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

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

Keywords: Sturgeon; Authenticity; Quality; Freshness; Targeted and untargeted techniques.
1. Introduction

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

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

According to Bronzi et al. (2019), the world’s production of sturgeon biomass has increased within the last decade and reached the world 102.327 tons by 2017. As a result of
fish hunting, the sturgeon production in the China Republic reached ~ 79.6 tons in 2017 representing 78% of the global series rate. Russia’s production represents ~ 6.8 tons which makes 6.6% of the global rates. Sturgeon species showed a growing tendency around the world due to their oxygen tolerance and rapid adaptation to different farming systems. These species are promising candidates for aquaculture due to their excellent characteristics such as easy adaptation to a farming environment as well as their expensive caviar and dense meat. In 2016, the commercial sturgeon farming data, for different sturgeon species, reveal that there are 12 pure species and six hybrid items among the analysed 25 species of *Acipenseridae* showing a major share in the fish production. The main species include the Russian sturgeon (*Acipenser gueldenstaedtii*), Beluga sturgeon (*Huso huso*), Sterlet sturgeon (*Acipenser ruthenus*), White sturgeon (*Acipenser transmontanus*), Persian sturgeon (*Acipenser persicus*), and some hybrids (Figure 1). By 2017, about 2329 commercial sturgeon farms have appeared in the world, which represents an increase of 7% compared to 2016 (Bronzi et al., 2019).

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

The sturgeon fish tissue consists of a complex combination of organic compounds – proteins, fats, carbohydrates, water, minerals, and vitamin compounds. These substances are easily split by digestive enzymes or the microorganisms’ fermentation (Ghaly, Dave, Budge, & Brooks 2010). Consequently, during storage, the fish lacks its nutritional values and
becomes inappropriate for consumption, and even acquires toxic characteristics. The spoilage of sturgeon could be attributed to the growth of microorganisms (Lougoivois, and Kyrana, 2014). Consequently, to preserve the quality of sturgeon and extend its shelf-life, different techniques including refrigeration, frosting, freezing (Hosseini et al., 2010; Rostamzad, Shabanpour, Kashaninejad, & Shabani, 2011), vacuum packaging, modified atmosphere packaging (Yue-wen Chen et al., 2020), enzyme inactivation by natural compounds like salting, smoking, plant solution rich in natural antioxidants, and so on were applied (Oliveira, Balaban, & O’Keefe, 2006; Sarah, Hadiseh, Gholamhossein, & Bahareh, 2010).

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

Although the ability of the physico-chemical, sensory, and microbiology methods is indisputable to determine the quality and authenticity of fish and fish products, the majority of them are considered to be relatively expensive, long-lasting, and time-consuming. Recently, an effort is devoted to the investigation of non-invasive and non-destructive instrumental methods such as infrared, and fluorescence spectroscopies among others. These techniques are considered to be rapid, relatively cheap, and environmentally friendly and can be carried out even by minimally trained personnel. They give a significant amount of information based on a single test. Moreover, spectroscopic techniques do not need much preparation of samples and in some cases can be held without any preparation (Karoui, Hassoun, & Ethuin, 2017).
This present review paper will provide a comprehensive overview of the application of different analytical techniques, in combination with multivariate data analysis, to determine the quality of sturgeon quality. A layout of the review theme is outlined in Figure 2.

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

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

2.1. Physico-chemical analysis

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

Total volatile basic amines (TVB-N) is one of the most widely used parameters of fish quality. This general term includes the measurement of trimethylamine produced by spoilage bacteria, dimethylamine produced by autolytic enzymes, and other volatile basic nitrogenous
compounds associated with seafood spoilage. Although the determination of TVB-N is simple, it only reflects the later stage of advanced spoilage that is generally considered insignificant for the measurements of spoilage during the first days of chilled storage. A level of 25 mg TVB-N/ 100 g of fish is considered to be the upper limit above which the seafood product is considered spoilt and unfit for human consumption (Boughattas, Vilkova, Kondratenko, & Karoui, 2020). Meanwhile, there are differences in the published data disclosing the amount of TVB-N in fish tissue which seems to vary among fish species. According to Chen et al. (2020) and Gharibzahedi & Mohammadnabi (2017), the TVB-N values show the tendency to increase gradually during the storage of Russian sturgeon (A. gueldenstaedtii) and Beluga sturgeon (H. huso) and attained limit for human consumption on days 12 and 7, respectively. Other authors report that the permissible limit of TVB-N for human consumption is up to 8-9 days of storage at 4 °C for both Beluga and Russian sturgeon (Bahram et al., 2016; Boughattas et al., 2020).

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

Lipid measurements are recognised by many authors to be the most commonly used indicator for measuring the biochemical assessment of sturgeon quality (Table 1). The sturgeon family belongs to the fatty fish and the fat content varied according to the species, season, and feeding (Wedekind, 2002). The lipid content of different cultured sturgeon
species varied from 5 to 10% (Pelic et al., 2019). The highly unsaturated fatty acid found in fish lipid is very sensitive to oxidation. These compounds can be detected by chemical methods that are usually used to determine the oxidation level. The peroxide value (PV) measurements showed an increase during sturgeon storage at 4 °C regardless of the fish species. For Beluga fillets, the initial PV value is generally very low reaching its maximum (3.5 meq O₂/Kg fat) on day 8 of storage (Bahram et al., 2016). Sarah, Hadiseh, Gholamhossein, & Bahareh (2010) pointed out in their investigations that the maximum PV was noted on day 8 of storage (8.06 meq oxygen/ kg lipid) for Persian sturgeon (A. persicus) and depended on the treatment conditions.

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

Russian sturgeon (A. gueldenstaedtii) and Beluga (H. huso) presented pH values of 6.32 and 6.58, respectively (Bahram et al., 2016; Yue wen Chen et al., 2020). A slight increase of pH values was observed during storage (Table 1) since it reached values of 7.47 (Bester, Asow-Hybrid, Sibster). This increase is due to the decomposition of glycogen (Song
et al., 2011), and the production of volatile basic components by microbial proteolysis (Goulas & Kontominas, 2005; Ocaño-Higuera et al., 2009). It should be kept in mind that the pH value is a function of the post-mortem evolution of the flesh, which is influenced by diet, season, and stress during the catch, initial state of microbial contamination (viral, bacterial, mycoses, protozoses, helminthiases). This pathophysiological state depends of the individual specimen and can occur as a result of human activity. The pH increase is dependent of the storage temperatures of fish. Indeed, the higher the storage temperature, the faster is the increase in pH values (Abbas, Mohamed, Jamilah, & Ebrahimian, 2008).

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

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

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

### 2.4. Sensory analysis

The appearance, odour, taste, colour, and texture are evaluated using the human senses. The sensory measurements that apply to sturgeon quality control can be divided into two main groups: tests that determine the differences between sturgeon samples (triangle test, ranking test) and tests that permit to distinguish the gradual alteration of sturgeon samples and they are relatively quick. The diversity in sensory response is related to the difference in
sensitivity of receptors to chemical stimuli. For example, the rancid flavour is not perceptible by everyone.

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

2.5. Microbiological analysis

Microbiological analysis is used to assess the availability of microorganisms in the sturgeon fish. Traditional bacteriological examinations are laborious, time-consuming, expensive, and required skilled operators. Consequently, the most frequently used
measurements include the determination of total viable counts (TVC) and psychrotrophic counts (PTC) (Table 3). A wide variety of microorganisms was observed during the storage of Beluga sturgeon fillets preserved with nettle essential oil. A gradual increase in the amount of PTC was scored during 15 days of storage at 4 °C. The treated samples presented a low amount compared to the control one (Gharibzahedi & Mohammadnabi, 2017). Based on the level of TVC and PTC, the maximum acceptable level of the raw Beluga sturgeon was fixed to 7 days of storage. However, based on microbiological analysis, samples showed a low level of microorganisms involved in extracts and solutions of plants during the entire storage period. The obtained results are in agreement with the findings of Bahram et al., (2016) who stated that the addition of essential oil into whey protein coating for Beluga sturgeon samples strongly inhibited the growth of TVC and PTC up to 20 days. Recently, Yue-wen Chen et al. (2020) applied DNA analysis for the amplification of the microflora of the Russian sturgeon (A. gueldenstaedtii). The composition of microbiota was obtained by using the PCR method. The results showed a relative abundance of 20 top genera (Chryseobacterium, Acinetobacter, Serratia, Pseudomonas, Salmonella) within different periods of cold sturgeon storage. The bacterial diversity decreased with storage time, while their number increased. The combination of salting and vacuum packaging was found to delay efficiently the growth of Pseudomonas which is the predominant microbiota found in the Russian sturgeon fillets (Yue-wen Chen et al., 2020).

2.6. Chromatographic analysis

Chromatographic techniques used for the determination of sturgeon quality are carried out by using liquid and/or gas chromatography. These methods are used to determine the amino acid and fatty acid composition of sturgeon fish. The separation of components is performed with the help of chromatographic techniques in which every component is
processed at a different rate in a two-phase system (Jalali-Heravi & Vosough, 2004; Tucker, & Pigott, 2003). Hosseini et al., (2010) pointed out that frozen storage mode negatively affected the fatty acid composition of Beluga sturgeon (*H. huso*). Fish muscles aged 12 months presented higher concentrations of total saturated fatty acids compared to fresh ones. The monounsaturated fatty acids levels of the fillets were similar during the 12 months of storage (*P* > 0.05). The n-3/n-6 ratio of Beluga sturgeon samples presented the highest level on day 0 and the lowest one on month 12 (*P* < 0.05). The eicosapentaenoic acid and docosahexaenoic acid levels decreased significantly from day 0 to month 12 (*P* < 0.05). Kaya, Turan, & Erdem (2008) depicted that hot temperature and wood smoke affected negatively the fatty acid composition, especially EPA, DHA, and some essential amino acids in the smoking process (Table 4). In a different approach, Vaccaro et al. (2005) indicated that in sturgeon hybrid, the levels of polyunsaturated fatty acids (PUFAs) is very high (34.7 %) as well as the monounsaturated fatty acids (37.9%). These hybrid species (*Acipenser naccarii × A. baerii*) contained high contents of EPA (C20:5n3) and DHA (C22:6n3). Nieminen, Westenius, Halonen, & Mustonen (2014) found that the nutritional value of the farmed Siberian sturgeon (*Acipenser baerii*) in regard to their fatty acid composition, is quite similar to other sturgeon species. The Siberian sturgeon was found to accumulate highly unsaturated fatty acids selectively in particular tissues, using either the incorporation of these fatty acids from dietary sources or the desaturation and elongation of PUFA in its tissues.

2.7. Polymerase chain reaction

The authentication of fish species is necessary to be able to assure consumers of accurate labelling and maintain confidence in their quality and safety. DNA-analysis by polymerase chain reaction (PCR) method was used to identify fish species (Hisar, Erdogan, Aksakal, & Hisar, 2006). This technique contributed to better, more reliable, regulation and
control of global trade of high value sturgeon products as well as to their management and conservation. The DNA-markers, as compared with the biochemical methods, possess several advantages. Indeed, to use of DNA fragments as markers solved a number of tasks related to the identification of the sturgeon species (Kuz’min & Kuz’mina, 2014). In the study of Albayrak, Şengör, & Yörük (2013) PCR analysis and DNA sequencing were used on Beluga sturgeon, Russian sturgeon and Sevruga the gonadotropin-releasing hormone (GnRH), insulin-like growth factor receptor I (ILGFRI), and androgen receptor (AR) genes coding and compared to reference Beluga sturgeon genome retrieved from database. The most similarity was calculated for AR gene and GnRH gene ranged from 48.5-95.71% and 23.48-83.91%, respectively, between the three species. A sample seized from poachers was found to be more like to Russian sturgeon samples (Table 5). These findings indicated a high level of diversity among and even within the same family. The authors depicted that the three genes could be useful for the identification of sturgeon species. The genetic polymorphism of ten sturgeon species (Russian sturgeon, Siberian sturgeon, Amur sturgeon, Sakhalin sturgeon, Persian sturgeon, Ship sturgeon, Sterlet, Sevruga sturgeon, Beluga sturgeon, and Kaluga sturgeon) was examined at five microsatellite loci (Afug41, Afug51, An20, AoxD161, AoxD165) in the investigation of Barmintseva & Mugue (2013). Alleles specific to different species was identified.

Five microsatellite markers were analysed and their alleles were sequenced for the Adriatic sturgeon (Acipenser naccarii), the Atlantic sturgeon (Acipenser oxyrinchus) and the European sturgeon (Acipenser sturio) by Chassaing, Hänni, & Berrebi (2011). Fixed mutations in the flanking regions or in the core repeat of microsatellites provided a clear distinction between the sturgeon species. These nuclear markers combined with mitochondrial markers was found to be used to identify hybridisation among the three species. Boscari et al. (2017) developed the first genetic nuclear marker for the identification of the Beluga
The interspecific variability at the second predicted intron of the RPS6 nuclear ribosomal gene was found to be a suitable marker for the identification of the Beluga sturgeon. The diagnostic nuclear marker characterised allowed the identification of pure Beluga and its first generation hybrids. In a similar approach, nuclear DNA markers was applied for the identification of Beluga sturgeon and Sterlet, and their Bester sturgeon hybrid (Havelka, Fujimoto, Hagihara, Adachi, & Arai, 2017). The authors employed double-digest restriction-associated DNA (ddRAD) sequencing to identify species-specific nucleotide variants, which were served as specific binding sites for diagnostic primers. The primers allowed the identification of Beluga sturgeon and Sterlet as well as their discrimination from other sturgeon species. The species-specific primers allowed the identification of Bester sturgeon (H. huso × A. ruthenus). Another two sister species of Atlantic sturgeon and European sturgeon were found to be difficult to distinguish solely by morphological traits (Panagiotopoulou, Baca, Popovic, Weglenski, & Stankovic, 2014). A simple PCR-restriction fragment length polymorphism based test was developed, enabling easy identification of specimens belonging to both species. The application of two restriction enzymes (BtsI and BsrDI) allowed a clear discrimination of 132 specimens of European sturgeon and Atlantic sturgeon (Table 5).

2.8. Morphological methods

Morphological analysis of sturgeons have a very long history and have been carried out to identify sturgeon species (Ludwig, 2008). However, authentication of sturgeon species based on morphological traits are scarce in the literature. Descriptive morphology allows to distinguish sturgeon by external features. Sturgeons as a like most other fish, have a body comprised of three regions: head, body, and fins. Each of these regions is characterised by a number of specialised adaptations – some typical of all sturgeons while others are species
specific. These sometimes subtle morphological variations are used to identify different sturgeon species or, in some cases, to identify different populations within a species. The main diagnostic characters of these family Acipenserinae including the genera Acipenser and Huso are the shape of the mouth and differences in gill-membrane attachment (Vasil’eva, 2009). The rostrum used in ecomorphological measurements as a criteria relating to flow and/or feeding methods. Spiracle is open above the gills in Huso and Acipenser and absent in Scaphirhynchus and Pseudoscaphirhynchus. Thick lips surround the mouth and the upper lip is interrupted in all species except Ship sturgeon (A. nudiventris). The sturgeon mouth is unique in lacking a jaw bone, and the mouth is capable of extensive downward and outward projection. Mouth dimensions in sturgeon are often used in ecomorphological analyses. In proportion to body size, the smallest mouth occurs in the Atlantic sturgeon (Acipenser transmontanus) that feeds primarily on bryozoans and small invertebrates, in contrast, white sturgeon (Acipenser transmontanus) has the largest mouth (Vecsei & Peterson, 2004).

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

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

3.1. Fluorescence spectroscopy

Although the interest of this technique, only very few studies have explored the potential of fluorescence spectroscopy to determine the quality of sturgeon. Sturgeon fish contains several fluorophores, including aromatic amino acids and nucleic acids (AAA+NA),
tryptophan, vitamins A, riboflavin, nicotinamide adenine dinucleotide (NADH), and many other compounds that can be detected in minimal concentrations. In this context, Boughattas et al., (2020) monitored the freshness level of Russian sturgeon (A. gueldenstaedtii) during storage at 4 °C. The emission spectra of riboflavin (405-650 nm) and NADH (360-600 nm) of sturgeon slices were acquired after excitation set at 380 and 340 nm, respectively. The maximum fluorescence intensity of riboflavin spectra is observed within ~ 460-490 nm that changed with the storage time. The observed peak was ascribed to different stable fluorescent oxidation products, which include the products formed by the reaction of unsaturated aldehydes with proteins and/or the photo breakdown of riboflavin products. The NADH spectra indicated several peaks located ~ 380, 460, and 485 nm. The authors concluded that the shape of NADH spectra was correlated with the freshness level of sturgeon samples. In fact, a decrease (~ 460 and 485 nm) and an increase (~ 380 nm) in the fluorescence intensity of sturgeon samples were noted during storage. A sharp decrease of the fluorescence intensity ~460 and 485 nm was ascribed by the authors to the NADH oxidation occurring during the sturgeon storage leading to the transformation of NADH to NAD+, and thus modifying the shape of the NADH fluorescence spectra. One of the main conclusions of their study was that NADH spectra could be used as fingerprints allowing to identify the level of sturgeon freshness. This result was confirmed following the application of common components and specific weights analysis to the riboflavin and NADH data tables since four groups were identified: 2 days; 5, 6 and 7 days; 8 and 9 days and 12 days. Another fluorophore namely AAA+NA was used for monitoring Russian sturgeon during cold storage. The AAA+NA emission spectra were recorded between 290 and 400 nm after excitation set at 250 nm (Boughattas et al., 2020). The authors observed that the maximum emission was observed ~ 375 nm and the shape of the spectra varied as a function of the storage time. The highest fluorescence intensity was noted for sturgeon samples aged 12 days, and the lowest one for
those aged 2 days. This difference might be explained by the difference in the protein-protein,
protein-water and/or protein-lipid interactions. Considering the vitamin A spectra, the shape
of the spectra showed a maximum located ~ 296 nm for sturgeon aged 2 days and 310 for the
aged ones. This red shift was attributed by the authors to the: i) physical states of the
triglycerides in the fat globules; and/or ii) interactions of the fat globule membrane with
protein network and/or lipid-lipid interactions.

In another way, fish authentication is important for correct product labelling as
promoted by recent regulatory actions (Ottavian, Fasolato, Facco, & Barolo, 2013). In this
context, the fluorescence spectroscopy was used to determine the impact of freeze-thaw
cycles (1, 2, 3, and 4) on the quality of Russian sturgeon (Acipenser gueldenstaedtii) kept in a
partial vacuum and a total vacuum (Vilkova, Chêné, Kondratenko, & Karoui, 2021). The
NADH emission spectra scanned on sturgeon samples subjected to different freeze-thaw
cycles illustrated two peaks located ~ 388 and ~ 470 nm. The highest fluorescence intensity at
388 nm was observed for fresh samples, while the highest fluorescence intensity at 470 nm
was noted for those subjected to 4 freeze-thaw cycles kept in a partial vacuum (Vilkova,
Chêné, Kondratenko, & Karoui, 2021). The vitamin A spectra demonstrated the highest
fluorescence intensity ~ 296 nm for fresh samples and those submitted to 1 freeze-thaw cycle
kept in partial vacuum and total vacuum. Moreover, a red shift of the maximum excitation
spectra of vitamin A was observed (i.e., from 296 nm for samples subjected to 1 freeze-thaw
cycle kept in a partial vacuum and total vacuum to 306 nm for those submitted to 2, 3, and 4
freeze-thaw cycles). The riboflavin spectra scanned on sturgeon samples showed two peaks ~
468 nm and ~ 500 nm. Changes ~ 500 nm that were related to riboflavin degradation and/or
interaction with other compounds such as proteins. The spectral range in the 405 – 480 nm
could be used to determine the degree of fish oxidation; among them, the products formed by
the reaction of unsaturated aldehydes with proteins (Karoui et al., 2017). To extract
information from the data sets, the authors applied the PCA separately to each intrinsic probe and the best results were obtained with the vitamin A and riboflavin spectra (Vilkova, Chène, Kondratenko, & Karoui, 2021). Indeed, a clear differentiation between fresh sturgeon samples and those subjected to 1 freeze-thaw cycle from the others was observed. In addition, a separation between samples subjected to 2, 3, and 4 freeze-thaw cycles was also noted.

3.2. Mid infrared spectroscopy

Mid-infrared (MIR) spectroscopy is an established method used for protein and peptide structural characterisation. In this context, the technique was used for the characterisation of sturgeon by Jiang Zheng, Rue-Zhang Guan (2008). The results showed that sturgeon samples exhibited absorption at 1376 (–COO\(^-\)), 1344 (–COOH, –C-O), 1310 (–COOH, –C-O), 1157 (C-O-C, C-O-H, C-O), 883 (C-H), and 856 (OSO\(_3\), C-O-S) cm\(^{-1}\). The chondroitin sulfates of sturgeon contain 4, 6-disulfated chondroitin sulfates.

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

In a different approach, the potential of MIR to differentiate fresh Russian sturgeon samples from those subjected to 1, 2, 3, 4 freeze-thaw cycles was determined (Vilkova, Chène, Kondratenko, & Karoui, 2021). Most of the spectral information was located in three
wavenumber regions: 3000–2800 cm$^{-1}$, 1700–1500 cm$^{-1}$, and 1500–900 cm$^{-1}$. The 1500-900 cm$^{-1}$ spectral region showed absorbance bands ~ 1083, 1118; 1158, 1239, 1314, 1371, 1396, 1418, and 1458 cm$^{-1}$. Fresh sturgeon samples exhibited two peaks ~ 1371 and 1418 cm$^{-1}$ which disappeared for sturgeon samples subjected to freeze-thaw cycles. The peak located ~1418 cm$^{-1}$ could be attributed to the combination of O–H bending of the C–O–H group and C–H bending of alkenes. The 1000-1200 cm$^{-1}$ spectral region differentiated clearly between fresh samples and those subjected to 4 freeze-thaw cycles kept in partial and total vacuum. The region located between 1700-1500 cm$^{-1}$ showed two peaks (1547 and 1637 cm$^{-1}$). The Amide I band (1600-1700 cm$^{-1}$) is recognised as the most useful spectral region used to determinate the secondary structure of proteins (Pinilla, Brandelli, López-Caballero, Montero, & Gómez-Guillén, 2020). During the freeze-thaw cycle of sturgeon samples, protein is subjected to the oxidation leading to some variation of α-helix, β-sheet, β-turn, and random coil levels that have an absorption band in the 1650–1660 cm$^{-1}$, 1600–1640 cm$^{-1}$, 1660-1690 cm$^{-1}$ and 1640–1650 cm$^{-1}$ spectral regions, respectively. The percentage of the secondary structure indicated a decrease in α-helix, β-sheet, and random coil, and an increase in β–turn. Indeed, an increase in β–turn (from 35.40% for fresh samples to 39.70 % and 37.06% for samples subjected to 4 freeze-thaw cycles kept in a partial vacuum and a total vacuum, respectively) and a decrease in α-helix (from 10.70% for fresh samples to 9.30 % and 9.23% for samples subjected to 4 freeze-thaw cycles kept in a partial vacuum and a total vacuum, respectively) were noted (Vilkova, Chêné, Kondratenko, & Karoui, 2021).

The region located between 3000 and 2800 cm$^{-1}$ corresponds to C–H bond of methyl and methylene groups of fatty acids. This spectral region presented two bands ~ 2852 and 2925 cm$^{-1}$ for fresh samples that disappeared during freeze-thaw cycles. Consequently, the potential use of MIR spectroscopy to rapidly identify commercial frauds in the fish sector and...
to solve some authentication was demonstrated (Vilkova, Chêné, Kondratenko, & Karoui, 2021).

4. Conclusion and future directions

Considerable interest is paid to sturgeon quality and authenticity due not only to its nutritive quality but also to the crises and scandals in the food industry, which have seriously undermined consumer confidence and grown the need for rapid analytical techniques to determine sturgeon quality and authenticity. This great need for quality assurance requires appropriate analytical tools for the determination of the quality of sturgeon samples. In this context, targeted methods such as -chemical, sensory, microbiological, chromatography techniques, morphological and PCR, considered as the official methods, were used to assess the quality and authenticity of the sturgeon. However, most of these methods are time consuming, destructive, and demand trained personnel. This requires the development of fast, environment-friendly and simple analytical techniques such as the spectroscopic ones that are relatively of low-cost and can be applied in both fundamental researches and the factory as on-line sensors for the determination of sturgeon quality. In this review, recent advances in sturgeon quality evaluation and authenticity by front-face fluorescence, and mid- infrared spectroscopies are presented and discussed. From the results presented in the present review, it could be mentioned that spectroscopic techniques coupled with chemometric tools have the potential to determine the quality and authenticity of sturgeon. Up-to-date, the use of these techniques alone and their combination of these spectroscopic techniques for the evaluation of the quality of sturgeon is scarce. Thus, the combination of untargeted techniques with targeted ones would make them more convenient and effective for the analysis of sturgeon allowing them to be used as rapid screening tools for determining rapidly the quality and authenticity of sturgeon.
Conflicts of interest:
The authors have declared that there is no conflict of interest.

Acknowledgments:
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References


Khodanazary, A. (2019). Freshness assessment of shrimp Metapenaeus affinis by quality


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Figure 2: Overview of the topics covered in this review; - biodiversity, biochemical composition and nutritive quality of sturgeon; - impact of temperature storage and processing treatment of samples on fish quality; - different tools used for authentication and quality assessment of sturgeon species.
Figure 1

Species of Sturgeon

Siberian Sturgeon (*Acipenser baeri*)

Bester Sturgeon (*Huso huso × Acipenser ruthenus*)

Sterlet Sturgeon (*Acipenser ruthenus*)

Russian Sturgeon (*Acipenser gueldenstaedtii*)

Persian Sturgeon (*Acipenser persicus*)

Adriatic sturgeon (*Acipenser naccarii*)

White Sturgeon (*Acipenser transmontanus*)
**Figure 2**

TVB-N: Total volatile base nitrogen; TMA-N: Trimethylamine nitrogen; TBARS: Thiobarbituric acid reactive substances; PV: Peroxide value; WHC: water holding capacity; CL: Cooking loss.
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| Persian sturgeon (*Acipenser persicus*) | 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 (*Huso huso*) | 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 |
<p>| | 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 &amp; Mohammadnabi, 2017 |</p>
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<tr>
<td>Russian sturgeon (<em>Acipenser gueldenstaedtii</em>)</td>
<td>PV, TBARS, TVB-N, texture profile analysis, pH, colour</td>
<td>–</td>
<td>To explore the potential use of textural, colorimetric, physico-chemical methods for monitoring sturgeon slices freshness</td>
<td>- The WBSF value of all samples decreased during cold storage</td>
<td>Boughattas, Vilkova, Kondratenko, &amp; Karoui, 2020</td>
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<td>Russian (<em>Acipenser gueldenstadi</em>) and Siberian (<em>Acipenser baerii</em>) sturgeons</td>
<td>TVB-N, TBARS, pH, Salt concentrations and vacuum packaging</td>
<td>–</td>
<td>The effects of different salt concentrations and vacuum packaging on the quality of Russian sturgeon fillets</td>
<td>- 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</td>
<td>Chen et al., 2020</td>
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<td>Bester sturgeon (<em>Huso huso × Acipenser ruthenus</em>)</td>
<td>SDS-PAGE analysis</td>
<td>–</td>
<td>Biochemical characterisation and assessment of fibril-forming ability of collagens extracted</td>
<td>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</td>
<td>Zhang et al., 2014</td>
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<td>Sterlet (<em>Acipenser ruthenus</em>), Russian sturgeon (<em>Acipenser gueldenstadi</em>)</td>
<td>Fat, protein, moisture, ash</td>
<td>–</td>
<td>To study of quality parameters of sturgeon meat</td>
<td>- 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</td>
<td>Pelic et al., 2019</td>
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| Bester sturgeon *(Huso huso × Acipenser ruthenus)*  
Asow-Hybrid *(Bester × A. gueldenstaedti)*  
Sibster *(A. baeri × A. ruthenus)* | 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 *(Acipenser transmontanus)*, Italian sturgeon *(Acipenser naccarii)* and Siberian sturgeon *(Acipenser baeri)* | 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 *(Acipenser baeri)*, Adriatic sturgeon *(Acipenser naccarii)* and White sturgeon *(Acipenser transmontanus)* | 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**: Total volatile base nitrogen; **SDS–PAGE**: Sodium dodecyl sulphate polyacrylamide gel electrophoresis; **WL**: Weight loss; **CL**: Cooking loss; **WPC**: Whey protein concentrate; **CEO**: Cinnamon essential oil; **WBSF**: Warner–Bratzler shear force
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| Persian sturgeon *(Acipenser persicus)* | 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 6th 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 |
<p>| Beluga sturgeon <em>(Huso huso)</em> | 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 &amp; Mohamadnab, 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, &amp; 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 <em>(Acipenser guldinstadti)</em> | 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 |</p>
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<td>Russian sturgeon fillets storage</td>
<td>- 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</td>
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23 AA: Ascorbic acid; CA: Citric acid; WPC: Whey protein concentrate; CEO: Cinnamon essential oil; TE: Tea extract; OJ: Onion juice; NEO: Nettle essential oil; BSFs: Beluga sturgeon fillet

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| **Beluga sturgeon** *(Huso huso)* | 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 | - 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 | - 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** *(Acipenser guldenstadtii)* | 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 | - 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 Chryseobacterium (34.3%), Acinetobacter (18.2%), Serratia (15.63%), and Pseudomonas (5.69%).  
- With increasing time, the communities of microbiota became less diverse, and the relative abundances of Chryseobacterium, Acinetobacter, and Serratia decreased, while Pseudomonas became the predominant bacterial group | Chen et al., 2020 |

TVC: Total viable counts; PTC: Psychrotrophic counts; DNA: Deoxyribonucleic acid; PCR: Polymerase chain reaction; WPC: Whey protein concentrate; CEO: Cinnamon essential oil; NEO: nettle essential oil; JG: Jujube gum;
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| **Beluga sturgeon (Huso huso)** | 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 |
<p>| <strong>White sturgeon (Acipenser transmontanus), Italian sturgeon (Acipenser naccarii) and Siberian sturgeon (Acipenser baeri)</strong> | 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 |</p>
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| Siberian sturgeon (Acipenser baeri), Adriatic sturgeon (Acipenser naccarii) and White sturgeon (Acipenser transmontanus) | Cholesterol, Fatty acid composition               | –                    | To study culture of Sturgeon muscle fatty acids                            | - *Acipenser baeri* 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, Stipia, Nanni, Gatta, & Manfredini, 1997 |
| Sturgeon hybrid (Acipenser naccarii × A. baerii)                                  | 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 (Acipenser baerii)                                              | 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 (Acipenser baeri × Acipenser medirostris)                         | 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: Saturated fatty acid.
31 SSZ: The reciprocal hybrid of Siberian sturgeon with green sturgeon; HUFA: Highly unsaturated fatty acid.
<table>
<thead>
<tr>
<th>Species of sturgeon</th>
<th>Methods/parameters</th>
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| Beluga sturgeon (*Huso huso*), Sevruga (*Acipenser stellatus*) and Russian sturgeon (*Acipenser Gueldenstaedtii*) | 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 | - 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 *H. huso* samples and the reference *H. huso* samples.  
-An unauthorized (a sample seized from poachers) fish samples was more closely related to *A. stellatus* | Albayrak, Şengör, & Yörük, 2013 |
| Russian sturgeon (*Acipenser Gueldenstaedtii*), Siberian sturgeon (*Acipenser baerii*), Amur sturgeon (*Acipenser schrenckii*), Sakhalin sturgeon (*Acipenser mikadoi*), 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 | - 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 |
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<td>sturgeon (Acipenser persicus), Ship sturgeon (Acipenser nudiventris), Sterlet (Acipenser ruthenus), Stellate sturgeon (Acipenser stellatus), Beluga sturgeon (Huso huso), and Kaluga sturgeon (Huso dauricus)</td>
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<td>PCR analysis</td>
<td>–</td>
<td>To describe species-specific nuclear markers for species determination and hybrid detection</td>
<td>- 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</td>
<td>Chassaing, Hänni, &amp; Berrebi, 2011</td>
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<td>European sturgeon (Acipenser sturio), Atlantic sturgeon (Acipenser oxyrinchus) and Adriatic sturgeon (Acipenser naccarii)</td>
<td>DNA analysis</td>
<td>–</td>
<td>To develop the first genetic nuclear marker for the identification of the Beluga sturgeon</td>
<td>- 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</td>
<td>Boscari et al., 2017</td>
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<tr>
<td>Beluga sturgeon (Huso huso)</td>
<td>Nuclear DNA analysis</td>
<td>–</td>
<td>To develop a molecular tool for routine identification two species (Beluga and Sterlet) as well as their hybrid, the Bester</td>
<td>- Identification of A. ruthenus and H. huso could be easier with the development of molecular tool since it is based on a simple method using dominant biallelic nuclear DNA markers.</td>
<td>Havelka, Fujimoto, Hagihara, Adachi, &amp; Arai, 2017</td>
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<tr>
<td>Species of sturgeon (Acipenser sturio) and Atlantic sturgeon (Acipenser oxyrinchus)</td>
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<td>PCR-RFLP based test</td>
<td>–</td>
<td>To develop a new species-determining test, which enables very easy and reliable identification two sturgeons species</td>
<td>- The markers allow detection of hybrids of <em>A. ruthenus</em> and <em>H. huso</em> with any tested species, as well as accurate identification of Bester sturgeon. - 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.</td>
<td>Panagiotopoulou, Baca, Popovic, Weglenski, &amp; Stankovic, 2014</td>
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33 *PCR*: Polymerase chain reaction; *DNA*: Deoxyribonucleic acid; *GnRH*: Gonadotropin-releasing hormone; *ILGFRI*: Insulin-like growth factor receptor I; *AR*: Androgen receptor; *mtDNA*: Mitochondrial deoxyribonucleic acid; *PCR-RFLP*: Polymerase chain reaction - restriction fragment length polymorphism.