



HAL
open science

A comprehensive review on the assessment of the quality and authenticity of the sturgeon species by different analytical techniques

Daria Vilkova, Christine Chèné, Elena Kondratenko, Romdhane Karoui

► To cite this version:

Daria Vilkova, Christine Chèné, Elena Kondratenko, Romdhane Karoui. A comprehensive review on the assessment of the quality and authenticity of the sturgeon species by different analytical techniques. Food Control, 2022, 133, pp.108648. 10.1016/j.foodcont.2021.108648 . hal-03653084

HAL Id: hal-03653084

<https://univ-artois.hal.science/hal-03653084>

Submitted on 5 Jan 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

21 **ABSTRACT**

22 The sturgeon species are related to a food delicacy and are known for their rich nutritive
23 properties that are essential for human health since prehistoric times. The intensive decline in
24 wild sturgeon populations has led to an increase of the farmed and hybrid species in
25 aquaculture production. The sturgeon meat contains highly digestible proteins, fats, vitamins
26 and minerals which are influenced by its biodiversity. This review will provide different
27 analytical techniques used for the determination of the quality and authenticity of [sturgeon](#)
28 [species](#). To attain these objectives, targeted techniques (chemical, sensory, microbiological,
29 chromatographic, [morphological](#), [polymerase chain reaction](#), and so on) and untargeted ones
30 (Fluorescence, and mid-infrared spectroscopies, and so on). The former techniques considered
31 as the official methods used to assess the quality and authenticity of sturgeon are time-
32 consuming and need a trained personnel team, while the latter ones based on the use of
33 fluorescence and mid-infrared spectroscopies are considered rapid, non-destructive, relatively
34 cheap, and environmentally friendly. The use of untargeted techniques as a promising tool is
35 not fully explored in the fish sector, particularly for sturgeon, which needs future research to
36 demonstrate and prove their robustness for the determination of the quality and authenticity of
37 this fish species.

38

39 **Keywords:** Sturgeon; Authenticity; Quality; Freshness; Targeted and untargeted techniques.

40

41 **1. Introduction**

42 The family sturgeon (*Acipenseridae*) refers to a valuable fish in the sphere of
43 commerce, which population is rapidly declining due to several factors such as changes in
44 river streams, construction of hydropower stations, illegal fishing, and other negative human
45 activities (Bronzi & Rosenthal, 2014). According to the International Union for Conservation
46 of Nature, sturgeons are the group of fish that falls under the level of extinction (IUCN,
47 2018). The *Acipenseriformes* display the highest level of critically endangered species among
48 all the other threatened animal breeds. A sharp decrease in the number of natural inhabitants
49 of sturgeons gave birth to a new branch in aquaculture named *commercial sturgeon farming*
50 (Erickson et al. 2005; Litvak, 2010).

51 It is well known that the chemical composition of fish can vary according to several
52 parameters such as species, body size, season, nutritional status, and so on (Al-Reza et al.,
53 2015). The sturgeon fish components include essential amino acids, vitamins, minerals,
54 phosphorus, potassium. Due to the presence of glutamic acid, the sturgeon flesh tastes
55 delicious (Kaya, Turan, & Erdem, 2008). Sturgeon meat has some of the long chains omega-3
56 fatty acids, including eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) (Pelic et
57 al., 2019). Omega-3 deficiency is associated with lower intelligence, depression, heart
58 disease, arthritis, cancer, and many other health problems. Moreover, fish items with their
59 high level of unsaturated fatty acids are essential for human health. Consequently, human
60 consumption of sturgeon affects positively people's blood pressure, metabolic process, skin
61 regeneration, and so on. Besides, this species of fish is considered to be dietary as sturgeon
62 possesses low-calorie rates preserving high energy values due to its rapid digestibility
63 (Ghomi, Nikoo, & Pourshamsian, 2012).

64 According to Bronzi et al. (2019), the world's production of sturgeon biomass has
65 increased within the last decade and reached the world 102.327 tons by 2017. As a result of

66 fish hunting, the sturgeon production in the China Republic reached ~ 79.6 tons in 2017
67 representing 78% of the global series rate. Russia's production represents ~ 6.8 tons which
68 makes 6.6% of the global rates. Sturgeon species showed a growing tendency around the
69 world due to their oxygen tolerance and rapid adaptation to different farming systems. These
70 species are promising candidates for aquaculture due to their excellent characteristics such as
71 easy adaptation to a farming environment as well as their expensive caviar and dense meat. In
72 2016, the commercial sturgeon farming data, for different sturgeon species, reveal that there
73 are 12 pure species and six hybrid items among the analysed 25 species of *Acipenseridae*
74 showing a major share in the fish production. The main species include the Russian sturgeon
75 (*Acipenser gueldenstaedtii*), Beluga sturgeon (*Huso huso*), Sterlet sturgeon (*Acipenser*
76 *ruthenus*), White sturgeon (*Acipenser transmontanus*), Persian sturgeon (*Acipenser persicus*),
77 and some hybrids (**Figure 1**). By 2017, about 2329 commercial sturgeon farms have appeared
78 in the world, which represents an increase of 7% compared to 2016 (Bronzi et al., 2019).

79 There are very few publications that are devoted to study sturgeon in the following
80 topics: aquaculture, fisheries, freshwater biology, environmental sciences, ecology,
81 biochemistry, and molecular biology (Jarić, Gessner, Acolas, Lambert, & Rochard, 2014).
82 [Research related to aquaculture, in particular, sturgeon reproduction was among the central](#)
83 [objects of the research. The genetic research, especially the use of DNA analysis, is becoming](#)
84 [increasingly popular and had the highest impact. Previously, limited number of research in](#)
85 [food industry was noted. Nevertheless, considering the current trend in output, it is very likely](#)
86 [that the most countries will surpass this sector within the next 5–10 years.](#)

87 The sturgeon fish tissue consists of a complex combination of organic compounds –
88 proteins, fats, carbohydrates, [water, minerals, and vitamin compounds](#). These substances are
89 easily split by digestive enzymes or the microorganisms' fermentation (Ghaly, Dave, Budge,
90 & Brooks 2010). Consequently, during storage, the fish lacks its nutritional values and

91 becomes inappropriate for consumption, and even acquires toxic characteristics. The spoilage
92 of sturgeon could be attributed to the growth of microorganisms (Lougovois, and Kyrana,
93 2014). Consequently, to preserve the quality of sturgeon and extend its shelf-life, different
94 techniques including refrigeration, frosting, freezing (Hosseini et al., 2010; Rostamzad,
95 Shabanpour, Kashaninejad, & Shabani, 2011), vacuum packaging, modified atmosphere
96 packaging (Yue-wen Chen et al., 2020), enzyme inactivation by natural compounds like
97 salting, smoking, plant solution [rich in natural antioxidants](#), and so on were applied (Oliveira,
98 Balaban, & O’Keefe, 2006; Sarah, Hadiseh, Gholamhossein, & Bahareh, 2010).

99 The quality of the sturgeon species could be determined by traditional techniques.
100 Among them, physico-chemical analyses comprising the determination of total volatile
101 nitrogen, lipid oxidation products such as thiobarbituric acid reactive substances (TBARS)
102 and peroxide value (PV) are commonly used as indicators of fish freshness (Manju, Jose,
103 Srinivasa Gopal, Ravishankar, & Lalitha, 2007). The sensory properties are performed by the
104 perceptible function of the human senses (colour, odour, flavour, texture, and taste) of raw
105 and cooked fish muscles (García et al., 2017).

106 Although the ability of the physico-chemical, sensory, and microbiology methods is
107 indisputable to determine the quality and authenticity of fish and fish products, the majority of
108 them are considered to be relatively expensive, long-lasting, and time-consuming. Recently,
109 an effort is devoted to the investigation of non-invasive and non-destructive instrumental
110 methods such as infrared, and fluorescence spectroscopies among others. These techniques
111 are considered to be rapid, relatively cheap, and environmentally friendly [and can be carried](#)
112 [out even by minimally trained personnel](#). They give a significant amount of information based
113 on a single test. Moreover, spectroscopic techniques do not need much preparation of samples
114 and in some cases can be held without any preparation (Karoui, Hassoun, & Ethuin, 2017).

115 This present review paper will provide a comprehensive overview of the application of
116 different analytical techniques, in combination with multivariate data analysis, to determine
117 the quality of sturgeon quality. A layout of the review theme is outlined in **Figure 2**.

118

119 **2. Targeted methods used for the determination of the quality and authenticity of** 120 **sturgeon**

121 In general, fish quality refers to the visual appearance and freshness which depends on
122 the spoilage level. The fish quality also refers to safety aspects such as the absence of the
123 pathogenic microorganisms, parasites and/or toxic elements. The methods used for the
124 evaluation of the fish quality and its freshness include physico-chemical, microbiological,
125 sensory analyses, and so on.

126

127 **2.1. Physico-chemical analysis**

128 After death, the quality of fish deteriorates because of the post-mortem changes. The
129 alteration processes are always accompanied by (bio)chemical reactions that induce the
130 formation of volatile and biogenic amines and changes in the pH, water content, cooking loss,
131 peroxide value, and others. **Table 1** shows a few studies that explored the use of physico-
132 chemical methods to assess the quality of sturgeon species. Undoubtedly, the proximate
133 analysis is important for obtaining nutritional values of different sturgeon species which
134 depends on the muscle composition that is observed in tissue quality parameters (Hosseini et
135 al., 2010). Recently, Pelic et al. (2019) determined a negative correlation between lipid level
136 and water content of sturgeon meat.

137 Total volatile basic amines (TVB-N) is one of the most widely used parameters of fish
138 quality. This general term includes the measurement of trimethylamine produced by spoilage
139 bacteria, dimethylamine produced by autolytic enzymes, and other volatile basic nitrogenous

140 compounds associated with seafood spoilage. Although the determination of TVB-N is
141 simple, it only reflects the later stage of advanced spoilage that is generally considered
142 insignificant for the measurements of spoilage during the first days of chilled storage. A level
143 of 25 mg TVB-N/ 100 g of fish is considered to be the upper limit above which the seafood
144 product is considered spoilt and unfit for human consumption (Boughattas, Vilkova,
145 Kondratenko, & Karoui, 2020). Meanwhile, there are differences in the published data
146 disclosing the amount of TVB-N in fish tissue which seems to vary among fish species.
147 According to Chen et al. (2020) and Gharibzahedi & Mohammadnabi (2017), the TVB-N
148 values show the tendency to increase gradually during the storage of Russian sturgeon (*A.*
149 *gueldenstaedtii*) and Beluga sturgeon (*H. huso*) and attained limit for human consumption on
150 days 12 and 7, respectively. Other authors report that the permissible limit of TVB-N for
151 human consumption is up to 8-9 days of storage at 4 °C for both Beluga and Russian sturgeon
152 (Bahram et al., 2016; Boughattas et al., 2020).

153 The trimethylamine nitrogen (TMA-N), which is a volatile amine, might be considered
154 as another parameter used to determine the quality of sturgeon. The TMA-N is generally
155 produced following the reduction of trimethylamine oxide (TMAO) by bacterial flora in fish
156 (Masniyom, 2011). According to Ünal Şengör, Alakavuk, Tosun, & Ulusoy (2010), raw
157 Beluga sturgeon showed 0.55 mg/100 g TMA-N values, while hot-smoked Beluga samples
158 exhibited higher TMA-N level (2.63 mg/100 g). However, the TMA-N values did not exceed
159 the upper limit of acceptability [proposed by Khodanazary \(2019\) for fish and fish products](#)
160 [that is fixed to 5 mg / 100g.](#)

161 Lipid measurements are recognised by many authors to be the most commonly used
162 indicator for measuring the biochemical assessment of sturgeon quality (**Table 1**). The
163 sturgeon family belongs to the fatty fish and the fat content varied according to the species,
164 season, and feeding (Wedekind, 2002). The lipid content of different cultured sturgeon

165 species varied from 5 to 10% (Pelic et al., 2019). The highly unsaturated fatty acid found in
166 fish lipid is very sensitive to oxidation. These compounds can be detected by chemical
167 methods that are usually used to determine the oxidation level. The **peroxide value (PV)**
168 measurements showed an increase during sturgeon storage at 4 °C regardless of the fish
169 species. For Beluga **fillets**, the initial PV value is generally very low reaching its maximum
170 (3.5 meq O₂/Kg **fat**) on day 8 of storage (Bahram et al., 2016). Sarah, Hadiseh,
171 Gholamhossein, & Bahareh (2010) pointed out in their investigations that the maximum PV
172 was noted on day 8 of storage (8.06 meq oxygen/ kg lipid) for Persian sturgeon (*A. persicus*)
173 and depended on the treatment conditions.

174 In the later stage of oxidation, the secondary oxidation products are usually present in
175 the fish and fish products. They contain aldehydes, ketones, short-chain fatty acids, and other
176 components, many of them possess a very unpleasant smell and taste, rancid and associated
177 with oxidised fish lipids. Some of the secondary oxidation products react with thiobarbituric
178 acid to form a pink-coloured product. In this context, the TBARS values were reported to be
179 the most used indicator for the assessment of the quality of Beluga during storage. A
180 significant increase (P<0.05) of TBARS values was observed on day 10 of storage since it
181 attained 2.12-3.02 mg MDA/kg of fish, regardless of the storage conditions: refrigerated
182 storage at 4 °C with/without jujube gum containing nettle essential oil (Gharibzahedi &
183 Mohammadnabi, 2017). In the same context, Rostamzad et al., (2011) noted that TBARS
184 values remained quite low for Persian sturgeon fillets kept in freezing storage for 3 months
185 since their values do not exceed 2 mg MDA/kg of fish.

186 Russian sturgeon (*A. gueldenstaedtii*) and Beluga (*H. huso*) presented pH values of
187 6.32 and 6.58, respectively (Bahram et al., 2016; Yue wen Chen et al., 2020). A slight
188 increase of pH values was observed **during storage (Table 1)** since it reached values of 7.47
189 (Bester, Asow-Hybrid, Sibster). This **increase** is due to the decomposition of glycogen (Song

190 et al., 2011), and the production of volatile basic components by microbial proteolysis
191 (Goulas & Kontominas, 2005; Ocaño-Higuera et al., 2009). It should be kept in mind that the
192 pH value is a function of the post-mortem evolution of the flesh, which is influenced by diet,
193 season, and stress during the catch, [initial state of microbial contamination \(viral, bacterial,](#)
194 [mycoses, protozooses, helminthiases\)](#). This pathophysiological state depends of the individual
195 [specimen and can occur as a result of human activity](#). The pH increase is dependent of the
196 [storage temperatures of fish](#). Indeed, the higher the storage temperature, the faster is the
197 [increase in pH values](#) (Abbas, Mohamed, Jamilah, & Ebrahimian, 2008).

198 Water holding capacity (WHC) and cook loss (CL) of fish muscle may be used as
199 indicators of fish quality. The WHC of muscle food is an important technological parameter
200 that depends on heat-induced structural changes, sarcomere length, pH, ionic strength (Zell,
201 Lyng, Cronin, & Morgan, 2010). The WHC in meat tissues is strongly related to myofibril
202 proteins. The increase of expressible moisture is a sign of the reduction of the WHC.
203 Wedekind (2002) noted that the approximate level of CL and WHC for sturgeon hybrids
204 ranged between 26-31% and 62-69%, respectively. The authors noted that the WHC of
205 muscle was fairly stable in Beluga fish. Moreover, the WHC tends to decrease gradually with
206 the increase of the frozen storage time since it passed from 70% to 62% after 8 months of
207 frozen storage. This could be explained by the fact that during the freezing-thawing process,
208 the denaturation of protein could be occurred causing the loss of WHC (Hosseini et al., 2010).
209 A gradual increase of CL values was noted during storage at 4 °C of Beluga sturgeon (*H.*
210 *huso*) since it passed from 26.51% to 40.32% during 15 days of storage (Gharibzahedi &
211 Mohammadnabi, 2017).

212

213 **2.2. Texture measurements**

214 The texture of fish muscle is an important feature of both raw and cooked sturgeon
215 quality that depends on several parameters such as hardness, cohesiveness, springiness,
216 chewiness, resilience, and adhesiveness, as well as the internal cross-linking of connective
217 tissues. The change in texture of fish depends on internal factors such as chemical
218 decompositions (lipid oxidation) and degradation of muscle proteins and some external
219 factors, such as sample handling (salting and smoking) and cold storage conditions (freezing
220 and thawing). Texture can be determined by instrumental technique that performs an accurate
221 subjective assessment. The most used one is named texture profile analysis (TPA) which
222 evaluates fish texture based on compression of a sturgeon sample with the TA. XTPlus texture
223 analyser. The softening processes of sturgeon muscles happen either as a result of frozen/cold
224 storage, or autolytic degradation (Cheng, Sun, Han, & Zeng, 2014). Boughattas et al. (2020)
225 noted that texture parameters (hardness, adhesiveness, gumminess, chewiness) showed a
226 significant difference ($P < 0.05$) between fresh sturgeon samples aged 2 days from those aged
227 8 days or more. However, springiness and cohesiveness parameters remained relatively stable
228 during storage. In another study, Gharibzahedi & Mohammadnabi, (2017) indicated that the
229 hardness decreased during Beluga sturgeon on day 7 of storage at 4°C. Indeed, the fresh
230 samples and those aged 7 days presented hardness values of 17.32 and 11.08, respectively.
231 The external quality criteria such as changes in springiness was determined for Russian
232 Sturgeon fillets kept in vacuum packaging and treated with different salt concentrations (Chen
233 et al., 2020). The level of springiness was low for the samples treated with 2% salt solution
234 and increased with salt concentration. However, the highest parameter of springiness was
235 observed for control (no treatment) and those kept in vacuum packaging on day 0. In general,
236 during the post-mortem condition, the muscle of fish get soft.

237

238 2.3. Colorimetric measurement

239 Fish tissue gradually turns to pale during storage; this change depends on different
240 storage conditions, as a result of which some pigments are destroyed. There are various
241 methods to measure the colour of sturgeon such as machine vision system that produces
242 significant information about colour attributes. Electronic measurement devices define colour
243 in terms of a^* (red/green), b^* (yellow/blue) and L^* (black/white) values. As far as the L^*
244 value is concerned, no significant difference ($P > 0.05$) was observed between sturgeon
245 samples kept at 4 °C for up to 12 days. The obtained results indicate that L^* parameter is not
246 affected through the storage time, while b^* value increased gradually during the storage time
247 of Russian sturgeon since it passed from 5.20 to 9.95 on days 2 and 9, respectively
248 (Boughattas et al., 2020). However, the lightness (L^* value) increased ($P < 0.05$) during 15
249 days of cold storage of Beluga sturgeon. This increase might be related to the degradation of
250 myofibrillar proteins and disorganization of the myofibrils (Gharibzahedi & Mohammadnabi,
251 2017). The colour of three cultured sturgeon hybrids determined by Wedekind (2002) was
252 found to be dependent of the measurement part inside the same fillet. Indeed, a more whitish
253 colour in the cranial, a more reddish in the medial area and yellowish flesh in the caudal of the
254 fillet was observed. The technological process induced changes in the colour of sturgeon flesh
255 since Ünal Şengör et al. (2010) observed a higher value of a^* for smoked sturgeon flesh
256 (6.75) in comparison to raw sturgeon meat (0.63).

257

258 **2.4. Sensory analysis**

259 The appearance, odour, taste, colour, and texture are evaluated using the human
260 senses. The sensory measurements that apply to sturgeon quality control can be divided into
261 two main groups: tests that determine the differences between sturgeon samples (triangle test,
262 ranking test) and tests that permit to distinguish the gradual alteration of sturgeon samples and
263 they are relatively quick. The diversity in sensory response is related to the difference in

264 sensitivity of receptors to chemical stimuli. For example, the rancid flavour is not perceptible
265 by everyone.

266 Gharibzahedi & Mohammadnabi (2017) studied the quality of Beluga sturgeon with
267 different analytical techniques including sensory one. The authors showed in their study that
268 the panellists' scores diminished significantly ($P < 0.05$) with the increase of storage time that
269 passed from 5 to 3.16, in agreement with the findings of Bahram et al. (2016) who noticed
270 that sensory properties (colour, odour, texture) of Beluga sturgeon decreased with the
271 increase of storage time. The sturgeon samples reached a limit score on days 8 since Beluga
272 sturgeon fillets revealed a slimy rancid odour with discoloration (**Table 2**). The results of
273 sensory evaluation of Persian sturgeon (*A. persicus*) during 8 days of storage at 4°C showed
274 the emergence of rancid odour within the increased storage time. Some differences were
275 depicted by Sarah et al. (2010) on days 6 for colour, odour, and flavour of Persian sturgeon
276 stored at 4 °C. A sharp increase of off-flavour was detectable in control samples and dipping
277 solution of 1% onion juice. By the end of storage time, samples dipped in solution with 1% of
278 onion juice and 1% of green tea extract as well as the control ones showed the lowest flavour
279 scores, while those treated with the upper concentrations of plant extracts (2.5-5 % of onion
280 juice and 2.5-5 % of green tea extract) indicated the highest flavour scores. Recently, Chen et
281 al. (2020) explored the impact of vacuum packaging on the shelf-life of the Russian sturgeon
282 and depicted that the shelf-life of the control group was 7 days, while those treated with salt
283 and kept in vacuum packaging were fixed to 16 days.

284

285 **2.5. Microbiological analysis**

286 Microbiological analysis is used to assess the availability of microorganisms in the
287 sturgeon fish. Traditional bacteriological examinations are laborious, time-consuming,
288 expensive, and required skilled operators. Consequently, the most frequently used

289 measurements include the determination of total viable counts (TVC) and psychrotrophic
290 counts (PTC) (**Table 3**). A wide variety of microorganisms was observed during the storage
291 of Beluga sturgeon fillets preserved with nettle essential oil. A gradual increase in the amount
292 of PTC was scored during 15 days of storage at 4 °C. The treated samples presented a low
293 amount compared to the control one (Gharibzahedi & Mohammadnabi, 2017). Based on the
294 level of TVC and PTC, the maximum acceptable level of the raw Beluga sturgeon was fixed
295 to 7 days of storage. However, [based on microbiological analysis](#), samples showed a low level
296 of microorganisms involved in [extracts and solutions of plants during the entire storage](#)
297 [period](#). The obtained results are in agreement with the findings of Bahram et al., (2016) who
298 stated that the addition of essential oil into whey protein coating for Beluga sturgeon [samples](#)
299 strongly inhibited the growth of TVC and PTC up to 20 days. Recently, Yue-wen Chen et al.
300 (2020) applied DNA analysis for the amplification of the microflora of the Russian sturgeon
301 (*A. gueldenstaedtii*). The composition of microbiota was obtained by using the PCR method.
302 The results showed a relative abundance of 20 top genera (*Chryseobacterium*, *Acinetobacter*,
303 *Serratia*, *Pseudomonas*, *Salmonella*) within different periods of cold sturgeon storage. The
304 bacterial diversity decreased with storage time, while their number increased. The
305 combination of salting and vacuum packaging was found to delay efficiently the growth of
306 *Pseudomonas* which is the predominant microbiota found in the Russian sturgeon fillets (Yue
307 wen Chen et al., 2020).

308

309 **2.6. Chromatographic analysis**

310 Chromatographic techniques used for the determination of sturgeon quality are carried
311 out by using liquid and/or gas chromatography. These methods are used to determine the
312 amino acid and fatty acid [composition](#) of sturgeon fish. The separation of components is
313 performed with the help of chromatographic techniques in which every component is

314 processed at a different rate in a two-phase system (Jalali-Heravi & Vosough, 2004; Tucker,
315 & Pigott, 2003). Hosseini et al., (2010) pointed out that frozen storage mode negatively
316 affected the fatty acid composition of Beluga sturgeon (*H. huso*). Fish muscles aged 12
317 months presented higher concentrations of total saturated fatty acids compared to fresh ones.
318 The monounsaturated fatty acids levels of the fillets were similar during the 12 months of
319 storage ($P > 0.05$). The n-3/n-6 ratio of Beluga sturgeon samples presented the highest level
320 on day 0 and the lowest one on month 12 ($P < 0.05$). The eicosapentaenoic acid and
321 docosahexaenoic acid levels decreased significantly from day 0 to month 12 ($P < 0.05$). Kaya,
322 Turan, & Erdem (2008) depicted that hot temperature and wood smoke affected negatively
323 the fatty acid composition, especially EPA, DHA, and some essential amino acids in the
324 smoking process (Table 4). In a different approach, Vaccaro et al. (2005) indicated that in
325 sturgeon hybrid, the levels of polyunsaturated fatty acids (PUFAs) is very high (34.7 %) as
326 well as the monounsaturated fatty acids (37.9%). These hybrid species (*Acipenser naccarii* ×
327 *A. baerii*) contained high contents of EPA (C20:5n3) and DHA (C22:6n3). Nieminen,
328 Westenius, Halonen, & Mustonen (2014) found that the nutritional value of the farmed
329 Siberian sturgeon (*Acipenser baerii*) in regard to their fatty acid composition, is quite similar
330 to other sturgeon species. The Siberian sturgeon was found to accumulate highly unsaturated
331 fatty acids selectively in particular tissues, using either the incorporation of these fatty acids
332 from dietary sources or the desaturation and elongation of PUFA in its tissues.

333

334 2.7. Polymerase chain reaction

335 The authentication of fish species is necessary to be able to assure consumers of
336 accurate labelling and maintain confidence in their quality and safety. DNA-analysis by
337 polymerase chain reaction (PCR) method was used to identify fish species (Hisar, Erdogan,
338 Aksakal, & Hisar, 2006). This technique contributed to better, more reliable, regulation and

339 control of global trade of high value sturgeon products as well as to their management and
340 conservation. The DNA-markers, as compared with the biochemical methods, possess several
341 advantages. Indeed, to use of DNA fragments as markers solved a number of tasks related to
342 the identification of the sturgeon species (Kuz'min & Kuz'mina, 2014). In the study of
343 Albayrak, Şengör, & Yörük (2013) PCR analysis and DNA sequencing were used on Beluga
344 sturgeon, Russian sturgeon and Sevruga the gonadotropin-releasing hormone (GnRH),
345 insulin-like growth factor receptor I (ILGFRI), and androgen receptor (AR) genes coding and
346 compared to reference Beluga sturgeon genome retrieved from database. The most similarity
347 was calculated for AR gene and GnRH gene ranged from 48.5- 95.71% and 23.48-83.91%,
348 respectively, between the three species. A sample seized from poachers was found to be more
349 like to Russian sturgeon samples (**Table 5**). These findings indicated a high level of diversity
350 among and even within the same family. The authors depicted that the three genes could be
351 useful for the identification of sturgeon species. The genetic polymorphism of ten sturgeon
352 species (Russian sturgeon, Siberian sturgeon, Amur sturgeon, Sakhalin sturgeon, Persian
353 sturgeon, Ship sturgeon, Sterlet, Sevruga sturgeon, Beluga sturgeon, and Kaluga sturgeon)
354 was examined at five microsatellite loci (Afug41, Afug51, An20, AoxD161, AoxD165) in the
355 investigation of Barmintseva & Mugue (2013). Alleles specific to different species was
356 identified.

357 Five microsatellite markers were analysed and their alleles were sequenced for the
358 Adriatic sturgeon (*Acipenser naccarii*), the Atlantic sturgeon (*Acipenser oxyrinchus*) and the
359 European sturgeon (*Acipenser sturio*) by Chassaing, Hänni, & Berrebi (2011). Fixed
360 mutations in the flanking regions or in the core repeat of microsatellites provided a clear
361 distinction between the sturgeon species. These nuclear markers combined with mitochondrial
362 markers was found to be used to identify hybridisation among the three species. Boscari et al.
363 (2017) developed the first genetic nuclear marker for the identification of the Beluga

364 sturgeon (*Huso huso*). The interspecific variability at the second predicted intron of the RPS6
365 nuclear ribosomal gene was found to be a suitable marker for the identification of the Beluga
366 sturgeon. The diagnostic nuclear marker characterised allowed the identification of pure
367 Beluga and its first generation hybrids. In a similar approach, nuclear DNA markers was
368 applied for the identification of Beluga sturgeon and Sterlet, and their Bester sturgeon hybrid
369 (Havelka, Fujimoto, Hagihara, Adachi, & Arai, 2017). The authors employed double-digest
370 restriction-associated DNA (ddRAD) sequencing to identify species-specific nucleotide
371 variants, which were served as specific binding sites for diagnostic primers. The primers
372 allowed the identification of Beluga sturgeon and Sterlet as well as their discrimination from
373 other sturgeon species. The species-specific primers allowed the identification of Bester
374 sturgeon (*H. huso* × *A. ruthenus*). Another two sister species of Atlantic sturgeon and
375 European sturgeon were found to be difficult to distinguish solely by morphological traits
376 (Panagiotopoulou, Baca, Popovic, Weglenski, & Stankovic, 2014). A simple PCR-restriction
377 fragment length polymorphism based test was developed, enabling easy identification of
378 specimens belonging to both species. The application of two restriction enzymes (BtsI and
379 BsrDI) allowed a clear discrimination of 132 specimens of European sturgeon and Atlantic
380 sturgeon (**Table 5**).

381

382 **2.8. Morphological methods**

383 Morphological analysis of sturgeons have a very long history and have been carried
384 out to identify sturgeon species (Ludwig, 2008). However, authentication of sturgeon species
385 based on morphological traits are scarce in the literature. Descriptive morphology allows to
386 distinguish sturgeon by external features. Sturgeons as a like most other fish, have a body
387 comprised of three regions: head, body, and fins. Each of these regions is characterised by a
388 number of specialised adaptations – some typical of all sturgeons while others are species

389 specific. These sometimes subtle morphological variations are used to identify different
390 sturgeon species or, in some cases, to identify different populations within a species. The
391 main diagnostic characters of these family *Acipenserinae* including the genera *Acipenser* and
392 *Huso* are the shape of the mouth and differences in gill-membrane attachment (Vasil'eva,
393 2009). The rostrum used in ecomorphological measurements as a criteria relating to flow
394 and/or feeding methods. Spiracle is open above the gills in *Huso* and *Acipenser* and absent in
395 *Scaphirhynchus* and *Pseudoscaphirhynchus*. Thick lips surround the mouth and the upper lip
396 is interrupted in all species except Ship sturgeon (*A. nudiiventris*). The sturgeon mouth is
397 unique in lacking a jaw bone, and the mouth is capable of extensive downward and outward
398 projection. Mouth dimensions in sturgeon are often used in ecomorphological analyses. In
399 proportion to body size, the smallest mouth occurs in the Atlantic sturgeon (*Acipenser*
400 *transmontanus*) that feeds primarily on bryozoans and small invertebrates, in contrast, white
401 sturgeon (*Acipenser transmontanus*) has the largest mouth (Vecsei & Peterson, 2004).

402

403 **3. Untargeted methods used for the determination of the quality of sturgeon**

404 Untargeted tools such as spectroscopic techniques have the advantage to be fast, low-
405 cost, and non-destructive to a large extent. The techniques have demonstrated their ability to
406 determine the quality and authenticity of fish (Hassoun & Karoui, 2016; 2017; Karoui and
407 Hassoun, 2017), dairy products (Blecker et al., 2012; Karoui et al., 2006; karoui et al., 2011),
408 egg (Karoui et al., 2007; 2008), and so on.

409

410 **3.1. Fluorescence spectroscopy**

411 Although the interest of this technique, only very few studies have explored the
412 potential of fluorescence spectroscopy to determine the quality of sturgeon. Sturgeon fish
413 contains several fluorophores, including aromatic amino acids and nucleic acids (AAA+NA),

414 tryptophan, vitamins A, riboflavin, nicotinamide adenine dinucleotide (NADH), and many
415 other compounds that can be detected in minimal concentrations. In this context, Boughattas
416 et al., (2020) monitored the freshness level of Russian sturgeon (*A. gueldenstaedtii*) during
417 storage at 4 °C. The emission spectra of riboflavin (405-650 nm) and NADH (360-600 nm) of
418 sturgeon slices were acquired after excitation set at 380 and 340 nm, respectively. The
419 maximum fluorescence intensity of riboflavin spectra is observed within ~ 460-490 nm that
420 changed with the storage time. The observed peak was ascribed to different stable fluorescent
421 oxidation products, which include the products formed by the reaction of unsaturated
422 aldehydes with proteins and/or the photo breakdown of riboflavin products. The NADH
423 spectra indicated several peaks located ~ 380, 460, and 485 nm. The authors concluded that
424 the shape of NADH spectra was correlated with the freshness level of sturgeon samples. In
425 fact, a decrease (~ 460 and 485 nm) and an increase (~ 380 nm) in the fluorescence intensity
426 of sturgeon samples were noted during storage. A sharp decrease of the fluorescence intensity
427 ~460 and 485 nm was ascribed by the authors to the NADH oxidation occurring during the
428 sturgeon storage leading to the transformation of NADH to NAD⁺, and thus modifying the
429 shape of the NADH fluorescence spectra. One of the main conclusions of their study was that
430 NADH spectra could be used as fingerprints allowing to identify the level of sturgeon
431 freshness. This result was confirmed following the application of common components and
432 specific weights analysis to the riboflavin and NADH data tables since four groups were
433 identified: 2 days; 5, 6 and 7 days; 8 and 9 days and 12 days. Another fluorophore namely
434 AAA+NA was [used for monitoring Russian sturgeon](#) during cold storage. The AAA+NA
435 emission spectra were recorded between 290 and 400 nm after excitation set at 250 nm
436 (Boughattas et al., 2020). The authors observed that the maximum emission was observed ~
437 375 nm and the shape of the spectra varied as a function of the storage time. The highest
438 fluorescence intensity was noted for sturgeon samples aged 12 days, and the lowest one for

439 those aged 2 days. This difference might be explained by the difference in the protein-protein,
440 protein-water and/or protein-lipid interactions. Considering the vitamin A spectra, the shape
441 of the spectra showed a maximum located ~ 296 nm for sturgeon aged 2 days and 310 for the
442 aged ones. This red shift was attributed by the authors to the: i) physical states of the
443 triglycerides in the fat globules; and/or ii) interactions of the fat globule membrane with
444 protein network and/or lipid- lipid interactions.

445 In another way, fish authentication is important for correct product labelling as
446 promoted by recent regulatory actions (Ottavian, Fasolato, Facco, & Barolo, 2013). In this
447 context, the fluorescence spectroscopy was used to determine the impact of freeze-thaw
448 cycles (1, 2, 3, and 4) on the quality of Russian sturgeon (*Acipenser gueldenstaedtii*) kept in a
449 partial vacuum and a total vacuum (Vilkova, Chèné, Kondratenko, & Karoui, 2021). The
450 NADH emission spectra scanned on sturgeon samples subjected to different freeze-thaw
451 cycles illustrated two peaks located ~ 388 and ~ 470 nm. The highest fluorescence intensity at
452 388 nm was observed for fresh samples, while the highest fluorescence intensity at 470 nm
453 was noted for those subjected to 4 freeze-thaw cycles kept in a partial vacuum (Vilkova,
454 Chèné, Kondratenko, & Karoui, 2021). The vitamin A spectra demonstrated the highest
455 fluorescence intensity ~ 296 nm for fresh samples and those submitted to 1 freeze-thaw cycle
456 kept in partial vacuum and total vacuum. Moreover, a red shift of the maximum excitation
457 spectra of vitamin A was observed (i.e., from 296 nm for samples subjected to 1 freeze-thaw
458 cycle kept in a partial vacuum and total vacuum to 306 nm for those submitted to 2, 3, and 4
459 freeze-thaw cycles). The riboflavin spectra scanned on sturgeon samples showed two peaks ~
460 468 nm and ~ 500 nm. Changes ~ 500 nm that were related to riboflavin degradation and/or
461 interaction with other compounds such as proteins. The spectral range in the 405 – 480 nm
462 could be used to determine the degree of fish oxidation; among them, the products formed by
463 the reaction of unsaturated aldehydes with proteins (Karoui et al., 2017). To extract

464 information from the data sets, the authors applied the PCA separately to each intrinsic probe
465 and the best results were obtained with the vitamin A and riboflavin spectra (Vilkova, Chèné,
466 Kondratenko, & Karoui, 2021). Indeed, a clear differentiation between fresh sturgeon samples
467 and those subjected to 1 freeze-thaw cycle from the others was observed. In addition, a
468 separation between samples subjected to 2, 3, and 4 freeze-thaw cycles was also noted.

469

470 **3.2. Mid infrared spectroscopy**

471 Mid-infrared (MIR) spectroscopy is an established method used for protein and
472 peptide structural characterisation. In this context, the technique was used for the
473 characterisation of sturgeon by Jiang Zheng, Rue-Zhang Guan (2008). The results showed
474 that sturgeon samples exhibited absorption at 1376 ($-\text{COO}^-$), 1344 ($-\text{COOH}$, $-\text{C-O}$), 1310 ($-\text{COOH}$,
475 $-\text{C-O}$), 1157 (C-O-C, C-O-H, C-O), 883 (C-H), and 856 (OSO_3 , C-O-S) cm^{-1} . The
476 chondroitin sulfates of sturgeon contain 4, 6-disulfated chondroitin sulfates.

477 Recently, Noman, Ali, AL-Bukhaiti, Mahdi, & Xia (2020) used MIR spectroscopy to
478 determine the quality of Chinese sturgeon (*Acipenser sinensis*). The spectra of the lyophilized
479 protein hydrolysate samples were scanned in the 4.000 - 500 cm^{-1} . The authors determined
480 the absorbance in the Amide regions with protein hydrolysate samples which appeared at
481 1626 cm^{-1} (Amide I), 1511 cm^{-1} (Amide II), and 1388 cm^{-1} (Amide III) for papain
482 hydrolysate sample, whereas the absorbance regions of alcalase hydrolysate samples occur at
483 1626 cm^{-1} (Amide I), 1518 cm^{-1} (Amide II), and 1388 cm^{-1} (Amide III). The liberation of
484 peptides and free amino acids of complex protein-rich substrates depends on both the raw
485 sturgeon quality and the enzymes used.

486 In a different approach, the potential of MIR to differentiate fresh Russian sturgeon
487 samples from those subjected to 1, 2, 3, 4 freeze-thaw cycles was determined (Vilkova,
488 Chèné, Kondratenko, & Karoui, 2021). Most of the spectral information was located in three

489 wavenumber regions: 3000–2800 cm^{-1} , 1700–1500 cm^{-1} , and 1500–900
490 cm^{-1} spectral region showed absorbance bands ~ 1083, 1118; 1158, 1239, 1314, 1371, 1396,
491 1418, and 1458 cm^{-1} . Fresh sturgeon samples exhibited two peaks ~ 1371 and 1418 cm^{-1}
492 which disappeared for sturgeon samples subjected to freeze-thaw cycles. The peak located
493 ~1418 cm^{-1} could be attributed to the combination of O–H bending of the C–O–H group and
494 C–H bending of alkenes. The 1000-1200 cm^{-1} spectral region differentiated clearly between
495 fresh samples and those subjected to 4 freeze-thaw cycles kept in partial and total vacuum.
496 The region located between 1700-1500 cm^{-1} showed two peaks (1547 and 1637 cm^{-1}). The
497 Amide I band (1600-1700 cm^{-1}) is recognised as the most useful spectral region used to
498 determinate the secondary structure of proteins (Pinilla, Brandelli, López-Caballero, Montero,
499 & Gómez-Guillén, 2020). During the freeze-thaw cycle of sturgeon samples, protein is
500 subjected to the oxidation leading to some variation of α -helix, β -sheet, β -turn, and random
501 coil levels that have an absorption band in the 1650–1660 cm^{-1} , 1600–1640 cm^{-1} , 1660-1690
502 cm^{-1} and 1640–1650 cm^{-1} spectral regions, respectively. The percentage of the secondary
503 structure indicated a decrease in α -helix, β -sheet, and random coil, and an increase in β -turn.
504 Indeed, an increase in β -turn (from 35.40% for fresh samples to 39.70 % and 37.06% for
505 samples subjected to 4 freeze-thaw cycles kept in a partial vacuum and a total vacuum,
506 respectively) and a decrease in α -helix (from 10.70% for fresh samples to 9.30 % and 9.23%
507 for samples subjected to 4 freeze-thaw cycles kept in a partial vacuum and a total vacuum,
508 respectively) were noted (Vilkova, Chèné, Kondratenko, & Karoui, 2021).

509 The region located between 3000 and 2800 cm^{-1} corresponds to C-H bond of methyl
510 and methylene groups of fatty acids. This spectral region presented two bands ~ 2852 and
511 2925 cm^{-1} for fresh samples that disappeared during freeze-thaw cycles. Consequently, the
512 potential use of MIR spectroscopy to rapidly identify commercial frauds in the fish sector and

513 to solve some authentication was demonstrated (Vilkova, Chèné, Kondratenko, & Karoui,
514 2021).

515

516 **4. Conclusion and future directions**

517 Considerable interest is paid to sturgeon quality and authenticity due not only to its
518 nutritive quality but also to the crises and scandals in the food industry, which have seriously
519 undermined consumer confidence and grown the need for rapid analytical techniques to
520 determine sturgeon quality and authenticity. This great need for quality assurance requires
521 appropriate analytical tools for the determination of the quality of sturgeon samples. In this
522 context, targeted methods such as -chemical, sensory, microbiological, chromatography
523 techniques, [morphological and PCR](#), considered as the official methods, were used to assess
524 the quality and authenticity of the sturgeon. However, most of these methods are time
525 consuming, destructive, and demand trained personnel. This requires the development of fast,
526 environment-friendly and simple analytical techniques such as the spectroscopic ones that are
527 relatively of low-cost and can be applied in both fundamental researches and the factory as
528 on-line sensors for the determination of sturgeon quality. In this review, recent advances in
529 sturgeon quality evaluation and authenticity by front-face fluorescence, and mid- infrared
530 spectroscopies are presented and discussed. From the results presented in the present review,
531 it could be mentioned that spectroscopic techniques coupled with chemometric tools have the
532 potential to determine the quality and authenticity of sturgeon. Up-to-date, the use of these
533 techniques alone and their combination of these spectroscopic techniques for the evaluation of
534 the quality of sturgeon is scarce. Thus, the combination of untargeted techniques with targeted
535 ones would make them more convenient and effective for the analysis of sturgeon allowing
536 them to be used as rapid screening tools for determining rapidly the quality and authenticity of
537 sturgeon.

538

539 **Conflicts of interest:**

540 The authors have declared that there is no conflict of interest.

541

542 **Acknowledgments:**

543 This work has been carried out in the framework of ALIBIOTECH project, which is financed
544 by the European Union, the French State and the French Region of Hauts-de-France. Mrs. D.
545 Vilkova is grateful to Vernadsky program for its financial support of her Ph.D. during her stay
546 at Artois University.

547 **References**

- 548 Abbas, K. A., Mohamed, A., Jamilah, B., & Ebrahimian, M. (2008). A review on correlations
549 between fish freshness and pH during cold storage. *American Journal of Biochemistry*
550 *and Biotechnology*, 4(4), 416–421. <https://doi.org/10.3844/ajbbsp.2008.416.421>
- 551 Al-Reza, S., Karmaker, S., Hasan, M., Roy, S., Hoque, R., & Rahman, N. (2015). Effect of
552 traditional fish processing methods on the proximate and microbiological characteristics
553 of laubuka dadiburjori during storage at room temperature. *Journal of Fisheries and*
554 *Aquatic Science*, 10(4), 232–243. <https://doi.org/10.3923/jfas.2015.232.243>
- 555 Albayrak, G., Şengör, G. F. Ü., & Yörük, E. (2013). Characterization of GnRH, ILGFRI and
556 AR Genes in Sturgeon's Genomics. *The Israeli Journal of Aquaculture*, (January), 9
557 pages.
- 558 Bahram, S., Rezaie, M., Soltani, M., Kamali, A., Abdollahi, M., Khezri Ahmadabad, M., &
559 Nemati, M. (2016). Effect of whey Protein Concentrate Coating Cinamon Oil on Quality
560 and Shelf Life of Refrigerated Beluga Sturgeon (Huso huso). *Journal of Food Quality*,
561 39(6), 743–749. <https://doi.org/10.1111/jfq.12227>
- 562 Barmintseva, A. E., & Muge, N. S. (2013). The use of microsatellite loci for identification of
563 sturgeon species (Acipenseridae) and hybrid forms. *Russian Journal of Genetics*, 49(9),
564 950–961. <https://doi.org/10.1134/S1022795413090032>
- 565 Blecker, C., Jiwan, J-M.H., & Karoui, R. (2012). Effect of heat treatment of rennet skim
566 milk induced coagulation on the rheological properties and molecular structure
567 determined by synchronous fluorescence spectroscopy and turbiscan. *Food Chemistry*,
568 35, 1809-1817.
- 569 Boscari, E., Vitulo, N., Ludwig, A., Caruso, C., Muge, N. S., Suci, R., ... Congiu, L.
570 (2017). Fast genetic identification of the Beluga sturgeon and its sought-after caviar to
571 stem illegal trade. *Food Control*, 75, 145–152.
572 <https://doi.org/10.1016/j.foodcont.2016.11.039>
- 573 Boughattas, F., Vilko, D., Kondratenko, E., & Karoui, R. (2020). Targeted and untargeted
574 techniques coupled with chemometric tools for the evaluation of sturgeon (Acipenser
575 gueldenstaedtii) freshness during storage at 4 °C. *Food Chemistry*, 312(December 2019),
576 126000. <https://doi.org/10.1016/j.foodchem.2019.126000>
- 577 Bronzi, P., & Rosenthal, H. (2014). Present and future sturgeon and caviar production and
578 marketing: A global overview. *Journal of Applied Ichthyology*, 30(6), 1536–1546.
579 <https://doi.org/10.1111/jai.12628>
- 580 Bronzi, Paolo, Chebanov, M., Michaels, J. T., Wei, Q., Rosenthal, H., & Gessner, J. (2019).
581 Sturgeon meat and caviar production: Global update 2017. *Journal of Applied*
582 *Ichthyology*, 35(1), 257–266. <https://doi.org/10.1111/jai.13870>
- 583 Chassaing, O., Hänni, C., & Berrebi, P. (2011). Distinguishing species of European sturgeons
584 Acipenser spp. using microsatellite allele sequences. *Journal of Fish Biology*, 78(1),
585 208–226. <https://doi.org/10.1111/j.1095-8649.2010.02852.x>
- 586 Chen, Yue-wen, Cai, W., Shi, Y., Dong, X., Bai, F., & Shen, S. (2020). Effects of different
587 salt concentrations and vacuum packaging on the shelf- stability of Russian sturgeon (
588 Acipenser gueldenstaedti) stored at 4 ° C. *Food Control*, 109(September 2019), 106865.
589 <https://doi.org/10.1016/j.foodcont.2019.106865>

- 590 Chen, Yue wen, Cai, W. qiang, Shi, Y. gang, Dong, X. ping, Bai, F., Shen, S. ke, ... Zhu, X.
591 (2020). Effects of different salt concentrations and vacuum packaging on the shelf-
592 stability of Russian sturgeon (*Acipenser gueldenstaedti*) stored at 4 °C. *Food Control*,
593 109. <https://doi.org/10.1016/j.foodcont.2019.106865>
- 594 Cheng, J. H., Sun, D. W., Han, Z., & Zeng, X. A. (2014). Texture and structure measurements
595 and analyses for evaluation of fish and fillet freshness quality: A review. *Comprehensive*
596 *Reviews in Food Science and Food Safety*, 13(1), 52–61. [https://doi.org/10.1111/1541-](https://doi.org/10.1111/1541-4337.12043)
597 4337.12043
- 598 Erickson, D. L., Lauck, L., Chakrabarty, P., Doukakis, P., & Pikitch, E. K. (2005). Status,
599 trends and management of sturgeon and paddlefish fisheries. *Fish and Fisheries*, 6(3),
600 233–265. <https://doi.org/10.1111/j.1467-2979.2005.00190.x>
- 601 García, M. R., Cabo, M. L., Herrera, J. R., Ramilo-Fernández, G., Alonso, A. A., & Balsa-
602 Canto, E. (2017). Smart sensor to predict retail fresh fish quality under ice storage.
603 *Journal of Food Engineering*, 197, 87–97.
604 <https://doi.org/10.1016/j.jfoodeng.2016.11.006>
- 605 Ghaly A.E., Dave D., S. B. and M. S. B. (2010). Fish Spoilage Mechanisms and Preservation
606 Techniques : Review Department of Process Engineering and Applied Science ,
607 Dalhousie University Halifax , Nova Scotia , Canada. *American Journal of Applied*
608 *Sciences*, 7(7), 859–877. <https://doi.org/10.3844/ajassp.2010.859.877>
- 609 Gharibzahedi, S. M. T., & Mohammadnabi, S. (2017). Effect of novel bioactive edible
610 coatings based on jujube gum and nettle oil-loaded nanoemulsions on the shelf-life of
611 Beluga sturgeon fillets. *International Journal of Biological Macromolecules*, 95, 769–
612 777. <https://doi.org/10.1016/j.ijbiomac.2016.11.119>
- 613 Ghomi, M. R., Nikoo, M., & Pourshamsian, K. (2012). Omega-6/omega-3 essential fatty acid
614 ratio in cultured beluga sturgeon. *Comparative Clinical Pathology*, 21(4), 479–483.
615 <https://doi.org/10.1007/s00580-012-1495-5>
- 616 Hassoun, A., & Karoui, R. (2016) Monitoring changes in whiting (*Merlangius merlangus*)
617 fillets stored under modified atmosphere packaging by front face fluorescence
618 spectroscopy and instrumental techniques. *Food Chemistry*, 200, 343-353
- 619 Hassoun, A., & Karoui, R. (2017). Quality evaluation of fish and other seafood by traditional
620 and nondestructive instrumental methods: Advantages and limitations. *Critical Reviews*
621 *in Food Science and Nutrition*, 57(9), 1976–1998.
622 <https://doi.org/10.1080/10408398.2015.1047926>
- 623 Havelka, M., Fujimoto, T., Hagihara, S., Adachi, S., & Arai, K. (2017). Nuclear DNA
624 markers for identification of Beluga and Sterlet sturgeons and their interspecific Bester
625 hybrid. *Scientific Reports*, 7(1), 1–8. <https://doi.org/10.1038/s41598-017-01768-3>
- 626 Hisar, O., Erdogan, O., Aksakal, E., & Hisar, S. A. (2006). Authentication of fish species
627 using a simple PCR-RFLP method. *Israeli Journal of Aquaculture - Bamidgeh*, 58(1),
628 62–65. <https://doi.org/10.46989/001c.20422>
- 629 Hosseini, S. V., Abedian-Kenari, A., Rezaei, M., Nazari, R. M., Feás, X., & Rabbani, M.
630 (2010). Influence of the in vivo addition of alpha-tocopheryl acetate with three lipid
631 sources on the lipid oxidation and fatty acid composition of Beluga sturgeon, *Huso huso*,
632 during frozen storage. *Food Chemistry*, 118(2), 341–348.
633 <https://doi.org/10.1016/j.foodchem.2009.04.131>

- 634 Jalali-Heravi, M., & Vosough, M. (2004). Characterization and determination of fatty acids in
 635 fish oil using gas chromatography – mass spectrometry coupled with chemometric
 636 resolution techniques. *Journal of Chromatography A*, 1024 (2004) 165–176, 1024, 165–
 637 176. <https://doi.org/10.1016/j.chroma.2003.10.032>
- 638 Jarić, I., Gessner, J., Acolas, M. L., Lambert, P., & Rochard, E. (2014). Modelling attempts
 639 utilized in sturgeon research: A review of the state-of-the art. *Journal of Applied*
 640 *Ichthyology*, 30(6), 1379–1386. <https://doi.org/10.1111/jai.12572>
- 641 Jiang Zheng, Rui-Zhang Guan, S.-Y. H. (2008). Comparative studies on the characteristics of
 642 the antilymphocyte sera. *Polish Medical Journal*, 10(2), 320–326.
- 643 Karoui, R., Dufour, É., & De Baerdemaeker, J. (2006). Front face fluorescence spectroscopy
 644 coupled with chemometric tools for monitoring the oxidation of semi-hard cheeses
 645 throughout ripening. *Food Chemistry*, 101(3), 1305–1314.
 646 <https://doi.org/10.1016/j.foodchem.2006.01.028>
- 647 Karoui, R., Hammami, M., Hamadi, R., & Blecker, C. (2011). Mid infrared and fluorescence
 648 spectroscopies coupled with factorial discriminant analysis technique to identify sheep
 649 milk from different feeding systems. *Food Chemistry*, 127, 743-748
- 650 Karoui, R., & Hassoun, H. (2017) Efficiency of Rosemary and Basil Essential Oils on the
 651 Shelf-life Extension of Atlantic Mackerel (*Scomber Scombrus*) Fillets Stored at 2 °C.
 652 *JAOC International*, 100, 335-344.
- 653 Karoui, R., Hassoun, A., & Ethuin, P. (2017). Front face fluorescence spectroscopy enables
 654 rapid differentiation of fresh and frozen-thawed sea bass (*Dicentrarchus labrax*) fillets.
 655 *Journal of Food Engineering*, 202, 89–98.
 656 <https://doi.org/10.1016/j.jfoodeng.2017.01.018>
- 657 Karoui, R., Kemps, B., Bamelis, F., De Ketelaere, B., Merten, K., Schoonheydt, R., ... De
 658 Baerdemaeker, J. (2006). Development of a rapid method based on front face
 659 fluorescence spectroscopy for the monitoring of egg freshness: 1-evolution of thick and
 660 thin egg albumens. *European Food Research and Technology*, 223(3), 303–312.
 661 <https://doi.org/10.1007/s00217-005-0204-x>
- 662 Karoui, R., Mouazen, A.M., Ramon, H., Schoonheydt, R., & De Baerdemaeker, J. (2006)
 663 Feasibility study of discriminating the manufacturing process and sampling zone in
 664 ripened soft cheeses using attenuated total reflectance MIR and fiber optic diffuse
 665 reflectance VIS-NIR spectroscopy. *Food Research International*, 39, 588-597.
- 666 Karoui, R., Nicolai, B., & De Baerdemaeker, J. (2008). Monitoring the egg-freshness during
 667 storage under modified atmosphere by fluorescence spectroscopy. *Food and Bioprocess*
 668 *Technology*, 1, 346-356.
- 669 Karoui, R., Schoonheydt, R., Decuyper, E., Nicolai, B., & De Baerdemaeker, J.
 670 (2007). Front face fluorescence spectroscopy as a tool for the assessment of egg freshness
 671 during storage at a temperature of 12.2 °C and relative humidity of 87%. *Analytica*
 672 *Chimica Acta*, 582, 83-91.
- 673 Kaya, Y., Turan, H., & Erdem, M. E. (2008). Fatty acid and amino acid composition of raw
 674 and hot smoked sturgeon (*Huso huso*, L. 1758). *International Journal of Food Sciences*
 675 *and Nutrition*, 59(7–8), 635–642. <https://doi.org/10.1080/09637480701585511>
- 676 Khodanazary, A. (2019). Freshness assessment of shrimp *Metapenaeus affinis* by quality

- 677 index method and estimation of its shelf life. *International Journal of Food Properties*,
678 22(1), 309–319. <https://doi.org/10.1080/10942912.2019.1580719>
- 679 Kuz'min, E. V., & Kuz'mina, O. Y. (2014). Polymorphism of the myogens locus in some
680 representatives of sturgeons (Acipenseridae). *Russian Journal of Genetics*, 50(9), 961–
681 968. <https://doi.org/10.1134/S1022795414090075>
- 682 Litvak, M. (2010). The sturgeons (Family: Acipenseridae). *Finfish Aquaculture*
683 *Diversification*, (April 2010), 178–199. <https://doi.org/10.1079/9781845934941.0178>
- 684 Lougovois V.P. and Kyrana V.R. (2014). *Freshness quality and spoilage of chill-stored fish*.
- 685 Ludwig, A. (2008). Identification of acipenseriformes species in trade. *Journal of Applied*
686 *Ichthyology*, 24(SUPPL. 1), 2–19. <https://doi.org/10.1111/j.1439-0426.2008.01085.x>
- 687 Manju, S., Jose, L., Srinivasa Gopal, T. K., Ravishankar, C. N., & Lalitha, K. V. (2007).
688 Effects of sodium acetate dip treatment and vacuum-packaging on chemical,
689 microbiological, textural and sensory changes of Pearlsplit (Etroplus suratensis) during
690 chill storage. *Food Chemistry*, 102(1), 27–35.
691 <https://doi.org/10.1016/j.foodchem.2006.04.037>
- 692 Masniyom, P. (2011). Deterioration and shelf-life extension of fish and fishery products by
693 modified atmosphere packaging. *Songklanakarin Journal of Science and Technology*,
694 33(2), 181–192.
- 695 Nieminen, P., Westenius, E., Halonen, T., & Mustonen, A. M. (2014). Fatty acid composition
696 in tissues of the farmed Siberian sturgeon (Acipenser baerii). *Food Chemistry*, 159, 80–
697 84. <https://doi.org/10.1016/j.foodchem.2014.02.148>
- 698 Noman, A., Ali, A. H., AL-Bukhaiti, W. Q., Mahdi, A. A., & Xia, W. (2020). Structural and
699 physicochemical characteristics of lyophilized Chinese sturgeon protein hydrolysates
700 prepared by using two different enzymes. *Journal of Food Science*, 85(10), 3313–3322.
701 <https://doi.org/10.1111/1750-3841.15345>
- 702 Oliveira, A. C. M., Balaban, M. O., & O'Keefe, S. F. (2006). Composition and Consumer
703 Attribute Analysis of Smoked Fillets of Gulf Sturgeon (Acipenser oxyrinchus desotoi)
704 Fed Different Commercial Diets. *Journal of Aquatic Food Product Technology*, 15(3),
705 33–48. https://doi.org/10.1300/j030v15n03_04
- 706 Ottavian, M., Fasolato, L., Facco, P., & Barolo, M. (2013). Foodstuff authentication from
707 spectral data : Toward a species-independent discrimination between fresh and frozen –
708 thawed fish samples. *Journal of Food Engineering*, 119(4), 765–775.
709 <https://doi.org/10.1016/j.jfoodeng.2013.07.005>
- 710 Panagiotopoulou, H., Baca, M., Popovic, D., Weglenski, P., & Stankovic, A. (2014). A PCR-
711 RFLP based test for distinguishing European and Atlantic sturgeons. *Journal of Applied*
712 *Ichthyology*, 30(1), 14–17. <https://doi.org/10.1111/jai.12328>
- 713 Pelic, M., Vidakovic Knezevic, S., Zivkov Balos, M., Popov, N., Novakov, N., Cirkovic, M.,
714 & Ljubojevic Pelic, D. (2019). Fatty acid composition of Acipenseridae - Sturgeon fish.
715 *IOP Conference Series: Earth and Environmental Science*, 333(1).
716 <https://doi.org/10.1088/1755-1315/333/1/012092>
- 717 Pinilla, C. M. B., Brandelli, A., López-Caballero, M. E., Montero, P., & Gómez-Guillén, M.
718 del C. (2020). Structural features of myofibrillar fish protein interacting with
719 phosphatidylcholine liposomes. *Food Research International*, 137(September).

720 <https://doi.org/10.1016/j.foodres.2020.109687>

721 Rostamzad, H., Shabanpour, B., Kashaninejad, M., & Shabani, A. (2011). Antioxidative
722 activity of citric and ascorbic acids and their preventive effect on lipid oxidation in
723 frozen persian sturgeon fillets. *Latin American Applied Research*, 41(2), 135–140.

724 Sarah, H., Hadiseh, K., Gholamhossein, A., & Bahareh, S. (2010). Effect of green tea
725 (Camellia sinenses) extract and onion (Allium cepa) juice on lipid degradation and
726 sensory acceptance of Persian sturgeon (Acipenser persicus) fillets. *International Food*
727 *Research Journal*, 17(3), 751–761.

728 Tucker, B.W. & Pigott, G. M. (2003). Composition and Properties. *Fish Oils| Composition*
729 *and Properties. Encyclopedia of Food Sciences and Nutrition*, Doi:10.1016/B0-12-
730 227055-x/00481-8, 2495–2501.

731 Ünal Şengör, G. F., Alakavuk, D. Ü., Tosun, Ş. Y., & Ulusoy, Ş. (2010). The chemical and
732 sensory quality of smoked sturgeon (Huso huso): A case study. *Journal of Aquatic Food*
733 *Product Technology*, 19(3–4), 310–317. <https://doi.org/10.1080/10498850.2010.520422>

734 Vasil'eva, E. D. (2009). Biology, Conservation and Sustainable Development of Sturgeons.
735 *Morphological and Morphometric Characters in Sturgeon Taxonomy and Phylogeny*,
736 (February), 51–61. <https://doi.org/10.1007/978-1-4020-8437-9>

737 Vecsei, P., & Peterson, D. L. (2004). Sturgeons and Paddlefish of North America. In *Sturgeon*
738 *Ecomorphology: A Descriptive Approach*. <https://doi.org/10.1007/1-4020-2833-4>

739 Wedekind, H. (2002). Chemical composition and processability of farmed sturgeon hybrids
740 with special emphasis on Bester. *International Review of Hydrobiology*, 87(5–6), 621–
741 627. [https://doi.org/10.1002/1522-2632\(200211\)87:5/6<621::AID-IROH621>3.0.CO;2-7](https://doi.org/10.1002/1522-2632(200211)87:5/6<621::AID-IROH621>3.0.CO;2-7)

742 Zell, M., Lyng, J. G., Cronin, D. A., & Morgan, D. J. (2010). Ohmic cooking of whole turkey
743 meat - Effect of rapid ohmic heating on selected product parameters. *Food Chemistry*,
744 120(3), 724–729. <https://doi.org/10.1016/j.foodchem.2009.10.069>

745

746

1

2 **List of Figures**

3

4 **Figure 1:** Biodiversity of sturgeon species

5

6 **Figure 2:** Overview of the topics covered in this review;

7 -biodiversity, biochemical composition and nutritive quality of sturgeon;

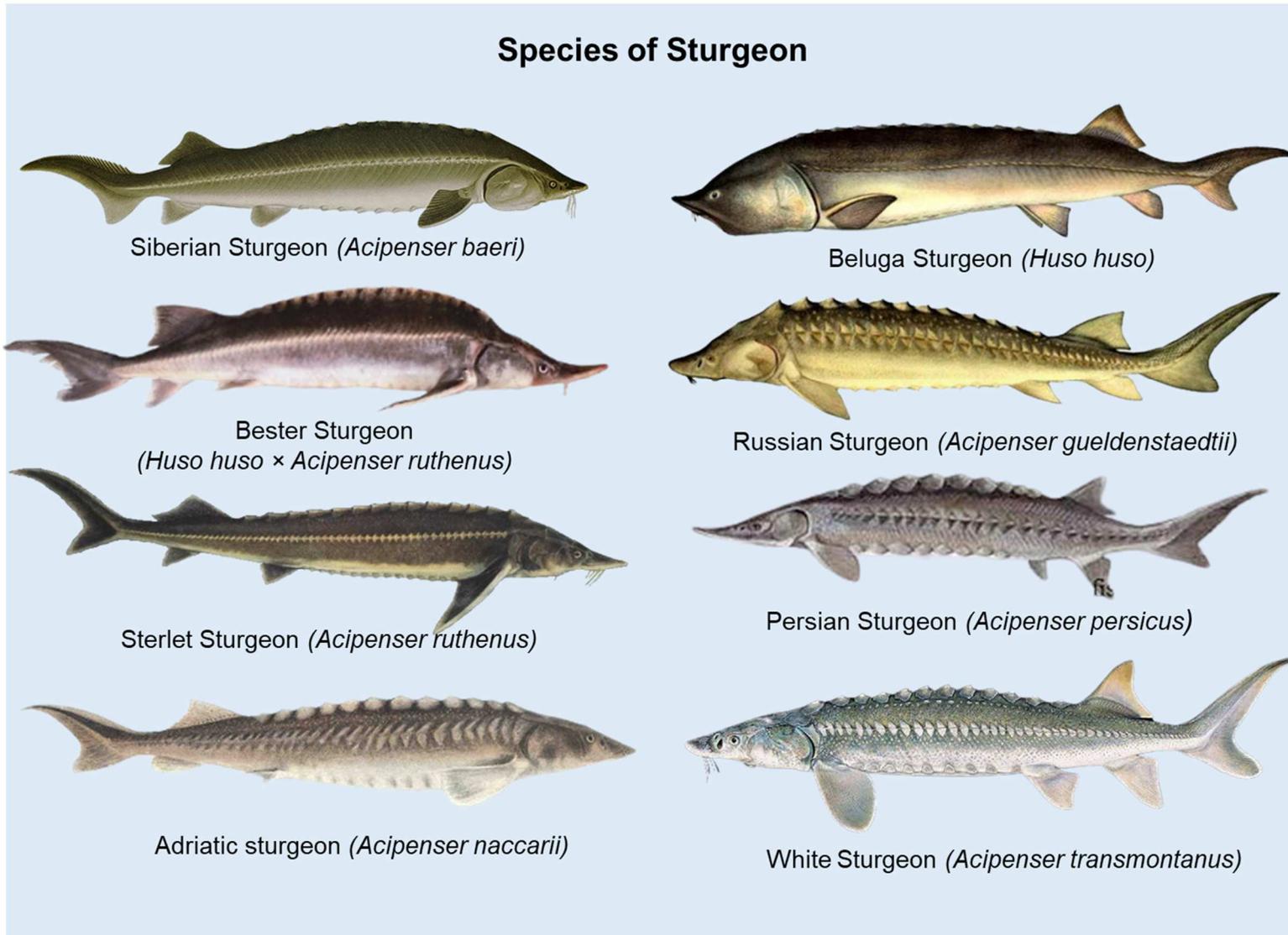
8 -impact of temperature storage and processing treatment of samples on fish quality;

9 - different tools used for authentication and quality assessment of sturgeon species.

10

11 **Figure 1**

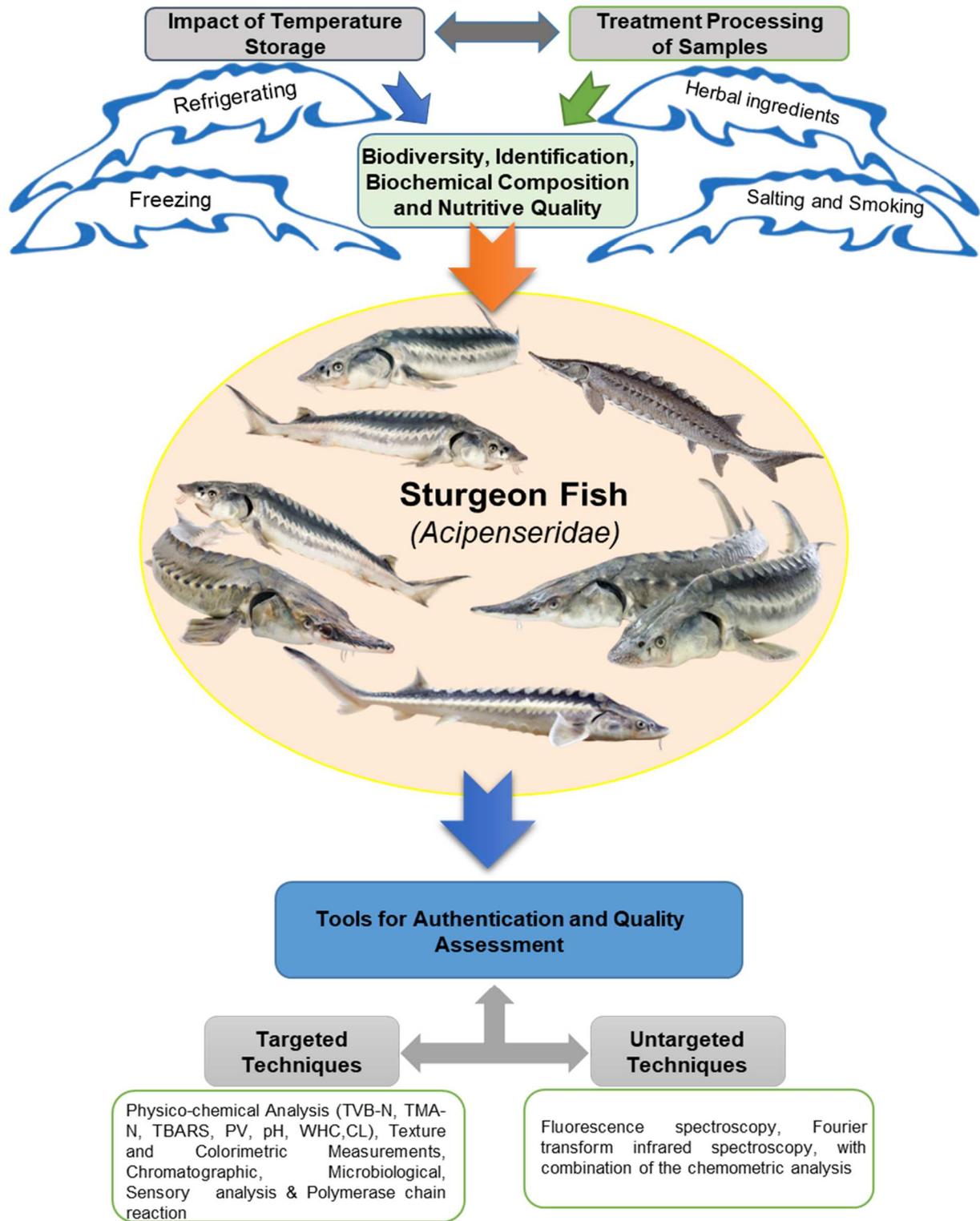
12



13

14 **Figure 2**

15



16

17 *TVB-N: Total volatile base nitrogen; TMA-N: Trimethylamine nitrogen; TBARS:*

18 *Thiobarbituric acid reactive substances; PV: Peroxide value; WHC: water holding capacity; CL:*

19 *Cooking loss*

20

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

List of Tables:

Table 1: Some examples of physico-chemical methods used for quality assessment of sturgeon species

Table 2: Some examples of sensory methods used for quality assessment of sturgeon species

Table 3: Some examples of microbiological analysis the used for quality assessment of sturgeon species

Table 4: Some examples of chromatography methods used for quality assessment of sturgeon species

Table 5: Some examples of polymerase chain reaction analysis used for authenticity of sturgeon species

18 **Table 1**

Species of sturgeon	Methods/ parameters	Treatment of samples	Objectives	Main results	Reference
Persian sturgeon (<i>Acipenser persicus</i>)	TBARS, pH, proximate composition (fat, protein, moisture, ash, PV)	Green tea extract and onion juice	Lipid oxidation of refrigerated fillets tumbled in aqueous solutions of onion juice and tea extract.	- The moisture, protein, lipid and ash contents of fresh sturgeon fillets were of 65.88%, 1.19%, 21.52% and 12.74%, respectively. - A slower increase in PV values, and TBARS during storage. - Increase in the pH value during 8 days of storage	Sarah, Hadiseh, Gholamhossein, & Bahareh, 2010
	Lipid damage measurements, pH, moisture content	Citric acid, ascorbic acid	Lipid stability during frozen storage	Significantly higher (P<0.05) peroxide formation during storage	Rostamzad, Shabanpour, Kashaninejad, & Shabani, 2011
Beluga sturgeon (<i>Huso huso</i>)	Proximate constituent (moisture, crude protein, crude lipid, ash, PV, TBARS, WHC)	Alpha-tocopheryl acetate	To investigate the effect of vitamin E on flesh quality parameters (mainly lipid oxidation) during frozen storage	- WHC in the experimental fish was fairly stable and gradually decreased as the frozen storage time increased. - α -tocopheryl acetate did not affect lipid hydrolysis	Hosseini et al., 2010
	pH, TMA-N, TVB-N, colour analysis, proximate composition (moisture content, total protein, ash, lipid content)	Smoking procedures	To determine the effect of smoking technology on sturgeon quality	- The fish were categorised to possess high quality characteristics with pH, total volatile base nitrogen (TVB-N), and trimethylamine nitrogen (TMA-N) values. - A decrease in L* value and increases in a* and b* values in the skin were determined; whereas all L*, a*, and b* values increased in the flesh samples	Ünal Şengör, Alakavuk, Tosun, & Ulusoy, 2010
	TBARS, PV, TVB-N, pH, moisture, lipid, protein and ash	Protein concentrate coating cinnamon oil	To evaluate the effect of WPC coating incorporated with CEO on the quality fillet during refrigerated storage	- Whey protein edible coating could extend preserving ability by about 8 days by retarding lipid oxidation. - The pH values increased gradually during storage and passed from 6.58 to 7.1	Bahram et al., 2016
	TBARS, PV, weight loss and cooking loss, TVB-N, colour, texture, pH	Jujube gum containing nettle essential oil	To study a new edible active coating on the physical and chemical parameters during the cold storage	- Extending the shelf-life using edible active coatings. An increase in the values of WL, CL, PV, TBA, TVB-N, and pH	Gharibzahedi & Mohammadnabi, 2017

Species of sturgeon	Methods/ parameters	Treatment of samples	Objectives	Main results	Reference
				-The WBSF value of all samples decreased during cold storage	
Russian sturgeon (<i>Acipenser gueldenstaedtii</i>)	PV, TBARS, TVB-N, texture profile analysis, pH, colour	–	To explore the potential use of textural, colorimetric, physico-chemical methods for monitoring sturgeon slices freshness	<ul style="list-style-type: none"> - The mean pH values of sturgeon samples slightly increased. - The levels of PV of sturgeon samples varied from 4.07 to 20.33 mEq/kg of fat. - Low values of TVB-N. - The intensity of b* values increased progressively during the storage time 	Boughattas, Vilkova, Kondratenko, & Karoui, 2020
	TVB-N, TBARS, pH	Salt concentrations and vacuum packaging	The effects of different salt concentrations and vacuum packaging on the quality of Russian sturgeon fillets	<ul style="list-style-type: none"> - A retarding of the production of TVB-N, delaying lipid oxidation. - The pH values decreased initially and then increased 	Chen et al., 2020
Russian (<i>Acipenser guldenstadti</i>) and Siberian (<i>Acipenser baerii</i>) sturgeons	Moisture, crude protein, crude lipids, ash	–	Assessment of proximate composition of edible portions	Range from 70-76% for moisture, 17-19% for protein, 5-10% for lipid, and 1-2% for ash; -116-151 calories per 100 grams of fresh fish	Chapman, 2005
Bester sturgeon (<i>Huso huso</i> × <i>Acipenser ruthenus</i>)	SDS–PAGE analysis	–	Biochemical characterisation and assessment of fibril-forming ability of collagens extracted	The relatively higher thermal stabilities compared with other fish species, and a better fibril-forming ability in skin and swim bladder type I collagen compared with mammalian type I collagen	Zhang et al., 2014
Sterlet (<i>Acipenser ruthenus</i>), Russian sturgeon (<i>Acipenser guldenstadti</i>)	Fat, protein, moisture, ash	–	To study of quality parameters of sturgeon meat	<ul style="list-style-type: none"> - A negative correlation between lipid and water contents of sturgeon meat. -The lipid content in the meat of different cultured sturgeon species varied and reported percentages ranged from 5 to 10%. - The water and protein contents of wild Sterlet was 75.38 g/100g, and 17.54 g/100g, respectively. Lipid content was in the 4.8-6.1 g/100 range 	Pelic et al., 2019

Species of sturgeon	Methods/ parameters	Treatment of samples	Objectives	Main results	Reference
Bester sturgeon (<i>Huso huso</i> × <i>Acipenser ruthenus</i>) Asow-Hybrid (<i>Bester</i> × <i>A. gueldenstaedti</i>) Sibster (<i>A. baeri</i> × <i>A. ruthenus</i>)	Proximate analysis (fat, protein, ash, pH), colour	–	To investigate the chemical composition in hybrids	- The long lasting decrease in pH and increase in electric conductivity during cold storage demonstrate the post mortem quality changes. - The fillet composition averaged 25% dry matter content, which was significantly correlated to the intramuscular fat content (r = 0.84). - Fillet protein and ash content was not very variable in the samples analysed	Wedekind, 2002
White sturgeon (<i>Acipenser transmontanus</i>), Italian sturgeon (<i>Acipenser naccarii</i>) and Siberian sturgeon (<i>Acipenser baeri</i>)	Cholesterol content, selected mineral and vitamin content, total and soluble collagen content, and purine bases	–	To determine the nutritional composition of sturgeon flesh	It was determined a high protein content of fairly good biological value, a medium fat and cholesterol content, fairly high levels of magnesium, niacin, pyridoxine, and vitamin B12, a high proportion of soluble collagen, and moderate amounts of uricogenic purine bases	A. Badiani et al., (1996)
Siberian sturgeon (<i>Acipenser baeri</i>), Adriatic sturgeon (<i>Acipenser naccarii</i>) and White sturgeon (<i>Acipenser transmontanus</i>)	Chemical composition, cholesterol content and energy value	–	To study culture of Sturgeon physical indices, processing yields, flesh composition	- The difference was noted between species in eviscerated yield. - Muscle lipid content 77.6, 106.4 and 44.9 g kg ⁻¹ was wet weight	Anna Badiani, Stipa, Nanni, Gatta, & Manfredini, 1997

19 TBARS: Thiobarbituric acid reactive substances; PV: Peroxide value; WHC: water holding capacity; TMA-N: Trimethylamine nitrogen; TVB-N:
20 Total volatile base nitrogen; SDS–PAGE: Sodium dodecyl sulphate polyacrylamide gel electrophoresis; WL: Weight loss; CL: Cooking loss; WPC:
21 Whey protein concentrate; CEO: Cinnamon essential oil; WBSF: Warner–Bratzler shear force

22 **Table 2**

Species of sturgeon	Methods/ parameters	Treatment of samples	Objectives	Main results	Reference
Persian sturgeon (<i>Acipenser persicus</i>)	Taste, colour and odour (cooked in hot water)	Green tea extract and onion juice	To compare the effectiveness of two plants with naturally occurring antioxidant components, and to optimize the level of green tea extract and onion juice addition to the fish fillet	- All treatments developed off-odour with increased storage time, with the lowest and the highest off-odour detected on samples treated with 5% TE and 1% OJ, respectively. - The discoloration changes of fish fillets dipped in 2.5% and 5% TE steadily increased with storage time	Sarah, Hadiseh, Gholamhossein, & Bahareh, 2010
	Flesh appearance, rancid odour, flesh consistency (raw)	Citric acid, ascorbic acid	Investigates the effect of AA, CA and combination of them on sensory changes	- A lower score at 6 th month in control samples in comparison with those treated with antioxidants. - At third month, AA+CA-treated samples had better odour according to sensory scores in comparison with other treatments	Rostamzad, Shabanpour, Kashaninejad, & Shabani, 2011
Beluga sturgeon(<i>Huso huso</i>)	Colour, odour, taste, tenderness and overall acceptability (after frying in canola oil)	Jujube gum containing nettle essential oil	To study a new edible active coating on the sensory properties during the cold storage	NEO considerably contributes to the extension of shelf-life of BSFs delaying the process of spoilage while imparting a pleasant flavour/odour to consumers	Gharibzahedi & Mohammadnab, 2017
	Taste, smoke flavour, flesh texture, sense of chewing, colour, and overall acceptance (hot smoking)	Smoking procedures	To determine the effects of smoking technology on sturgeon	The sensory evaluation indicated that the smoked sturgeon was generally accepted by the panellists who reported perfectness and delicacy of the smoked product	Ünal Şengör, Alakavuk, Tosun, & Ulusoy, 2010
	Odour, texture, colour and overall acceptability (raw)	Protein concentrate coating cinnamon oil	To evaluate the effect of WPC coating incorporated with CEO on the quality fillet during refrigerated storage	All sensory attribution scores showed a declining trend. The samples reached limit score at day 8, when the beluga sturgeon fillets first exhibited a slimy, off odour with discoloration	Bahram et al., 2016
Russian sturgeon (<i>Acipenser guldenstadti</i>)	Colour, texture, odour, and overall acceptability (salty)	Salt concentrations and vacuum packaging	The effects of different salt concentrations and vacuum packaging on the quality of	- The overall acceptability attribute score decreased with increasing storage time in all samples	Chen et al., 2020

Species of sturgeon	Methods/ parameters	Treatment of samples	Objectives	Main results	Reference
			Russian sturgeon fillets storage	<ul style="list-style-type: none"> - The shelf-life of the control group was 7 days, and 9 days for group 1 due to sensory scores. - There was no significant differences in the sensory scores between group 2 and group 4 , which still kept score of 21.25 at 16 days 	

23 *AA: Ascorbic acid; CA: Citric acid; WPC: Whey protein concentrate; CEO: Cinnamon essential oil; TE: Tea extract; OJ: Onion juice; NEO:*

24 *Nettle essential oil; BSFs: Beluga sturgeon fillet*

25

26 **Table 3**

Species of sturgeon	Methods/ parameters	Treatment of samples	Objectives	Main results	Reference
Beluga sturgeon (<i>Huso huso</i>)	Total bacterial counts and psychotropic bacterial counts	Jujube gum containing nettle essential oil	To study a new edible active coating on the microbiological properties during the cold storage	<ul style="list-style-type: none"> - The edible coatings were evaluated with a significantly better microbial quality compared to the control. - The best formulation in reducing microorganisms for 15-day cold storage was the film-coating containing 3.5% NEO and 12% JG 	Gharibzahedi & Mohammadnabi, 2017
	Bacteriological Assays (TVC, PTC)	Protein concentrate coating cinnamon oil	To evaluate the effect of WPC coating incorporated with CEO on the quality fillet during refrigerated storage	<ul style="list-style-type: none"> - TVC was below the maximum acceptable level in raw fish on day 8 of storage. - The initial PTC in sturgeon fillet was 3.89 and reached 10.1 for the control, 9.25 for the coated samples and 7.96 for coated under cinnamon oil samples on day 20 	Bahram et al., 2016
Russian sturgeon (<i>Acipenser guldenstadti</i>)	DNA isolation and PCR amplification, Total viable counts	Salt concentrations and vacuum packaging	To determine the effects of different salt concentrations and vacuum packaging on the quality and microbiota dynamics of Russian sturgeon fillets stored	<ul style="list-style-type: none"> - The high throughput sequencing was used to detect microbiota composition. -The top 20 genera for different storage periods. - The most abundant genera at the initial storage were <i>Chryseobacterium</i> (34.3%), <i>Acinetobacter</i> (18.2%), <i>Serratia</i> (15.63%), and <i>Pseudomonas</i> (5.69%). - With increasing time, the communities of microbiota became less diverse, and the relative abundances of <i>Chryseobacterium</i>, <i>Acinetobacter</i>, and <i>Serratia</i> decreased, while <i>Pseudomonas</i> became the predominant bacterial group 	Chen et al., 2020

27 TVC: Total viable counts; PTC: Psychrotrophic counts; DNA: Deoxyribonucleic acid; PCR: Polymerase chain reaction; WPC: Whey protein concentrate;

28 CEO: Cinnamon essential oil; NEO: nettle essential oil; JG: Jujube gum;

29 **Table 4:**

Species of sturgeon	Methods/ parameters	Treatment of samples	Objectives	Main results	Reference
Beluga sturgeon (<i>Huso huso</i>)	Fatty acid composition	Alpha- tocopheryl acetate	To investigate the effects of vitamin E on muscle fatty acid composition of flesh during frozen storage	- The FA composition of the muscle underwent slow changes during frozen storage. The EPA and DHA levels decreased significantly from day 0 to month 12. - The MUFA levels of the fillet were similar during the 12 months of storage The n-3/n-6 ratio of the fillet was the highest on day 0 and the lowest on month 12	Hosseini et al., 2010
	Fatty acid and amino acid composition	Hot smoking	To determine the effects of hot smoking on the fatty acid and amino acid composition	The temperature and the wood smoke components in the smoking process negatively affect the fatty acid composition, especially EPA, DHA and some essential amino acids	Kaya, Turan, & Erdem, 2008
	Fatty acid profile	–	To evaluate the changes in fatty acid composition of Beluga fillets	- The raw sample consists of 29.1 g/100 g saturated fatty acids (SFA), 42.554 g/100 g monounsaturated fatty acids (MUFA), and 28.126 g/100 g polyunsaturated fatty acids (PUFAs). - In fried samples, levels of C18 fatty acid groups, MUFA, PUFA, and n6/n3 ratio increased while SFAs, EPA, and DHA content decreased. Upon chill storage, C18:2 fatty acid and n6/n3 ratio decreased while n3 fatty acids increased slightly	Nikoo, Benjakul, & Xu, 2015
White sturgeon (<i>Acipenser transmontanus</i>), Italian sturgeon (<i>Acipenser naccarii</i>) and Siberian sturgeon (<i>Acipenser baeri</i>)	Fatty acid composition, Amino acid composition	–	To determine the nutritional composition of sturgeon flesh	- The fatty acid composition proved to be rather high in the n-3 PUFA content and n -3/n - 6 ratio. Saturated, monounsaturated, and polyunsaturated (PUFA) fatty acid contents were 1.76, 3.12, and 1.46 g/100 g wet weight, respectively; n - 3 -PUFAs reached 1.18 g/100 g, whereas n -6 PUFAs were 0.28 g/100 g. The n - 3/n - 6 ratio was 4.23	Badiani et al., 1996

Species of sturgeon	Methods/ parameters	Treatment of samples	Objectives	Main results	Reference
Siberian sturgeon (<i>Acipenser baeri</i>), Adriatic sturgeon (<i>Acipenser naccarii</i>) and White sturgeon (<i>Acipenser transmontanus</i>)	Cholesterol, Fatty acid composition	–	To study culture of Sturgeon muscle fatty acids	- <i>Acipenser baeri</i> had the lowest saturated and the highest polyunsaturated fatty acid contents. -The level of polyunsaturated fatty acids (PUFA) was very high (34.7 %), being similar to that of monounsaturated fatty acids (37.9%). - The PUFA-n3/PUFA-n6 ratio (6.74) was noticeably higher in this hybrid than in the other cultured sturgeon species	Anna Badiani, Stipa, Nanni, Gatta, & Manfredini, 1997
Sturgeon hybrid (<i>Acipenser naccarii</i> × <i>A. baerii</i>)	Measurements fatty acid methyl esters (FAMEs)	–	Analyses of fatty acids from the dorsal muscle of fish	- The level of polyunsaturated fatty acids (PUFA) was very high (34.7 %); - The monounsaturated fatty acids were (37.9%). There were high contents of EPA (C20:5n3) and DHA (C22:6n3)	Vaccaro, Buffa, Messina, Santulli, & Mazzola, 2005
Siberian sturgeon (<i>Acipenser baerii</i>)	Fatty acid composition	–	To assess the FA composition of various tissues of sturgeon	The FA profile of the diet diverged from the FA signatures of the tissues, where the sturgeons accumulated particular highly-unsaturated FA (HUFA)	Nieminen, Westenius, Halonen, & Mustonen, 2014
Sturgeon hybrid (<i>Acipenser baeri</i> × <i>Acipenser medirostris</i>)	Fatty acid composition	–	To evaluate the tissue quality of the new hybrid	A 100 g portion of the SSZ tissue for consumption contains a higher total amount of n-3 acids as well as EPA and DHA than the parent fish, with a higher difference in comparison with Siberian sturgeon	Jankowska, Kolman, Szczepkowski, & Zmijewski, 2005

30 FA: Fatty acid; EPA: Eicosapentaenoic acid; DHA: Docosahexaenoic acid; MUFA: monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; SFA:

31 Saturated fatty acid; SSZ: The reciprocal hybrid of Siberian sturgeon with green sturgeon; HUFA: Highly unsaturated fatty acid

32 **Table 5:**

Species of sturgeon	Methods/ parameters	Treatment of samples	Objectives	Main results	Reference
Beluga sturgeon (<i>Huso huso</i>), Sevruga (<i>Acipenser stellatus</i>) and Russian sturgeon (<i>Acipenser Gueldenstaedtii</i>)	PCR analysis and DNA sequencing	–	To examine three genes coding for gonadotropin-releasing hormone (GnRH), insulin-like growth factor receptor I (ILGFRI), and androgen receptor (AR) of muscle tissue	<ul style="list-style-type: none"> - The ILGFRI gene showed the most similar sequences (75.96-96.15%) for the 3 species. - Gene sequence similarity obtained for AR gene ranged from 48.5-95.71%. - The GnRH gene had more distant sequences (23.48-83.91%) between species. - There was similarity between <i>H. huso</i> samples and the reference <i>H. huso</i> samples. -An unauthorized (a sample seized from poachers) fish samples was more closely related to <i>A. stellatus</i> 	Albayrak, Şengör, & Yörük, 2013
Russian sturgeon (<i>Acipenser Gueldenstaedtii</i>), Siberian sturgeon (<i>Acipenser baerii</i>), Amur sturgeon (<i>Acipenser schrenckii</i>), Sakhalin sturgeon (<i>Acipenser mikadoi</i>), Persian	DNA isolated and purified by the method of column absorption or salt extraction	–	To examine five microsatellite loci (Afug41, Afug51, An20, AoxD161, AoxD165) in 3821 samples	<ul style="list-style-type: none"> - The examined loci were successfully amplified with the same primer set in all samples tested and demonstrated a high level of variation. - Alleles are identified to different species of Sturgeon family, which allows them to be used to identify species - The possibility of identifying hybrid forms of Sturgeon species is demonstrated 	Barmintseva & Mugue, 2013

Species of sturgeon	Methods/ parameters	Treatment of samples	Objectives	Main results	Reference
sturgeon (<i>Acipenser persicus</i>), Ship sturgeon (<i>Acipenser nudiventris</i>), Sterlet (<i>Acipenser ruthenus</i>), Stellate sturgeon (<i>Acipenser stellatus</i>), Beluga sturgeon (<i>Huso huso</i>), and Kaluga sturgeon (<i>Huso dauricus</i>)					
European sturgeon (<i>Acipenser sturio</i>), Atlantic sturgeon (<i>Acipenser oxyrinchus</i>) and Adriatic sturgeon (<i>Acipenser naccarii</i>)	PCR analysis	–	To describe species-specific nuclear markers for species determination and hybrid detection	-A total of 94 different allele sequences is obtained. -Fixed mutations in the flanking regions or in the core repeat of microsatellites allowed a clear discrimination between the different Sturgeon species	Chassaing, Hänni, & Berrebi, 2011
Beluga sturgeon (<i>Huso huso</i>)	DNA analysis	–	To develop the first genetic nuclear marker for the identification of the Beluga sturgeon	- The diagnostic nuclear marker was suitable for the analyses of both tissue and caviar, and allows the identification of pure Beluga sturgeon - The marker can contribute to the identification of interspecific hybrids in which the Beluga is one of the parent species, which produces one of the most mislabelled caviars in trade	Boscari et al., 2017
Beluga sturgeon (<i>Huso huso</i>) and Sterlet (<i>Acipenser ruthenus</i>)	Nuclear DNA analysis	–	To develop a molecular tool for routine identification two species (Beluga and Sterlet) as well as their hybrid, the Bester	- Identification of <i>A. ruthenus</i> and <i>H. huso</i> could be easier with the development of molecular tool since it is based on a simple method using dominant biallelic nuclear DNA markers.	Havelka, Fujimoto, Hagihara, Adachi, & Arai, 2017

Species of sturgeon	Methods/ parameters	Treatment of samples	Objectives	Main results	Reference
				- The markers allow detection of hybrids of <i>A. ruthenus</i> and <i>H. huso</i> with any tested species, as well as accurate identification of Bester sturgeon	
European sturgeon (<i>Acipenser sturio</i>) and Atlantic sturgeon (<i>Acipenser oxyrinchus</i>)	PCR-RFLP based test	–	To develop a new species-determining test, which enables very easy and reliable identification two sturgeons species	- Application of this test precludes misclassification of these two species on the mitochondrial DNA level - The test could be useful as a valuable supplementary tool to accompany microsatellite analysis in introgression and hybridisation detection of sturgeon species.	Panagiotopoulou, Baca, Popovic, Weglenski, & Stankovic, 2014

33 *PCR: Polymerase chain reaction; DNA: Deoxyribonucleic acid; GnRH: Gonadotropin-releasing hormone; ILGFRI: Insulin-like growth factor receptor I; AR:*
34 *Androgen receptor; mtDNA: Mitochondrial deoxyribonucleic acid; PCR-RFLP: Polymerase chain reaction - restriction fragment length polymorphism*

35

36