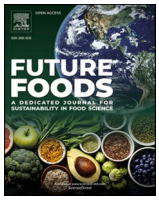
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DNA-based species authentication certification in seafood: An exploratory assessment of consumer acceptance using decision tree analysis

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ABSTRACT

Seafood authenticity is a growing concern due to the globalisation of food supply chains and the frequent occurrence of species substitution and mislabelling, particularly in processed products. Currently, official control authorities primarily rely on morphological criteria to assess species authenticity. While some voluntary certification schemes incorporate species testing within their internal auditing processes, systematic DNA-based verification is not formally embedded in existing certification standards. This study uses a data mining approach to investigate the factors influencing Italian consumers' fish-purchasing behaviour and their interest and willingness to pay (WTP) for a DNA-based certification of seafood species authenticity. Data were collected via a direct consumer survey (n = 408) and analysed using a C4.5 decision-tree model. The results revealed that consumers typically have a limited ability to correctly identify fish species and lack knowledge of existing certification schemes. Nonetheless, 72.8% of respondents expressed interest in the potential implementation of a DNA-based certification scheme, with 68% indicating a WTP a premium price (mostly up to 5–10%). The decision tree revealed that the main variables influencing consumers' interest in DNA-based certification were their previous engagement with products, household income, education attainment, weekly fish expenditure, and trust in labelling information. While these findings are based on an exploratory convenience sample, they suggest that implementing a DNA-based certification scheme is a potentially valuable tool for the seafood industry, helping to reinforce consumer trust, enhance transparency and traceability in supply chains, and create new opportunities for strategic market differentiation.

1. Introduction

The European Union (EU) is one of the world's largest and most significant markets for fishery and aquaculture products (EUMOFA, 2023; Jacobs et al., 2015). In 2023, EU household expenditure on fish and seafood exceeded €138 per capita – approximately one-quarter of the amount spent on meat – reflecting a substantial and consistent market (EUMOFA, 2024). European consumers typically purchase fresh, frozen and tinned seafood. The popularity of processed products, such as breaded items and ready meals, is increasing, especially among young consumers due to their convenience and ease of preparation (EUMOFA, 2024).

In recent years, the globalisation of food supply chains and the emergence of numerous food scandals have raised consumer concerns regarding the authenticity and safety of seafood (Wu et al., 2021). Indeed, in modern food systems, consumers have gradually lost contact with the food supply chain. As their knowledge of and involvement in food production has decreased, their uncertainty and anxiety regarding food risks has increased (Tonkin et al., 2016). Food quality attributes are commonly categorised as search, experience and credence

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characteristics (Darby and Karni, 1973). Specifically, search attributes are related to food features that consumers can verify before purchase by directly assessing the food's visual or physical characteristics, such as species, colour, ripening grade, price and so on (Schrobback et al., 2023; Wu et al., 2021). Experience attributes are sensory attributes that can only be ascertained after food consumption, such as taste and texture. By contrast, consumers cannot evaluate credence attributes directly at the time of purchase or after consumption. Even after purchase and consumption, credence attributes are expensive to evaluate. Examples include the environmental sustainability of food production and distribution processes (Darby and Karni, 1973). This generates a phenomenon known as information asymmetry, which affects both consumers and supply chain stakeholders (Caswell and Mojduszka, 1996). In this situation, sellers have a more comprehensive understanding of product features than buyers. This can easily lead to misperceptions regarding the risks and hazards associated with consuming certain foods. For this reason, information and guarantees relating to food quality are recognised as a public good. Indeed, in many countries, aspects and requirements relating to the accuracy of food information are governed by legislation. In this regard, food labelling represents the primary tangible instrument that assists consumers in making informed purchasing decisions, as it provides direct access to food information, providing assurances regarding food authenticity and traceability (Basanisi et al., 2020; Kaczorowska et al., 2021). However, with the growth of global trade and changing lifestyles, consumers have become distanced from the origin of their food, which, in turn, has contributed to their limited ability to accurately recognise fish species (Cusa et al., 2021).

With regard to the seafood regulatory framework, in 2013, the EU implemented seafood labelling regulation aimed at improving consumer awareness of the seafood supply chain and safeguard public health by promoting food safety, nutrition and informed choices. In particular, EU Regulation No 1379/2013 on the Common Organisation of the Markets in Fishery and Aquaculture Products, set out the key information that seafood product labels must display. This includes the commercial and scientific name of the species, the production method, the catch or harvest area, the type of fishing gear used and whether the product has been previously frozen .

Currently, the verification of the species name declared on mandatory seafood labels relies on conventional approaches, primarily based on morphological identification and documentation-based traceability systems. Although these systems play a central role in official controls, they present inherent limitations that may reduce their effectiveness in detecting species substitution or mislabelling (Christiansen et al., 2018; Lorusso et al., 2024; Mottola et al., 2022, 2024; Muñoz-Colmenero et al., 2016; Wong and Hanner, 2008). This is particularly evident in prepared and processed seafood products, where diagnostic morphological features are lost, making alternative tools, such as DNA-based ones, necessary for species identification (Staats et al., 2016).

Among several molecular methods (e.g., HRM, ddPCR, LAMP), DNA barcoding has demonstrated strong reliability for species authentication (Antil et al., 2023; Mottola et al., 2022; Panprommin and Manosri, 2022; Senathipathi et al., 2024; Xing et al., 2025), and its use is gradually expanding globally. Since 2011, it has been recognised by the U.S. Food and Drug Administration (FDA) as an official tool for fish species verification (Handy et al., 2011). In addition, EU Member States are encouraged by the above-mentioned Regulation to integrate DNA testing into official controls against mislabelling.

The same Regulation also acknowledges the role of voluntary certification schemes in addressing consumers' concerns about the sustainability of fish production. In this context, a variety of certification schemes have emerged in different countries to inform sourcing of fishery products. Among the most recognised are those issued by non-governmental organisations such as the Marine Stewardship Council (MSC) and the Aquaculture Stewardship Council (ASC) (Vince and Haward, 2019). These certifications are communicated through a mark, tag, or other descriptive material associated with a brand or label. This offers consumers the assurance that eco-friendly production patterns and practices have been adhered to during the production process (Meijer et al., 2021).

At the same time, food business operators (FBOs) often implement and adopt a variety of voluntary food safety and quality certification schemes, such as IFS Food Standard, the BRCGS Global Standard for Food Safety, ISO 9001, ISO 22000 and others, in order to increase their market competitiveness and gain easier access into large-scale retail distribution. These schemes aim to ensure compliance of production processes with specific standards (process certification) or that the final product meets defined quality and safety requirements (product certification), thereby supporting product quality assurance and consumer expectations. Sometimes, certified FBOs employ DNA-based methods to mitigate food fraud vulnerabilities in their control plans and supplier verification procedures (Galimberti et al., 2013; Giusti et al., 2023).

In this sense, a DNA-based certification scheme could systematically verify seafood products. Positioned within product certification systems, it could communicate this information through logos on labels, providing scientific evidence of authenticity and increasing transparency for consumers.

To date, several studies have investigated consumers' interest and acceptance of traceability systems (Hoque et al., 2022; Rodriguez-Salvador and Calvo Dopico, 2023; Violino et al., 2025). For instance, Violino et al. (2025) examined Italian consumers' willingness to pay (WTP) for traceable seafood products, emphasising the potential of blockchain technology (BT) to enhance transparency and support the economic sustainability of the fish supply chain. Hoque et al. (2022) explored seafood markets by assessing the demand for traceability information attributes.

Despite the increasing use of molecular tools for seafood authentication in regulatory and research contexts, little empirical evidence exists on the determinants of consumer interest and WTP for DNA-based certification schemes. Therefore, to investigate the most relevant variables affecting consumers' fish purchase decisions and to detect the actual interest of consumers in certification schemes, particularly those aimed at identifying fish species and preventing mislabelling, the decision tree methodology was applied.

Through a direct inquiry, several key aspects have been explored: (i) consumers' ability to recognise and distinguish common whole specimens and prepared seafood species available on the market; (ii) consumers' knowledge of the certifications available for seafood products; (iii) their interest and trust in a possible DNA-based seafood certification able to provide reliable, verifiable indications regarding the species marketed; (iv) their WTP a premium price for certified seafood products. The decision tree methodology allowed a systematic and effective analysis of consumer preference and highlighted the most relevant variables affecting consumers' choices.

2. Materials and methods

2.1. Data collection

An online questionnaire was set up using the Google Forms platform in order to collect the necessary data for analysis (Supplementary File 1). Data collection took place in Italy over a period of four months. Participation was voluntary and anonymous, and respondents were free to withdraw from the survey at any time. Informed consent was obtained in accordance with the EU Regulation No 679/2016 and the national ethical requirements of the Italian Personal Data Protection Code (Law Decree No 196/2003). The questionnaire began with a preface explaining the research aims and providing the following definition of the DNA-based certification scheme: "Genetic certification can identify species through DNA extracted from tissue samples. It guarantees that the fish you are buying and consuming corresponds to what is stated on the label". The questionnaire was designed as a survey-based stated preference study aimed at eliciting consumers' attitudes, behaviours and

preferences. It adopted a contingent valuation framework to assess respondents' interest in and WTP for a hypothetical DNA-based certification scheme using a payment-card format for WTP elicitation, while interest in the certification scheme was assessed through a dichotomous response format. Specifically, the questionnaire was structured into two sections: (i) consumers' socio-economic features and fish consumption habits, using predefined categorical response formats (nominal or ordinal, depending on the variable). This section also investigated respondents' ability to recognise the most frequently consumed fish species according to the European Market Observatory for Fisheries and Aquaculture Products (EUMOFA, 2024), shown through six pictures (three whole specimens and three fillets). Specifically, the three whole specimens were Atlantic mackerel (*Scomber scombrus*), European hake (*Merluccius merluccius*) and European seabass (*Dicentrarchus labrax*), while the three fillets were Nile perch (*Lates niloticus*), Blue shark (*Prionace glauca*) and Smooth-hound (*Mustelus mustelus*). Respondents were asked to write the name of the species under each image in an open-ended format, which was adopted to avoid guessing effects associated with multiple-choice options and to better capture respondents' actual species recognition ability. All images were presented in the same order and standardized in terms of visual quality to ensure consistency in the identification task. However, the size of the fish in the images did not necessarily correspond to their real-world dimensions; (ii) consumers' knowledge of fish and aquaculture certifications, measured on ordinal categorical scales (none, partial, high), the WTP, a premium price for genetically certified fish, was elicited through predefined intervals (payment-card format based on percentage premium categories), and interest in purchasing genetically certified fish was measured through a dichotomous contingent valuation format. Before distribution, the questionnaire was validated through a pilot test by involving a small sample of 20 consumers. Subsequently, it was distributed via social media (i.e., WhatsApp, Facebook, LinkedIn). The data collection provided a convenience sample of 408 Italian fish consumers. This sampling approach, particularly the snowball technique, was adopted to obtain an exploratory dataset capturing a wide range of consumer characteristics, attitudes and behaviours. This method is typically associated with cost-efficiency and ease of data collection. Although this approach does not allow statistical representativeness of the target population, it is commonly used in exploratory consumer research aimed at identifying relevant patterns and relationships among variables (Bimbo et al., 2022). As a consequence, the composition of the sample may not reflect the broader population in terms of the socio-demographic structure, behaviours and attitudes, and may therefore be subject to sampling bias. Accordingly, the results should be interpreted as indicative of patterns within the surveyed sample rather than as statistically representative of the general population.

The data collection yielded 411 completed questionnaires, of which 408 were correctly filled in and formed the final database. The geographic origin of respondents was not included among the variables analysed in this research, as it focuses on consumers' characteristics, attitudes and behaviours related to fish consumption. Moreover, since the questionnaire link was shared through social media, the total number of individuals who received the survey cannot be determined; therefore, a response rate cannot be calculated.

2.2. The decision tree

The dataset obtained from the questionnaire was then elaborated through the decision tree, using the Orange Data Mining software (version 3.38.0). In this research, the decision tree was used as an exploratory analytical tool aimed at identifying the patterns and relationships among the variables within the surveyed sample, rather than drawing conclusions about the broader population or developing a predictive model intended for population-level generalisation. The decision tree is considered an intuitive and frequently used technique in data science, having several advantages reported in the scientific literature (Ottomano Palmisano et al., 2021; Piscitelli et al., 2023; Smith, 2017; Song and Lu, 2015; Tan et al., 2019; Witten et al., 2025). The decision tree: (i) selects only the most relevant input variables from the dataset involved in the formulation of consumer decision-making; (ii) identifies the key variables among those selected. The greater the importance of a variable, the higher its effect on consumer choice. The decision tree also: (iii) deals with both numerical and nominal variables; (iv) handles missing data by setting them as target variables to be replaced with predicted values.

The decision tree has the shape of a flowchart made up of nodes and branches, where the variables are analysed. The main steps for building the decision tree are splitting, stopping and pruning (Witten et al., 2025). Splitting divides a node into two or more child nodes; only the input variables linked to the dependent (target) variable are used to split the nodes into purer child nodes. Stopping determines when to end splitting, while pruning reduces the tree complexity by removing sections that may be based on noisy or erroneous data. Basically, the C4.5 algorithm performs the variables evaluation and selection through a top-down induction process. At each node, all the input variables are compared and the variable maximizing the gain ratio is selected to partition the data into increasingly homogeneous subgroups (Quinlan, 1993; Rokach and Maimon, 2015; Witten et al., 2025). The gain ratio favours the variables providing stable and informative discrimination while penalising overly fragmented or unbalanced partitions (Molnar, 2022; Quinlan, 1993; Tan et al., 2019; Zhou, 2012). Therefore, the variables are not excluded a priori, but they are omitted from the final tree when they do not provide additional discriminatory power at any node, when their information content is redundant with respect to other variables, or when their contribution is removed during reduced error pruning aimed at limiting overfitting (Cherfi et al., 2018; Hall et al., 2003).

In this research, the C4.5 algorithm was applied following the procedure firstly described by Quinlan (1993). The variable "interest in a genetic certification scheme" was selected as the target variable (i.e. the dependent variable), while the other variables were considered as input variables. The specific C4.5 parameters set to build the decision tree were gain-ratio as the splitting criterion, a minimum of 9 instances per leaf to control tree complexity and preserve interpretability, and reduced error pruning to mitigate potential overfitting. The model performance was evaluated using leave-one-out cross-validation (LOOCV) applied to the full sample. Under LOOCV, each observation is iteratively used once as a test case while the remaining observations are used for training. This procedure provides an out-of-sample assessment of the model performance and mitigate optimistic bias. Also, the confusion matrix (Table 4) was calculated to evaluate the classification performance of the C4.5 algorithm considering the dataset. This matrix provides the overall accuracy of classification, as the ratio between the correct classified consumers (reported along the diagonal of the matrix) and all the consumers, and can be expressed as a percentage (Ting, 2011). A classification algorithm performs well when the classification accuracy is higher than 70% (Lantz, 2013).

For a more detailed description of the decision tree procedure and the C4.5 algorithm, see Cherfi et al. (2018); Ottomano Palmisano et al. (2021); Piscitelli et al. (2023); Quinlan (1993); Singh & Giri (2014); Smith (2017); Tan et al. (2019); Witten et al. (2025).

3. Results and discussion

3.1. Socio-economic and demographic characteristics of consumers

The socio-economic and demographic characteristics of the sample are reported in Table 1. The overall sample consisted of 408 Italian consumers, of whom 54.2% were female. In terms of age, 35.6% of respondents were aged 20–29, about 21% were aged 50–59, while 15.7% were aged 30–39. The relatively high proportion of younger respondents may partly reflect the online mode of questionnaire distribution, which

Table 1
Summary of the socio-economic and demographic characteristics of the sample.

Variable and code	Scale of measurement	Frequency (no.)	Percentage (%)
Gender [Gender]	Male	179	43.9
	Female	221	54.2
	Prefer not to say	8	2.0
Age [Age]	<19 years old	3	0.7
	20–29 years old	149	36.5
	30–39 years old	64	15.7
	40–49 years old	62	15.2
	50–59 years old	87	21.3
	60–69 years old	38	9.3
	70–79 years old	4	1.0
	>80 years old	1	0.2
Household members [House_memb]	1	33	8.1
	2	82	20.1
	3	99	24.3
	4	150	36.8
	>4	44	10.8
Education level [Edu]	Primary school degree	2	0.5
	Secondary school degree	16	3.9
	High school degree	161	39.5
	University degree	229	56.1
Monthly household income [Income]	Low (with my income, I struggle to make ends meet).	62	15
	Medium (my income is sufficient to make ends meet)	232	57
	High (my income allows me to save money).	114	28

tends to facilitate participation among younger individuals who are generally more familiar with web-based survey tools. It may also be due to the non-probability sampling approach adopted in the research. About 37% of respondents had a family made up of four members, followed by three (24.3%) and two (20.1%). Regarding education level, about 56% of respondents held a university degree, followed by high school qualifications (39.5%). Similarly to the age distribution, the relatively high share of respondents with a university degree may partly reflect the online mode of questionnaire distribution, which often facilitates participation among individuals with higher levels of education, and the non-probability sampling approach adopted. Finally, most of the respondents (57%) declared that their household monthly income allowed them to make ends meet (i.e., medium level), 28% claimed to put money aside at the end of the month (i.e., high level), while only 15% of respondents claimed to have an income that does not allow them to make ends meet (i.e., low level). As data collection was based on a convenience sample, these results suggest that socio-demographic factors may play a role in fish consumption patterns, in agreement with a previous study performed in Nigeria, Portugal, Bangladesh and the United States (Issifu et al., 2022). However, this procedure, less expensive and requiring less time than other sampling methods, was considered suitable for the explorative aim of the research.

3.2. Consumer purchasing habits and behaviours

Table 2 shows the respondents' purchasing habits and behaviours. Specifically, most of the respondents (43%) reported consuming fish weekly, while approximately 18% indicated less frequent fortnightly consumption. Almost the same proportion of consumers declared a monthly and rare consumption. Fewer than 20% of respondents who declared a frequency of consumption of more than once a week, fully complied with national guidelines. These findings are consistent with previous research conducted in Bangladesh by Rahman & Islam (2020), which reported comparable trends in fish consumption patterns. This consumption pattern is consistent with the steady per capita

Table 2
Consumers' purchase habits, behaviours and knowledge.

Variable and code	Scale of measurement	Frequency (no.)	Percentage (%)
Fish purchase frequency [Fish_pur_freq]	Rarely	44	10.8
	Monthly	34	8.3
	Fortnightly	75	18.4
	Weekly	175	42.9
	More than once a week	80	19.6
Average weekly spending for fish [Week_spend_fish]	<10 €	77	18.9
	Between 10 and 20 €	169	39.7
	>20 €	162	41.4
Type of purchased fish [Type_pur_fish]	Frozen (slices, fillets, preparations)	26	6.4
	Fresh (whole fish)	127	31.1
	Various types (fresh/frozen/canned or smoked)	249	61.0
	Canned or smoked	6	1.5
Origin of purchased fish [Origin_pur_fish]	Farmed fish	22	5.4
	Caught fish	193	47.3
	Both farmed and caught fish with the same frequency	69	16.9
	I do not pay attention	124	30.4
Place of usual purchase [Where_buy]	Direct purchase from the fishermen or fish farmers	8	2.0
	Street market	21	5.1
	Specialized retailers or departments of the large-scale distribution	182	44.6
	Large scale distribution (supermarkets without a seafood department)	47	11.5
	Various places	150	36.8
Knowledge of sustainable fishery certification (MSC and FOS) [K_MSC_FOS]	None (two wrong answers)	204	50.0
	Partial (one correct answer)	172	42.2
	High (two correct answers)	32	7.8
Knowledge of sustainable aquaculture certification (GLOBAL G.A.P. and ASC) [K_GGAP_ASC]	None (two wrong answers)	280	68.6
	Partial (one correct answer)	118	28.9
	High (two correct answers)	10	2.5
Trust in the information reported on the label of purchased fish [Label_decl]	I am not always sure	215	52.7
	I am always sure	122	29.9
	I do not pay attention	71	17.4
Habit to purchase certified fish [Buy_certif_fish]	Never	12	2.9
	Occasionally	89	21.8
	Always	115	28.2
	I do not pay attention	192	47.1
Interest in a genetic certification scheme for fish products (dependent variable)	No	111	27.2
	Yes	297	72.8
WTP for genetically certified fish with respect to similar product not certified [WTP_genetic_cert]	I would not pay a premium price	96	23.5
	At most 5% more than the price of not certified fish	178	43.6
	At most 10% more than the price of not certified fish	100	24.5

(continued on next page)

Table 2 (*continued*)

Variable and code	Scale of measurement	Frequency (no.)	Percentage (%)
	Over 10% more than the price of not certified fish	34	8.3

consumption level in Italy which reached 30 kg per person in 2023, higher than the EU average (23.51 kg per person) (EUMOFA, 2024). The positive attitude of Italian consumers towards fishery products is correlated with a good availability of fishery products due to Italy's extensive coastal access, traditional fish-eating cultures, and growing awareness of the health benefits associated with fish intake (Lofstedt et al., 2021; Sacchettini et al., 2021).

Regarding weekly spend on fish products, many consumers (41.4%) claimed to spend >20 euros, followed by 39.7% who spend between 10 and 20 euros per week. This characteristic aligns with the well-established tendency of Italian consumers to allocate a substantial portion of their food budget to fish products. According to EUMOFA data, Italy heads the EU table for total family spending on fishery and aquaculture products, in both absolute terms (12,875 M€) and in terms of growth trends (+6% between 2022 and 2023) (EUMOFA, 2024). In 2023, EU households spent an average of over 138 euros per capita on fish and seafood products, compared to Italian consumers who spent 218 euros per capita and ranked fourth after Portuguese, Spanish, French and Luxembourg citizens. Italian consumers confirm their preference for fish products, spending around a quarter on fish compared with their meat budget, with all other countries showing lower percentages (EUMOFA, 2024). Such a trend may be related to Italian consumers' awareness about the health benefits of seafood (Sacchettini et al., 2021).

Furthermore, the majority of respondents (61%) reported consuming different forms of fish in combination, i.e., fresh, frozen, canned, or smoked, while less than a third (31%) preferred to consume only fresh fish, mirroring the global trend towards diversifying the processing and preparation of fish as part of a diet (Golden et al., 2022; Sun et al., 2023). Moreover, these findings are in accordance with the (EUMOFA, 2024) EU Fish Market report (2024), which in 2023 highlighted a decline in household fresh fish consumption due to rising prices (EUMOFA, 2024). It should be noted that, during the pandemic emergency of COVID-19 between 2020 and 2022, following the crisis of the restaurant and hospitality sector, an increase in household consumption of fresh seafood was observed. Additionally, approximately 47% of consumers expressed a preference for wild-caught over farmed fish. This result may reflect the commonly reported perception that wild fish are more natural, healthier and of higher quality than farmed fish. Previous studies have shown that farmed fish often have a less favourable image compared to their wild-caught counterparts, partly due to consumer concerns about freshness and antibiotic use and, more generally, limited awareness of the benefits of aquaculture products (Bimbo et al., 2022; Carlucci et al., 2015, p.; López-Mas et al., 2021, 2023).

Moreover, around 30% of respondents do not consider the origin of the fish they purchase. As other authors reported (Carrassón et al., 2021; López-Mas et al., 2023; Menozzi et al., 2023) consumers' lack of information about aquaculture and the quality of farmed products, and limited knowledge of production methods can lead to confusion at the point of purchase, affecting consumer trust and acceptance of seafood in the marketplace.

Regarding the place of usual purchase, 44.6% of consumers preferred to buy fish from specialized retailers or from specialized large-scale distribution departments, followed by 11.5% who buy fish from supermarkets without a seafood department and by 5.1% from local street markets. The data reveal that organized food distribution systems (encompassing logistics, cold-chain, traceability, and data-driven inventory strategies) play a key role in modern food purchases. They enhance and ensure food safety, improve operational efficiency and cost savings, support sustainability, and foster consumer confidence and satisfaction (Burgess et al., 2024; Burgess and Sunmola, 2022).

Concerning consumer awareness of seafood certification, Table 2 showed low awareness of certification schemes for fisheries and aquaculture, particularly MSC, FOS, GLOBAL G.A.P., and ASC. Indeed, half of the sample had no knowledge of MSC and FOS certifications, and over 40% had only partial knowledge. Similarly, approximately 68% of respondents were unaware of GLOBAL G.A.P. and ASC certifications, while approximately 29% had partial knowledge of them. Low awareness of seafood certifications is a widespread phenomenon. Indeed, Winson et al. (2022) observed limited consumer awareness on the Canadian market, while Jonell et al. (2016) found low awareness on the Swedish market. Again, in small comparative studies conducted on a city in the United States and one in the United Kingdom; Gutierrez & Thornton (2014) observed low recognition of seafood certifications. Moreover, this study aligns with the findings of Fiorile et al. (2023), who examined consumer knowledge of seafood traceability and awareness of sustainability certifications in Italy and Spain. Similarly, the present study highlights the importance of raising consumers' awareness of certifications in order to encourage them to choose products with sustainability labels (Calvo Dopico et al., 2016). Therefore, targeted dissemination strategies are essential for increasing public knowledge of seafood traceability and sustainability. These efforts may encourage more informed purchasing decisions and reward companies that provide transparent, detailed information while adhering to animal welfare and environmental standards (Fiorile et al., 2023).

The results also highlight the low level of consumer trust in the information displayed on product labels. Indeed, more than half of the sample (52.7%) said they were not always trustful of label claims, while approximately a third stated they were always sure, emphasizing the need to strengthen trust through more effective seafood labelling (Czarnezki et al., 2015; Penca, 2020). In this context, the introduction of a possible DNA-based certification could represent an innovative and valuable advance, although only about a third of consumers ever buy certified fish and about 47% of consumers do not pay attention to buying certified fish. Such certification would contribute to increasing the reliability and scientific validity of the information presented on the label, offering consumers greater transparency and assurance regarding the product authenticity and safety. To the best of our knowledge, research specifically addressing consumers' interest in DNA-based certification schemes for fish products remains scarce. In the present research, over 72% of respondents expressed interest in such a certification scheme. These findings indicate a growing consumer sensitivity towards issues of food authenticity and the potential value of certification systems aimed at improving transparency in seafood supply chains. Specifically, the results reveal significant interest in DNA-based certification as an effective response to the rising complexity of global seafood supply chains and the associated risks of fraud, including species substitution, mislabelling of geographical origin, and product adulteration. The findings also suggest that consumers recognise the potential role of DNA-based certification as a tool to prevent fraudulent practices – often proving more reliable than traditional labelling and certification systems. These genetic methods are increasingly recognised as emerging and powerful molecular tools for food authenticity verification, offering improved species identification and traceability across various sectors of the food industry (Kumar et al., 2022).

The interest in DNA-based certification is further confirmed by the other point regarding WTP for genetically-certified fish: approximately 44% of Italian consumers stated that they were willing to pay a maximum of 5% above the price of non-certified fish, followed by 24.5% who were willing to pay a maximum of 10% more, while 23.5% would not pay a premium price. Furthermore, the data obtained regarding consumers' WTP a premium price for certified seafood are broadly consistent with literature on consumer attitudes towards certified seafood products, including studies by Asche & Bronnmann (2017), Jaffry et al. (2016) and Vitale et al. (2020). It should be noted that the WTP

measure reported in this research is intended as an indicative measure of consumers' price attitudes towards the proposed certification rather than a precise economic valuation. Specifically, the WTP was elicited using a simplified contingent valuation approach based on a payment-card format, capturing respondents' stated maximum acceptable premium price for genetic certification compared to an otherwise identical uncertified product. While this approach is commonly used in exploratory studies, it does not rely on a full random utility–based framework and therefore does not aim to estimate exact monetary valuations.

The observed consumer interest and WTP for verifiable species authentication suggest that the development of molecular certification tools could provide tangible benefits for consumers, producers and regulators (Hassoun et al., 2022). However, the practical implementation of such a scheme would involve additional costs related to molecular testing, administrative management, and compliance monitoring (Liberty et al., 2025; Stein et al., 2014). These costs would include laboratory analyses for species identification, certification management procedures, and periodic verification activities along the supply chain. Nevertheless, the continuous reduction in the cost and turnaround time of molecular techniques may progressively improve the economic feasibility of DNA-based authentication. From an operational perspective, standardized molecular methods are already available (e.g., UNI EN ISO 17174:2024, ISO 22949–1:2021, EN ISO 20813:2022, UNI CEN/TS 17303:2019), and verification procedures could be carried out through accredited laboratories and independent third-party certification bodies. Compliance could be monitored through targeted analytical testing, documentation checks, and periodic audits conducted within existing food control frameworks (Di Pinto et al., 2019). Importantly, a DNA-based certification scheme would not replace current traceability systems but rather complement them. While conventional traceability mechanisms primarily rely on documentation and product labeling, DNA-based authentication would provide an additional layer of verification by directly confirming species identity at different stages of the supply chain. In this sense, molecular certification could function as an independent validation tool that strengthens the reliability of existing traceability mechanisms and helps detect potential cases of species substitution or mislabeling.

3.3. Consumers' ability to recognise fish species

The study demonstrated that consumers generally have a limited ability to identify various fish species, often struggling to distinguish between common commercial fish, with accuracy rates varying depending on the species (Table 3). Factors such as familiarity with retailed fish (e.g., whole vs. filleted) and consumption habits might influence identification success. When consumers were asked to recognise fish species via images, the questionnaire results showed overall difficulty, for both whole and filleted specimens.

Table 3
Consumers' ability to recognise fish species.

Variable and code	Scale of measurement	Frequency (no.)	Percentage (%)
Ability to identify the whole fish specimen [Know_whole_fish]	None (three wrong answers)	118	28.9
	Low (one correct answer)	91	22.3
	Medium (two correct answers)	115	28.2
	High (three whole specimens correctly identified)	84	20.6
Ability to identify the fish fillets [Know_fillet_fish]	None (three wrong answers)	375	91.9
	Low (one correct answer)	31	7.6
	Medium (two correct answers)	2	0.5
	High (three fillets correctly identified)	0	0.0

Regarding whole specimens, approximately one-third of consumers (28.9%) failed to identify any of the three species, while 28.2% of consumers identified two, corresponding to medium ability. Furthermore, 22.3% of consumers showed low ability, identifying only one specimen, and only approximately 20% identified all three specimens. Furthermore, the majority of the sample was unable to identify any of the three species in fillet form (91.9%), followed by only 7.6% and 0.5% of consumers who identified one and two fillets, respectively, corresponding to low and medium ability. None of the consumers identified all three fillets. The lack of familiarity among Italian consumers with the appearance of the most common fish species sold in Italy was confirmed by the specific identification rates (Fig. 1 A-B). Indeed, as expected, correct identification of whole specimens was higher than fillets. In particular, the rate of correct identification of whole specimens was 47.1% while only 9.2% of correct identifications was observed for fillets. Among the whole specimens, Atlantic mackerel was the fish that was most correctly identified by 60.5% of consumers, followed by seabass that was correctly identified by 52.2% of consumers. Surprisingly, hake, a popular fish species, highly appreciated by consumers in southern Europe and widely used in baby foods (Pappalardo et al., 2020; Quinteiro et al., 2001), was recognised only by 28.7% of respondents, probably because it is mainly purchased in prepared or processed forms such as fillets, sticks and cutlets. Atlantic mackerel was mainly confused with sardine or seabass in 20.7% of cases, and with hake in 16.1% of cases. Sea bass was confused with gilthead sea bream in 50.8% of cases, while 16.1% of respondents mistook sea bass for trout (16.1% cases) or for salmon (7.6% cases). Hake was mainly confused with red mullet (28.9% of incorrect answers), seabass (11.6% of incorrect answers), mackerel (9.9% of incorrect answers) or sardine (8.3% of incorrect answers). A high rate of incorrect answers was registered when trying to identify fillets: perch was the most correctly identified species (19.6% of answers), followed by blue shark (4.4% of answers), and smooth-hound (3.7% of answers). In detail, fillets of Nile perch were mainly confused with salmon, hake, plaice or grouper (16.2%, 10.7%, 10% and 7.9% of incorrect answers); slices of blue shark were mainly confused with swordfish, common smooth-hound or tuna (52.8%, 10.3% and 5.3% of wrong answers); and common smooth-hound slices were mainly erroneously associated with swordfish, hake, or grouper (15.8%, 9.7% and 6.4% of wrong answers), respectively. Our results were in line with the overall European consumers' inability to identify and distinguish fish species available on the market, as previously investigated by Cusa et al. (2021), who underscored a persistent gap in consumer knowledge that compromises the effectiveness of informed choices. Therefore, seafood market transparency remains open to malpractice and fraud (Cusa et al., 2021), as the lack of species recognition facilitates undetected mislabelling or substitution of products. These findings highlight the urgent need for improved transparency and traceability measures within the seafood supply chain to protect consumers from fraudulent actions.

3.4. Decision tree interpretation

The application of the C4.5 algorithm provided a decision tree describing the decision-making process in the event that a DNA-based certification scheme for fish products were to be introduced. It consists of 4 main branches, 5 levels, 47 nodes and 12 variables (Fig. 2). The algorithm generated the tree structure through a top-down induction process based on the gain ratio criterion combined with the reduced error pruning to limit overfitting (Quinlan, 1993; Witten et al., 2025). Given the exploratory nature of the research and the sample size ($n = 408$), the resulting model shows a balanced level of complexity with limited depth, indicating a satisfactory ability to identify stable patterns in responses (Ford et al., 2023; Lantz, 2013; Ottomano Palmisano et al.,

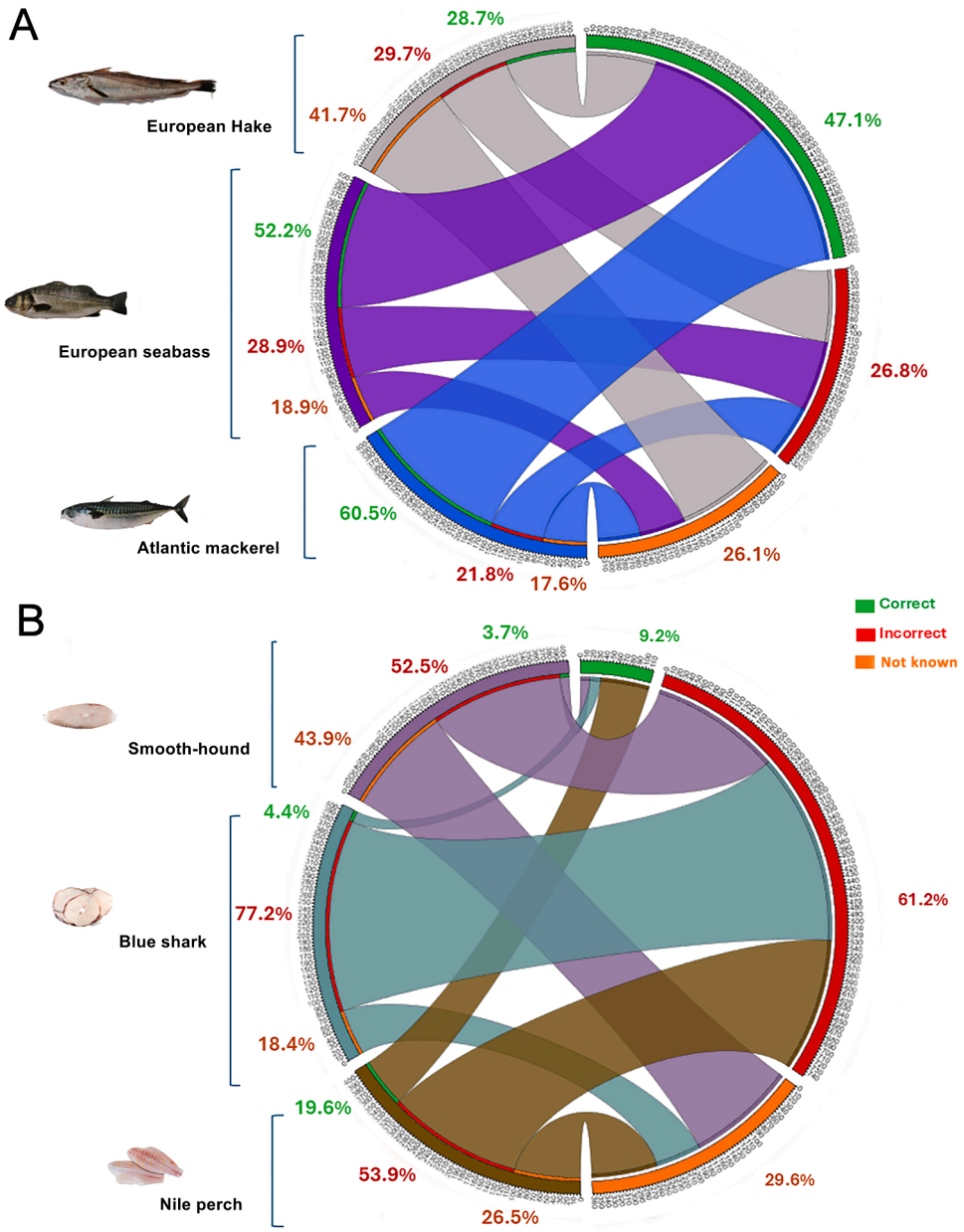


Fig. 1. The rates of identification of single species as whole specimens (A) and fillets (B).

2021; Piscitelli et al., 2023).

It should be noted that some variables were not included in the tree, namely "Number of household members", "Origin of purchased fish", "Ability to identify the species as whole fish", "Ability to identify the species as filleted fish" and "WTP for genetically-certified fish with respect to similar uncertified product". This is because, with the C4.5 tree-building procedure, these variables failed to provide any additional improvement in the classification of consumers' interest beyond the variables already selected, since the algorithm retains only variables that provide the largest improvement in classification at each split. Accordingly, the variables included in the decision tree should be interpreted as the most relevant attributes associated with consumers' interest in DNA-based certification, rather than as an exhaustive or causal ranking of all potential determinants, which is consistent with the use of decision trees in food-related consumer research (Carrillo et al., 2023; Ford et al., 2023; Vindigni et al., 2022). Apart from the variable-selection mechanism of the C4.5 algorithm, some interpretative insights can be drawn from the exclusion of certain variables from the final decision tree. With reference to the exclusion of consumers' ability to identify fish species, the model structure suggests that objective product knowledge may play a more limited role in shaping interest in DNA-based certification. Conversely, the model highlights the greater relevance of behavioural and socio-economic factors in shaping consumers' interest. This interpretation is consistent with previous research indicating that consumers often rely on behavioural and informational cues when product characteristics cannot be directly verified (Macready et al., 2025; Peiró Signes et al., 2023). The absence of WTP from the final tree may also reflect its conceptual relationship with interest in DNA-based certification, as WTP can be interpreted as a potential behavioural consequence of such interest rather than a determinant of it.

The red boxes in Fig. 2 indicate non-interest in a DNA-based certification scheme, while the green boxes highlight consumers' interest; the increasing colour intensity indicates the "magnitude" of interest (green) and non-interest (red). The overall results showed a strong consumer interest in a DNA-based certification scheme for fish products, in line with previous studies exploring consumers' interest in quality,

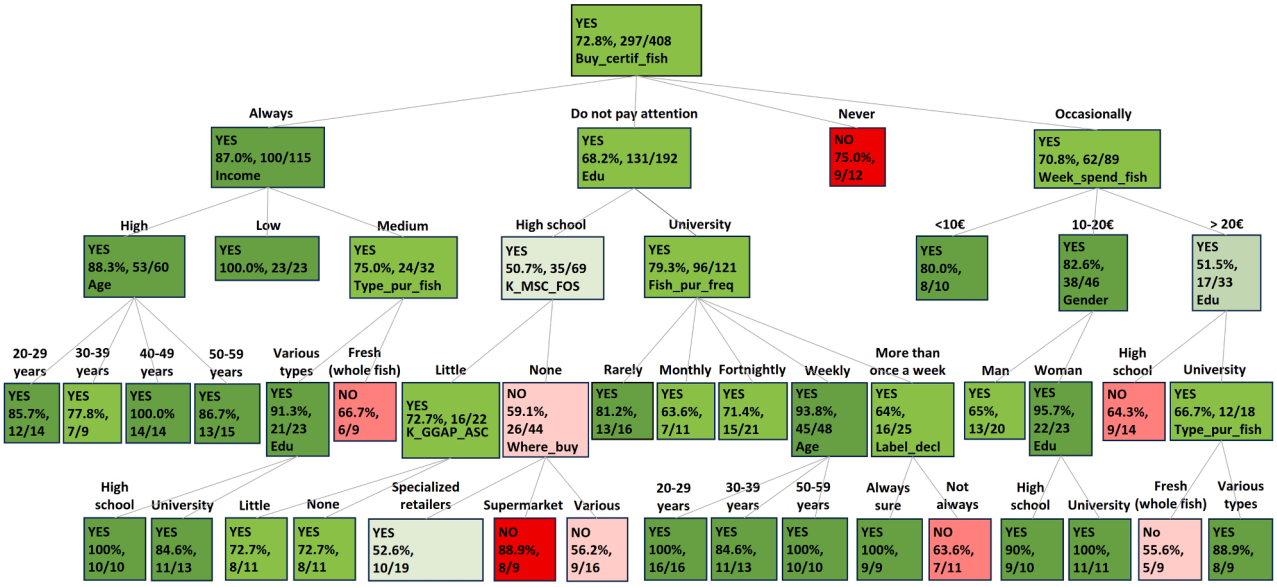


Fig. 2. The decision tree resulted from the application of the C4.5 algorithm.

safety and credence aspects related to these products (Bimbo et al., 2022; Calvo Dopico et al., 2016; Maesano et al., 2020).

Consumers' certified-fish purchasing habits emerged as the most discriminative variable in the model, accounting for 297 out of the 408 respondents. It generated four branches as the number of categorical values assumed by this variable. Consumers who always buy certified fish products in general were greatly interested in a DNA-based certification of fish species (100 consumers out of 115). The use of labels reporting credence cues is an important search attribute for consumers and a key tool for promoting sustainable fish products; in fact, these labels can guide consumers' choices in line with their specific attitudes and preferences (Maesano et al., 2020). Moreover, Galati et al. (2022) highlighted a positive relationship between consumers' purchase intention and their interest in information on the labels of certified fish products; in this regard, the authors found that consumers are looking for certification schemes, because they reflect their concerns for the protection of natural resources and the well-being of society as a whole. Also, Carlucci et al. (2015), De Devitiis et al. (2018), Nicolosi et al. (2021) pointed out that Italian consumers are very interested in several reputational attributes related to certified fish products, such as the sustainable use and management of natural resources, the support for local fishing communities and the use of sustainable fishing practices.

The greatest interest was reported by the consumers with a low income (23 out of 23), followed by consumers with high income (53 out of 60) aged between 40 and 49 years (14 out of 14) and between 50 and 59 years (13 out of 15). This heterogeneity in terms of income and age is in line with research by Carlucci et al. (2015), who found that the scientific literature on purchasing behaviour towards fish and seafood products led to very different consumers' socio-demographic profiles, particularly in relation to sustainable labelling. However, it should be noted that the subgroup of consumers with low income includes a limited number of observations; therefore, this specific result should be interpreted with caution as classifications based on small terminal nodes may be statistically unstable.

Non-interest was declared by consumers with medium income level and who usually buy fresh whole fish (6 out of 9). This purchasing behaviour is consistent with the results reported by Fiorile et al. (2023), who pointed out that the consumers more accustomed to buying fresh whole fish may believe there is no point in receiving further information, since they are confident in their own ability to recognise the species purchased.

Although the largest group of consumers (131 out of 192 in this node) do not pay attention to certifications when purchasing fish products, they were quite interested in a DNA-based certification. Among these consumers, those holding a university degree (96 respondents) showed a higher level of interest than those with a high-school diploma. Many authors pointed out that a high level of education can stimulate greater attention to healthy diets, increase awareness and concerns about the risks associated with food adulteration, and steer purchases towards more guaranteed fish products (Hoque et al., 2022; Menozzi et al., 2020). However, the relatively high proportion of respondents with a university degree in the sample may also influence the observed interest in DNA-based certification, as higher education levels are often associated with greater awareness of food attributes and certification schemes (Annunziata and Vecchio, 2013; Grunert et al., 2014). A further analysis of these university graduates highlighted that the greatest interest was found among those buying fish products weekly (45 out of 48) regardless of their age. This result is corroborated by the research of Cantillo et al. (2021), who reported that the increase in consumption of fishery and aquaculture products is strongly influenced by their origin, quality labels, and environmental, social or ethical impacts. On the other hand, non-interest was declared by 7 university graduates out of 11, who purchase fish products more than once a week and are not always sure that the species of a fish product is as declared on the label. This result seems to be more strongly associated with consumers' trust in the information reported on product labels, rather than with their education level and purchase frequency alone. In this regard, Saidi et al. (2022) carried out an exploratory analysis in Mediterranean countries to investigate the drivers of fish product choices, and found that trust in the supply chain is a very critical element in guiding the decisions of consumers, especially towards local products. Among consumers with a high school diploma, lack of interest was primarily reported by those unfamiliar with MSC and FOS certifications (26 out of 44). This was especially evident among those purchasing fish products from supermarkets without seafood department (8 out of 9) or via alternative channels, such as direct sales from fish farms, street markets, specialized shops or departments within large retail chains (9 out of 16). In this regard, Menozzi et al. (2020) emphasized the need to bring in effective strategies to educate European consumers about the importance of seafood certifications, which serve as key tools for communicating both supply chain sustainability and associated health benefits. Moreover, Giacomarra et al. (2021) found that MSC and FOS

certifications play a key role in raising awareness of sustainable fish, and consequently are therefore instrumental in supporting the transition towards sustainable consumption patterns.

A small number of consumers who never purchased certified fish (9 out of 12) were not interested at all. This finding is in line with the research by Aung & Chang (2014), who underlined that such tools alone may not guarantee food safety, quality and authenticity.

Finally, 62 consumers out of 89 who occasionally paid attention to purchasing certified fish products expressed interest regardless of their weekly expenditure, although those spending more than 20€ weekly showed comparatively less interest. Recent research points out that, due to the globalisation of food systems, consumers are increasingly concerned about food safety, quality and origin fraud of fish products, and are therefore seeking more reliable information. Nevertheless, the information provided may be perceived as unclear and not easily accessible (Rodriguez-Salvador and Calvo Dopico, 2023; Zander et al., 2022). Among them, 11 female university graduates spending between 10€ and 20€ weekly were strongly interested. This result is supported by previous research, showing that consumers with higher levels of education tend to have a more positive attitude towards certified fishery and aquaculture products (Brécard et al., 2009; Polymeros et al., 2014; Salladarré et al., 2010). Additionally, Marinac Pupavac et al. (2022) found that women with higher levels of education tend to consume fish products more frequently, primarily due to their belief in the associated health benefits. Conversely, 9 out of 14 consumers with a high school diploma who spent more than 20€ weekly on fish expressed no interest. This higher weekly expenditure on fish products could reflect a preference for premium-priced products and/or larger quantities purchased. According to the first hypothesis, in line with previous findings (Maciel et al., 2013; Saidi et al., 2022; Santeramo et al., 2018), it can be assumed that a high price is perceived as a sign of high quality. Price may reassure consumers about the quality of the fish they purchase, independently of the presence of certifications. Alternatively, the higher weekly expenditure may reflect the purchase of larger quantities of fish products by consumers who feel more confident in their ability to identify fish species accurately (Santeramo et al., 2017). Likewise, a lack of interest was reported by 5 out of 9 graduates with the same weekly expenditure who typically purchased whole fresh fish. This purchasing behaviour is consistent with the findings of Fiorile et al. (2023), who observed that consumers who are more accustomed to buying whole fresh fish often see no need for additional information, since they are confident in their own ability to identify fish species without help. Overall, a higher level of interest in certifications guaranteeing the authenticity of the ingredients shown on the label was observed among consumers accustomed to diversifying their purchases including both fresh whole fish and processed products. Processed products, especially those containing mixed ingredients such as surimi, fish burgers, and breaded cutlets, are especially vulnerable to fraudulent substitution, as consumers often struggle to detect undeclared or foreign ingredients (Hu et al., 2025; Lorusso et al., 2024; Piredda et al., 2022; Zhang et al., 2025). Furthermore, it is important to note that processed fish products, such as frozen, canned or smoked fish, are more frequently certified as sustainable than fresh whole fish (Marine Stewardship Council, 2024). This suggests that consumers who regularly buy different types of processed fish may be more familiar with certifications.

The accuracy of the C4.5 algorithm was calculated using the confusion matrix (Table 4), by computing the ratio between the number of correctly classified consumers (on the diagonal of the matrix) and the total number of consumers. The matrix rows show consumers in actual classes, whereas the columns correspond to the predicted classes. Table 3 shows the cross-validated classification accuracy of 0.74, indicating a satisfactory predictive performance for an exploratory consumer-behaviour model. This score means that 74% of consumers were correctly classified in terms of their interest in DNA-based certification for fish products, suggesting that the C4.5 algorithm performed an overall reliable classification. Thus, the results can be considered valid.

Table 4
The confusion matrix. Each column reports the consumers in a predicted class (YES - interest in a DNA-based certification; NO – lack of interest), while each row includes the consumers in an actual class. Correct classified consumers are reported in the diagonal.

		PREDICTED		
		NO	YES	TOT.
ACTUAL	NO	39	72	111
	YES	34	263	297
	Tot.	73	335	408

4. Conclusions

This exploratory research provides preliminary insights into consumer interest in a DNA-based certification scheme aimed at preventing unintended or fraudulent substitution of fish species. The decision tree highlighted that a significant proportion of consumers, who overall demonstrated very limited abilities to recognise fish species, may perceive DNA-based certification as a potentially reassuring tool.

The most important variables influencing consumers' interest were prior habits of purchasing certified fish, household income and education, and household weekly spending on fish products. These were followed by age, type of fish purchased, awareness of sustainable fishery certifications, frequency of fish purchases, place of purchase and trust in the labelling information. Unsurprisingly, around a quarter of consumers, although interested, declared that they would not be willing to pay a premium price for fish whose species is guaranteed by DNA-based certification. This reluctance may stem, on one hand, from an overestimation of their ability to recognise fish species and a limited understanding of the benefits offered by such certification; on the other hand, it may reflect a belief that food safety is a right that should be ensured by public authorities at no additional cost to the consumer. The implementation of DNA labelling could serve not only as a tool for the reliable characterization of seafood's added value, but also as a means to foster a more trustworthy relationship between consumers and the seafood sector. In this regard, it should be pointed out that implementing DNA-based certification is not a cost-free option for companies, as it entails compliance with stricter production and management standards than those applied to conventional products. The impact of the DNA-based certification costs depends not only on management skills and structure, but also on the volume of products placed on the market. As such, DNA-based certification can serve as an efficient tool for developing strategies and actions to improve supply chain efficiency, enhance consumer knowledge and awareness, and promote market transparency, ultimately supporting the overall safety and sustainability of fish supply chains.

5. Limitations and future research directions

This research has some limitations that should be considered. First, the data were collected through a non-probability sampling approach (i.e. snowball sampling). Although this approach is commonly used in exploratory consumer research, it does not ensure statistical representativeness of the broader population; therefore, the results should be interpreted as indicative of patterns within the surveyed sample.

Second, as with most survey-based studies, responses may be affected by social desirability bias. In addition, the responses about WTP should be interpreted with caution, as stated preferences may be subject to hypothetical bias. In this regard, no specific design features to control for hypothetical bias or anchoring effects (e.g. cheap talk scripts or certainty scales) were implemented, as the study adopts an exploratory approach. Therefore, WTP responses should be interpreted as indicative

attitudinal measures rather than precise economic valuations. Moreover, since the data are cross-sectional, the analysis identifies associations between variables rather than causal relationships.

Finally, the decision-tree model was used as an exploratory analytical tool to identify the patterns and relationships among the variables within the surveyed sample, rather than drawing conclusions about the broader population or developing a predictive model intended for population-level generalisation. Although the model was internally validated through leave-one-out cross-validation, external validation using independent datasets would further strengthen the robustness of the findings. Future research could therefore extend the analysis by using probability-based samples and benchmarking alternative machine-learning classifiers. Further studies could also investigate the determinants of species recognition ability, for example through recognition indices and their relationship with socio-demographic characteristics.

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Ethical statement

This study involved human participants through a voluntary survey. It did not include any experimental or clinical interventions on humans or animals, nor the collection, transmission, or dissemination of sensitive non-health-related personal data. Respondents were informed of the purpose of the study before completing the questionnaire. The information was collected anonymously and in compliance with EU Regulation No 679/2016 and Italian Legislative Decree No 196 of 30 June 2003, and was used exclusively in aggregate form. Participation could be withdrawn at any time, and informed consent was obtained from all participants. The research and data collection comply with current ethical standards.

CRediT authorship contribution statement

Giovanni Ottomano Palmisano: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Chiara Intermite:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Formal analysis, Data curation. **Anna Mottola:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Lucilia Lorusso:** Writing – review & editing, Writing – original draft, Visualization, Software, Investigation, Formal analysis, Data curation. **Lucia Ranieri:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation. **Roberta Piredda:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Rocco Roma:** Writing – original draft, Validation, Software, Investigation, Formal analysis, Data curation. **Angela Di Pinto:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Annalisa De Boni:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.fufo.2026.101037.

Data availability

Data will be made available on request.

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