.148	0.710
IC	12.78	28.403	0.001	-7.01	3.333	0.105	3.54	0.097	0.763
ICR	12.16	8.908	0.017	3.72	0.240	0.638	8.35	0.765	0.407
VSI	-3.38	0.078	0.788	38.40	14.071	0.006	28.56	10.516	0.012
HSI	10.19	0.287	0.606	20.36	2.020	0.193	30.67	4.410	0.069
GSI	100.46	4.080	0.078	91.10	14.808	0.005	133.33	5.987	0.040
SSI	7.14	0.092	0.770	16.67	0.337	0.578	-21.46	0.720	0.421
HtSI	-25.00	2.736	0.137	-11.76	0.443	0.525	-19.87	1.390	0.272

Nguen Din Fung (2014) found that the heartsomatic, hepatosomatic and spleenosomatic indices of cultured and wild Russian sturgeon did not differ significantly, even though the cultured fish were twice the body weight. Evgrafova et al. (2020), in a study of internal organ indexes in the parental species (Beluga and Ship) and their hybrids (Beluga x Ship; Ship x Beluga), found that hepatosomatic index values could vary significantly between seasons. The authors found no significant differences in the heartsomatic index.

All of the above emphasizes the complex interrelationships between fish growth, development, and various internal and external factors.

CONCLUSIONS

In summary, it can be stated that in Siberian sturgeon, body weight had no significant influence on the relative share of the head, gills, fins and tail, swim bladder, pyloric appendage, chord, bone plates, spleen and heart. In Russian sturgeon, with increasing body weight, the relative share of head without gills ($p<0.05$), gills ($p<0.01$), pyloric appendage ($p<0.05$), chord ($p<0.05$) and bone plates ($p<0.05$) decreased significantly. In hybrids, the relative share of the head without gills ($p<0.05$), fins and tail ($p<0.05$), and chord ($p<0.05$) also decreased significantly. The study demonstrated that the effect of body weight on major slaughter traits was not unidirectional across fish of different genotypes. A significant influence of fish body weight was found only on some of the studied traits. A significant ($p<0.05$) negative influence of increasing body weight on slaughter yields (Sv1 and Sv2) was found in Russian sturgeon and hybrid. In Siberian sturgeon, higher body weight significantly increased the relative share of whole fillets in the carcass ($p<0.05$). In Russian sturgeon, the high-backed index ($p<0.01$) improved with increasing body weight, along with increases in the relative share of viscera (VSI; $p<0.01$) and gonads (GSI; $p<0.01$) increased. In hybrids, no significant effect of body weight on e exterior was found. However, increases in the relative share of viscera (VSI; $p<0.05$), liver (HIS; $p<0.05$), and gonads (GSI; $p<0.05$) were observed with increasing fish weight. Only in Siberian sturgeon, did fattening, calculated by the indices IC ($p<0.01$) and ICR ($p<0.05$), improve significantly with increasing weight.

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