J Sci Food Agric 1997, **74**, 257–264

Physical Indices, Processing Yields, Compositional Parameters and Fatty Acid Profile of Three Species of Cultured Sturgeon (Genus *Acipenser*)*

Anna Badiani,‡ Sandra Stipa, Nadia Nanni, Pier Paolo Gatta and Manfredo Manfredini

Istituto di Approvvigionamenti Annonari, Mercati e Industrie degli Alimenti di Origine Animale, Università degli Studi di Bologna, Via Tolara di Sopra n 50, 40064 Ozzano Emilia, Italy

(Received 10 April 1996; revised version received 30 October 1996; accepted 22 January 1997)

Abstract: Cultured Siberian sturgeon (*Acipenser baeri*), Adriatic sturgeon (*Acipenser naccarii*) and white sturgeon (*Acipenser transmontanus*) of market size were examined for condition factor, eviscerated and dressed yields, white flesh yield, viscera-, hepato-somatic- and gonado-somatic indices. Muscle pH, chemical composition, cholesterol content and fatty acid profile of flesh were also determined. Significant differences were noted between species in eviscerated yield and white flesh yield (lowest in *A naccarii*, highest in *A transmontanus*), viscera index and gonado-somatic index (lowest in *A transmontanus*), but not in dressed yield. Muscle lipid content was 77·6, 106·4 and 44·9 g kg^{-1} wet weight in *A baeri*, *A naccarii* and *A transmontanus*, respectively. *Acipenser baeri* had the lowest saturated and the highest polyunsaturated fatty acid content, especially of the ω-3 series (as % total fatty acid methyl esters). Given the differences that emerged under uniform feeding regimen and environmental conditions, it would be reasonable to market the three species under their proper names, rather than under the generic term of 'sturgeon' as is presently done in Italy.

Key words: acipenseridae, body measurements, chemical composition, species differences, aquaculture.

INTRODUCTION

Fish farming has developed considerably in Italy in recent years, contributing to a notable increase in the consumption of finfish and shellfish. Certain conditions (the exploitation of hot water coming from a number of foundries in the North) has favoured the farming of sturgeon, to the extent that Italy is now the major producer of this fish within the EU, with an annual production of approximately 400 t. Recent estimates indicate that *Acipenser transmontanus* Richardson (white sturgeon) accounts for 75% of total production, with *Acipenser baeri* Brandt (Siberian sturgeon) at 15% and *Acipenser naccarii* Bonaparte (Adriatic or Italian sturgeon) accounting for the other 10%. *Acipenser transmontanus* is used mainly for human consumption, while other possible uses are sport angling, in the case of *A baeri*, and restocking for *A naccarii* (Bronzi *et al* 1994). A large part of cultured sturgeon (81%) is produced for sale as whole fresh fish, often sold to the consumer in steaks; approximately 17% is marketed live for sport fishing and the remaining 2% is sold as smoked fillets or pre-cooked slices (Arlati and Bronzi 1993).

This fish is marketed under the general name of 'sturgeon' with no reference being made to the different species. Moreover, we found no comparative trials in

* Results partly presented at the 42nd International Congress of Meat Science and Technology, 1–6 September 1996, Lillehammer, Norway.

‡ To whom correspondence should be addressed.

J Sci Food Agric 0022-5142/97/$17.50

the literature which aimed to assess if, and to what extent, the three species differed, once commercial size was reached, as regards important economic and nutritional characteristics.

Hence, this study aims to characterise cultured white sturgeon, Siberian and Adriatic sturgeon ready for sale on the basis of certain physical indices, processing yields, flesh composition and muscle fatty acids in order to establish if it would be sensible, in the interest of both processors and consumers, to distinguish clearly between these species at the time of sale.

MATERIALS AND METHODS

Physical indices and processing yields

Thirty raceway-reared sturgeon (10 *A baeri*, 10 *A naccarii*, 10 *A transmontanus*, whose karyotypes had been previously described by Fontana (1994)) were obtained from an intensive commercial fish farm.

Fish were maintained in three outdoor parallel raceways (one for each species) throughout the fattening period (average density 30 kg m^{-3}). Each raceway (400 × 7·5 m, divided into eight sections) was supplied with filtered water from a nearby network of canals at a flow rate of 100 litres s^{-1}. Water temperature ranged between 12 and 16°C and dissolved oxygen content averaged 6 mg $litre^{-1}$. The fish were fed the same commercial pelleted diet for sturgeon (Trouvit Europa Storioni, Hendrix SpA, Mozzecane, Italy), containing herring meal, fish meal and fish oil as major ingredients (reported composition 500 g kg^{-1} protein, 180 g kg^{-1} lipid, 95 g kg^{-1} ash, 10 g kg^{-1} fibre). Feeding was not discontinued before harvesting. The three groups, of 10 sturgeon each, used for this trial were selected from fish weighing 3·35–5·70 kg, the dominant size in the market place. Age of the fish ranged from 42 to 54 months.

Freshly caught sturgeon, sacrificed by a blow on the head and bled, were immediately packed in crushed ice and transported to the laboratory of the institute, where they were weighed, measured and processed.

The length was measured from the tip of the snout to the end of the upper lobe of the caudal fin (fork length). The peritoneal cavity was opened along a ventral midline incision. The entire visceral mass, including liver, pre-gonadal tissue and perivisceral fat, was weighed as a whole. Liver and pre-gonadal tissue were also weighed separately. Kidneys were left on the carcass and weighed with it (eviscerated weight).

The head was removed right behind the opercula and the tail was cut off at the beginning of the upper lobe of the caudal fin, thus yielding the dressed carcass. Each carcass was held in a polyethylene bag at 1 ± 1°C for 40 h; afterwards, muscle pH was directly measured in intact muscle using an Orion pH meter model 250A (Orion Research Inc, Boston, MA, USA) equipped with an Ingold Xerolyt combination electrode type 406-M6-DXK-S7/25 (Mettler-Toledo AG, Analytical, Urdorf, Switzerland). Temperature compensation was ensured by an Orion ATC probe cat No 917006 connected to the pH meter. Probes were inserted on both sides into the middle section of the dressed carcass, midway between lateral line and dorsum and at a 45° angle. The pH was averaged from the values on both sides of each fish.

Three cross-sectional slices were cut from each dressed carcass according to the AOAC method No 937.07 (AOAC 1990), modified in that much thicker steaks (6 cm each) were taken to counteract any possible non-uniform distribution of carcass fat. The three steaks were weighed as a whole (untrimmed steak weight): skin, bony scutes, subepithelial fat layers, dark muscle, cartilage and gut cavity lining were carved away and discarded. The three steaks thus obtained, containing white flesh only (which was intended as the edible portion), were weighed (trimmed steak weight).

In addition, a calculation was made of the percentage of body weight represented by each of the following: eviscerated carcass (eviscerated yield), dressed carcass (dressed yield), head, tail, viscera (viscera index), liver (hepato-somatic index), pre-gonadal tissue (gonado-somatic index). The condition factor was calculated as the % ratio between body weight and fork length cubed. A 'white flesh yield' was obtained as the % ratio between trimmed and untrimmed steak weight.

Chemical composition, cholesterol content and energy value

The three trimmed steaks obtained from each dressed carcass were finely diced (about 0·13 cm^3), thoroughly mixed and homogenised in three 5-s bursts with a Moulinette S food processor (Moulinex SpA, Milano, Italy) set at 10 000 rpm.

The homogeneous sample mass prepared from each fish was immediately analysed in duplicate for moisture, ash and total nitrogen using AOAC (1990) methods No 950.46B, 920.153 and 981.10, respectively. Total protein was calculated from Kjeldahl nitrogen using a 6·25 conversion factor.

Oil was extracted from 10 g of each homogenised sample following the method of Folch *et al* (1957) as modified by Michaelsen *et al* (1991), using chloroform/methanol (2 : 1, v/v) for extraction. Total lipids were measured gravimetrically on an aliquot of this extract. A second aliquot of the fat extract was transferred to a screw cap test tube, stored in a refrigerator (4°C) and used within 24 h for fatty acid analysis.

Cholesterol content was determined in duplicate by direct saponification (Adams *et al* 1986), without derivatisation, in accordance with Engeseth and Gray (1989). A known amount of 5-α-cholestane (Sigma Chemical

Company Ltd, St Louis, MO, USA) was added to each sample as an internal standard. Analysis of the cholesterol was performed on a Carlo Erba Fractovap 2350 gas chromatograph (Carlo Erba Instruments, Milano, Italy) designed to accommodate a 1·83 m × 4 mm glass column packed with 3% OV-17 on Gas Chrom Q (100–120 mesh) (Alltech Associated Inc, Deerfield, IL, USA). Nitrogen served as the carrier gas at a flow rate of 20 ml min^{-1}. Temperatures of the injector, oven and detector were 300, 262 and 300°C, respectively. The injected volume was 4 μl and the run time was 40 min. The output signal from the detector was amplified at an electrometer sensitivity of 10^1. A DP 700 computing integrator (Carlo Erba Instruments, Milano, Italy) was used to calculate retention times and peak areas. Cholesterol was identified by comparing retention time to that of an authenticated standard (Sigma Chemical Company Ltd, St Louis, MO, USA).

Energy value was obtained by multiplying the amount of protein and fat by the factors 17 and 37, respectively (EEC 1990) and expressing the result in MJ kg^{-1} wet weight.

Fatty acid composition

Lipid extracted from each sample was used in duplicate for fatty acid determination. The lipid sample (50–60 mg, accurately weighed) was dissolved in toluene (1 ml). Free fatty acids were obtained and esterified using methanolic sulphuric acid (1%), according to the procedure described by Christie (1989). The recovered fatty acid methyl esters (FAME) were added with 10 mg methyltricosanoate (23 : 0) as an internal standard and analysed on a fused silica capillary column (Omegawax 320; 30 m × 0·32 mm; 0·25 μm coating thickness; Supelco Inc, Bellefonte, PA, USA) in a Fisons Instruments HRGC 8560 Series Mega 2 gas chromatograph (Fisons Instruments, Milano, Italy) equipped with a flame ionisation detector (FID) and operated with a split ratio of 100 : 1. High purity helium served as the carrier gas at a flow rate of 105 kPa. High purity hydrogen (50 kPa) and chromatographic air (100 kPa) were supplied to the FID. The injector and detector temperatures were 250 and 260°C, respectively. Oven temperature was 180°C for 2 min, programmed to 200°C at 5°C min^{-1}, held for 10 min, then programmed to 210°C at 10°C min^{-1}, then held for 10 min. The injected sample was 1 μl and the run time was 27 min. The output signal from the detector was amplified at an electrometer sensitivity of 10^1. Retention times and peak areas were automatically computed by a DP 700 computing integrator (Carlo Erba Instruments, Milano, Italy).

Methyl esters were identified and quantified by comparing the retention time and peak area of the unknowns with those of known FAME standard mixtures (Supelco Inc, Bellefonte, PA, USA; Alltech Associated Inc, Deerfield, IL, USA). Fatty acid content was reported as percentage of individual FAME based on total FAME present in injected sample. The quantitative amounts of fatty acids (expressed as g kg^{-1} edible portion) were determined by relating their peak areas to that of 23 : 0 as internal standard. In addition, the peroxidisability index (Erickson 1992) was computed to express the relationship between the fatty acid composition and the susceptibility of muscle lipids to oxidation.

Statistical analysis

A Statistica/Mac™ software package, release 3.0 (StatSoft Inc, Tulsa, OK, USA) was used for statistical analysis of the data. As the three groups of sturgeon were significantly different for fork length and body weight, the remaining body measurements were subject to analysis of covariance (ANCOVA) using these two variables as fixed covariates. Tissue and organ weights expressed as a relative percentage of body weight were transformed to arc-sine values, whereas proximate composition and fatty acid data (as % FAME) were log-transformed. The transformed data, as well as the fatty acid contents (as g kg^{-1} edible portion), were then subject to one-way analysis of variance (ANOVA). Where, for a given trait, significant differences emerged from ANCOVA or ANOVA, differences among species were determined using Duncan's *post hoc* multiple range test. Statistical significance was tested at the 0·05 probability level.

RESULTS AND DISCUSSION

Physical indices and processing yields

Body measurements and relative tissue and organ weights are shown in Table 1. As mentioned above, the three groups of sturgeon were purposely sampled within the weight range most commonly found on the market, a criteria not linked to the weight distribution within the three raceways. Of the three samples examined, *A transmontanus* (AT) was significantly longer than *A baeri* (AB) and *A naccarii* (AN); AB had a significantly lower body weight than AN and AT. Hence, the condition factor was highest for AN and lowest for AT, although the difference between species was not statistically significant. The three values of the condition factor fell within the 0·40–0·90 range identified as being typical in sexually immature sturgeon (Doroshov 1985).

The most important results to be obtained from Table 1 regard processing yield. In the weight ranged examined, AT would have the highest number of commercial assets. It had the lowest proportion of viscera and hence the highest eviscerated yield. The superiority

TABLE 1
Physical indices, processing yields and muscle pH of the three species[a,b]

Trait[c]	Acipenser baeri	Acipenser naccarii	Acipenser transmontanus
Fork length (FL, cm)	90·2b ± 1·1	91·4b ± 1·4	96·6a ± 1·7
Body weight (BW, g)	4292b ± 170	4844a ± 157	4974a ± 169
Eviscerated weight (EW, g)	3704c ± 141	4078b ± 130	4399a ± 129
Dressed weight (DW, g)	3112c ± 118	3473b ± 122	3628a ± 112
Untrimmed steak weight (USW, g)	1089c ± 38	1167b ± 30	1201a ± 45
Trimmed steak weight (TSW, g)	640b ± 24	639b ± 21	794a ± 35
Head (H, g)	515·9b ± 21·7	532·8b ± 13·4	680·1a ± 25·1
Tail (T, g)	63·6b ± 2·6	55·4c ± 2·8	83·7a ± 4·4
Viscera (V, g)	522·5b ± 50·9	628·4a ± 41·4	440·3b ± 38·7
Liver (L, g)	127·1 ± 16·5	157·0 ± 12·2	116·4 ± 13·9
Pre-gonadal tissue (G, g)	218·3a ± 30·4	231·9a ± 43·4	120·3b ± 18·1
Condition factor (CF)	0·58 ± 0·02	0·63 ± 0·02	0·56 ± 0·03
Eviscerated yield (EY, %)	86·38b ± 0·66	84·23c ± 0·75	88·58a ± 0·70
Dressed yield (DY, %)	72·57 ± 0·55	71·68 ± 0·80	73·02 ± 0·62
White flesh yield (WFY, %)	58·04b ± 0·62	54·81c ± 1·09	64·66a ± 0·98
Head (%)	12·03b ± 0·20	11·06c ± 0·30	13·70a ± 0·35
Tail (%)	1·48b ± 0·03	1·15c ± 0·05	1·68a ± 0·07
Viscera index (VI)	12·06a ± 0·94	12·97a ± 0·78	8·80b ± 0·67
Hepato-somatic index (HSI)	2·95 ± 0·34	3·23 ± 0·20	2·36 ± 0·31
Gonado-somatic index (GSI)	4·96a ± 0·57	4·83a ± 0·93	2·38b ± 0·32
Muscle pH	6·10 ± 0·07	6·29 ± 0·09	6·15 ± 0·06

[a] Values are mean ± standard error of 10 fish for each species.
[b] Means in the same row with different following letters differ ($P \leq 0{\cdot}05$).
[c] V is inclusive of L + G; $CF = BW \times 100/FL^3$; EY = EW × 100/BW; DY = DW × 100/BW; WFY = TSW × 100/USW; Head % = H × 100/BW; Tail % = T × 100/BW; VI = V × 100/BW; HSI = L × 100/BW; GSI = G × 100/BW.

of this species was noticeably reduced, however, when the dressed yield was taken into consideration, because of the higher proportion of head and tail. Nonetheless, AT regained first place when the steaks were trimmed, giving the highest white flesh yield. For all the processing yields AT was followed by AB. AN had the highest proportion of visceral mass as well as the lowest proportion of head and tail. Consequently, its eviscerated yield was the lowest of the three species, while the dressed yield differed only slightly from that of the other two. However, the percentage of waste at the trimming of the steaks was particularly high for AN, due above all to the high proportion of subcutaneous fat observed.

Both Hung *et al* (1987) and Price *et al* (1989), when studying cultured AT aged 32 and 43 months respectively, found higher eviscerated yields (approximately 91 and 93%, respectively). Moreover, Hung *et al* (1987) observed a lower hepato-somatic index (1·80) and a higher gonado-somatic index (3·34) than in the AT presently considered, when the reverse should have been the case, as the latter were considerably older.

The three species examined did not differ for muscle pH values, which fell into the rather narrow range (6·1–6·4) found by Izquierdo-Pulido *et al* (1992) for the muscle of cultured AT during the first week of storage.

Chemical composition, cholesterol content and energy value

The three species of sturgeon showed noticeable differences as regards the chemical composition and energy value of the flesh (Table 2), to the extent that they fell into different classes of the model proposed by Stansby (1976) for the classification of fish from the standpoint of oil and protein content. AT can be classified as a low oil–high protein species, whereas both AB and AN are medium oil–high protein fish. In fact the flesh of the three species of sturgeon showed significant differences in moisture, lipid and thus in energy value; the flesh of AN contained lower levels of protein and ash compared to the other species, though the effect on nutritional value was slight. AB had the highest cholesterol content. However, the difference between the three species for this parameter would not be of particular importance for human consumption.

TABLE 2
Proximate composition, cholesterol content and energy value of muscle tissue (g kg^{-1} wet wt, unless otherwise noted)[a,b]

Trait[c]	Acipenser baeri	Acipenser naccarii	Acipenser transmontanus
Moisture	721·1b ± 5·8	698·1c ± 6·0	755·5a ± 5·4
Protein	194·7a ± 2·4	186·4b ± 2·7	195·7a ± 2·8
Lipid	77·6b ± 5·9	106·4a ± 7·6	44·9c ± 4·1
Ash	11·0a ± 0·2	10·2b ± 0·4	11·4a ± 0·3
Cholesterol	0·704a ± 0·014	0·648b ± 0·020	0·614b ± 0·016
Energy value (MJ kg^{-1})	6·18b ± 0·20	7·10a ± 0·26	4·99c ± 0·17

[a] Values are mean ± standard error of 10 fish individually analysed in duplicate for each species.
[b] Means in the same row with different following letters differ ($P \leq 0{\cdot}05$).
[c] Energy value calculated according to EEC (1990).

Since diet and environmental conditions were the same for the three species of sturgeon, it is reasonable to suppose that genetic factors are at the basis of the differences observed, although an age effect cannot be ruled out (Hung *et al* 1987; Price *et al* 1989).

The most interesting element to be observed in Table 2 is undoubtedly the lipid content, which would seem to be completely independent of the final body weight reached by the three species. The striking differences in lipid content between AN, AB and AT have considerable impact on nutritional value. One serving (0·1 kg) of AT flesh would provide 6·7% of the daily fat intake of 67 g, currently recommended for an adult on a normocaloric diet with no more than 30% energy from fat (National Research Council 1989). This percentage rises to 11·6 for AB and reaches 15·9 for AN, an aspect which would certainly be of considerable interest for any health conscious consumer and which alone should be sufficient to suggest commercial differentiation between the species.

Fatty acid composition

The fatty acid profiles of the three species (Table 3) presented as a common feature the clear predominance of monounsaturated fatty acids (MUFAs), followed by saturated (SFAs) and polyunsaturated (PUFAs) fatty acids. AN had the highest content of MUFAs, while not differing from AT as regards SFAs. AB had the highest content of PUFAs (both of the ω-6 and ω-3 families) and the lowest content of SFAs, and thus the lowest saturated/unsaturated fatty acid ratio (SFA/UFA). The same fatty acids were seen to predominate in all three species. However, their percentage within the fatty acid group to which they belonged differed according to the species. For instance, palmitic acid (16 : 0) accounted for slightly more than 74% of all the SFAs in both AB and AT, while in AN it was over 79%. Oleic acid (18 : 1, both isomers) ranged from a minimum of 58·2% of total MUFAs in AB to a maximum of 64·1% in AN; palmitoleic acid (16 : 1 ω-7) represented 12·8% of MUFAs in AT, as against 17·2% in AN. The proportion of eicosapentaenoic acid, or EPA (20 : 5 ω-3), on overall PUFAs was highest in AB (25·9%) and lowest in AN (23·8%), while the opposite was true for docosahexaenoic acid, or DHA (22 : 6 ω-3), with 38·5 and 43·5% for AB and AN, respectively.

The ω-3/ω-6 ratio was significantly different in the three species, being highest in AN and lowest in AB. In any case, this ratio was, to varying degrees, beyond the 0·50–3·80 range given by Henderson and Tocher (1987) for freshwater fish. When compared to these fish, the three species of sturgeon present other differences, such as the rather high levels of eicosenoic (20 : 1) and docosenoic (22 : 1) acid, clearly of dietary origin (Ackman *et al* 1980), the low quantity of trienes (in particular α-linolenic acid, 18 : 3 ω-3) and tetraenes (especially arachidonic acid, 20 : 4 ω-6) (Henderson and Tocher 1987).

The data in the literature concerning the fatty acid composition of the muscle lipids of the three species examined here are not very numerous (Shimma and Shimma 1968, on cultured AB; Agradi *et al* 1993, on cultured AN; Xu *et al* 1993 and Bianchi Paleari and Grimaldi 1994, on cultured AT). Besides these species, *Acipenser oxyrhynchus* Mitchill (both wild and cultured) were examined by Ackman *et al* (1975) and Chen *et al* (1995). The feeding trials performed by Agradi *et al* (1993), Xu *et al* (1993) and Chen *et al* (1995) invariably showed the fatty acid composition of the muscle lipids as reflecting that of the diet fed each time, demonstrating at the same time that these chondrostean fish have the ability to elongate and desaturate both linoleic (18 : 2 ω-6) and α-linolenic acids to longer chain PUFAs. In the latter three papers, as well as in this study, DHA content was higher than that of EPA to a greater or lesser extent. This contrasts with the findings of Bianchi Paleari and Grimaldi (1994) on cultured AT and of Ackman *et al* (1975) on wild *A oxyrhynchus*.

TABLE 3
Fatty acid composition of muscle tissue (% total fatty acid methyl esters)[a,b]

Trait[c]	Acipenser baeri	Acipenser naccarii	Acipenser transmontanus
14 : 0	3·96a ± 0·12	3·27b ± 0·14	3·62ab ± 0·19
15 : 0	0·39a ± 0·01	0·31b ± 0·01	0·33b ± 0·02
16 : 0	18·38b ± 0·26	20·91a ± 0·46	19·94a ± 0·22
18 : 0	1·75b ± 0·03	1·60c ± 0·04	2·80a ± 0·13
19 : 0	0·28a ± 0·01	0·25a ± 0·02	0·21b ± 0·01
∑ SFA[c]	24·75b ± 0·37	26·34a ± 0·44	26·88a ± 0·29
14 : 1	0·17 ± 0·003	0·16 ± 0·005	0·16 ± 0·006
16 : 1ω-7	7·14b ± 0·11	8·23a ± 0·38	5·83c ± 0·17
18 : 1ω-9	23·32b ± 0·41	28·17a ± 0·87	26·74a ± 0·98
18 : 1ω-7	2·82a ± 0·08	2·40b ± 0·10	2·27b ± 0·07
20 : 1ω-11	1·67a ± 0·06	1·35b ± 0·03	1·71a ± 0·08
20 : 1ω-9	5·55a ± 0·10	4·22c ± 0·19	4·96b ± 0·18
22 : 1ω-11	3·52a ± 0·08	2·68b ± 0·21	3·15ab ± 0·26
22 : 1ω-9	0·49a ± 0·01	0·30b ± 0·02	0·38b ± 0·04
24 : 1	0·25a ± 0·01	0·18b ± 0·01	0·25a ± 0·01
∑ MUFA[c]	44·89b ± 0·44	47·70a ± 0·63	45·39b ± 0·58
18 : 2ω-6	3·86a ± 0·09	2·59b ± 0·09	2·89b ± 0·08
18 : 3ω-6	0·18 ± 0·01	0·14 ± 0·01	0·14 ± 0·01
20 : 2ω-6	0·29a ± 0·01	0·21b ± 0·01	0·23b ± 0·01
20 : 3ω-6	0·13a ± 0·01	0·11b ± 0·01	0·13a ± 0·01
20 : 4ω-6	0·84a ± 0·03	0·54b ± 0·02	0·88a ± 0·04
∑ PUFA[c] ω-6	5·23a ± 0·11	3·51c ± 0·10	4·18b ± 0·08
18 : 3ω-3	0·79a ± 0·01	0·68b ± 0·03	0·62b ± 0·03
18 : 4ω-3	1·25 ± 0·02	1·19 ± 0·07	1·01 ± 0·08
20 : 5ω-3 (EPA)[c]	6·54a ± 0·21	4·81c ± 0·19	5·55b ± 0·23
21 : 5ω-3	0·29a ± 0·01	0·25b ± 0·01	0·25b ± 0·01
22 : 5ω-3	1·42a ± 0·04	0·97c ± 0·04	1·14b ± 0·04
22 : 6ω-3 (DHA)[c]	9·70 ± 0·26	8·77 ± 0·31	9·06 ± 0·25
∑ PUFAω-3	19·98a ± 0·51	16·66b ± 0·60	17·62b ± 0·54
∑ PUFA	25·21a ± 0·58	20·17b ± 0·69	21·81b ± 0·60
∑ UFA[c]	70·10a ± 0·25	67·87b ± 0·29	67·20b ± 0·39
Unknown sum	1·10b ± 0·04	1·80a ± 0·09	1·23b ± 0·04
SFA/UFA	0·35b ± 0·01	0·39a ± 0·01	0·40a ± 0·01
ω-3/ω-6	3·83c ± 0·09	4·74a ± 0·08	4·21b ± 0·08
EPA + DHA	16·23a ± 0·45	13·58b ± 0·47	14·61b ± 0·42
(EPA + DHA)/ω-3	0·81 ± 0·002	0·82 ± 0·004	0·83 ± 0·006
(EPA + DHA)/ω-6	3·11c ± 0·08	3·87a ± 0·07	3·49b ± 0·06
PEROX. INDEX[d]	142·73a ± 3·65	118·94b ± 4·06	127·57b ± 3·50

[a] Values are mean ± standard error of 10 fish individually analysed in duplicate for each species.
[b] Means in the same row with different following letters differ ($P \leq 0{\cdot}05$).
[c] SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid; UFA, unsaturated fatty acid.
[d] Peroxidisability index = (0·025 × monoenes) + (1 × dienes) + (2 × trienes) + (4 × tetraenes) + (6 × pentaenes) + (8 × hexaenes) (Erickson 1992).

The percentage of the single ω-3 PUFAs on the total content of these fatty acids found by Agradi *et al* (1993) in AN fed either a 'control' diet or a 'fish oil' diet does not differ much from that found in this study. Both the group of cultured AT fed a 'cod liver oil' diet (Xu *et al* 1993) and the group of *A oxyrhynchus* fed a commercial salmon diet (Chen *et al* 1995) had a fatty acid composition similar to those found here, although the ω-6 PUFA content was higher.

The three species of sturgeon examined here had very different lipid levels. Consequently, it would be reasonable to expect that: (a) the triglyceride (TG) content and not the phospholipid (PL) content would be of much greater importance in differentiating between the three species; (b) the TG would be proportionately more abundant in the muscle lipids of the fattest species (AN) than in those of the leanest species (AT), where the effect of the presence of the PL would be more evident; (c) as

the fatty acid patterns of the TG are more affected by dietary lipids than those of the PL, the fatty acid composition of the muscle lipids in AN would be more greatly influenced by the fatty acid composition of the diet; (d) moreover, the muscle lipids of AT would be expected to be less endowed with MUFAs compared to those of AN and would present a lower proportion of fatty acids (Exler *et al* 1975; Weihrauch *et al* 1977; Opstvedt 1984; Henderson and Tocher 1987; Ackman 1989; Polvi and Ackman 1992; Gershanovich and Kiselev 1993; Ackman 1995). The above is confirmed by the percentage of total fatty acids on fat content which was 86·2% for AN, 85·2% for AB and 78·4% for AT.

Some interesting considerations emerged from the quantitative fatty acid profile (data not tabulated), above all as regards AB. Despite the fact that AB had a noticeably lower fat content than AN, its ω-6 and ω-3 PUFA contents did not differ significantly from those of the latter species (respectively, 3·56 and 13·51 g kg^{-1} edible portion in AB, 3·29 and 15·37 g kg^{-1} in AN). AB probably had a superior selective retention of dietary ω-6 and ω-3 PUFAs and/or a different ability to elongate and desaturate them, which could be genetically based.

Thus, AB would seem to be the species of greatest nutritional interest, in that it combines a moderate fat content with a high amount of the much sought-after EPA + DHA (10·97 g kg^{-1} edible portion) and the lowest amount of SFAs (17·26 g kg^{-1}). Even if AN is able to provide greater quantities of EPA + DHA (12·60 g kg^{-1} edible portion), the flesh of this species is the richest in fat and has a much higher content of SFAs (25·69 g kg^{-1}). AB is perfectly well able to provide the daily requirements of EPA + DHA, estimated by various sources as around 0·3–0·4 g day^{-1} (Ackman 1988; Pigott and Tucker 1990; Lemarchal *et al* 1992), with 2–3 servings per week, a capacity quite similar to that of the much publicised cultured salmon (Ackman and Takeuchi 1986; Ackman 1989; Cronin *et al* 1991; Polvi and Ackman 1992). Nonetheless, it must not be overlooked that AB, because of its higher PUFA content, scored the highest peroxidisability index (Table 3), which leads us to hypothesise that, for processing and storage, AT would be the most suitable species (lower fat content, lower peroxidisability index, hence higher 'dietetic profile').

As the species of cultured sturgeon considered here differed noticeably as regards processing yields, chemical composition of the flesh and fatty acid profile of muscle lipids, it would be reasonable to differentiate between them when they are sold for human consumption.

ACKNOWLEDGEMENTS

Financial support for this work was provided by the Italian Ministry of University and Scientific and Technological Research (MURST '60%' Funds, Financial Year 1994).

REFERENCES

Ackman R G 1988 Concerns for utilization of marine lipids and oils. *Food Technol* **42** (5) 151–155.

Ackman R G 1989 Nutritional composition of fats in seafoods. *Prog Food Nutr Sci* **13** 161–241.

Ackman R G 1995 Composition and nutritive value of fish and shellfish lipids. In: *Fish and Fishery Products*, ed Ruiter A. CAB International, Wallingford, UK, pp 117–156.

Ackman R G, Takeuchi T 1986 Comparison of fatty acids and lipids of smolting hatchery-fed and wild Atlantic salmon *Salmo salar*. *Lipids* **21** 117–120.

Ackman R G, Eaton C A, Linke B A 1975 Differentiation of freshwater characteristics of fatty acids in marine specimens of the Atlantic sturgeon, *Acipenser oxyrhynchus*. *Fish Bull* **73** 838–845.

Ackman R G, Sebedio J-L, Kovacs M I P 1980 Role of eicosenoic and docosenoic fatty acids in freshwater and marine lipids. *Mar Chem* **9** 157–164.

Adams M L, Sullivan D M, Smith R L, Richter E F 1986 Evaluation of direct saponification method for determination of cholesterol in meats. *J AOAC* **69** 844–846.

Agradi E, Abrami G, Serrini G, Mckenzie D, Bolis C, Bronzi P 1993 The role of dietary *n*-3 fatty acid and vitamin E supplements in growth of sturgeon (*Acipenser naccarii*). *Comp Biochem Physiol* **105A** 187–195.

AOAC 1990 *Official Methods of Analysis* (15th edn), ed Helrich K. AOAC, Arlington, VA, USA.

Arlati G, Bronzi P 1993 Sturgeon farming in Italy. In: *Proc 2nd Int Symp* '*Sturgeon-93*'. VNIRO Publ, Moscow, Russia, pp 321–332.

Bianchi Paleari M A, Grimaldi P 1994 Studio della composizione chimica dello storione bianco (*Acipenser transmontanus*): un esempio di approccio scientifico al problema della qualità nei pesci di allevamento. *Il Pesce* **11** (1) 56–61.

Bronzi P, Arlati G, Cataudella S, Rossi R 1994 Sturgeon presence and distribution in Italy. In: *Proc Int Conf* '*Sturgeon Biodiversity and Conservation*', New York, NY, USA, 19 pp (in press).

Chen I-C, Chapman F A, Wei C-I, Portier K M, O'Keefe S F 1995 Differentiation of cultured and wild sturgeon (*Acipenser oxyrhynchus desotoi*) based on fatty acid composition. *J Food Sci* **60** 631–635.

Christie W W 1989 *Gas Chromatography and Lipids. A Practical Guide*. The Oily Press, Ayr, UK, pp 64–84.

Cronin D A, Powell R, Gormley R 1991 An examination of the *n*-3 and *n*-6 polyunsaturated fatty acid status of wild and farmed Atlantic salmon (*Salmo salar*). *Irish J Food Sci Technol* **15** 53–62.

Doroshov S I 1985 Biology and culture of sturgeon acipenseriformes. In: *Advances in Aquaculture* (Vol 2), eds Muir J F & Roberts R J. Westview Press, Boulder, CO, USA, pp 251–274.

EEC 1990 Council directive on nutrition labelling for foodstuffs (90/496). *Offic J Eur Communities* (L276) 40–44.

Engeseth N J, Gray J I 1989 Total cholesterol determination. Evaluation of analytical methods and survey of meat products. In: *Proc 35th Int Congr Meat Sci Technol* (Vol 2). Danish Meat Research Institute, Roskilde, Denmark, pp 568–572.

Erickson M C 1992 Variation of lipid and tocopherol composition in three strains of channel catfish (*Ictalurus punctatus*). *J Sci Food Agric* **59** 529–536.

Exler J, Kinsella J E, Watt B K 1975 Lipids and fatty acids of important finfish: new data for nutrient tables. *J Am Oil Chem Soc* **52** 154–159.

Folch J, Lees M, Sloane Stanley G H 1957 A simple method for the isolation and purification of total lipides from animal tissues. *J Biol Chem* **226** 497–509.

Fontana F 1994 Chromosomal nucleolar organizer regions in four sturgeon species as markers of karyotype evolution in Acipenseriformes (Pisces). *Genome* **37** 888–892.

Gershanovich A D, Kiselev G A 1993 Growth and haematological response of sturgeon hybrids Russian sturgeon (*Acipenser guldenstadti* Brandt) × beluga (*Huso huso* L.) to protein and lipid contents in the diet. *Comp Biochem Physiol* **106A** 581–586.

Henderson R J, Tocher D R 1987 The lipid composition and biochemistry of freshwater fish. *Prog Lipid Res* **26** 281–347.

Hung S S O, Lutes P B, Conte F S 1987 Carcass proximate composition of juvenile white sturgeon (*Acipenser transmontanus*). *Comp Biochem Physiol* **88B** 269–272.

Izquierdo-Pulido M L, Hatae K, Haard N F 1992 Nucleotide catabolism and changes in texture indices during ice storage of cultured sturgeon, *Acipenser transmontanus*. *J Biochem* **16** 173–192.

Lemarchal Ph, Bourre J M, Darcet P, Durand G, Klére J, Legrand P, Mendy F, Renaud S, Zwoboda F 1992 Apports nutritionnels conseillés en acides gras essentiels. In: *Apports Nutritionnels Conseillés Pour la Population Française*, eds Dupin H, Abraham J, Giachetti I. Lavoisier, Paris, France, pp 74–81.

Michaelsen S A, Johnson D D, West R L, Leak F W 1991 *Determination of Cooking Characteristics for Lean Retail Beef Cuts.* Meat Science Section, Department of Animal Science, University of Florida, Gainesville, FL, USA.

National Research Council 1989 *Recommended Dietary Allowances* (10th edn). Nutritional Academy Press, Washington, DC, USA.

Opstvedt J 1984 Fish fats. In: *Fats in Animal Nutrition*, ed Wiseman J. Butterworths, London, UK, pp 53–82.

Pigott G M, Tucker B W 1990 *Seafood—Effects of technology on nutrition.* Marcel Dekker Inc, New York, NY, USA, pp 258–293.

Polvi S M, Ackman R G 1992 Atlantic salmon (*Salmo salar*) muscle lipids and their response to alternative dietary fatty acid sources. *J Agric Food Chem* **40** 1001–1007.

Price R J, Hung S S O, Conte F S, Strange E M 1989 Processing yields and proximate composition of cultured white sturgeon (*Acipenser transmontanus*). *J Food Sci* **54** 216–217.

Shimma Y, Shimma H 1968 Fatty acid composition of *Acipenser baeri* cultivated in Tokyo. *Bull Freshwater Fish Res Lab* (*Tokyo*) **18** 179–184.

Stansby M E 1976 Chemical characteristics of fish caught in the northeast Pacific Ocean. *Mar Fish Rev* **38** (9) 1–11.

Weihrauch J L, Posati L P, Anderson B A, Exler J 1977 Lipid conversion factors for calculating fatty acid content of foods. *J Am Oil Chem Soc* **54** 36–40.

Xu R, Hung S S O, German J B 1993 White sturgeon tissue fatty acid compositions are affected by dietary lipids. *J Nutr* **123** 1685–1692.