Journal of Food and Nutrition Research, 2013, Vol. 1, No. 5, 108-112
Available online at http://pubs.sciepub.com/jfnr/1/5/5

DOI:10.12691/jfnr-1-5-5

Nutritional Composition of Caviar from Three Commercially Farmed Sturgeon Species in China

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Received October 12, 2013; Revised November 04, 2013; Accepted November 05, 2013

Abstract The main nutritional composition of caviar obtained from Siberian sturgeon (*Acipenser baerii*), Amur sturgeon *(Acipenser Schrenckii)* and Hybrid sturgeon *(Huso dauricus* ♀× *A. schrenkii* ♂*)* cultured in China was characterized. Three caviar samples from each species have been analyzed for proximate chemical composition, amino acids and fatty acids. Moisture content of sturgeon caviars averaged between 47.72%-51.80% and together with crude protein 23.98%-25.55% (wet weight), crude lipid 14.23%-16.22% (wet weight) and ash 3.28%-3.84% (wet weight). Eighteen amino acids were identified in caviar samples, and glutamic acid was the most abundant amino acid (7.29%-7.69%). Total amino acids (TAA) content ranged from 50.31% to 53.54% (dry weight). Essential amino acids (EAA) and delicious amino acids (DAA) accounted for 37.44%-38.04% (dry weight), and 32.64%-32.88% (dry weight) of TAA, respectively. Functional amino acids constituted 55.60%-55.98% (dry weight) of TAA. All of the essential amino acids scores (AAS) were > 1. The monounsaturated fatty acids (38.93%-43.29%, % of total fatty acids) were the main group of fatty acids followed by polyunsaturated fatty acids (29.52%-35.61%, % of total fatty acids) and saturated fatty acids (24.74%-25.44%, % of total fatty acids). The main fatty acids were C16:0, C18:1ω-9, C18:2ω-6, C22:6ω-3 (DHA), and 20:5ω-3 (EPA). The ratio of ω-3 to ω-6 PUFAs in the present study ranged from 0.90 to 1.14. The present study indicated that the caviar from these three species could be considered as good sources of essential amino acids, functional amino acids, DHA and EPA.

Keywords: *sturgeons, caviar, amino acid, amino acid score, fatty acid*

Cite This Article: Yangyang Gong, Yanqing Huang, Lujiao Gao, Jianxue Lu, Yuan Hu, Lianjun Xia, and Hongliang Huang, "Nutritional Composition of Caviar from Three Commercially Farmed Sturgeon Species in China." *Journal of Food and Nutrition Research* 1, no. 5 (2013): 108-112. doi: 10.12691/jfnr-1-5-5.

1. Introduction

Caviar is commonly used to describe the lightly salted fish roe products, especially from sturgeon species [1]. The most famous and highly appreciated caviars are derived from wild sturgeons in the area of the Caspian Sea [2]. However, due to human activities such as habitat destruction, water pollution and overfishing, there has been a sharp decline, even depletion in wild sturgeon stocks [3,4]. Thus, the CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) decided to limit caviar trade by putting all sturgeon species on the list of Annex II of the convention in 1997 [5].

The shortage in supply but higher demand for this luxury product has increased the possibility of intensive sturgeon farming for caviar in many countries such as Italy, France, Germany and Spain. The Chinese production of sturgeons for caviar has recently increased year by year since 2006 [6]. The annual production of caviar in China reached over 15 tons in the year of 2010, accounting for nearly 15% of global farmed caviar production (102 tons) [7]. However, no studies have been reported to examine the nutritional quality of caviar from farmed sturgeons in China. Therefore, the aim of the present study was to evaluate and compare the nutritional value of caviar obtained from three economically important farmed sturgeon species in China, Siberian sturgeon (*Acipenser baerii*) (SS), Amur sturgeon (*Acipenser Schrenckii*) (AS) and Hybrid sturgeon (*Huso dauricus* ♀×*A. schrenkii* ♂) (HS).

2. Materials and Methods

2.1. Sampling

Female sturgeons were reared in circular concrete ponds with flowing through water and fish were fed with same commercial sturgeon extruded feeds during the whole experiment. The sturgeons were weighed and sacrificed for caviar sampling in October, 2012. The ovary of each sturgeon was removed, weighed, cut into small pieces and sieved into loose eggs. The eggs were then washed with cold water and drained. Finally, caviar was processed by adding sodium chloride to eggs. The samples were put into 50g small tins, vacuumed and immediately stored at -3°C until analyzed. A total of nine tins was sampled; three tins for each species.

2.2. Proximate Composition Analysis

Caviar samples were analyzed for moisture, protein, lipid and ash by using AOAC (Association of Official Analytical Chemists) standard methods [8]. Briefly, moisture was measured after drying the sample at 105°C to constant weight. Crude protein content was measured by determining nitrogen content (× 6.25) using automated Kjeldahl analysis (Foss Tecator Kjeltec Auto 2200 analyzer, Warrington, U.K). Fat was determined by petroleum ether extraction (Foss Tecator 148 Soxtec system 2043 Auto Extraction apparatus, Warrington, U.K). Ash was determined by combustion to a constant weight in a muffle furnace at 550°C (Lindberg/Blue M, Thermo Fisher Scientific Inc., Waltham, USA).

2.3. Amino Acid Composition Analysis

For amino acid analysis, the freeze-dried sample was hydrolyzed with 6 $mol \cdot L^{-1}$ and determined on a Biochrom 20 amino acids analyzer (Biochrom Ltd., Cambridge, UK) in accordance with the methods of Chinese Standard GB/T 5009.124-2003 [9]. For tryptophan content measurements, each sample was hydrolyzed with 5 $mol \cdot L^{-1}$ NaOH prior to analysis. The content of the amino acids were calculated by comparison with retention time and peak areas of standard amino acids.

2.4. Fatty Acid Composition Analysis

Total lipids were extracted and fatty acid methyl esters were prepared according to the method of Chinese Standard GB/T 22223–2008 [10]. In brief, lipid was extracted using a chloroform-methanol solution (2:1, v/v). Fatty acid methyl esters (FAMEs) were prepared using a 15% (w/v) BF3-methanol reagent. FAMEs were then measured by using HP-6890 GC series gas chromatograph (Agilent Technologies Inc., Santa Clara, CA, USA). The composition of fatty acids was determined by comparing the areas of the various fatty acids analyzed to the areas of a fixed concentration of the individual and mixed FAME standard.

2.5. Calculations and Statistical Analysis

The following formulas were applied to the biometrical data:

$$\text{Ovary yield}\,(\%) = \text{Ovary weight }(\text{OW}) / \text{Body weight}\,(\text{BW}) \times 100$$

$$\text{Eggs yield}\,(\%) = \text{Eggs weight }(\text{EW}) / \text{Body weight }(\text{BW}) \times 100$$

$$\text{Egg : ovary weight ratio }(\%) = \text{Eggs weight}\,(\text{EW}) / \text{Ovary weight}\,(\text{OW}) \times 100$$

Amino acid score (AAS) was calculated according to FAO/WHO reference amino acid standard for adults. The AAS was calculated using the following formula:

$$\text{Amino acid score} = \text{Sample amino acid}\,(\text{mg/gN}) / \text{Reference amino acid}\,(\text{mg/gN})$$ [11].

Analysis was carried out in triplicate and the results were presented as mean and standard deviation. The data were analyzed by one-way analysis of variance (ANOVA) using SAS 9.0 statistical software (SAS Institute Inc., Cary, NC, USA). Significant ($P < 0.05$) differences among treatments were ranked by Duncan's Multiple Range Test.

3. Results and Discussion

3.1. Biometrical Values

Biometrical values recorded during the experiment are showed in Table 1. Sturgeon caviars had an average ovary yield of 18.50%, in which Siberian sturgeon (SS) caviar showed highest contribution (19.40%), followed by Hybrid sturgeon (HS) caviar (18.21%) and Amur sturgeon (AS) caviar (17.88%). Eggs yield averaged between 13.01-15.06%, which was similar to the reported data of white sturgeon caviar [12]. Significantly higher eggs and ovary ratio was observed in AS (81.90%) and HS (82.58%) caviar compared with SS caviar (66.42%).

Table 1. Biometrical Values of Caviar among Farmed Siberian Sturgeon, Amur Sturgeon and Hybrid Sturgeon n=15, means ± SD

	SS	AS	HS
Ovary yield, %	19.40±3.45	17.88±2.02	18.21±2.05
Eggs yield, %	13.01±3.38	14.75±2.90	15.06±2.02
Eggs: ovary, %	66.42±10.77^{b}	81.90±8.61^{a}	82.58±3.76^{a}

SS, Siberian Sturgeon; AS, Amur Sturgeon; HS, Hybrid Sturgeon
Within the same row, values with different superscripts are significantly different ($P < 0.05$).

3.2. Proximate Chemical Composition

Proximate chemical composition of caviar from three sturgeon species is shown in Table 2. Moisture content of sturgeon caviars averaged between 47.72%-51.80% and together with crude protein (23.98%-25.55%), crude lipid (14.23%-16.22%) and ash (3.28%-3.84%). These results were similar to those of reported sturgeon caviars, which were determined to be 48.40%-56.33%, 23.89%-31.13%, 10.19%-19.41%, 3.44%-4.80% in percentage composition of moisture, crude protein, crude lipid and ash, respectively [12,13,14]. Among the three sampled caviar in the present work, a significant higher content of moisture was found in Siberian sturgeon (SS) caviar (51.80%) than that of in Hybrid sturgeon (HS) caviar (47.72%) ($P < 0.05$), but no significant differences in protein, lipid and ash contents were observed among sturgeon caviar samples ($P > 0.05$), although a numerically higher content was found in HS caviar. Overall, no big variation was found in different sturgeon caviars, all of them could be a good source of protein, lipid and ash.

Table 2. Proximate Compositions of Caviar among Farmed Siberian Sturgeon, Amur Sturgeon and Hybrid Sturgeon (%, wet basis) n=3, means ± SD

Compositions	SS	AS	HS
Moisture	51.80±0.98^{a}	48.65±0.90^{ab}	47.72±1.62^{b}
Crude protein	23.98±0.78	24.27±1.93	25.55±1.82
Crude lipid	14.23±0.71	15.99±0.93	16.22±1.12
Ash	3.84±0.01	3.84±0.41	3.28±0.11

SS, Siberian Sturgeon; AS, Amur Sturgeon; HS, Hybrid Sturgeon
Within the same row, values with different superscripts are significantly different ($P < 0.05$).

3.3. Amino Acid Composition

Table 3. Amino Acids Composition in Caviar among Farmed Siberian Sturgeon, Amur Sturgeon and Hybrid Sturgeon (%, dry basis) n=3, means ± SD

Amino acids	SS	AS	HS
Isoleucine	2.62±0.07[a]	2.60±0.01[ab]	2.47±0.03[b]
Leucine△	4.57±0.11[a]	4.57±0.01[a]	4.31±0.02[b]
Lysine	4.43±0.14[a]	4.30±0.03[ab]	4.15±0.03[b]
Threonine	2.58±0.12	2.57±0.03	2.40±0.02
Valine	2.95±0.06[a]	2.92±0.02[a]	2.73±0.02[b]
Phenylalanine	2.11±0.10	2.07±0.00	1.94±0.02
Methionine△	0.29±0.04	0.53±0.02	0.61±0.17
Tryptophan△	0.49±0.03	0.47±0.02	0.47±0.00
EAA	20.04±0.54	20.01±0.23	19.07±0.14
Arginine△	3.64±0.15	3.64±0.00	3.49±0.01
Histidine	1.46±0.03	1.45±0.01	1.43±0.00
SEAA	5.10±0.18	5.09±0.01	4.92±0.01
Aspartic acid*△	4.78±0.20	4.73±0.05	4.49±0.04
Glutamic acid*△	7.69±0.28	7.55±0.08	7.29±0.05
Glycine*△	1.61±0.06[a]	1.55±0.01[ab]	1.48±0.01[b]
Alanine*	3.52±0.17	3.35±0.03	3.26±0.04
Proline△	2.35±0.13	2.28±0.01	2.15±0.03
Tyrosine△	2.07±0.06[a]	2.07±0.02[a]	1.93±0.01[b]
Cystine△	2.28±0.55	2.06±0.09	1.95±0.09
Serine	4.10±0.19	3.92±0.03	3.78±0.07
NEAA	28.41±0.63	27.50±0.20	26.33±0.28
TAA	53.54±0.36	52.61±0.03	50.31±0.14
DAA	17.60±0.70	17.17±0.09	16.52±0.14
FAA	29.78±1.47	29.44±0.02	28.16±0.02
EAA/TAA	37.44±0.63	38.04±0.42	37.90±0.40
EAA/NEAA	70.61±2.15	72.78±1.37	72.42±1.32
DAA/TAA	32.88±0.14	32.64±0.15	32.84±0.19
FAA/TAA	55.60±0.29	55.96±0.07	55.98±0.21

SS, Siberian Sturgeon; AS, Amur Sturgeon; HS, Hybrid Sturgeon
TAA is total amino acids, EAA is total essential amino acids, SEAA is total semi-essential amino acids, NEAA is total nonessential amino acids, DAA is total delicious amino acids and FAA is total functional amino acids. Within the same row, values with different superscripts are significantly different ($P < 0.05$).
* Delicious amino acids. △ Functional amino acids

The detailed amino acid composition of caviar sampled from three farmed sturgeon species is given in Table 3. The most abundant amino acid in all of them was glutamic acid (7.29%-7.69%), followed by aspartic acid, leucine, lysine, serine and arginine in that order. It was found that among the caviar samples in the present study, the content of isoleucine, leucine, lysine, valine, glycine and tryptophan differed markedly, with a higher content in Siberian sturgeon caviar (SS) than in Hybrid sturgeon caviar (HS) ($P < 0.05$). The total amino acid (TAA) content ranged from 50.31% to 53.54%. The essential amino acids content (EAA) of all samples was lower than non-essential amino acid content (NEAA); the ratio of EAA/NEAA (expressed as percentage) ranged from 70.61% to 72.78%. The EAA and delicious amino acids (DAA) accounted for 37.44%-38.04%, and 32.64%-32.88% of the total amino acid content (TAA) of the three caviar samples, respectively. Recent evidence suggests that some amino acids are important regulators of key metabolic pathways and are necessary for maintenance, growth, nutrient utilization, and immunity in organisms [15]. These amino acids are called functional amino acids (FAA), which include arginine, cystine, glutamic acid, leucine, proline, tryptophan, glycine, tyrosine, methionine and aspartic acid [16]. In caviar samples, these amino acids constituted 28.16%-29.78% of dry matter (55.60%-55.98% of the total amino acids), and caviar is considered to be a good source of functional amino acids. Caviar samples were also found to be rich in lysine, which could supplement the lack of this amino acid in plant-protein based diets [17].

Amino acid concentrations are summarized in Table 4. As shown in Table 4, the concentration of total essential amino acids in three sampled caviars was higher than reference FAO/WHO pattern, and the concentrations of all single amino acid were higher than the reference data as well. Among them, leucine was the EAA with the highest concentration in Siberian sturgeon caviar (596 mg/g N), Amur sturgeon caviar (604 mg/g N) and Hybrid sturgeon caviar (552 mg/g N). Lysine concentrations in caviar samples (ranging from 530 to 578 mg/g N) were much higher than the concentration in reference pattern (340 mg/g N). Tryptophan was found to be the EAA with the lowest content, and it would be the limiting amino acid in these three caviar samples. Moreover, when compared to the reference amino acid pattern, all of the essential amino acids scores (AAS) were > 1 (Table 5). Thus, the protein in these three farmed sturgeon caviars was well-balanced in essential amino acid composition and the caviar can be considered as a good source of amino acids.

Table 4. Essential Amino Acid Concentration s of Farmed Siberian Sturgeon, Amur Sturgeon and Hybrid Sturgeon Caviar Compared to a Reference FAO/WHO Pattern (mg/g N)

Essential amino acids	FAO/WHO pattern	SS	AS	HS
Isoleucine	250	342	344	315
Leucine	440	596	604	552
Lysine	340	578	569	530
Threonine	250	336	340	307
Valine	310	385	386	349
Phenylalanine+Tyrosine	380	545	547	494
Methionine+Cystine	220	335	342	326
Tryptophan	60	64	62	61
Total	2250	3180	3195	2935

SS, Siberian Sturgeon; AS, Amur Sturgeon; HS, Hybrid Sturgeon

Table 5. Essential Amino Acids Score (AAS) in Farmed Siberian Sturgeon, Amur Sturgeon and Hybrid Sturgeon Caviar

Essential amino acids	SS	AS	HS
Isoleucine	1.37	1.38	1.26
Leucine	1.35	1.37	1.25
Lysine	1.70	1.67	1.56
Threonine	1.35	1.36	1.23
Valine	1.24	1.25	1.13
Phenylalanine+Tyrosine	1.43	1.44	1.30
Methionine+Cystine	1.52	1.56	1.48
Tryptophan	1.06	1.04	1.02

SS, Siberian Sturgeon; AS, Amur Sturgeon; HS, Hybrid Sturgeon

3.4. Fatty Acid Profile

The percentage of the fatty acids of caviar from three farmed sturgeon species is presented in Table 6. The overall fatty acid composition of caviar samples in the present study was similar to other published farmed or wild sturgeon [18,19]. The monounsaturated fatty acids (MUFAs) (38.93%-43.29%) were the main group of fatty acids in three caviar samples followed by polyunsaturated fatty acids (PUFAs) (29.52%-35.61%) and saturated fatty acids (SFAs) (24.74%-25.44%). No significant differences in SFAs or MUFAs among the three groups were observed ($P > 0.05$), but a significant higher percentage of PUFAs was found in Siberian sturgeon (SS) caviar compared with Amur sturgeon (AS) and Hybrid sturgeon (HS). The most abundant saturated fatty acid in caviar samples was palmitic acid (C16:0), which was similar to the data reported in the literatures for other sturgeon species [12,13,19]. With monounsaturated fatty acids, the oleic acid (C18:1ω-9) was the most abundant. And Siberian sturgeon (SS) caviar showed a significantly lower level (P < 0.05) of this fatty acid than the other two sturgeon species. Linoleic acid (18:2ω-6), followed by docosahexaenoic acid (DHA, 22:6ω-3), eicopentaenoic acid (EPA, 20:5ω-3) were the main PUFAs in caviar from three sturgeon species. The linoleic acid has been used to distinguish the origin of eggs from farmed and wild sturgeons because of its higher content in caviar that was farm-raised compared with caviar from wild caught [20,21]. Similarly high amount of DHA and EPA is also reported in other sturgeon caviars in the literature [12,13,19]. These two fatty acids are reported to be linked to decreased risk of cardiovascular disease and inflammation [22,23] and improved learning ability [24]. It should be emphasized that the total amount of EPA and DHA were considerably higher in SS caviar than that of the other two (P < 0.05). The ω-3 and ω-6 PUFAs of the three caviars ranged 14.00%-18.62% and 14.89%-16.40% of the total fatty acids, respectively. And the higher percentage of total ω-3 PUFAs (P < 0.05) in SS caviar were mainly due to higher sum of DHA and EPA. The ratio of ω-3 to ω-6 PUFAs in the present study ranged from 0.90 to 1.14, which is similar for reported farmed sturgeon eggs (1.20) [25], and lower than those reported for marine fish eggs (8.70-29.40) [26,27]. And although a higher ω-3/ω-6 ratio in SS caviar, no significant difference was observed.

Table 6. Fatty Acids Profile in Caviar among Farmed Siberian Sturgeon, Amur Sturgeon and Hybrid Sturgeon (% of total fatty acids) n=3, means ± SD

Fatty acids	SS	AS	HS
C14:0	0.86±0.05	0.99±0.17	1.13±0.14
C15:0	0.15±0.00	0.07±0.00	0.08±0.00
C16:0	20.80±0.61	21.38±0.13	21.46±0.10
C17:0	0.11±0.00 ^{b}	0.17±0.00^{a}	0.17±0.03^{a}
C18:0	2.82±0.11	2.89±0.48	2.60±0.04
SFAs	24.74±0.45	25.43±0.52	25.44±0.25
C16:1	4.39±0.61	3.24±0.07	3.84±0.15
C17:1	0.16±0.02	0.18±0.00	0.19±0.01
C18:1ω-9	33.19±0.57 ^{b}	38.02±1.03^{a}	38.26±0.40^{a}
C20:1ω-9	1.19±0.38	0.91±0.02	1.00±0.01
MUFAs	38.93±0.83	42.35±1.16	43.29±1.53
C18:2ω-6	13.13±0.77	12.97±0.78	12.20±0.96
C18:3ω-6	1.31±0.36	0.70±0.09	0.89±0.13
C20:2ω-6	0.25±0.02	0.83±0.78	0.29±0.01
C20:3ω-6	0.31±0.03^{b}	0.44±0.09^{a}	0.28±0.01^{b}
C20:4ω-6	1.66±0.21	1.73±0.08	1.52±0.07
C22:2	0.34±0.00	0.37±0.02	0.34±0.02
EPA C20:5ω-3	4.63±0.80	3.69±0.01	3.94±0.29
C22:5ω-3	1.21±0.12	1.02±0.08	1.13±0.02
DHA C22:6ω-3	12.78±0.52^{a}	9.52±0.18^{b}	8.93±0.60^{b}
PUFAs	35.61±0.52^{a}	31.27±0.75^{b}	29.52±0.83^{b}
EPA+DHA	17.41±0.29^{a}	13.21±0.19^{b}	12.87±0.89^{b}
ω-3 PUFAs	18.62±0.41^{a}	14.23±0.10^{b}	14.00±0.90^{b}
ω-6 PUFAs	16.40±0.93	15.83±0.85	14.89±0.93
ω-3/ ω-6 PUFAs	1.14	0.90	0.94

SS, Siberian Sturgeon; AS, Amur Sturgeon; HS, Hybrid Sturgeon
SFAs is total saturated fatty acids; MUFAs is total monounsaturated fatty acids; PUFAs is total poly unsaturated fatty acids. Within the same row, values with different superscripts are significantly different (P < 0.05).

4. Conclusions

Present study was carried out to find out the nutritional value of caviar from three commercially farmed sturgeons. This is, to the best of our knowledge, the first study documenting the amino acid composition, fatty acid profile of farmed sturgeon caviars in china. Results showed that these caviars may be considered as good sources of high-quality protein, lipid, ash, amino acids and fatty acids. Proteins were rich in essential amino acids, functional amino acids and lipids contained high amount of ω-3 PUFAs, such as DHA and EPA. And it is possible to stress that caviar obtained from cost effective, environmentally friendly farmed sturgeon is able to help in decreasing pressure on wild stocks and support the increasing demand for this luxury product without compromising nutritional quality.

Statement of Competing Interests

The authors have declared that no competing interests exist.

List of Abbreviations

SS means Siberian Sturgeon; AS means Amur Sturgeon; HS means Hybrid Sturgeon; TAA means total amino acids; EAA means essential amino acids; SEAA means semi-essential amino acids; NEAA means nonessential amino acids; DAA means delicious amino acids and FAA means functional amino acids. SFA means saturated fatty acid; MUFA means monounsaturated fatty acid; PUFA means poly unsaturated fatty acid.

Acknowledgements

Financial support for this research was provided mainly by a grant, “Transformation and Application of Sturgeon Breeding and Farming Technology,” from the Ministry of Industry and Information Technology of the People’s Republic of China (grant No.ZD-2012-345), partly by Kaluga Queen Sturgeon Company, and by special fund from the East China Sea Fisheries Research Institute (2012M04).

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