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Morpho-physiological characteristics, slaughter yield and meat quality of Paddlefish (*Polyodon spathula*, Walbaum 1792)

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Abstract

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The study was carried out on five-summer old paddlefish, reared in a full-scale carp pond. Paddlefish diet was based on natural food in the pond, and the forage was planned only for carp. The results showed that paddlefish, cultivated in a complex polyculture, showed good slaughter performance and meat quality. Slaughter yield was over 82% and the relative share of the fillet with skin to the whole fish and to the eviscerated carcass was 49.42% and 87.26%, respectively. The mean value of Fulton's coefficient was 2.27, which shows that the applied technology of polyculture fish rearing provides very good conditions for paddlefish. The results obtained give reason to classify paddlefish as fat protein fish. The meat was rich in protein (16.23%) and fat (14.98%), it contains 1.02% mineral substances and over 32% dry matter. The total energy content of meat was 983.35 kJ.100^{-1} g and the protein-based energy reached 39.45%. Paddlefish meat was rich in essential amino acids. Calculation of the AA score showed that two amino acids – valine and leucine exhibited results up to 100%. The other results for the amino acid score were over 100%. Lysine score was the highest in the paddlefish meat sample. The highest value obtained for the non-essential amino acids was that of aspartic acid. The saturated fatty acids (SFAs) accounted for 31.26% of total fatty acids; monounsaturated fatty acids (MUFAs) – 47.46% and polyunsaturated fatty acids (PUFAs) – 21.28%. In paddlefish meat, unsaturated fatty acids (UFAs) were most abundant, with straight chain formed by 16–22 carbon atoms. Three forms of vitamin E (α-T, γ-T and δ-T) were detected in the paddlefish meat sample. Alpha-tocopherol was the major tocopherol in our study (93%). The relative share of γ- and δ-tocopherols was 2 and 5%, respectively.

Keywords: polyculture, morphometric measures, exterior indices, Fulton's coefficient, protein, amino acids, fatty acids, tocopherols

Introduction

Paddlefish originated from North America, where the species was highly valued (Mims, 2001). Paddlefish, as the only zooplanktonophagous species of Acipenseriformes, has significant potential to become an important fish species to be raised outside its natural habitat (Vinogradov et al., 2003; Melchenkov & Kanidieva, 2015). Promoting the consumption of low-trophic aquatic animals is a key strategy for the efficient use of aquatic bioresources (Ahern et al., 2021).

The acclimatization of paddlefish started in the last century in the former Soviet Union, where a number of research studies were conducted (Elnakeeb et al., 2021). In Europe, paddlefish aquaculture developed mainly in Eastern and Central Europe (Jarić et al., 2018). In Bulgaria, the species was also of interest (Grozev et al., 1999) and fertilized eggs and larvae were imported several times (Hubenova & Zajkov, 2010). Despite its good qualities, paddlefish has not yet been reared on a large scale in Bulgaria. Larger quantities of consumable fish have appeared in statistical data since 2016, the maximum quantities for the country being reported in 2019 (Table 1).

Paddlefish can significantly increase the efficiency of warm water polyculture. In Bulgarian carp farming, after the introduction of herbivorous fish species, polyculture has been traditionally applied with different technological approaches (Nikolova et al., 2008). Paddlefish can be included in polyculture instead of bighead carp. Occupying the same ecological niche, only at the expense of plankton, paddlefish provides products with a higher price.

The meat and caviar of paddlefish have qualities similar to sturgeon species. Mims (2001) emphasized that paddlefish meat was very well accepted by the consumers. Jarić et al. (2018) noted a lack of data on paddlefish aquaculture in Europe. In Bulgaria, there are no research studies related to morpho-physiological and meat-yielding qualities of paddlefish when reared in carp ponds.

The aim of the present study was to evaluate the morpho-physiological and slaughter characteristics and the quality of paddlefish meat when raised in polyculture in a carp pond.

Materials and Methods

The study was carried out on five-summer old paddlefish (*Polyodon spathula*, Walbaum 1792), reared in a full-scale carp pond. The farm is located in Central Bulgaria in a transitional-continental climate area. The region is suitable for worm water fish farming and is characterized by mild winters. The ponds on the farm are characterized by good development of natural food (phytoplankton, zooplankton and benthos) and are moderately overgrown with macrophytes. All fattening ponds in the winter are dried up /overwintering/. The vegetation season in the year of the study started in the first decade of March and ended in the last decade of November.

Paddlefish were raised in a complex polyculture, in a fattening pond with an area of 320 dka. The pond was earthen, with a soft *sediment* bottom, the average depth being 1.3 m. Sediment thickness varied from 10 to 30 cm.

The ponds were stocked with: Paddlefish (B_4), (*Polyodon spathula*) – 1 200 pcs/pond – with an average total body weight (TW) 6500 g; Carp (K_2), (*Cyprinus carpio*) – 38000 pcs/pond – TW – 560 g; Bighead carp (T_2), (*Hypophthalmichthys nobilis*) – 170 pcs/pond – TW – 2000 g; European catfish (C_2), (*Silurus glanis*) – 500 pcs/pond – TW – 800 g.

Planktonophagous and predatory fish fed on natural food in the pond and the forage was planned for carp only. Special granulated carp feed was imported into the pond every day, two or three times, depending on the water temperature and fish biomass in the ponds. The forage was supplied from the dike at a strip of about 400 m.

Water temperature in the pond during the vegetation period varied from 13 to 26°C; pH – from 8.4 to 8.8; dissolved oxygen from 5.0 to 8.8 $mg.l^{-1}$; oxygen saturation from 60 to 95%. The mean values were: biochemical oxygen demand (BOD_5) – 3.5 $mg.l^{-1}$; total nitrogen – 1.8 $mg.l^{-1}$; total phosphorus – 0.07 $mg.l^{-1}$; nitrates – 0.5 $mg.l^{-1}$; nitrites – 0.013 $mg.l^{-1}$.

After catching the fishes, they were sorted out by species and placed in storage ponds, from which five paddlefish were randomly selected and immediately transported to the laboratory. Classical methods for exterior measurements were applied for the morpho-physiological analysis (Pravdin, 1966; Vinogradov et al., 2003) and the slaughter analysis (Todorov and Ivancheva, 1992; Pokorni, 1988; Prikryl and Janecek, 1991). Based on the analyses performed, the indices related to fish fattening, as well as morphometric and morpho-physiological indices were calculated. Table 2 presents the studied characteristics and indices, as well as the codes with which they were labelled.

During the slaughter analysis of each fish (n = 5), a muscle tissue sample was collected for biochemical analysis.

Proximate analysis was performed by classical methods. The crude protein content was established by the Kjeldahl method (AOAC, 1990) with a conversion coefficient of 6.25. Total lipids were evaluated as described by Bligh & Dyer (1959). Ash content was determined by a standardized method (ICC Standard No. 104/1, 1990). The dry weight was

Table 1. Production of paddlefish in Bulgaria (according to Ministry of Agriculture and Foods (MAF), 2014-2021; NAFA, 2005)

Indices	Year								
	2004	2013	2014	2015	2016	2017	2018	2019	2020
	Pieces	t							
Fingerling	32 500	0.6	1.9	1.9	7.5	2.50	6.04	14.00	41.93
Fish for consumption	–	1.0	2.2	3.6	47.6	67.71	59.71	129.14	57.69
Total	–	1.6	4.1	5.5	55.2	70.21	65.74	143.14	99.61

Table 2. Codes of studied characteristics and indices

Characteristics	Code
Total body weight, g	TW
Eviscerated weight, kg	EW
Standart lenght, cm	SL
Maximum body height, cm	BH
Maximum body width, cm	BT
Maximum body girth, cm	aO
Gonads weight, g	GO
Liver weight, g	LW
Spleen weight, g	SW
Heart weight, g	Ht
Carcass weight (TW without intestines, whole head and fins), g	CW
Slaughter value 1 (EW/TW)*100, %	Sv1
Slaughter value 2 (TW without intestines and gills/ TW)*100, %	Sv2
Slaughter value 3 (CW/TW)*100, %	Sv3
High-backed index (SL/BH)	IHB
Broad-backed index (BT/SL)*100, %	IBB
Hardness index (aO/SL)*100, %	IH
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 by Jones et al., 1999 (according to Richter et al., 2000), (TW/(SL^2BH)*100	ICR
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

determined by drying the samples to a constant weight at a temperature of 105°C.

Chemicals and reagents

All chemicals and solvents used in the study were analytical grade. The standards α-, γ- and δ-tocopherols were obtained from Sigma Aldrich (Germany) and a mix of amino acid standards from Waters. Individual fatty acids were purchased from Sigma Aldrich (Germany).

Extraction and determination of tocopherols

Tocopherols were extracted as described by Stoyanova (2020). Qualitative and quantitative determination of tocopherols was performed by using Elite LaChrome (Hitachi) HPLC system equipped with DAD and ELITE LaCHrome (Hitachi) software. Separation of the tocopherols was performed by Supelco Discovery HS C18 column (5 µm, 25 cm × 4.6 mm), operated at 30°C, with the mobile phase consisting of methanol: water (98:2, v/v). The detection of compounds was carried out at 285 nm and the flow rate was 0.8 ml/min.

GC analysis of fatty acids

Fish oil for fatty acid analysis was extracted as described by Bligh & Dyer (1959). Fatty acids were analyzed as fatty acid methyl esters using the GC method. Fatty acids were transformed into fatty acid methyl esters by direct transesterification of oil samples (ISO 5509:2000. Animal and vegetable fats and oils, Preparation of methyl esters of fatty acids).

The fatty acid composition was determined by gas chromatography (GC; 17 A. Shimadzu), equipped with a flame ionization detector and 3.0 m × 0.32 cm steel column. Nitrogen was used as a carrier gas (flow rate, 1 ml/min), (ISO 5508:1990. Analysis by gas chromatography of methyl esters of fatty acids).

Amino acid analysis

Samples were hydrolyzed with 6 N HCl at 105°C for 24 h followed by neutralization and filtration (Blackburn, 1968). The hydrolysates were derivatized by using AccQ-Fluor TM Reagent kit (Waters Corporation, Milford, MA, USA) following the manufacturer's instructions. The amino acid analyses were carried out on high-performance liquid chromatography (ELITE LaChrome, Hitachi High Technologies America, Inc., San Jose, CA, USA) equipped with a C18 AccQ-Tag (3.9 mm × 150 mm) reversed-phase chromatographic column and a diode array detector.

Amino acid score (AAS) was calculated as a ratio of the amount of each essential amino acid in a sample (g/100 g protein) and the amount of the respective amino acid in an 'ideal' protein (g/100 g protein) as defined by the World Health Organization (WHO, 2007). The results were multiplied by 100 to be expressed as a percentage.

Determination of meat caloric value

Meat caloric value was calculated on the basis of the chemical composition of fish and the rates of 23.9 $kJ.g^{-1}$ for the proteins and 39.75 $kJ.g^{-1}$ for the fats (Hadjinikolova et al., 2008).

Data were analysed by one-way analysis of variance (ANOVA) using the software product SPSS Statistics 21.

Results and Discussion

The slaughter characteristics of paddlefish are presented in Table 3. The total body weight of the four-summer-old fish shows that the fish showed very good growth performance under the applied technology. The growth rate and development of fish is determined by a number of genetic and paratypical factors and that is why it is important to study the meat yield characteristics and meat quality under specific production conditions (Nikolova, 2010, 2013; Balev et al., 2017). Paddlefish is known to grow faster when cultivated in carp ponds than in its natural habitat (Gorski & Yarjombek, 2003).

The data obtained in the present study show that paddlefish was characterized by good slaughter performance. Slaughter values 1, 2 and 3 were 82.9; 77.97; 56.63%, respectively, and the relative shares of the fillet with skin to the whole fish and to the eviscerated carcass weight were 49.42% and 87.26%, respectively. The lower value of the yield for the canning industry (slaughter value 3) in that species is determined by the large head with a very well-developed rostrum.

Melchenkov & Kanidieva (2015) pointed out that paddlefish showed good meat yield performance (up to 61%) and could be used in the canning industry at the age of two.

The analysis of the results obtained by different authors shows that the meat-yield characteristics of paddlefish can differ significantly. That depends on the age and the total weight of the fish studied. The differences may also come from the methods used for the slaughter analysis. Lou et al. (2000) established 27.0% average fillet yield in paddlefish with an average body weight of 7.7 kg. Analyzing the carcass characteristics of paddlefish, Decker et al. (1991) found out dressed yields of 47.3% (with tails) and 45.0% (without tails) and the fillet yields -33.5%. In studies by Dvoryaninova et al. (2016), the fillet content of paddlefish with a total weight of 1662.30 ± 408.86 g was 45.7%. In the present study, that indicator was higher, but the difference in the total weight of the fishes was large. There was also a big difference in the individual internal organs in the above-mentioned study of paddlefish: the relative share of gonads to the whole fish was 41.50% and of liver – 18.4%. In our study those values were significantly lower – 11.72 and 1.18%, respectively.

In a study of bighead carp, a species close to paddlefish by the nature of its diet, Nikolova and Dochin (2017) established a slaughter value 3 of 54.3% and a relative share of the fillet – 35.4%.

Exterior and interior indices are widely used in fish studies (Hansson et al., 2017; Firdaus et al., 2018). Body proportions are related to the feeding habits of fish (Weliange & Amarasinghe, 2007). Reis-Neto et al. (2012) found out that morphometric parameters are related to yields of carcass and fillet. Thus, the ratio of the head length to body height is most directly related to the carcass yield and the ratio of body width and head length – to the fillet yield.

Table 3. Slaughter and morpho-physiological characteristics of paddlefish

Indices	n = 5		
	ΔX	±SE	SD
Total body weight, g	8910.0	691.10	1382.21
Slaughter value 1, %	82.9	0.50	1.01
Slaughter value 2, %	77.97	0.85	1.71
Slaughter value 3, %	56.63	0.81	1.63
Relative share of live weight, %			
Head without gills	18.34	0.39	0.79
Gills	4.96	0.56	1.12
Fins and tail	3.00	0.36	0.71
Pyloric appendage	0.28	0.06	0.12
Fillet with skin	49.42	0.78	1.56
Fillet with skin without belly flap	42.55	0.62	1.25
Relative share of carcass weight, %			
Fillet with skin	87.26	0.67	1.34
Fillet with skin without belly flap	75.15	0.81	1.63
Morphometric and morpho-physiological indices			
IHB	5.0	0.08	0.16
IBB	10.02	0.23	0.46
IH	51.03	0.69	1.39
CFF	2.27	0.16	0.33
CFC	1.88	0.14	0.28
IC	7.34	0.10	0.20
ICR	7.82	0.38	0.77
VSI	17.07	0.50	1.01
HIS	1.18	0.11	0.22
GSI	11.72	0.50	1.01
SSI	0.45	0.06	0.11
HtSI	0.16	0.04	0.07

Morphometric indices characterize the physical condition of fish (Hards et al., 2019). High-backed index (IHB) is one of the major indices used in fish breeding. In the present study, IHB (high back index) was 5 ± 0.08. A study by Simeanu et al. (2010) shows that in paddlefish with lower total weight and younger in age that coefficient was 6.89 ± 0.11 and 6.35 ± 0.2. In the same study, the authors reported CFF of 0.61 – 0.65, relating the fattening conditions to very good maintenance and feeding. CFF could vary greatly from one species to another (Mousavi & Ghafor, 2014). It depends mainly on fish age, sex and other factors. CFF of paddlefish in the present study was 2.27, which shows that the polyculture technology provided very good conditions for raising the species.

Onders et al. (2005) calculated CFF of 0.238 on average in juvenile paddlefish with an average total body weight of 223.6 g, fed on forage. HIS in the same fish was 1.91%. In the present study HIS had a lower value of 1.18%.

The meat of the studied fish showed good characteristics (Table 4). It was rich in protein (16.23%) and fat (14.98%), it contained 1.02% minerals and over 32% dry matter. The total energy content was 983.35 kJ.100^{-1} g and the protein-based energy was 39.45%.

Fats in the fish body are unevenly distributed and in sturgeon species they accumulate between the muscle fibres, sometimes exceeding 30% (Amineva and Yarjombek, 1984). Levkin (2016) noted that the amount of fat determined the nutritional and taste value of fish. The author pointed out that depending on the fat content, fish could be divided into 4 groups: low fat (lean) – up to 2%; medium-fat – 2-8%; fat – 8-15%; high fat – over 15%. The same classification was also adopted by Kharenko & Sopina (2020). Plotnikov et al. (2018) proposed a ranking according to which fish were divided into the following groups by the amount of body fat: lean – 1% (perch); medium-fat – 1-5% (carp); fat – 5-15% (sturgeon); high fat – over 15% (eels). According to the above classifications, paddlefish in the present study refers to fat fish.

In general, fish fat increases with age and body weight gain, but the amount of fat depends on many other genetic and paratypical factors: species, sex, physiological condition, food availability, season and other factors. In a study of juvenile paddlefish, Shi et al. (2013) found that the crude fat content was lower and the moisture and crude protein contents higher in fish fed on live feed compared to formula fed fish. The chemical composition of paddlefish meat in different studies varied considerably. Thus Decker et al. (1991) found the lipid concentration of whole fillets of 1.53% in seventeen-month-old paddlefish with live weight from 394.4 to 666.5 g. Dvoryaninova et al. (2016) established the following values in the meat of paddlefish with an average live weight of 1662.30 ± 408.86 g: protein 25.8%, fat 8.40%, 2.5% minerals and 178.8 kcal/100 g. Similar results for paddlefish were obtained by Kolpanosova et al. (2011) – 26.13% proteins, 8.0% fats and 2.5% mineral substances. Onders et al. (2005), in young paddlefish fed with different commercial pellets, did not find differences in the content of proteins (14.9%) and moisture (80.9%) in meat, while the lipids ranged from 2.42 to 4.45%.

We found higher levels of fat, but the fish in the present study had a higher total weight. In larger paddlefish with a body weight of 7.7 kg, Lou et al. (2000) established 3.1% fat, 17.5% protein, 1% ash and 79% moisture. The authors classified paddlefish as non-fat fish. Significantly less fat content was reported compared to the values in the present study. In terms of protein content, the difference between our study and the one cited above was smaller, the difference being mainly at the expense of moisture. In fish, there was an inverse relationship between water content and lipids in the body, so that with continuous changes in the composition of the body, the total live weight remained almost unchanged (Smith, 1986). Lou et al. (2000) found that the fat content in paddlefish was positively correlated and the moisture content was negatively correlated with body weight.

Simeanu et al. (2012; 2017) also classified paddlefish to non-fat fish. In a study of meat quality of paddlefish of different ages (from one to four years of age), the authors established the moisture content of 75.41 to 78.37%, with the dry matter content increasing with the increase of fish age; protein 18.08 – 19.89%; fat 2.45 – 3.45%; ash 1.1 – 1.25%, the content increasing with age.

Fish could be classified in 4 groups according to the protein content: low-protein – less than 10%; medium protein – 10-15%; protein – 15-20%; high protein – more than 20% (Kharenko & Sopina, 2020). Paddlefish in the present study refers to the protein fish type.

In addition to the protein content, their amino acid composition is also important. Fish proteins have a good combination of amino acids (AA) that are important for human health, especially lysine and methionine (FAO, 2016). Therefore, fish refers to the products with pronounced lipotropic properties and the high content of lysine and arginine makes fish very important for child nutrition (Petrovskij, 1975).

Paddlefish meat is rich in essential amino acids, especially lysine (Table 5). It also has a good content of isoleucine, phenylalanine and threonine. The content of leucine and methionine is relatively lower.

Table 5 shows the amino acids score of paddlefish meat, calculated based on FAO/WHO. Chemical score provides an estimate of the nutritive value of protein by comparing the

Table 4. Proximate composition and energy content of paddlefish meat, mean ± SD

Moisture, %	Content, %			Energy content	
	Crude protein	Total lipids	Ash	Total energy, kJ.100^{-1}g	Protein based energy, %
67.77±0.004	16.23±0.005	14.98±0.011	1.02±0.003	983.35	39.45

levels of essential amino acids between samples and standard proteins. Two amino acids – valine and leucine, exhibited results up to 100%. The other results for the amino acid score were over 100%. Lysine score was the highest in the paddlefish meat sample, followed by isoleucine, threonine, phenylalanine (or + tyrosine) and methionine (or + cysteine). The score of the essential amino acids in the samples had values exceeding 100%, so they can be a good food source.

Djabarov (2006) pointed out that, despite differences in the total amount of amino acids in the different tissues in fish, their qualitative composition was almost the same. In a study of different species (sturgeon, trout, carp), the author found that the levels of alanine and glycine were higher than the other amino acids. In the present study, the levels of those AAs were high. As for the non-essential AAs, the levels of aspartate and histidine were the highest. The contents of alanine, arginine, glutamate, glycine, and serine were also relatively high. The content of proline and tyrosine was relatively lower. We did not find cysteine in the paddlefish meat sample.

Simeanu et al. (2018) found cysteine in paddlefish meat, the content of that amino acid being the lowest of all. It should be mentioned that the amounts of the amino acids established by us, were significantly higher than those found by the authors cited. The difference in lysine and aspartate content was especially large.

Shi et al. (2013) found seventeen kinds of amino acids in juvenile paddlefish fed on live food and formula feed and the meat of fish fed on live food was richer in amino acids. The glutamate content was the highest. In both groups, the authors found cysteine, the amount of that amino acid being the lowest compared to the others.

In studies by Dvoryaninova et al. (2016), all the essential amino acids were found in paddlefish meat, leucine being in the first place. The meat was rich in lysine, but its content was lower than in the present study.

The significant differences in the amino acid composition of proteins of the same species in different studies show the large influence of the habitat and dietary conditions on the quality of the products obtained.

Table 5. Essential amino acid composition and amino acid score of Paddlefish, mean± SD

Amino acid	Amino Acid Content* (g/100 g protein)	Amino Acid Score %
Val	3.61±0.20	93
Leu	2.66±0.04	45
Iso	6.09±0.21	203
Thr	4.22±0.22	183
Lys	11.64±0.28	256
Phe+ Tyr	5.13±0.11	135
Met+Cys	2.41±0.33	110

*Contents are calculated on a dry matter basis (32.23±0.025 %)

The non-essential amino acids identified in the course of the analysis are presented in Table 6. The highest value obtained was that of aspartic acid (14.34 g/100 g protein) followed by histidine (10.67 g/100 g protein), proline (8.11 g/100 g protein) and arginine (6.46 g/100 protein).

Table 6. Non-essential amino acid composition and amino acid score of paddlefish, mean ± SD

Non-essential amino acids	content* (g/100 g protein)
Asp	14.34±0.20
Glu	6.11±0.04
Gly	5.87±0.21
Arg	6.46±0.22
Ala	4.22±0.28
Pro	8.11±0.11
His	10.67±0.33
Ser	4.88±0.29

*Contents are calculated on a dry matter basis (32.23±0.025 %)

Table 7 presents the fatty acid composition of paddlefish meat. 15 fatty acids were detected in our study. Fatty acids were categorized into saturated fatty acids (SFAs), which accounted for 31.26% of total fatty acids; monounsaturated fatty acids (MUFAs), which constituted 47.46%; and polyunsaturated fatty acids (PUFAs), which comprised 21.28%. In paddlefish meat, unsaturated fatty acids (UFAs) were most abundant, with straight chain formed by 16–22 carbon atoms. The result of MUFAs content in our study were consistent with some of the previous publications, while the SFAs contents were higher than other sturgeons and the content of PUFAs were lower (Shi et al., 2013). Wood et al. (2008) suggested that the best ratio of PUFA/SFA should be above 0.4 and the studied fish had favourable PUFA/SFA ratio (0.68). The fatty acid compositions were closely related to fat food source, season, water temperature, water physical and chemical factors, light etc. (Codier et al., 2002). The content of individual FA in fish lipids was strongly influenced by the FA composition of dietary lipids (Tocher, 2003).

The results from the present study show that the main fatty acids were oleic (44.82 %), palmitic (16.34%), and linoleic (15.60 %) acids. Palmitic acid was the major SFA in the current study. Stearic acid was found to be the second SFA (8.20 %). SFAs found in small levels were myristic acid (0.59%) and heptadecanoic acid (0.15%).

Many researchers reported that palmitic acid is the dominant saturated fatty acid in fish oils. The results for C16:0

and C18:0 were quite close to those reported by other authors. (Haliloglu et al., 2004; Shi et al., 2013). Ibeas et al. (1996) found out that C16:0 and C18:0 had an important function for the organism not only as the energy source, but also as the critical components of membrane phospholipids. The third predominant SFA is arachidic acid (3.55%), which is a precursor for prostaglandin and thromboxane biosynthesis. Arachidic acid can interfere with the blood clotting process and attach to endothelial cells during wound healing (Pompeia et al., 2002).

GC analyses of the monounsaturated fatty acids profile of paddlefish meat reveals that oleic acid is the major MUSF (44.80 %). Similar to the results of the present study, many researchers reported that oleic acid was the dominant fatty acid among MUFAs (Tanakol et al., 1999; Saglik & Imre, 2001; Abbas et al., 2009).

That is of great importance, because of their valuable biological activities. Oleic acid is an essential fatty acid and is an important component of phospholipids (Dou et al., 2020).

Heptadecenoic and eicosenic acids were found to be in low levels, similar to the previous study of paddlefish meat (Shi et al., 2013).

Significant amount of the biologically important PUFAs, such as C18:2 n6 was found in the present research study.

Fish is attracting increasing attention as a unique source of docosahexaenoic and eicosapentaenoic acids, which play an important role for the good condition of the cardiovascular system and overall human development (FAO, 2016; Drouin et al., 2019). Out of the five PUFAs, identified in the present study, paddlefish meat was rich in arachidonic acid. The values of the others were above one, the highest content being that of linoleic acid. From polyunsaturated fatty acids, linolenic acid was not found.

In the study of Simeanu et al. (2015), the authors found that paddlefish meat was rich in monounsaturated and polyunsaturated fatty acids (linoleic, linolenic, arachidonic, eicosapentaenoic, docosapentaenoic and docosahexaenoic).

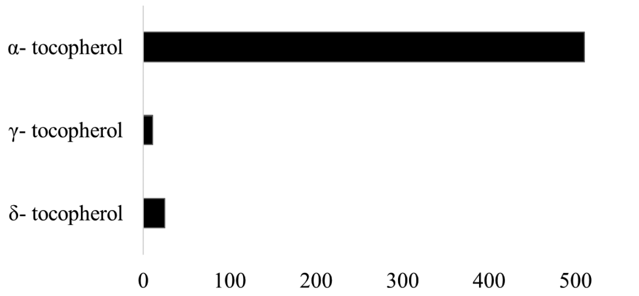
Three forms of vitamin E (α-T, γ-T and δ-T) were detected and quantified in fish oils with HPLC analysis. The content of tocopherols is presented in Figure 1. Alpha-tocopherol is the natural antioxidant in fish oils and it was the major tocopherol established in the present study (93%).

The relative share of γ- and δ-tocopherols was 2 and 5%, respectively. A similar correlation between the content and the levels of the three forms of vitamin E in other fish species was reported by other authors. α-tocopherol is generally the tocopherol found at the highest value and it was confirmed in previously published data (Özogul et al., 2011; Kulas et al., 2002). On the other hand, the concentration of α-tocopherol (510.07 µg/g) in our sample was higher than the values found in the others studies. Values between 9.45 and 79.25 mg/kg α-tocopherol content in different fish species were reported. The high content of α-tocopherol in our sample shows that paddlefish meat is a good source of that tocopherol. α-tocopherol is considered to have the highest nutritional value of all the different forms of tocopherols, which is believed to protect the body against cancer and cardiovascular diseases (Giusepponi et al., 2017).

Saldeen & Saldeen (2005) emphasized the importance of γ- and δ-tocopherols, pointing out that their lack in most

Table 7. Fatty acid composition of paddlefish, mean±SD

Fatty acid	Fatty acid content (%)
Saturated Fatty acids (SFAs)	
$\mathbf{C_{12:0}}$ (Lauric acid)	2.50±0.445
$\mathbf{C_{14:0}}$ (Myristic acid)	0.59±0.327
$\mathbf{C_{16:0}}$ (Palmitic acid)	16.34±0.344
$\mathbf{C_{17:0}}$ (Heptadecanoic acid)	0.15±0.012
$\mathbf{C_{18:0}}$ (Stearic acid)	8.13±0.076
$\mathbf{C_{20:0}}$ (Arachidic acid)	3.55±0.586
Monounsaturated fatty acids (MUSFs)	
$\mathbf{C_{16:1}}$ (Palmitoleic acid)	1.60±0.098
$\mathbf{C_{17:1}}$ Heptadecenoic acid	0.75±0.040
$\mathbf{C_{18:1}}$ (Oleic acid)	44.80±0.095
$\mathbf{C_{20:1}}$ (Eicosenic acid)	0.31±0.059
Polyunsaturated fatty acids (PUFA)	
$\mathbf{C_{18:2}}$ (Linoleic acid)	15.60±0.252
$\mathbf{C_{18:3}}$ (Linolenic acid)	Не е установена
$\mathbf{C_{20:4}}$ (Arachidonic acid)	2.40±0.083
$\mathbf{C_{20:5}}$ (Eicosapentaenoic acid)	1.05±0.053
$\mathbf{C_{22:5}}$ (Docosapentaenoic acid)	1.09±0.026
$\mathbf{C_{22:6}}$ (Docosahexaenoic acid)	1.14±0.061



	δ- tocopherol	γ- tocopherol	α- tocopherol
µg/g fat	24.99	10.67	510.07

Fig. 1. Content of tocopherols, µg/g fat

supplements containing vitamin E may be a limiting factor of their health-promoting effects.

Conclusions

Paddlefish reared in a complex polyculture system in a carp farm was characterized by good slaughter characteristics and meat quality. Slaughter yield was over 82% and the relative share of the fillet with skin to the whole fish and to the eviscerated carcass was 49.42% and 87.26%, respectively. The mean value of Fulton's coefficient was 2.27, which shows that the applied technology of polyculture fish rearing provides very good conditions for paddlefish.

The results obtained give reason to classify paddlefish as fat protein fish. The meat of the studied fish was rich in protein (16.23%) and fat (14.98%), it contains 1.02% mineral substances and over 32% dry matter. The total energy content of meat was 983.35 kJ.100^{-1} g and the protein-based energy reached 39.45%.

Paddlefish meat was rich in essential amino acids. Calculation of the AA score showed that two amino acids – valine and leucine exhibited results up to 100%. The other results for the amino acid score were over 100%. Lysine score was the highest in the paddlefish meat sample. The highest value obtained for the non-essential amino acids was that of aspartic acid.

The saturated fatty acids (SFAs) accounted for 31.26% of total fatty acids; monounsaturated fatty acids (MUFAs) – 47.46% and polyunsaturated fatty acids (PUFAs) – 21.28%. In paddlefish meat, unsaturated fatty acids (UFAs) were most abundant, with straight chain formed by 16–22 carbon atoms.

Three forms of vitamin E (α-T, γ-T and δ-T) were detected in the paddlefish meat sample. Alpha-tocopherol was the major tocopherol in our study (93%). The relative share of γ- and δ-tocopherols was 2 and 5%, respectively.

The present experiment shows that fish should be included in the human diet for at least three reasons: as a general source of nutritional components; as high quality protein food and as a source of monounsaturated and polyunsaturated fatty acids.

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