

**Caviar products sold on Chinese Business to Customer (B2C) online platforms: labelling  
assessment supported by molecular identification.**

Xia Zhang<sup>a1</sup>, Lara Tinacci<sup>b1</sup>, Siyun Xie<sup>a</sup>, Huiru Kang<sup>a</sup>, Jing Wen<sup>c\*</sup>, Andrea Armani<sup>b\*</sup>

<sup>a</sup> *Henry Fok College of Food Science, Shaoguan University, Shaoguan, 512005, China*

<sup>b</sup> *FishLab, Department of Veterinary Sciences, University of Pisa, 56124, Pisa, Italy*

<sup>c</sup> *Department of Biology, Lingnan Normal University, Zhanjiang, 524048, China*

<sup>1</sup> These authors equally contributed to this work.

**\*Corresponding authors:**

Jing Wen, Lingnan Normal University, Zhanjiang, 524048, China

Email: [jw82123@126.com](mailto:jw82123@126.com)

Andrea Armani, FishLab, Department of Veterinary Sciences, University of Pisa, 56124, Pisa,  
Italy

Email: [andrea.armani@unipi.it](mailto:andrea.armani@unipi.it)

## Abstract

In this study the labelling compliance of 40 caviar products collected from a major Chinese Business to Customer online platform was assessed. The label information was analyzed according to the requirements of the Chinese standard for prepackaged food and of the Convention on International Trade in Endangered Species (CITES) Resolution on Conservation and trade in sturgeons and paddlefish. A molecular analysis based on DNA barcoding targeting two mitochondrial genes (*COI* and *cytb*) was used to support the label assessment. All products were fully compliant to the national labelling standard, and they were verified as belonging to Chinese producing plants. On the contrary, CITES requirements were never satisfied and no reference to the production method (wild catch or aquaculture) and to the origin of the roes processed for caviar production was reported. The sturgeon species or hybrid were declared in 32.5% of the products. Despite the limits in discriminating among *Acipenser* spp. and commercial hybrids, the molecular analysis was confirmed as an effective screening tool to monitor products authenticity. The molecular analysis highlighted no counterfeiting with heterologous species, being all the products confirmed as sturgeon species. However, 42.5% of the products did not fully match their label information. Evidences from the study stressed the need to fill an evident gap in the traceability of caviar products by promoting the use of CITES labelling to ensure products fair trade and sustainability, as well as consumers protection.

## Keywords

Sturgeon, labelling compliance, Chinese market, CITES, molecular analysis

## 1. Introduction

44 Caviar, the product obtained by a salting curing process of sturgeon roe, is considered a luxury  
45 seafood delicacy at the international level (CXS 291-2010). The species of origin, the roe collection  
46 procedure (slaughtering or hormonal induced roe release) and the curing process greatly affect the  
47 final caviar organoleptic properties and price. In addition, processing can significantly modify the  
48 initial quality of the product (Bronzi et al., 2019, Tavakoli et al., 2021). Common commercial types  
49 include: *Malossol*, lightly salted product, with a percentage of salt not exceeding 5%; *salted* caviar  
50 that generally contains 8 to 12% salt by weigh; *pressed caviar*, also known as *payusnaya ikra*, a  
51 lower quality product obtained by roes salting and pressing procedure preceded by sturgeon ovaries  
52 soaking in saturated brine (Tavakoli et al., 2021). Thus, different types of commercial products are  
53 sold on the market with different prices (Pappalardo et al., 2019; Tavakoli et al., 2021).

54 Over the years, caviar production has particularly contributed to a dramatic decline in sturgeon  
55 wild stock populations due to overfishing and illegal, unreported, and unregulated (IUU) practices,  
56 to the point that, in 1997, all wild sturgeon species were officially included in the Convention on  
57 International Trade in Endangered Species (CITES) (Bronzi & Rosenthal, 2014; Bronzi et al., 2019).  
58 CITES, also considering the species reported by the Codex Alimentarius Standard for caviar  
59 production (amended in 2018) (CXS 291-2010), currently includes 27 sturgeon species belonging  
60 to the *Acipenseridae* family and 2 paddlefish species belonging to *Polyodontidae* family (Table 1).

61 Thanks to the improvement of aquaculture techniques and the increased consumers' awareness of  
62 the wild stocks overexploitation, caviar obtained from farmed species gained similar acceptance as  
63 those from wild ones on the international market (Bronzi et al., 2019; Tavakoli et al., 2021).  
64 Therefore, the global production of caviar from aquaculture has progressively increased to cope  
65 with the rising demand. The more commonly reared sturgeon species belong to *Acipenser* spp.,

66 *Huso* spp. and their hybrids, preliminarily evaluated for suitability and production under farming  
67 conditions (Table 2). In this respect, specific studies were addressed to the selection of not sterile  
68 hybrids (Fain et al., 2013).

69 China, which has acquired a major role in both caviar production and export over the latest years,  
70 represents the leading country in sturgeon aquaculture and caviar trade followed by Russia, USA,  
71 and Europe (Harris & Shiraishi 2018). Although the total volume of caviar sold in China is still  
72 significantly lower than in the major importing countries (Europe, USA, Japan), the internal demand  
73 is increasing and producers made considerable efforts to promote caviar on the Chinese market  
74 (FAO, Globefish, 2019).

75 Over the years, caviar-like products made of roe from other fish species have been proposed to  
76 attract a wider range of consumers globally (Pappalardo et al., 2019; Tavakoli et al., 2021). In  
77 parallel, cases of fraudulent replacement of roe caviar with other fish species, such as Northern Pike  
78 (*Esox lucius*), flying fish (*Hirundichthys* sp.), Lumpfish (*Cyclopterus lumpus*) and Capelin  
79 (*Mallotus villosus*) have been highlighted (Doukakis et al., 2012; Ludwig et al., 2015; Günther et  
80 al., 2017; Pappalardo et al., 2019). In addition, other biological substances, such as fish flesh,  
81 seaweed, or vegetables (processed to resemble sturgeon roe) have been reported as caviar substitutes  
82 (Ludwig et al., 2015; Tavakoli et al., 2021).

83 In this respect, CITES also implemented a caviar labelling system, as described in the Resolution  
84 12.7 on “*Conservation of and trade in sturgeons and paddlefish*” (CITES Res. Conf. 12.7-Rev.  
85 CoP17), which implies the application of an alphanumeric string on the products as a nonreusable  
86 tag, obtained using mandatory information including a standard species code, a source code, the  
87 ISO code of the country of origin and of repackaging, the year of harvest or re-packaging, the

88 producing plant code and the lot number (Figure 1SM). This system complements the general  
89 requirements on the labelling of food products provided by national legislations, that, in China, is  
90 represented by the GB7718-2011 standard.

91 In addition, DNA based techniques, that are currently routinely applied for the authentication of  
92 seafood products, represent a valid support tool for the assessment of labelling compliance.  
93 Cytochrome b (*cytb*) and cytochrome oxidase subunit I (*COI*) mitochondrial genes (Teletchea et al.,  
94 2005, Ward et al., 2009), were selected as elective molecular markers for the identification of many  
95 fish species (Bartlett and Davidson, 1991, Branicki et al., 2003, Pepe et al., 2005, Hebert et al., 2003,  
96 Ward et al., 2009, Ivanova et al., 2007; Handy et al., 2011, Tinacci et al., 2018, Acutis et al., 2019,  
97 Pappalardo et al., 2021), including sturgeon and paddlefish (Tavakoli et al., 2021, Ludwig et al.,  
98 2015, Johnson & Iyengar, 2015; Krieger, et al., 2008; Ludwig, 2008; Mugue et al., 2008), despite  
99 some limits in discriminating among closely related species and in identifying some of the hybrids  
100 often used in aquaculture (Ludwig, 2008; Doukakis et al., 2012; Boscari et al., 2014; Boscari et al.,  
101 2017). Alternatively, the analysis of species-specific polymorphisms located on mitochondrial or  
102 nuclear markers was proposed (Chandra & Fopp-Bayat, 2021). However, the latter diagnostic  
103 methods, other than being time and cost consuming, present limits in the number of discernible  
104 sturgeon species (Böhme et al., 2019, Chandra & Fopp-Bayat, 2021). Therefore, despite its limits,  
105 molecular techniques based on the analysis of mitochondrial genes, especially by DNA barcoding  
106 (Hebert et al., 2003), represent effective screening methods to support labelling assessing and to  
107 highlight counterfeit incidents (Pappalardo et al., 2019).

108 Caviar may be particularly exposed to deceptive practices through the e-commerce channel, that  
109 in China has become a front-runner at retail level (Wang & Somogyi, 2018) and that is especially

involved in this issue (Xiong et al., 2016; Xiong et al., 2020), with detriment of business operators and final consumers (Bronzi and Rosenthal, 2014; Sicuro, 2019; Tavakoli et al., 2021).

The aim of the present study was to assess the labelling compliance of products sold on the Chinese e-commerce platforms to the Chinese standard for prepackaged food (GB7718-2011) and CITES requirements (CITES Res. Conf. 12.7-Rev. CoP17). The labelling assessment was also supported by a molecular analysis based on DNA barcoding approach targeting the standard *COI* gene or, alternatively, the *cytb* gene.

## **2. Materials and Methods**

### ***2.1. Sampling and labelling compliance to Chinese standard for prepackaged foods and CITES requirements.***

*2.1.1 Sampling.* A convenience, non-probabilistic sampling was conducted, structured to include a proportional number of products per brand according to the e-market availability. Forty caviar products were purchased from Taobao (www.taobao.com), one of the largest Business to Customer (B2C) online platforms in China. Three boxes of each caviar product were purchased, and three roes were randomly selected from each box for a total of 360 roe samples. A selection of the products collected in this study is shown in Figure 1. The products were kept in their original packaging and stored according to the manufacturer's instructions until further analysis.

### ***2.1.2 Labelling compliance to Chinese standard for prepackaged foods and CITES requirements.***

The labelling information on the products were checked according to the mandatory requirements and general recommendations related to Chinese mandatory labelling rules of prepackaged foods, Article 4 (GB7718-2011). As regards the mandatory requirements the analysis was addressed to highlight: 1) name of the food, 2) list of ingredients, 3) net content (net weight) and configuration,

132 4) manufacturer and/or distributor's name, 5) date of production and expiration, 6) storage  
133 conditions, 7) food production license number, 8) code of the product standard and other contents  
134 needed to be labeled. Moreover, the presence of the following recommended information was also  
135 verified: a) batch identification, b) instruction of use, c) declaration of food or ingredients causing  
136 allergies. In addition, the presence of the requirement of CITES Resolution Conf. 12.7 (Rev. CoP17)  
137 was assessed. Finally, the commercial variety and price were recorded for each caviar product  
138 analyzed.

## 139 **2.2. DNA extraction, amplification, and sequencing**

140 Total DNA extraction was performed using the TIANamp Marine Animals DNA Kit (TIANGEN,  
141 China) according to the manufacturer's instructions. The qualities and quantities of the DNA from  
142 each sample were determined with a U-1800 spectrophotometer (Hitachi, Japan). The primer pair  
143 FishF1 (5'-TCAACCAACCACAAAGACATTGGCAC-3') and FishR1 (5'-  
144 TAGACTTCTGGGTGGCCAAAGAATCA-3') (Ward et al., 2005) was used for the amplification  
145 of an expected 655 bp *COI* region. An alternative primer pair L14735 (5'-  
146 AAAAACCACCGTTGTTATTCAACTA-3') and H15149 (5'-  
147 GCCCCTCAGAATGATATTTGTCCTCA-3') (Kocher et al., 1989; Burgener & Hubner, 1998)  
148 was used for the amplification of an expected 411 *cytb* bp region (without primers) in case of failure  
149 of the *COI* amplification. PCR amplification were performed using 100 ng of template DNA and 50  
150 µL master mix containing 2 µL each primer (10 µmol/L), 5 µL of 10×Ex Taq buffer (20 mmol/L  
151 Mg<sup>2+</sup> plus), 4 µL dNTP mixture (2.5 mmol/L each, TaKaRa, Japan), and 0.25 µL Ex Taq DNA  
152 polymerase (2 U/µL) (TaKaRa, Japan). PCR amplifications were carried out in a C1000 touch  
153 thermal cycler (Bio-Rad, USA). For the *COI* gene the amplification conditions were a denaturing

154 step at 94 °C for 2 min, 35 cycles of 30 s at 94 °C for denaturation, 30 s at 52 °C for annealing and  
155 1 min at 72 °C for extension, and a final extension at 72 °C for 10 min. Amplification conditions  
156 for the *cytb* gene were 96 °C for 3 min of initial denaturation followed by 40 cycles of: denaturation  
157 at 96°C for 30 s; annealing at 55°C for 1 min, extension at 72°C for 1 min and amplification ended  
158 with a 3 min final extension step followed by a 4°C hold. The PCR products were analyzed by 1.2%  
159 agarose gel (11.5×6 cm) electrophoresis at 160 V for 30 min. The lengths of the fragments were  
160 determined by comparison with the DL2000 DNA ladder (TaKaRa, Japan). PCR products were  
161 purified with the AxyPrep™ DNA Gel Extraction Kit (Axygen, USA) and sequenced in both  
162 directions with the Applied Biosystems 3730 Automatic Sequencer.

### 163 ***2.3. Sequence editing and comparison with databases.***

164 The sequences were analyzed with the Chromas lite v2.23 software and aligned using Editseq  
165 software (DNASTAR Lasergene Version 7.1.0) and Jellyfish v1.4 software. The final sequences  
166 were queried by Basic Local Analysis Search Tool (BLAST) selecting the program Highly similar  
167 sequences (megablast) and, in the case of *COI*, also by the BOLD Identification System (ID's)  
168 selecting the program Species Level Barcode Records (Ratnasingham & Hebert, 2007) against the  
169 reference sequences available on GenBank (<http://www.ncbi.nlm.nih.gov>) and Barcode of Life Data  
170 system (BOLD) (<http://www.boldsystems.org/>), respectively. A match with a 100% query coverage  
171 and a sequence similarity of at least 98% was used to designate potential species identification for  
172 the *COI* (Hebert, Cywinska, Ball, & deWaard, 2003). As regards the *cytb*, while maintaining the  
173 100% query coverage match, a specific identification was attributed for identity values of 99-100%  
174 according to Parson et al., (2000). Outcomes from this phase were compared to those from the labels  
175 analysis phase (section 2.1) to assess the eventual occurrence of counterfeit incidents and the



correctness of the trade names declared on the products. Since the sequences obtained in this study were not derived from voucher samples or expertly-identified fish specimens, they were not submitted neither to GenBank nor to BOLD. The sequences produced within the study are however available for consultation in a separate supplementary document (SM1).

### **3. Results and discussions**

#### ***3.1 Labelling compliance to GB7718-2011 standard and market analysis***

*3.1.1 Mandatory information.* All the 40 caviar products presented a label fully compliant to the Article 4 (labelling information) of the national standard GB7718-2011 (Table 3) similarly to what Xiong et al., (2018) highlighted in a survey on prepackaged roasted fish fillet purchased at retail level on the Chinese market.

In this section, among the mandatory information, the name of the food and manufacturer and/or distributor's name are discussed in detail. As regard the name of the food, all the products were described by the term caviar accompanied by a specific trade name (Siberian sturgeon, Russian sturgeon, Amur sturgeon, Beluga and Kaluga,). Siberian sturgeon caviar was the most represented (25%; 10/40) followed by Russian sturgeon (20%; 8/40), Amur sturgeon (15%; 6/40), Beluga (10%; 4/40) and Kaluga (7.5%; 3/40). The remaining products were not identified by a specific trade name but as "Hybrid sturgeon" (20%; 8/40) or "Sturgeon" (2.5%; 1/40) . Furthermore, in one product (2.5%), labelled as "Hybrid sturgeon", a mention to the specific trade name (Amur and Kaluga) was included (Table 3).

All the specific trade names found on the products (Siberian sturgeon, Russian sturgeon, Amur sturgeon, Kaluga, Beluga) are internationally valid as univocally associated to *Acipenser baerii*, *A. gueldenstaedtii*, *A. schrenckii*, *Huso dauricus* and *H. huso* , respectively (Bronzi & Rosenthal, 2014).

198 In four caviar products labelled as Russian Sturgeon, the food name was also enriched by the term  
199 “Oscietra” representing a misspelling of “Osetra or Ossetra” belonging to the Russian term осётр  
200 also associated with the species *A. gueldenstaedtii* (Bronzi & Rosenthal, 2014; Pappalardo et al.,  
201 2019) and specifically mentioned by the Codex Standard as usual name for the species *A.*  
202 *gueldenstaedtii* and *A. persicus* (CXS 291-2010). Finally, a specific scientific name was reported  
203 on 13 caviar products belonging to: Siberian sturgeon (n=4; *A. baerii*), Russian sturgeon (n=2; *A.*  
204 *gueldenstaedtii*), Amur sturgeon (n=3; *A. schrenckii*), hybrid sturgeon products (n=3; *A. schrenckii*  
205  $\times$  *H. dauricus*) and in the only product generically labelled as “Sturgeon caviar” (*A. schrenckii*  $\times$   
206 *H. dauricus*) (Table 3). The results obtained in the study are consistent with Bronzi et al., (2019)  
207 and Farag et al., (2021) describing *A. baerii* as the species most frequently used for caviar  
208 production, followed by *A. gueldenstaedtii* and the hybrid *H. dauricus*  $\times$  *A. schrenckii*. All these  
209 species/hybrids have a lower market price compared to Beluga caviar (*H. huso* roes), which is  
210 generally deemed as the finest product (see section 3.1.3).

211 The use of standard commercial names for the different species of sturgeon and the use of  
212 additional terms such as Oscietra, although not perfectly adhering to the accepted wording (CXS  
213 291-2010), plausibly express the willingness of operators to adhere to international nomenclature  
214 standard as previously stated by Wei et al., (2011). This willingness is further suggested by the  
215 voluntary use of the corresponding scientific name in 32.5% of the cases.

216 Despite the manufacturer information does not provide any information on the origin of the raw  
217 material used in the preparation, all the species declared in the study are among those farmed on a  
218 large scale both in extensive and semi-intensive aquaculture in China (Yang et al., 2018),  
219 strengthening the hypothesis of a national origin (Table 2). China is in fact internationally

220 recognized for its consolidate leadership in sturgeon and caviar production (Bronzi et al., 2019).  
221 This hypothesis is further reinforced by the relative high presence of Amur sturgeon caviar (*A.*  
222 *schrenckii*). *A. schrenckii*, originally native of the Amur river, from which it takes its name, is in  
223 fact highly appreciated for the caviar production in China and is currently farmed in running water  
224 concrete ponds systems, both in purity and in hybridization (*A. schrenckii* x *H. dauricus*, *A.*  
225 *schrenckii* x *A. baerii*) (Yang et al., 2018). On the contrary, at the international level it is rather used  
226 for meat production (Bronzi et al., 2019).

227 **3.1.2 Recommended information.** The lot and the methods of use were reported in 100% and 82.5%  
228 of the products, respectively (Table 3). On the contrary, none of the products showed declaration of  
229 food or ingredients causing allergies. This aspect appears relevant and may be of interest for future  
230 investigations since the standard amendment proposal, currently under discussion for final approval  
231 and publication, will include the indication of the allergens among the mandatory requirements  
232 (GAIN, 2020). The new version of the standard, if amended accordingly, will therefore align itself  
233 with the requirements imposed by the legislation on food labelling adopted as for example at  
234 European level (Reg. EU No.1169/2011).

### 235 **3.1.2 Labelling compliance to CITES requirements.**

236 CITES is the principal international trade treaty to safeguard wildlife (Wiersema, 2018). As  
237 regards the traceability of sturgeon species and their products (meat and caviar) CITES provides for  
238 the declaration of all the information related to the species, the species source (catch or aquaculture),  
239 country of origin, year of hatchery and operator who is also responsible for the product identification  
240 (Figure 1 SM). All the operators in the supply chain must be included in a specific register freely  
241 available online. Therefore, each operator is identified by a unique registration number also

242 reporting the country of origin (<https://cites.org/eng/common/reg/ce/CN>). The encoded label must  
243 be applied for the identification, up to the final purchase, of all the products, newly produced or  
244 repackaged caviar, and intended for domestic or international market (CITES Res. Conf. 12.7-Rev.  
245 CoP17).

246 All caviar products included in this study were not found to fully comply with the CITES labelling  
247 system. Neither an alphanumeric string sealing the external packaging nor a printed label reporting  
248 the required information according to the resolution were observed. However, as discussed in the  
249 previous paragraph, an explicit reference to the sturgeon species or hybrid was highlighted in the  
250 32.5% of the products and information about the producing plant and batch lot numbers were  
251 reported in all the products and directly available to the final consumer, albeit not in the form  
252 required by the CITES labelling system.

253 On the contrary, the explicit declaration on the production method (wild, captive breeding or  
254 aquaculture origin) and the roes origin was not found in any products. However, the Chinese origin  
255 of the products was assumed based on the data obtained by the analysis of the label (section 3.1.1 -  
256 mandatory information) and according to the literature (Wei et al., 2004; Shen et al., 2014; Yang  
257 et al., 2018).

258 Overall, this evidence agrees with a recent study on the identification of geographic hotspots for  
259 the legal and illegal trade in caviar by Shiraishi & Harris, (2019). The authors showed that products  
260 destined to the Chinese, Russian and US domestic market were generally not compliant with CITES  
261 requirements on caviar labelling, despite the presence of partial information relating to the caviar  
262 origin, roe production method and the species used on the products labels..

### 263 **3.1.3 Price analysis**

264 The price analysis (Figure 2), derived from the label information, perfectly fitted into the range  
265 presented by Sicuro (2019). A significant price gap between the two species of *Huso* spp. (*H. huso*  
266 and *H. dauricus*) and the others belonging to *Acipenser* spp. or hybrids products was observed. This  
267 confirms Beluga sturgeon caviar (*H. huso*) as the premium product on the national market, also in  
268 accordance with its international value (Farag et al., 2021; Tavakoli et al., 2021). The higher  
269 commercial value of Beluga caviar is mainly due to the peculiar roes fatty acid content composition,  
270 that influence the organoleptic properties (Gessner et al., 2002). However, also the time needed by  
271 the bred specimens to reach maturity influences the final price. This parameter significantly affects  
272 the farming length and costs: therefore, the selection of fast-growing species and hybrids has lately  
273 been preferred over the final organoleptic quality (Bronzi et al., 2019). This process has led to the  
274 selection of few species and hybrids with a subsequent price reduction and levelling (Tavakoli et  
275 al., 2021; Bronzi et al., 2019). In this regard, the prices observed in this study could be interpreted  
276 as an effect of this leveling phenomenon with the distribution of products in two price ranges,  
277 approximately equivalent respectively to 2000 and 5000-6000 \$/kg (Figure 2). This data would  
278 further confirm the origin of the sampled products from aquaculture production.

279 To identify sensitive price variations between products belonging to the same sturgeon species,  
280 any additional names relating to the commercial type offered for sale were also collected, according  
281 to the classification of Tavakoli et al., (2021). The term *malossol* was included in the 45% of the  
282 products, highlighting an apparent relevant consumers' preference for low salt products,  
283 commercially recognized as best quality caviar (Sicuro, 2019). Nevertheless, observing the prices  
284 of *malassol* products and of products without indication of the type of processing, no variations

were highlighted. It should be noted that these data have a purely descriptive value and are limited to the samples size of the present study.

### **3.2 DNA extraction, amplification, sequencing, and sequences comparison to reference databases**

DNA was successfully extracted from all the 360 roe samples. A total of 309 *COI* gene and 51 *cytb* gene PCR products were obtained and sequenced. All the sequences had the expected maximum length of 655pb and 411pb, respectively. The *COI* gene was selected as first choice target being already validated and routinely applied as diagnostic marker for fish species identification to verify the labelling compliance (Handy et al., 2011; Tinacci et al., 2018) also among sturgeon species (Pappalardo et al., 2019). *Cyt b* was selected as alternative target due to its high interspecies and low intraspecific divergence observed in sturgeons (Fain et al., 2013; Chandra & Fopp-Bayat, 2021). Chang et al., (2016) successfully used the *COI* gene for the *H. dauricus* identification. Azuma et al., (2017) described distinct clustering of the species *H. dauricus* and *H. huso* clearly separate from *Acipenser* sp. species by analyzing the *cytb* gene. This confirmed the validity of both the targets used for these species' characterization or for the identification of the maternal lineage in commercial hybrids. In fact, the present analysis was limited to the detection of the maternal lineage and therefore, for hybrids, it was possible to identify only half of the parental species involved in the inbreeding process. The results of the sequences comparison to the databases are summarized in Table 4.

Overall, the combination of BLAST and BOLD ID's results confirmed all the products belonging to *Acipenseridae* family, and particularly to *Acipenser* spp. or *Huso* spp. A total of 270 sequences

306 (*COI* n=234, *cytb* n=36) belonging to 30 products and 18 sequences (*COI* n=16, *cytb* n=2) belonging  
307 to 2 distinct products were assigned to the species *H. dauricus* and *H. huso*, respectively.

308 On the contrary the results confirmed the failure of both targets to identify closely related species  
309 included in the so-called “*A. gueldenstaedtii* complex” consisting of Russian sturgeon (*A.*  
310 *gueldenstaedtii*), Adriatic sturgeon (*A. naccarii*), Siberian sturgeon (*A. baerii*) and Persian  
311 (*Acipenser persicus*) as extensively described by Doukakis et al., (2012) and Boscari et al., (2017).  
312 A failure in the discrimination between *A. schrenckii* and *A. transmontanus* was also highlighted in  
313 agreement with the hypothesis by Azuma et al., (2017) of a paraphyletic origin of the two species.

314 In this regard, Pappalardo et al., (2019) proposed the association of the barcoding analysis to a  
315 Restriction Fragment Length Polymorphism (RFLP) technique to improve the species resolution  
316 and accuracy of the identification procedure on the *COI* marker. In their study, the COIbar-PCR  
317 RFLP technique proposed by the authors finally led to the identification of specific restriction  
318 patterns for *A. stellatus*; *A. gueldenstaedtii*; *A. transmontanus* and *H. huso*.

319 A further consideration to be noted is related to the sequences polymorphism. The overall  
320 alignments of *COI* and *cytb* sequences showed the presence of five clusters of identical sequences  
321 for both markers (Table 4). Therefore, also taking into consideration the study by Fain et al. (2013)  
322 on the distribution of species-specific polymorphisms and intra-species divergency rate in relation  
323 to the different geographical areas of the species populations, our results would strengthen the  
324 hypothesis of the common geographic origin and production method for all the products analyzed.  
325 These were thus presumably of national origin and derived from aquaculture, as they displayed  
326 stable haplotypes and low genetic polymorphism. In this respect, Azuma et al., (2017) observed  
327 *COI* and *cytb* unique haplotypes in reared against wild exemplars .

### 3.3 Comparison of label assessment and molecular analysis

In this study, the labelling assessment supported by the molecular analysis highlighted the absence of counterfeits with heterologous species in all the samples. As regards the correctness of the declared trade name, considering that the scientific name was not available for all the collected products, the standards CXS 291-2010 and Conf. 12.7-Rev. CoP17 (Table 1) were used to associate the trade name to the corresponding species subsequently defined as expected ID. The results of the comparison are summarized in Table 5.

The comparative analysis was limited to the products properly identified at species level (*H. huso* and *H. dauricus*) (see section 3.2), except for 5 of them, for which no information on the hybrids was reported on the label. However, since the maternal lineage belonging to *H. dauricus* was confirmed in these 5 products, it was hypothesized that they corresponded to *H. dauricus* ♀ x *A. schrenckii* ♂, which, together with the reverse cross *A. schrenckii* ♀ x *H. dauricus* ♂, is recognized as a major hybrid for caviar production in Chinese sturgeon aquaculture, due to its fast growth, easy domestication, high - quality of the caviar obtained, and thus representing on of top three cultured species in the caviar trade (Yang et al., 2018; Tavakoli et al., 2021).

The molecular results did not match the product expected ID in 53.1% (17/32) of the products included in the comparative analysis, corresponding to the 42.5% (17/40) of the overall products included in the study, originally labelled as: Beluga (*H. huso*) (n=2), Russian sturgeon (*A. gueldenstaedtii*) (n=7), Amur sturgeon (*A. schrenckii*) (n=4) and Siberian sturgeon (*A. baeri*) (n=4). According to the molecular results, all the products were indeed verified to be identifiable either as *H. dauricus* or as the commercial hybrid *Huso dauricus* ♀ x *Acipenser schrenckii* ♂. Both are farmed on the large scale within the national territory but attribution to the hybrid is more plausible



350 by virtue of the higher production volumes compared to Kaluga, as discussed above (Yang et al.,  
351 2018; Bronzi et al., 2019; Tavakoli et al., 2021).

352 This evidence, in addition to underlining evident gaps in the product traceability monitoring  
353 system, highlights the failure to comply with the obligations of transparency and loyalty towards  
354 the consumer as well as a possible voluntary frauds perpetrated for economic purposes. This last  
355 aspect refers particularly to the two mislabelling cases affecting products labelled as Beluga, which,  
356 as discussed in previous sections (3.1.3), achieve a significantly higher market price than other  
357 species and commercial hybrids.

#### 358 **4. Conclusion**

359 The present study was primarily directed to the conformity assessment of the labelling of caviar  
360 products sold on the Chinese e-commerce domestic market. The analysis carried out confirmed  
361 caviar products' compliance to the national food labelling mandatory rules, highlighting, however,  
362 the complete lack of application of the CITES international labelling standard specifically addressed  
363 to the protection of sturgeon overexploiting and deceptive incidents.

364 The molecular analysis, while excluding the presence of fraudulent counterfeiting of sturgeon  
365 caviar with caviar substitutes, highlighted evident gaps in the traceability system of the products  
366 resulting in their consequent potential exposure to phenomena of substitution of valuable species of  
367 sturgeon with sturgeon species or hybrids of lesser commercial value to the detriment of  
368 transparency towards the final consumer.

369 Despite some limits of the methodological approach, principally applied to exclude the presence  
370 of heterologous substitution phenomena and not for sturgeon species molecular characterization on

caviar products, the analytical protocol proposed was confirmed as a valid screening tool to contrast illegal incidents affecting the caviar production chain.

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### **Figure captions**

#### **Figure 1.**

Selection of caviar products analyzed in this study

#### **Figure 2**

Average price associated with the different commercial caviar products according to trade name

#### **Figure 1SM**

Description of the alphanumeric string, including the mandatory information provided by the Resolution 12.7 on “*Conservation on and trade in sturgeons and paddlefish*”.

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