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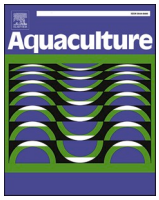

Insect-based feed in aquaculture: A consumer attitudes study

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ABSTRACT

The aquaculture industry is currently faced with the major challenge of finding alternative protein sources for feeding aquatic species. The goal is to mitigate the environmental impact of conventional feed production in order to satisfy the demand of consumers for sustainable and environmentally friendly food. Fishmeal and fish oil have been the predominant substrates used in the fish farming industry to date, but insects are now emerging as promising feed substitutes. However, the feeding of insects to fish continues to be perceived as unconventional by consumers, although only few studies have actually explored European consumers' attitudes towards animal food products fed with insects.

This study aimed to fill this gap by investigating consumer behaviors towards the consumption of fish fillets obtained from fish fed an insect-based feed. The overall goal was to understand the interconnection between sociodemographic variables, namely levels of knowledge, food neophobia, and food consumption sustainability, and attitudes towards feed quality, climate change, shopping sustainability, and the sustainability of insect-based feed. To this end, an online survey was conducted on 303 Italian consumers aged 18–78 years (52.4% men). The analysis of the dataset was conducted by modelling the independent categorical variables with their attitudes towards the four topics studied by Multiple Linear Regression, after having established their effects using the Pearson Chi-Square test and one-way ANOVA. Our results demonstrate that sociodemographic variables, such as gender and age, are strongly correlated with attitudes towards climate change, while diet is associated with attitudes towards shopping sustainability. The measured level of food consumption sustainability correlates with both attitudes. At the same time, a high level of knowledge correlates with a strong attitude towards the sustainability of insect-based feed. Overall, we conclude that providing specific groups of consumers with meaningful information related to the use of insect-based feed in aquaculture will increase the likelihood of their accepting this innovation. Our study also offers insights that can help identify categories of consumers who could be more interested in choosing products from insect-fed animals.

1. Introduction

The world population is expected to increase to 9 billion by 2050, with a consequent growth in the demand for food, including fish consumption (*The State of World Fisheries and Aquaculture* 2020, 2020). According to the FAO, from 1990 to 2018 global fish production (from capture fisheries and aquaculture) grew by 541% and consumption levels rose by 122% (*The State of World Fisheries and Aquaculture* 2020, 2020). In the report for 2022, the FAO states that 88 million tons of fish were produced through aquaculture in 2020 (49% of global fish production), with a total first sale value of USD 265 billion (*The State of World Fisheries and Aquaculture 2022,* 2022). Fish products provide high-quality nutrients for human consumption in both developed and developing countries. The role of aquaculture in the context of global food insecurity is also important: fish contributed 20% of animal protein intake for 3.2 billion people worldwide (Ahmed et al., 2019).

According to the European Market Observatory for Fisheries and Aquaculture (EUMOFA), a market intelligence tool on the European Union fisheries and aquaculture sector, developed to increase market transparency and efficiency, to analyze European market dynamics, and

Abbreviations: ACC, Acceptance; API, Aquaculture Plants in Italy; CCI, Climate Change Impact; EDU, Education; FCS, Food Consumption Sustainability; FNS, Food Neophobia Scale; FQ, Feed Quality; IBFS, Insect-Based Feed Sustainability; KOF, Knowledge On Fish; REG, Regulation; SS, Shopping Sustainability; WTB, Willingness To Buy.

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to support business decisions and policymaking, more than 800 aquaculture facilities are present in Italy. They produce nearly 140.000 tons of fish per year: 40% of the national fishery production and about 30% of the EU demand for fresh fish products (Shepherd and Jackson, 2013). In 2018, Italian aquaculture production, including fish and shellfish, was estimated at 142,726 tons, with a value of approximately 439 million euros. Farmed fish represented 27% of the total Italian fish production (50,154 tons). The most common commercial fish species in 2018 were farmed trout (average price 3.0 €/kg), sea bass (average price 8.0 €/kg), and seabream (average price 7.6 €/kg) (European Commission. Directorate General for Maritime Affairs and Fisheries, 2021).

EUMOFA estimated that, in 2018, the consumption of fishery and aquaculture products in Italy reached approximately 31 kg of live weight per capita, ranking Italy seventh among the EU member states (European Commission, Directorate General for Maritime Affairs and Fisheries., 2021). Considering the growth in aquaculture, this sector must now face the challenge of finding alternative sources for feed production that are more sustainable and environmentally friendly. At present, the most common sources of feed for farmed fish are fishmeal and fish oil (Ferrer Llagostera et al., 2019), the production of which has a high economic and environmental impact. Fishmeal has the consistency of a brown powder and comes from the processing of fresh raw fish and fish by-products. Its production also gives rise to a liquor (a mixture of fish oil, water and soluble proteins). Fish oil is removed from the liquor via centrifugation, producing a clear brown or yellow liquid that can then be subjected to further refinement (Shepherd and Jackson, 2013). Latin America, primarily Peru and Chile, is the leading area for fishmeal processing, followed by Asia, especially Thailand, then Europe (*The State of World Fisheries and Aquaculture* 2022, 2022). In recent years, interest in insects as an alternative raw material to feed to farmed fish has been growing: the environmental impact of their production is lower than that of conventional feed materials due to their short supply chain (Madau et al.,2020), while their conversion feed rate is very high, as is their nutrient content, especially with respect to proteins (Barroso et al., 2014; Lock et al., 2018). Indeed, insect meal is regarded a high-quality and environmentally friendly feed source for aquaculture (Hoffmann et al., 2021). Moreover, the use of insects for aquaculture feed production was recently approved by EU legislation (Lähteenmäki-Uutela et al., 2021). Several studies have already demonstrated the benefits of introducing insects into the diet of farmed fish (Abdel-Tawwab et al., 2020; Xu et al.,2020; Zarantoniello et al., 2021); however, the acceptance of insect proteins in aquaculture is not only related to technical and economic limitations (Smetana et al., 2016) but also to consumers preferences and attitudes (de Domingues et al., 2020).

Data on consumer attitudes towards the use of insects in animal feed is limited. One source of data is provided by the EU-funded project PROteINSECT, which surveyed 1300 consumers from 71 countries located in the EU (including the UK) and the Far East (East Asia, Russian Far East, and Southeast Asia). The project found that 73% of consumers were willing to eat fish, chickens or pork from animals fed on a diet containing insect protein (Fitches and Smith, 2018). Furthermore, more than 80% of those polled wanted to learn more about insect utilization, with 64% believing that eating farmed animals fed insect meal poses no or little risk to human health (Fitches and Smith, 2018).

Mancuso et al. (2016) explored the attitudes and behaviors of Northern Italian consumers towards farmed fish fed with insects and found that almost 90% of consumers were interested to know about research performed on more sustainable sources of feed to use in aquaculture, demonstrating a positive attitude towards insect meals as feed in fish farming. The authors reported that most respondents would be willing to purchase and eat farmed fish fed insect meals.

In a survey conducted by Laureati et al. (2016), approximately 53% of consumers claimed to support the incorporation of insects into animal diets and confirmed that they would eat fish and livestock reared on an insect-based feed. More recently, Baldi et al. (2021) investigated the relationship between various dimensions of the environmental attitudes of young Italian consumers and the acceptance of insect-fed fish. According to their findings, the use of psychometric variables to assess the acceptability of a novel food product was particularly appropriate, and they identified some socio-demographic variables accounting for this acceptance, namely men and younger consumers were more likely to accept the product. The study also demonstrated that information can play a critical role in promoting the acceptance of a new product (Baldi et al., 2021).

Based on the above-reported background, more studies are needed to understand the relationship between social variables and attitudes towards the use of insect-based feed in farmed fish production.

The aim of the present study was to increase our understanding of this relationship by gathering data on consumer attitudes related to the quality of animal feed, climate change, grocery shopping sustainability, and the sustainability of insect-based feed. The variables taken into consideration included sociodemographic characteristics, knowledge levels, food neophobia, and food consumption sustainability. Our study also investigates the consumer variables that can influence the propensity towards this type of product.

2. Materials and methods

2.1. Data collection

To evaluate consumer attitudes towards fish-based products fed with insect-based feed, we developed an online questionnaire in the Italian language and distributed it to consumers around Italy between January and March 2021. The questionnaire was created using Google Forms (University of Trento, C3A - Center Agriculture Food Environment). Informed consent was obtained from each participant, according to the European Data Protection Regulation (UE 679/2016). Before its national distribution, the survey was first tested on a small sample (25 individuals) of researchers and people involved in the topic of interest to identify any potential problems related to the survey flow. Based on the feedback received, we made the necessary adjustments to the questionnaire. The final version of the questionnaire was then distributed by means of snowball sampling (Goodman, 1961), a non-probability sampling technique in which existing study subjects recruit further subjects from among their acquaintances. In addition to the official channels of the University of Trento C3A department, participation in the survey was promoted via social media (e.g., Facebook, Instagram, Twitter, LinkedIn). The inclusion criteria were being 18 years old or older and residing in Italy. The final sample consisted of 303 unpaid consumers who voluntarily completed the survey.

2.1.1. Questionnaire

The final questionnaire consisted of five main sections, collecting data on the respondents' purchasing and eating habits, knowledge, attitudes, emotions, and personal data. Table 1 presents details on the survey questions, items, scales, and response options.

2.1.1.1. Purchasing and eating habits. In this section, participants were asked to indicate their weekly fish consumption (5 items: 3 to 4 times per week, once or twice per week, once a month or less, a few times per year, or never).

Participants were asked to indicate their typical diet by choosing from the ten statements adapted from De Backer and Hudders (2015). They were classified as belonging to one of four categories: omnivores, flexitarians, vegetarians, and vegans, in accordance with Monteleone et al. (2017), Cliceri et al. (2018) and Endrizzi et al. (2021).

Purchasing habits were evaluated with a series of four questions characterized by different items: their preferred place to purchase fish (6 response options: fish market, supermarket with fish counter, supermarket, market, online, or other); their preferred fish product format (6 response options: whole fish, fresh fillets, frozen fillets, as ingredient for

Table 1
Purchasing and eating habits, knowledge questions, attitudes, emotions, personal data, their relative acronyms, number of items, rating scale, response options and references.

Section	Question	Items	Scale and Response Options	References
Purchasing and eating habits	Fish consumption	5	3–4 times per week; 1–2 times per week; once a month or less; few times per year; never	Developed by the authors
	Diet	10	Omnivores, flexitarians, vegetarians, and vegans; classification based on the eating diet chosen out of a list of 10	Adapted from De Backer and Hudders (2015)
	Place of purchasing	6	Fish market; Supermarket with fish counters; Supermarket; Market; Online; Other	Developed by the authors
	Product format	6	Whole fish; Fresh fillets; Frozen fillets; As ingredients ready for recipes; Ready to eat products; Other	Developed by the authors
	Fresh-or-saltwater	3	Freshwater; Saltwater; Both	Developed by the authors
	Farmed fish or wild fish	3	Farmed fish; Wild fish; Both	Developed by the authors
Knowledge	Knowledge On Fish (KOF)	6	9-point Likert scale (1 = totally disagree; 9 = totally agree)	Developed by the authors
	Aquaculture plants in Italy (API)	2	Yes/No	Developed by the authors
	Regulation (REG)	2	Yes/No	Developed by the authors
	Acceptance (ACC)	2	Yes/No	Developed by the authors
	Willingness to buy (WTB)	2	Yes/No	Developed by the authors
Attitudes	Food Consumption Sustainability (FCS)	18	9-point Likert scale (1 = totally disagree; 9 = totally agree)	Endrizzi et al. (2021)
	Food Neophobia Scale (FNS)	10	9-point Likert scale (1 = totally disagree; 9 = totally agree)	Pliner and Hobden (1992)
	Feed Quality (FQ)	1	9-point Likert scale (1 = not at all important; 9 = extremely important)	Developed by the authors
	Climate Change Impact (CCI)	1	9-point Likert scale (1 = not at all impactful; 9 = totally impactful)	Developed by the authors
	Shopping Sustainability (SS)	1	9-point Likert scale (1 = not at all impactful; 9 = totally impactful)	Developed by the authors
	Insect-Based Feed Sustainability (IBFS)	1	9-point Likert scale (1 = totally disagree; 9 = totally agree)	Developed by the authors
Emotions	Selection of all the emotions related to fish fed with insect-based feed consumption	10	Chosen by a list of 10	Menozzi et al. (2021)
Personal data	Region of provenance	20	Chosen by a list of 20	–
	Gender	2	M/W	–
	Age		Age in number (open answer)	–
	Annual income	5	<15.000 €; 15.000–28.000 €; 28.001–55.000 €; 55.001–75.000 €; >75.001 €	–
	Level of education	6	Primary; Lower secondary; Upper secondary; Bachelor's degree; Master's degree; Post-graduate degree	–
	Current occupation	7	Full-time job; Part time job; Self-employed; Household; Unemployed; Retiree; Student; Other	–

recipes, ready-to-eat products, or other); their preference for freshwater or saltwater fish (3 response options: freshwater, saltwater, or both); and their preference for farmed or wild fish (3 response options: fresh fish, wild fish, or both).

2.1.1.2. Knowledge. Knowledge about the aquaculture sector was evaluated by asking participants to rate the level to which they agreed with six (true and positive) statements about fish diets using a 9-point Likert scale (1 = totally disagree; 9 = totally agree) (Tandler, 1985; Henry et al., 2015), defined through the text as Knowledge On Fish (KOF). Four additional questions in which the respondent could answer "yes" or "no" were included to evaluate general knowledge about the aquaculture sector; specifically, the presence of aquaculture plants in Italy (API); regulation related to the use of insect-based feed (REG);

Table 2
Mean (M) and Standard Deviation (SD) values for each statement of Knowledge On Fish.

Item	Knowledge On Fish	References	M	SD
1	The life cycle of fish includes 4 main stages (egg, larvae, young fish, adult fish)	(Tandler, 1985)	6.82	2.24
2	There are carnivorous fish.	(Henry et al., 2015)	7.44	2.31
3	There are herbivorous fish.	(Henry et al., 2015)	6.54	2.69
4	There are omnivorous fish.	(Henry et al., 2015)	6.75	2.53
5	There are insectivorous fish.	(Henry et al., 2015)	6.26	2.83
6	In the wild, fish usually eat insects.	(Henry et al., 2015)	6.96	2.34

acceptance of fish products fed with insect-based feed (ACC), and willingness to buy such products (WTB) (See Tables 2 and 3).

2.1.1.3. Attitudes. This section focused on aspects related to Food Consumption Sustainability (FCS, Endrizzi et al., 2021) and Food Neophobia (FN Scale, Pliner and Hobden, 1992). Participants were asked to respond using a 9-point Likert scale (1 = totally disagree; 9 = totally agree) to 18 positive and negative statements about FCS, and 10 positive and negative statements about FNS. Four additional questions were incorporated into this section, each utilizing a 9-point Likert scale to gauge the respondents' perspectives. These questions delved into the significance of feed quality (FQ), the environmental impact of the aquaculture and livestock sectors on climate change (CCI), considerations of sustainability during grocery shopping (SS), and agreement with the notion of insect-based feeds as a component of sustainability (IBFS), and questions posed were:

1. Feed Quality (FQ): On a scale of 1 to 9, how is important for you the quality of feed used for animal origin products you purchase?
2. Climate Change Impact (CCI): On a scale of 1 to 9, how much do you think the livestock and aquaculture sectors impact climate change?
3. Shopping Sustainability (SS): On a scale of 1 to 9, how much does the concept of sustainability impacts your grocery shopping?
4. Insect-Based Feed Sustainability (IBFS): Please indicate your level of agreement on a scale of 1 to 9, with the statement: "Using insect-based flour makes the production of farmed fish more sustainable."

2.1.1.4. Emotions. The respondents were asked to indicate their feelings in relation to the possible consumption of a fish fillet obtained from fish fed an insect-based feed by selecting from a list of 10 items. The question was structured as follows: "Imagine eating a fish fillet obtained from a fish fed with insect-based feed, how does it make you feel? Check all the options that apply to the product concerned." Respondents used the CATA (Check-All-That-Apply) method to respond to the question. The 10 emotions listed were: "It makes me curious", "It makes me feel indifferent", "It pleasantly surprises me", "It makes me feel disgust", "It makes me worried", "It makes me happy", "It satisfies me", "It makes me angry", "It makes me feel guilty" and "None of the above".

2.1.1.5. Demographic data. This section included socio-demographic items about gender, age (under or over 30 years), region of provenance, annual income (<€15.000, €15.000–28.000, €28.001–55.000, €55.001–75.000, >€75.000), level of education (primary school, lower secondary, upper secondary, bachelor's degree, master's degree, post-graduate degree, and current occupation (full-time job, part-time job, self-employed, houseperson, unemployed, retiree, student, other).

2.2. Data analysis

Data analyses were conducted using the software package SPSS 26.0 (IBM, NY, USA). After performing a data quality check, the demographic data and purchasing and eating habits of the study participants were described in terms of the number of observations and percentages.

Table 3
Full text for each general knowledge question.

Abbreviation	Question full text
API	In Italy, more than 800 aquaculture plants are present, and they produce 140,000 tons of fish per years, which account for the 40% of national fish production. Did you know that?
REG	The EU Regulation 893/2017 states that insects can be used in feed production for farmed animals. Did you know that?
ACC	Would you be prepared to consider using insect meal for feeding farmed fish?
WTB	In the present state of your knowledge, would you be prepared to buy farmed fish fed with insect meal?

Concerning diet, since the majority of respondents (75%) declared to follow an omnivorous diet, the other respondents (flexitarians and vegetarians) were grouped into a single category (non-omnivores) to perform a more robust comparison with omnivores.

The Pearson Chi-Square statistic was used to test the effects of the independent explanatory variables (gender, age, diet, income, and education) on general knowledge about the aquaculture sector, including the presence of aquaculture plants in Italy (API), regulation on the use of insect-based feed (REG), acceptance (ACC) and willingness to buy (WTB) fish fed an insect-based diet. Post-hoc analyses were performed on comparisons with a $P \leq 0.05$ using standardized residuals and the percentage of relative and absolute contributions of the individual cells. To identify which discrepancies between observed and expected values were larger than what would be expected by chance, we calculated the standardized residual for each cell. The relative contribution was computed by dividing each chi-square cell by the chi-square value, while for the absolute contribution, each chi-square cell was divided by the numerosity of the sample (Beasley and Schumacker, 1995).

Concerning Knowledge On Fish (KOF), Food Consumption Sustainability (FCS), and Food Neophobia Scale (FNS), respondents were ranked according to the total score obtained for each scale, then classified into three categories representing three different levels of knowledge, attitude, or phobia – low (L), medium (M), or high (H) – according to the 33rd and 66th percentiles.

The internal validity of each scale was previously tested using Cronbach's alpha (Carmines and Zeller, 1979). According to Ursachi et al. (2015), Cronbach's alpha values higher than 0.6 can be considered acceptable, and values higher than 0.7 are good to optimal.

The Pearson Chi-Square statistic was then used to test the association of each scale (KOF, FCS and FNS) with gender, age, diet, income, and education.

One-way analysis of variance (ANOVA; $P \leq 0.05$) was used to test the effects of gender, age, diet, education, Aquaculture Plants in Italy (API), Regulation (REG), Acceptance (ACC), Willingness to Buy (WTB), Knowledge on Fish (KOF), Food Consumption Sustainability (FCS) and the Food Neophobia Scale (FNS) on the dependent variables, namely: Feed Quality (FQ), Climate Change Impact (CCI), Shopping Sustainability (SS), and Insect-Based Feed Sustainability (IBFS). To identify significant effects after Bonferroni correction ($P \leq 0.0045$), we applied the post-hoc HSD Tukey's test for multiple comparisons whenever appropriate. We used the non-parametric Kruskal-Wallis test in cases of heteroskedastic data.

To explore multivariate relationships between the dependent variables, Feed Quality (FQ), Climate Change Impact (CCI), Shopping Sustainability (SS) and Insect-Based Feed Sustainability (IBFS) and the independent categorical variables, multiple linear regression (MLR) models were estimated using the stepwise method. Each independent categorical variable was converted into Dummy variables as follows: MEN (0 = women, 1 = men); OVER30 (0 = under 30, 1 = over 30); OMNIVORES (0 = non-omnivores, 1 = omnivores); EDU (0 = low level, 1 = high level); API (0 = negative answer, 1 = positive answer); REG (0 = negative answer, 1 = positive answer); ACC (0 = negative answer, 1 = positive answer); WTB (0 = negative answer, 1 = positive answer); FCS-1 (0 = low level, 1 = medium level); FCS-2 (1 = high level); FNS-1 (0 = low level, 1 = medium level); FNS-2 (1 = high level). To obtain the score (Δ) for each regression model, the sum (or subtraction) of each regressor was calculated considering all the possible cases.

To analyze the Check-All-That-Apply (CATA) data, we calculated the percentage of times that each of the 10 listed emotions was selected using the methodology described by Spinelli et al. (2014). Furthermore, the Pearson Chi-Square statistic was employed to assess the relationship between the most frequently selected emotions and the statement regarding Insect-Based Feed Sustainability (IBFS). This analysis involved categorizing responses to the IBFS statement into three groups: low (L), medium (M), and high (H), based on their positioning within the 33rd and 66th percentiles.

3. Results

3.1. Sociodemographic characteristics of respondents

Table 4 describes and summarizes the distribution of the sample in terms of socio-demographic features, including gender, age, place of residence, income level, level of education, job occupation, and purchasing and eating habits. We compared the socio-demographic characteristics of our sample against the Italian general population using data extracted from the Italian National Institute of Statistics (ISTAT) database.

A total of 303 subjects (52.4% men) aged between 18 and 78 (51.8% under the age of 30) participated in the survey. Compared with the Italian population, our sample includes a higher percentage of young people (under the age of 30). Overall, the participants had a high level of education, with 36.9% declaring to have completed high school, and 26.7% having obtained a master's degree. In general, this result is in line with the data for the Italian population, in which 20% of citizens have a high education level. None of the participants declared to have stopped their education prior to the secondary school level. Based on this finding, the "primary school" level was not considered in the subsequent data analyses. Most respondents declared an annual income of less than €15,000 (42.8%), while 30.3% declared to have an annual income between €15,000 and €28,000. The remaining 25.6% reported an annual income greater than €28,000. This is in line with the average annual income for the Italian population of €21,570. Most respondents reported full-time employment (44.8%). Regarding the region of provenance, 73.5% of respondents lived in a region situation in Northern Italy. The remainder (26.4%) lived in the Central or Southern Italy or the islands. Regarding purchasing and eating habits, most respondents declared to follow an omnivorous diet (74.5%), and 67.7% reported to consume fish once or twice per week. Finally, the sample's purchasing habits can be summarized as follows: 44.5% mainly buy fish at supermarkets with fish counters; 42.5% prefer to buy whole fish rather than other product formats; 65.6% favor saltwater fish over freshwater fish; and 59.7% mainly purchase wild fish rather than farmed fish.

3.2. Effects of participant profile on general knowledge, Knowledge On Fish (KOF), Food Consumption Sustainability (FCS) and Food Neophobia Scale (FNS)

3.2.1. General knowledge of the aquaculture sector

Fig. 1 presents the percentage frequency distribution of Yes/No answers to the general knowledge questions asked and opinions about the aquaculture sector. Eighty-six percent of the respondents declared to have no knowledge about the number of aquaculture plants in Italy (API), and 62.4% had no knowledge about the European regulation related to the use of insect-based feed in aquaculture (REG). Nevertheless, 75.9% and 74.5% of respondents declared being in favor of the use of insect-based feed in aquaculture (ACC) and to be willing to buy fish fillets from animals fed with insect-based feed (WTB), respectively.

The main results of the Chi-Square statistics are shown in Table 5. Education level significantly affects knowledge about European regulation, acceptance and willingness to buy insect-fed animal products, whereas gender, age, diet, and income did not demonstrate a significant effect.

Fig. 2 shows the frequency distribution of the respondents by education level according to responses to REG.

The distribution of respondents' education levels based on their responses to ACC is displayed in Fig. 3.

The frequency distribution of respondents by their education level in relation to their responses to WTB is depicted in Fig. 4.

3.2.2. Knowledge On Fish (KOF), Food Consumption Sustainability (FCS) and Food Neophobia Scale (FNS)

We tested the internal validity of the three scales by calculating

Table 4
Socio-demographic data, purchasing and eating habits of the consumers compared to the Italian population.

	Survey sample		Italian population[a]
	N	%	%
Gender			
Men	159	52.4	49
Women	144	47.5	51
Age[b]			
Under 30	157	51.8	15
Over 30	146	48.1	64.8
Region			
Northern Italy	223	73.5	46.5
Central/Southern Italy – Islands	80	26.4	53.5
Annual income[c]			
<15.000 euro	130	42.8	NA
15.000–28.000 euro	92	30.3	NA
28.001–55.000 euro	60	19.8	NA
55.001–75.000 euro	9	1.9	NA
>75.001 euro	12	3.9	NA
Level of education			
Primary school	0	0	15
Lower secondary	8	2.6	30
Upper secondary	112	36.9	35
Bachelor's degree	45	14.8	
Master's degree	81	26.7	20[d]
Post-graduate degree	57	18.8	
Job occupation			
Full-time job	136	44.8	NA
Part-time job	21	6.9	NA
Self-employed	28	9.2	NA
Houseperson	5	1.6	NA
Unemployed	19	6.2	NA
Retiree	11	3.5	NA
Student	71	23.4	NA
Other	12	3.6	NA
Diet			
Omnivores	226	74.5	NA
Non-omnivores (*)	77	25.4	NA
Weekly fish consumption			
¾ times per week	44	14.5	NA
½ times per week	205	67.6	NA
once a month or less	46	15.1	NA
few times per year	7	2.3	NA
Never	1	0.3	NA
Place of purchasing			
Fish market	79	26.0	NA
Supermarket with fish counter	135	44.5	NA
Supermarket	55	18.1	NA
Market	25	8.2	NA
Online	2	0.6	NA
Other	7	2.2	NA
Product format			
Whole fish	129	42.5	NA
Fresh fillets	71	23.4	NA
Frozen fillets	54	17.8	NA
As ingredient for recipes	17	5.6	NA
Ready to eat products	24	7.9	NA
Other	8	2.5	NA
Fresh-or-saltwater			
Freshwater	14	4.6	NA
Saltwater	199	65.6	NA
Both	90	29.7	NA
Farmed fish or wild fish			
Farmed fish	76	25.0	NA
Wild fish	181	59.7	NA
Both	46	15.1	NA

[a] Values from Italian National Institute of Statistics (ISTAT).
[b] Percentages related to the two categories (i.e., Under 30; Over 30) were calculated on the total of Italian population, divided by age groups considered in the survey (i.e., 18–30; 31–78).
[c] The average annual income for Italian population is 21,570 € (source: Ministry of Economy and Finance, press release of April 13th, 2022).
[d] Data include the sum from Bachelor's, Master's and Post graduate degree.

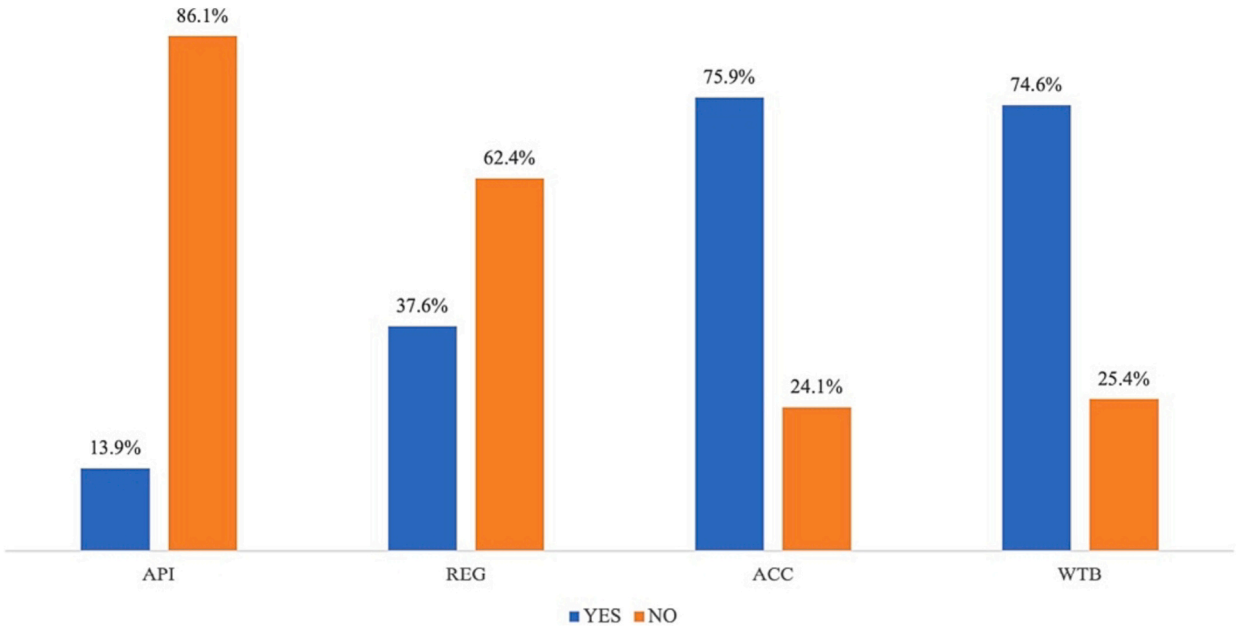

Fig. 1. Frequency distribution (%) of Aquaculture Plants in Italy (API), Regulation (REG), Acceptance (ACC) and Willingness To Buy (WTB) responses (Yes/No).

Table 5
Results from the Chi-Square statistics for Regulation (REG), Acceptance (ACC) and Willingness To Buy (WTB) per level of education.

χ^2 Tests	N	Value	Df	P
REG	303	11.9	4	0.018
ACC	303	20.5	4	<0.001
WTB	303	19.2	4	<0.001

Cronbach's alpha (Table 6). All values were greater than 0.6, indicating them to be reliable. The table also summarizes the percentages of respondents for each group, defined according to three levels of attitude (L, M, and H): 51.1% of respondents belonged to the medium level category for all the scales.

According to Chi-Square test ($P \leq 0.05$), only the categorical variable gender (2.5% of the variance) affected the distribution of attitude levels for FCS. Tendentially, the highest percentages of respondents with high levels of attitudes towards FCS concerned female consumers. Fig. 5 presents the frequency distribution for each attitude level.

3.3. Effects of gender, age, diet, education, Aquaculture Plants in Italy (API), Regulation (REG), Acceptance (ACC), Willingness to Buy (WTB), Knowledge on Fish (KOF), Food Consumption Sustainability (FCS) and Food Neophobia Scale (FNS) on Feed Quality (FQ), Climate Change Impact (CCI), Shopping Sustainability (SS), and Insect-Based Feed Sustainability (IBSF) as assessed by one-way ANOVA

The main results are summarized in Table 7. For FQ, we observed a significant effect for API and FCS: respondents who declared to be aware of the status of aquaculture plants in Italy appeared to pay more attention to aspects related to sustainable food consumption and to the quality of animal feed used for the food products of animal origin they purchase. Regarding CCI, significant effects were observed for gender, age, diet, and FCS. In particularly, men, those aged over 30 years old,

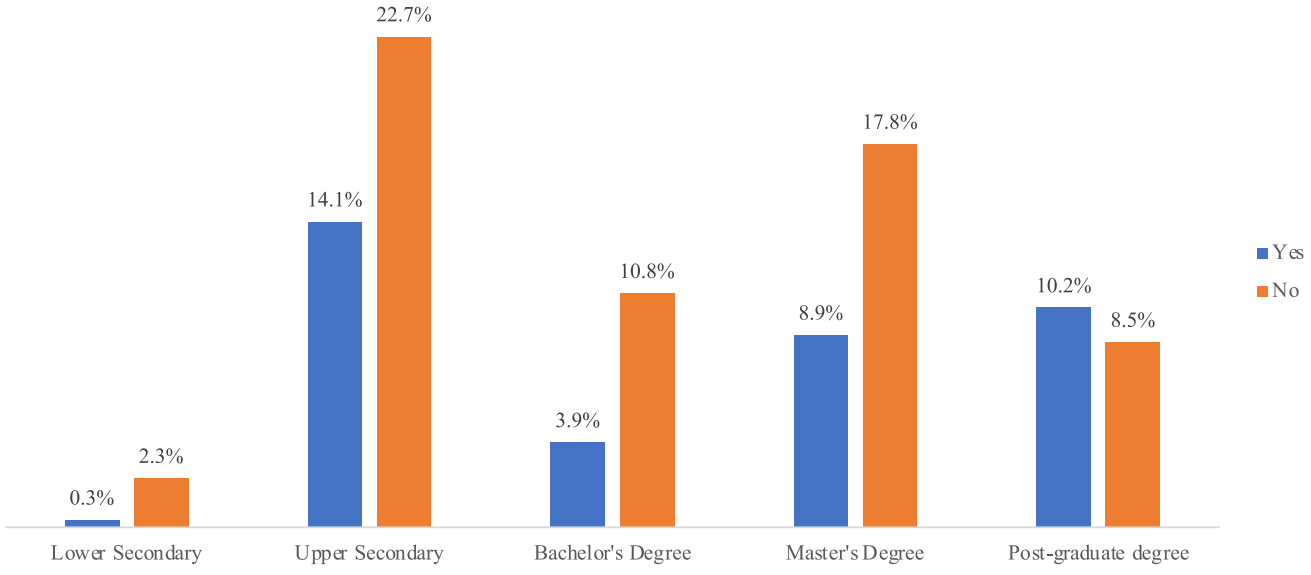

Fig. 2. Marginal row percentage of Regulation (REG) responses (Yes/No) per level of education.

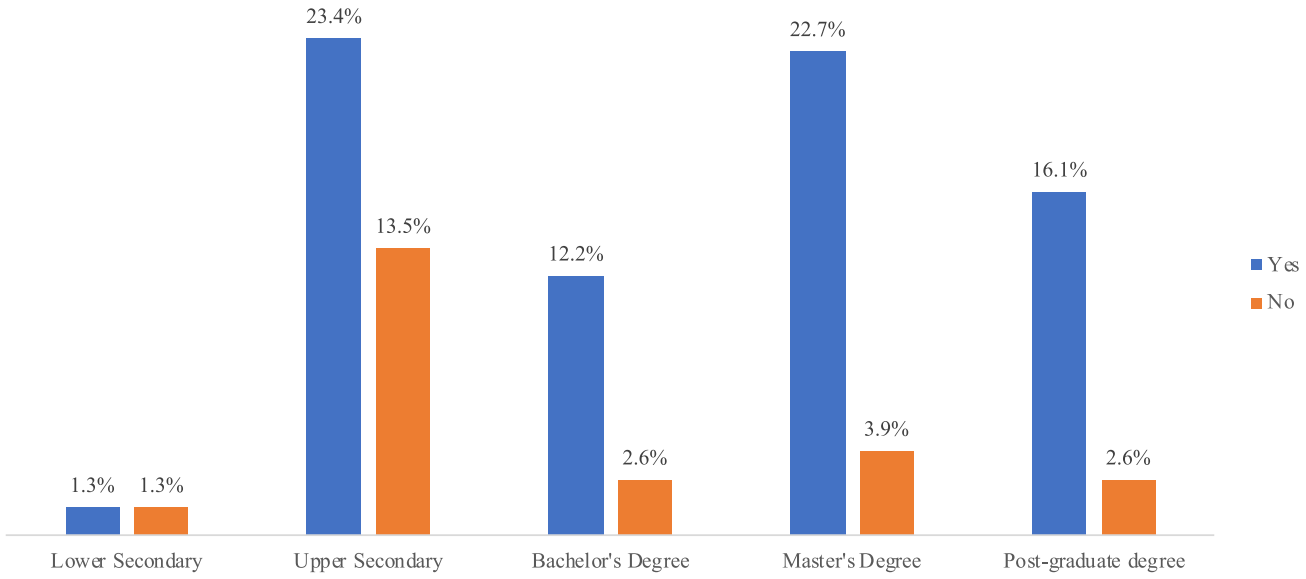

Fig. 3. Marginal row percentage of Acceptance (ACC) responses (Yes/No) per level of education.

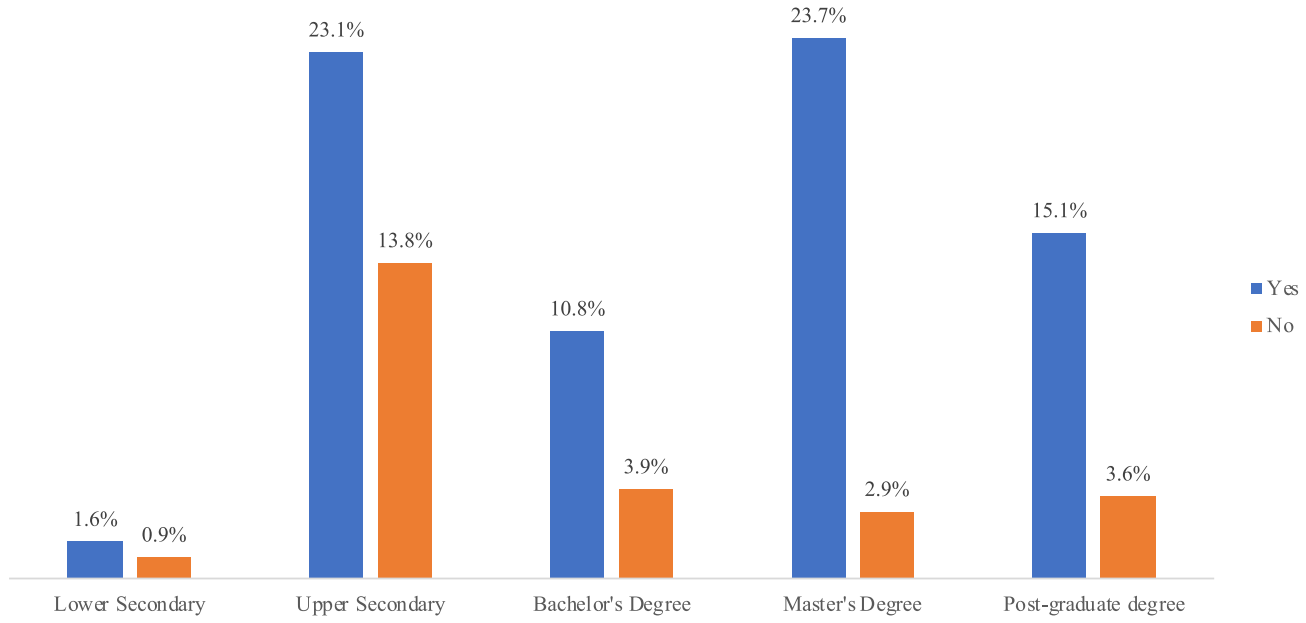

Fig. 4. Marginal row percentage of Willingness To Buy (WTB) responses (Yes/No) per level of education.

Table 6
Means (M), standard deviations (SD), percentiles, and levels of attitude for Knowledge on Fish (KOF), Food Consumption Sustainability (FCS) and Food Neophobia Scale (FNS).

Scale	M	SD	33rd	66th	L (%)	M (%)	H (%)	Cronbach's α
KOF	40.8	10.7	36	46	21	51	28	0.80
FCS	117.1	15.4	110	123	25.1	51.8	23.1	0.63
FNS	35.9	14.7	26	39	23.8	51.1	25.1	0.81

omnivores, and respondents characterized by low or medium levels of food consumption sustainability assigned significantly lower scores to the statement that the livestock and aquaculture sectors have a major impact on climate change. Shopping sustainability (SS) was significantly affected by gender, diet, API, and FCS. Men and omnivores who declared not to have any knowledge about aquaculture plants in Italy generally paid less attention to sustainability aspects during their grocery shopping. Education level, awareness about EU regulation, acceptability, and willingness to buy insect-fed animal products and food neophobia significantly affected the sustainability perception of insect-based feed (IBFS) products among consumers. A high level of education and a low level of food neophobia, and positive responses to REG, ACC, and WTB showed significantly higher levels of agreement with the statement that insect-based feed makes the aquaculture sector more

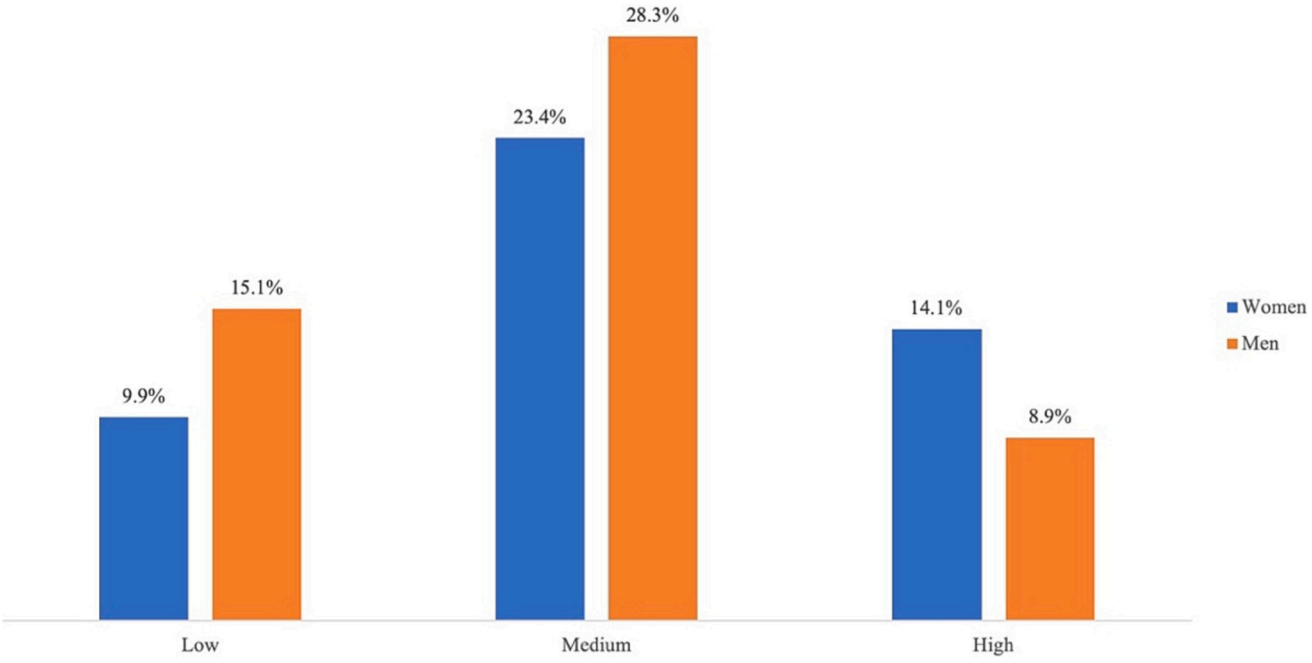

Fig. 5. Frequency distribution (%) of respondents per gender and levels of Food Consumption Sustainability (FCS) scale.

Table 7
Effect of categorical variables on Feed Quality (FQ), Climate Change Impact (CCI), Shopping Sustainability (SS), and Insect-Based Feed Sustainability (IBFS).

Groups	FQ			CCI		SS		IBFS	
	N	M (SD)	P	M (SD)	P	M (SD)	P	M (SD)	P
W	144	7.47 (1.85)		6.99 (1.65)		6.76 (1.53)		6.20 (2.06)	
M	159	7.36 (1.95)	0.623	5.90 (2.12)	***<0.001***	6.31 (1.92)	**0.045**	6.30 (2.12)	0.676
AGE < 30	157	7.28 (1.78)	0.201	6.86 (1.66)	***<0.001***	6.41 (1.80)	0.229	6.27 (1.99)	0.908
AGE > 30	146	7.56 (2.02)		5.95 (2.19)		6.65 (1.71)		6.24 (2.19)	
DIET0	77	7.47 (2.06)	0.794	6.57 (2.02)	**0.042**	6.96 (1.60)	**0.008**	6.39 (1.92)	0.488
DIET1	226	7.40 (1.85)		6.37 (1.97)		6.38 (1.79)		6.21 (2.15)	
EDU1	120	7.33 (1.98)	0.548	6.30 (2.06)	0.404	6.55 (1.92)	0.845	5.93 (2.14)	**0.032**
EDU2	183	7.47 (1.85)		6.50 (1.93)		6.51 (1.65)		6.46 (2.03)	
API0	261	7.31 (1.97)	**0.027**	6.33 (1.97)	0.057	6.40 (1.76)	***0.001***	6.26 (2.00)	0.913
API1	42	8.07 (1.22)		6.98 (2.01)		7.29 (1.55)		6.21 (2.61)	
REG0	189	7.27 (2.03)	0.070	6.46 (1.94)	0.647	6.41 (1.85)	0.120	5.71 (1.99)	***<0.001***
REG1	114	7.66 (1.65)		6.35 (2.06)		6.72 (1.58)		7.15 (1.94)	
ACC0	73	7.55 (2.03)	0.517	6.58 (2.07)	0.455	6.64 (2.03)	0.550	4.44 (1.90)	***<0.001***
ACC1	230	7.37 (1.86)		6.37 (1.96)		6.49 (1.67)		6.83 (1.80)	
WTB0	77	7.52 (2.01)	0.595	6.51 (2.04)	0.662	6.61 (2.03)	0.655	4.48 (1.93)	***<0.001***
WTB1	226	7.38 (1.87)		6.39 (1.96)		6.50 (1.66)		6.86 (1.78)	
KOF1	84	7.27 (1.96)		6.42 (2.05)		6.24 (2.05)		6.11 (2.19)	
KOF2	154	7.38 (1.88)	0.422	6.45 (1.96)	0.924	6.45 (1.96)	0.247	6.32 (1.95)	0.749
KOF3	65	7.68 (1.88)		6.34 (1.98)		6.34 (1.98)		6.28 (2.29)	
FCS1	76	6.93 [a] (1.93)		6.08 [a] (1.99)		6.01 [a] (2.02)		6.51 (1.94)	
FCS2	157	7.62 [b] (1.81)	**0.037**	6.26 [a] (1.88)	***0.003***	6.45 [a] (1.62)	***<0.001***	6.18 (2.05)	0.427
FCS3	70	7.49 [a b] (2.01)		7.14 [b] (2.05)		7.24 [b] (1.55)		6.13 (2.32)	
FNS1	72	7.50 (1.82)		6.82 (1.95)		6.67 (1.64)		6.82 [a] (1.88)	
FNS2	155	7.59 (1.77)	0.098	6.37 (1.98)	0.098	6.62 (1.74)	0.197	6.17 [a b] (2.21)	**0.010**
FNS3	76	6.97 (2.17)		6.13 (1.98)		6.20 (1.87)		5.88 [b] (1.93)	

Statistically significant effects are reported in bold. Statistically significant effects after Bonferroni correction ($P \leq 0.0045$) are reported in bold and italic.
W: Women; M: Men; DIET0: non omnivores; DIET1: omnivores; EDU1: Lower and Upper Secondary; EDU2: Bachelor's and Master's degree, Post graduate degree; API0: No; API1: Yes; REG0: No; REG1: Yes; ACC 0: No; ACC1: Yes; WTB0: No; WTB1: Yes.

sustainable.

3.4. Modelling Feed Quality (FQ), Climate Change Impact (CCI), Shopping Sustainability (SS), and Insect-Based Feed Sustainability (IBFS) with categorical variables

Table 8 reports MLR models found to be significant.

The key findings referring to each attitudinal question are as follows:

1. API and FNS-2 were significant factors influencing attitudes about feed quality (FQ). Specifically, respondents who were aware of the status of aquaculture plants in Italy and had a low level of food neophobia scored the highest in the FQ model, with an estimated score of $\Delta = 8.06$;
2. In the case of climate change impact (CCI), gender, age, and FCS-2 were significant factors. The highest estimated scores ($\Delta = 7.99$) were seen among women aged less than 30 with a high level of attitude towards sustainability. Conversely, the lowest estimated

Table 8
Significant Multiple Linear Regression models for Feed Quality (FQ), Climate Change Impact (CCI), Shopping Sustainability (SS), and Insect-Based Feed Sustainability (IBFS).

Attitudinal questions	R^2	P
FQ = 7.310 + 0.752 (API) - 0.583 (FNS-2)	0.037	0.004
CCI = 7.258–1.044 (MEN) - 0.957 (OVER30) + 0.739 (FCS-2)	0.160	0.000
SS = 6.646 + 0.910 (FCS-2) + 0.879 (API) - 0.607 (OMNIVORES)	0.101	0.000
IBFS = 4.013 + 1.316 (WTB) + 0.866 (REG) + 1.111 (ACC)	0.315	0.000

MEN: 0 = women, 1 = men; OVER30: 0 = under 30 1 = over 30; OMNIVORES: 0 = non omnivores 1 = omnivores; EDU: 0 = low level 1 = high level; API:0 = negative answer 1 = positive answer; REG: 0 = negative answer 1 = positive answer; ACC: 0 = negative answer 1 = positive answer; WTB: 0 = negative answer 1 = positive answer; FCS-1: 0 = low level 1 = medium level; FCS-2:1 = high level; FNS-1: 0 = low level 1 = medium level; FNS-2: 1 = high level.

score (Δ = 5.25) was found for men aged over 30 with "low" attitudes towards sustainability;

3. Regarding shopping sustainability (SS), FCS-2, API, and DIET were found to be significant. The highest estimated score (Δ = 8.43) was associated with respondents who were non- of aquaculture plants in Italy. On the other hand, the lowest estimated score (Δ = 6.03) was found among omnivorous respondents with a low level of attitude towards sustainability who responded negatively to API.
4. Finally, only categorical variables related to general knowledge (REG, ACC, and WTB) were found to be significant factors for attitudes on insect-based feed sustainability (IBFS). The highest score (Δ = 7.30) for the belief that insect-based feed makes the aquaculture sector more sustainable was associated with respondents who answered positively to all three general knowledge questions. Conversely, the lowest score (Δ = 4.01) was found among respondents who answered negatively to the questions on regulation, acceptance, and willingness to buy.

The R^2 value for each model was generally low. The impact of the y variables considered was only partially explained by the explanatory variables included in the questionnaire. As seen in Table 8, only 3.7% of FQ could be explained by API and FNS-2. CCI was explained by variables MEN, OVER30, and FCS-2 by 16%, and SS was explained by FCS-2, API, and OMNIVORES by 10%. Finally, IBFS was explained by the variables concerning general knowledge by 31%, making it the most robust model.

3.5. Emotions

Fig. 6 presents the percentage frequency distribution of responses reflecting how respondents feel about the potential consumption of a fillet obtained from fish fed an insect-based feed according to the list of 10 items. In the response to the question "Imagine eating a fish fillet obtained from fish fed with insect-based feed, how does it make you feel?", 45.2% of respondents selected the option "it makes me curious", while 36.3% of respondents selected the option "it makes me feel indifferent". Regarding negative feelings, 10.9% and 9.6% of respondents chose "disgust" and "worry", respectively, while "anger" and "blame" were selected by less than1% of respondents (0.9% each).

The association between the two most selected emotions, "it makes me curious" and "it makes me feel indifferent," with the Insect-Based Feed Sustainability (IBFS) statement was examined using Chi-Square statistics. While the level of response to IBFS did not demonstrate a significant effect on the emotion "indifference," the emotion "it makes me curious" was found to be significantly influenced by this attitude ($P \leq 0.05$). Specifically, respondents who assigned higher scores to IBFS tended to express their sense of curiosity. Fig. 7 illustrates the frequency distribution of respondents who reported the emotion "it makes me curious" across different levels.

4. Discussion

The present study investigated the role of attitudes towards sustainability aspects in aquaculture and the consumption of fish fillets from fish fed an insect-based feed. Specifically, we explored the interrelation between attitudes related to purchasing and sustainability issues, general knowledge about the aquaculture sector, and explanatory variables to understand how all these aspects intersect in terms of consumer behavior. The consumption of edible insects is generally characterized by negative attitudes and beliefs in Western countries (Verkerk

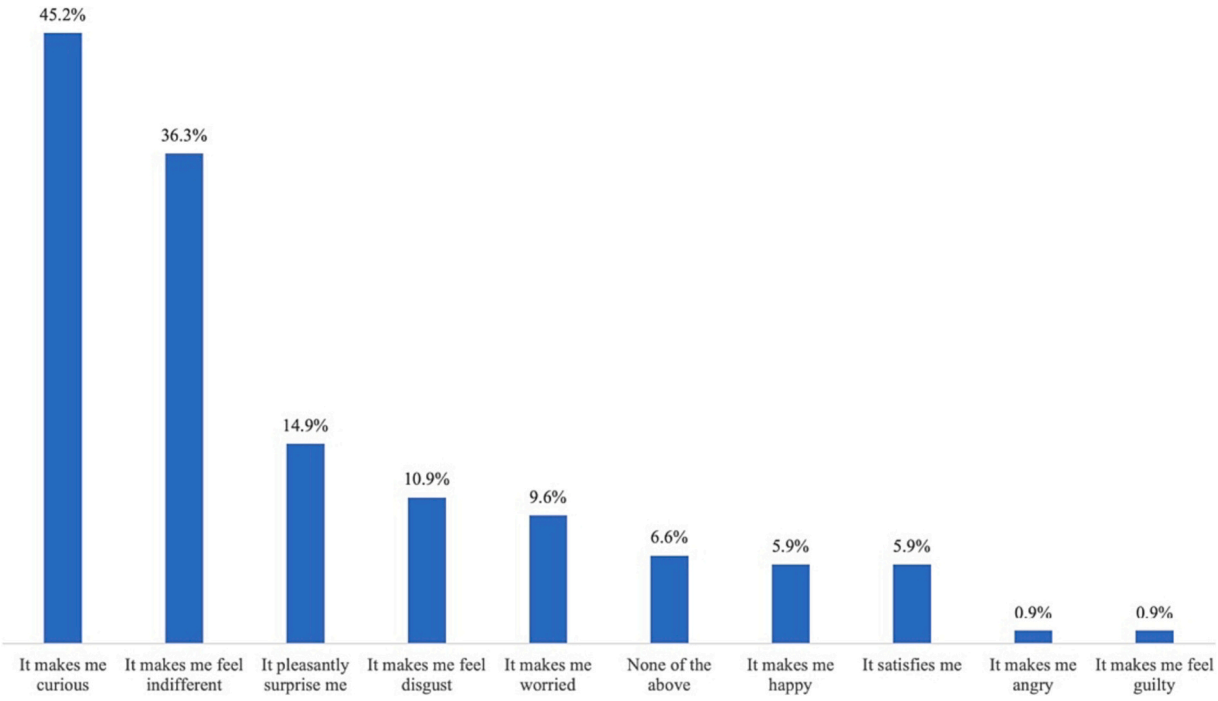

Fig. 6. Percentage frequency distribution of responses according to the emotional items.

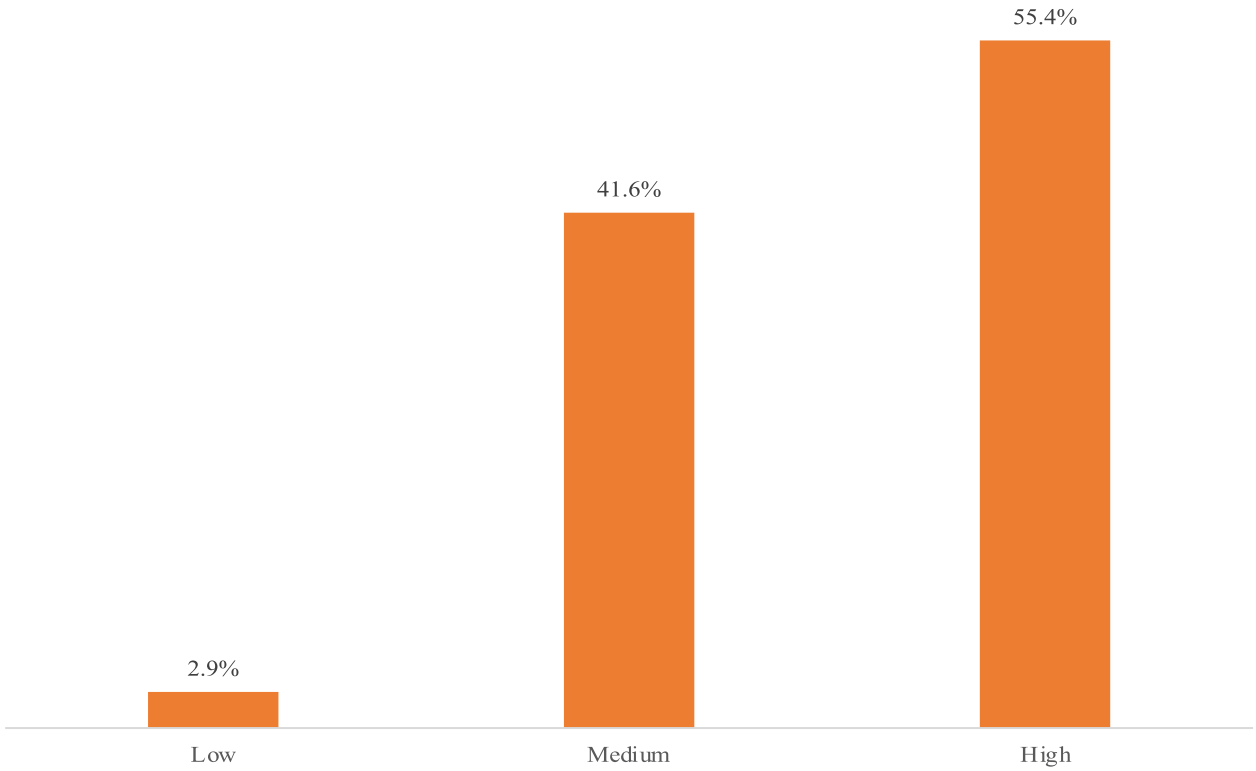

Fig. 7. Frequency distribution (%) of respondents who elicited the emotion "it makes me curious" per levels of response to Insect-Based Feed Sustainability (IBFS).

et al., 2007; Vanhonacker et al., 2013), including Italy. This extends to views about using insects as feed for animals destined for human consumption, although attitudes tend to be less negative here (Higa et al., 2021).

According to our results, 86.1% of the consumers surveyed had no knowledge about the status of aquaculture plants in Italy, while 62.4% were unfamiliar with European regulation on the use of insect-based feed in aquaculture (Fig. 1). Consumers are not generally informed about the supply chain involved in insect-based feed production (Smetana et al., 2021), which could lead to hesitancy or reluctance to try these innovative products. At the same time, the costs related to insect production and commercialization are still very high (House, 2016), making the final product more expensive than conventional products (House, 2016), and thus less accessible to some consumers. Although the role of price was not investigated in the present study, it is known to be a main driver of consumer choices (Ankamah-Yeboah et al., 2018). In the case of insect-based products, food neophobia and/or disgust may play a leading role in the decision-making process.

A higher level of food neophobia limits the importance that consumers give to price (Jaeger et al., 2017) and to feed quality. Food neophobia has been identified as one of the main barriers to the introduction of insect-based food and feed in certain dietary patterns (Verbeke, 2015; Tuccillo et al., 2020). In our study, a high level of food neophobia negatively influenced the perception of feed quality (Table 8). Consequently, the perception of final product quality is affected by this attitude. This finding is in line with the results by Barrena and Sánchez (2013), who suggested food neophobia to be a significant factor in consumer choice of novel foods, and could also influence the perception of product quality.

In this study, gender and age were identified as barriers to innovative aquaculture products, particularly when the consumers were men and over 30. Women, on the other hand, tended to be more sensitive to climate change problems. Additionally, consumers under 30 exhibited a similar tendency to women in that they considered the livestock and aquaculture sectors as being among those most responsible for climate change. The results of one-way ANOVA confirmed the effect of gender and age on this issue (Table 7), which was further confirmed by the Climate Change Impact MLR model (Table 8). The study by Clayton and Karazsia (2020) found younger people and women to exhibit higher levels of distress associated with the topic of climate change, while Bush and Clayton (2022) support the theory that women are more concerned about climate change issues than men.

Diet is an important factor to consider in the context of barriers as the results show that non-omnivorous respondents tend to exhibit more sustainable shopping behavior. This respondent category primarily consists of flexitarians, or people who follow a mostly vegetarian diet but occasionally eat meat or fish (Dagevos, 2021). On the other hand, omnivorous consumers show less interest in following a sustainable dietary pattern (Noguerol et al., 2021). In the context of insect consumption, Naranjo-Guevara et al. (2021) have already posited that flexitarians may assume a pivotal role as a prominent market segment for these emerging products. This is especially relevant as a potential feed source within the animal origin supply chain. This assumption is further supported by research conducted by Elorinne et al. (2019): by comparing three dietary patterns (vegans, vegetarians and omnivores), the authors demonstrated omnivores and vegetarians (flexitarians are included in this last category) to express stronger intentions and more positive attitudes towards the consumption of edible insects compared with vegans.

Contrary to the challenges mentioned earlier, the identified drivers (Verbeke, 2015; Sogari, 2015), have a positive impact on consumer attitudes towards animal-origin products fed with insect-based feed. These influential factors serve as a foundation for implementing strategies to enhance the adoption and consumption of such products, even in the face of their higher price. The Food Consumption Sustainability scale, based on the tenet of a 15-item Welsh screening tool for sustainability (Poortinga and Darnton, 2016), was developed by Endrizzi et al. (2021) to measure attitudes towards local food, green restaurants, and domestic food waste. Our results show that more sustainable behaviors are pivotal in measuring attitudes towards climate change and grocery shopping

(Tables 7 and 8). In contrast with food neophobia, food consumption sustainability is crucial for consumers acceptance and willingness to consume and pay for innovative products, particularly when consumer believe these products and their supply chains are environmentally friendly (Menozzi et al., 2017; Ferrer Llagostera et al., 2019). Additionally, as reported by Laureti and Benedetti (2018) respondents with a high attitude towards sustainability are more likely to adopt sustainable grocery shopping pattern. Finding positive consumer attitudes towards these products is key for overcoming barriers that limit their circulation among Western consumers.

Interestingly, respondents who answered positively to general knowledge questions showed a higher degree of agreement with the assumption that "The use of insect-based feed makes the aquaculture sector more sustainable" and stronger attitudes regarding the importance of feed quality. The available literature suggests that a greater level of information on the use of insects as feed in aquaculture (Baldi et al., 2021), farmed poultry (e.g., duck; Menozzi et al., 2021), and as both food and feed (Laureati et al., 2016), is positively associated with a greater consumer tendency to accept and consider this innovation as beneficial. A study by Altmann et al. (2022), conducted on German consumers investigated the use of insect-fed poultry products and confirmed the effect of information on consumers' acceptance and willingness to pay for such products. Similarly, Bazoche and Poret (2021) also underlined that providing information on the benefits of using insect-based feed in aquaculture could reduce French consumers' distrust of these products. At the same time, UK consumers also seem to also be influenced by information campaigns, as shown by Popoff et al. (2017) and Spartano and Grasso (2021). In the study by Popoff et al., providing information increased the willingness of consumers to eat Scottish salmon fed an insect-based feed, whereas the study by Spartano and Grasso demonstrated information provision to increase the willingness to try and to pay for eggs derived from laying hens fed an insect-based feed. Sogari et al. (2021) and Wongprawmas et al. (2022) also examined the role of information related to insect-based feed in poultry and aquaculture production. The papers confirmed that the information provision to be essential for effective communication about edible insects. Similarly, Carrassón et al. (2021) and Hoerterer et al. (2022) have studied consumer perceptions about general aquaculture production in Spain and Germany, respectively. Both studies found information to significantly improve consumer perceptions. They also identified specific clusters of consumers with greater interest in the sustainability-related aspects of aquaculture production. In another study, Cantillo et al. (2023) demonstrated the potential of using positive words instead of Likert scales in the analysis of consumer perception of aquaculture products. In the abovementioned studies, the tendency to reject products derived from animals fed an insect-based feed was repeated associated with low levels of knowledge of the matter. Our results confirm the importance of providing consumers with information: the more informed consumers, they more they will be inclined to accept innovative products. Moreover, as pointed out by Woolf et al. (2019) and Wassmann et al. (2021), "unfamiliarity" is the main barrier to the consumption of novel foods. Reducing this "unfamiliarity" results in an increase in willingness to buy. This is in line with our main result related to Insect-Based Feed Sustainability, where willingness to buy was the variable that accounted for the model the most. This finding stands out as one of the most intriguing outcomes of our research. Our initial goal was to conduct an exploratory analysis, and it was surprising that a statement presented in such a limited manner yielded such a significant result. We recommend that future research investigating insect-based feed and sustainability delve into this topic deeper.

Indeed, the CATA methodology revealed that attitudes towards Insect-Based Feed Sustainability were linked to the sense of curiosity. This suggests that there may not necessarily be a negative connotation associated with consuming products derived from animals fed an insect-based feed. In fact, as highlighted in the study by Sogari et al. (2017), curiosity about edible insects should be considered a motivating factor (driver), particularly when targeting specific market segments for the implementation of such products.

The correlation analysis conducted between attitudes and explanatory variables constitutes an innovative element of this study. The literature on edible insects has mostly investigated the role of individual attitudes and variables, but no previous studies had explored their correlation. This approach should be applied in future studies investigating the perception and acceptance of edible insects used as food or feed. Our findings are consistent with the global conversation about the challenges and opportunities the aquaculture industry faces in its pursuit to ensure sustainable and environmentally friendly food production. As stated in this study, the aquaculture sector is grappling with the pressing need to identify alternative animal feed protein sources to mitigate the environmental impacts of conventional feed production. Simultaneously, the call to meet consumer demands for sustainable and ethical food choices drives industry innovation. However, while the potential of insect-based feed is recognized in academic and industry circles, consumer acceptance remains a critical factor in realizing its full potential. In future research, the methods applied here should be expanded to explore the influence of individual values on consumer attitudes regarding aquaculture products fed with insects. Additionally, investigating how these individual values may shape consumers' willingness to pay for such products could be a valuable extension to this study.

5. Limitations and implications

The data collection process for this research encountered challenges due to the COVID-19 pandemic, which made recruiting participants more difficult; however, we were still able to enroll a sufficient number of participants, primarily individuals under 30 years old, by recruiting from our close contacts and the broader research community. Although the predominant representation of a consumer segment with a high level of education did not significantly influence the overall outcome, it is important to recognize that the findings may be more reflective of the perspectives and behaviors of individuals with higher educational attainment and may not be representative of the broader population. This nuance should be considered when interpreting and generalizing the results to ensure a more accurate and balanced understanding of the data. Secondly, although the majority of the sample reported being in full-time employment, many of them reported low annual incomes. Moreover, the specific question proposed did not specify whether it was referring to gross or net income. In Italy, this question is usually taken to refer to net income, but the lack of distinction could have led to discrepancies in the responses and thus misleading conclusions being made. Also, responses to this question may have been subjected to cognitive bias (Suchman, 1962), and this aspect should be improved upon. Future studies should take measures to ensure that the sample of respondents is more representative of the general population, in particular with regard to the age groups considered. Our reliance on self-reported data collected via an online survey raises the possibility of social desirability bias and response inaccuracy.

Adding objective measures or observational studies to our findings could provide a more complete understanding of consumer behavior. Furthermore, because cultural and regional factors can influence food preferences, conducting similar research in different countries or regions would contribute to a more comprehensive understanding of global consumer attitudes.

Furthermore, it is worth noting that the sample size calculation was performed post hoc; however, this did not compromise the reliability of our results, as the number of responses obtained ($n = 303$) surpassed the minimum ($n = 289$) indicated by the sample size calculation which was based on the positive responses to general knowledge questions, specifically in relation to acceptance (ACC) and willingness to buy (WTB). The effect size for the Insect-Based Feed Sustainability (IBFS) attitude was derived from these calculations and revealed that 25% of IBFS variance is explained by ACC and 24% by WTB. This underscores the

importance of conducting further research on consumer attitudes towards the sustainability of insect-based feed providing a more comprehensive understanding of the dynamics influencing consumer perceptions and behaviors.

Finally, Item Response Theory (Baker, 2001) was employed to evaluate "Knowledge On Fish", and although this methodology allows for precise measurement of a latent phenomenon, the utilization of a Likert scale to assess the accuracy of all true statements may appear unconventional. The choice to exclusively incorporate only verifiable statements concerning fish nutrition was made to mitigate the dissemination of inaccurate information.

Despite these limitations, our research has several practical implications for the aquaculture industry. First and foremost, aquaculture companies stand to benefit from targeted marketing and educational initiatives. Recognizing the importance of socio-demographic factors and knowledge levels in shaping consumer attitudes and tailoring campaigns to specific consumer segments can help bridge the acceptance gap for insect-fed animal products.

6. Conclusions

Consumer attitudes towards fish-based products derived from fish fed an insect-based feed were evaluated through an online questionnaire. The attitude towards sustainability and a high level of information/knowledge related to the use of insect-based feed in aquaculture were identified as drivers for the acceptance of these products. At the same time, characteristics such as gender, age, diet, and food neophobia were recognized as barriers. By examining the relationship between explanatory variables and attitudes, this study provides insight into potential consumer profiles for these innovative products. Our study contributes to this ongoing dialogue by shedding light on the interplay between socio-demographic factors, knowledge levels, and sustainability attitudes among European consumers, illuminating avenues for future research and practical implementation in the global aquaculture sector. Our findings highlight the significance of sustainability messaging. In particular, emphasizing the environmental benefits of insect-based feed may help increase market acceptance of insect-fed fish products by resonating with consumers who prioritize sustainability. Furthermore, the development of novel product lines and distinct branding strategies may help differentiate these products in the marketplace. Finally, encouraging collaborations between academia, industry, and regulatory bodies may stimulate additional research into the safety, quality, and consumer perceptions of insect-fed animal products, ultimately supporting the sector's sustainable development and meeting the growing demand for environmentally friendly food.

CRediT authorship contribution statement

Rosalba Roccatello: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Isabella Endrizzi:** Formal analysis, Methodology, Supervision, Writing – review & editing. **Eugenio Aprea:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Sihem Dabbou:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

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

Data availability

The data that support the findings of this study are available from the corresponding author upon request.

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