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Microplastics in seafood: Consumer preferences and valuation for mitigation technologies

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ABSTRACT

Microplastics, an emerging pollutant, have garnered widespread attention due to potential repercussions on human health and the environment. Given the critical role of seafood in food security, growing concerns about microplastics might be detrimental to meeting future global food demand. This study employed a discrete choice experiment to investigate Chilean consumers' preferences for technology aimed at mitigating microplastic levels in mussels. Using a between-subjects design with information treatments, we examined the impact of informing consumers about potential human health and environmental effects linked to microplastics pollution on their valuation for the technology. We found that the information treatments increased consumers' willingness to pay for mussels. Specifically, consumers were willing to pay a premium of around US$ 4 for 250 g of mussel meat with a 90 % depuration efficiency certification. The provision of health impact information increased the price premium by 56 %, while the provision of environmental information increased it by 21 %. Furthermore, combined health and environmental information significantly increased the probability of non-purchasing behavior by 22.8 % and the risk perception of microplastics for human health by 5.8 %. These results emphasized the critical role of information in shaping consumer preferences and provided evidence for validating investment in research and development related to microplastic pollution mitigation measures.

1. Introduction

Seafood is a cornerstone in designing food systems for the next generations because it is a rich source of nutrients, has a low environmental footprint in many systems, is essential for supporting livelihoods in vulnerable communities, may displace the consumption of less healthy meat, among other reasons (Golden et al., 2021; Tigchelaar et al., 2022). Costello et al. (2020) calculated that food from the sea represents 17 % of the globally produced edible meat by 2017, which will increase between 36 % and 74 % by 2050. However, this substantial growth might depend on factors such as policy reforms, technology improvements, or shifts on the demand side. This variation in demand can be led, among many other reasons, by concerns related to emergent pollutants that could compromise food security.

One of the seafood sectors with the highest production potential is bivalve mariculture because it is not constrained by feed limitations (Costello et al., 2020) and poses a high nutritional potential at a lower environmental impact than other species (Koehn et al., 2022). Bivalves are filter feeders that capture food particles by water filtration. Unfortunately, this mechanism also bioaccumulates other types of particles, including pollutants such as metals (Waykar & Deshmukh, 2012), or microplastics (MP, plastic debris with a diameter below 5 mm), which is an emerging pollutant that might harmfully affect plants, soils, wildlife, or even humans. Particularly, mussels are a subgroup of bivalves that have been proposed as a global bioindicator of coastal MP pollution because of their wide distribution, susceptibility to MP uptake, and close

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connection with marine predators and human consumption (Li et al., 2019). Then, mussels are a dominant species used for field research on MP pollution.

The widespread presence of MP in the environment and the already confirmed exposure of humans through inhalation or ingestion of these particles could generate risks to food security and human health (De la Torre, 2020). Recent studies have identified MP in human stools (Schwabl et al., 2019; Zhang et al., 2021), blood (Leslie et al., 2022), placenta (Braun et al., 2021; Ragusa et al., 2021), lung tissue (Jenner et al., 2022), and colon (Ibrahim et al., 2021). Nevertheless, the direct impacts of these MP particles on human health are still largely unknown, and further research is needed (Koelmans et al., 2017; Leslie et al., 2022; Smith et al., 2018). However, an increasing number of publications on social media have awakened public concern about MP contamination in food products, which can discourage the consumption of seafood, which is essential for food security. Consequently, researchers have begun investigating technologies that could reduce MP contamination in food products. Particularly in shellfish, such as mussels, researchers have proposed depuration as an additional step that could significantly reduce the MP content (Birnstiel et al., 2019; Fernández & Albentosa, 2019; Li et al., 2021). The depuration technique consists of placing the harvested shellfish into water tanks until they meet the criteria needed to put them on the market (Sun et al., 2022). However, the depuration process in practice is mainly used to eliminate microbiological content (e.g., *escherichia coli*), so most mussels in the market likely still contain MP.

No study has examined how consumers would value this emergent technology to reduce the presence of MP in food products. This is important since technology development might be influenced, among other factors, by consumers' willingness to pay (WTP) for it. This study contributed to filling this gap. Moreover, we tested how additional information about the potential effects of MP on human health (HEA), on the environment (ENV), and a combination of them (HEA-ENV) impacted: 1) consumers' WTP for mussel's attributes, 2) consumption avoidance behavior, and 3) MP riskiness perception. Furthermore, we offered additional analyses for those consumers with high certainty about their answers, high perceived policy consequentiality, and previous knowledge about MP. Evaluating consumers' preferences for emerging technology designed to mitigate MP pollution is challenging, given that these technologies are still in the research and development phases. Therefore, accessing market prices for the products under study is unfeasible due to their absence in the market. In such cases, stated preference (SP) methods are a popular tool to estimate consumer preferences as they can create a hypothetical market and elicit respondents' preferences for characteristics of the relevant good. For instance, using an SP method known as a discrete choice experiment (DCE), we could estimate theoretically consistent economic values for specific attributes of the products, such as certifications and labels. Although its hypothetical nature generates limitations such as hypothetical bias, broad research offers guidance to mitigate its flaws (see Johnston et al. (2017) for a comprehensive discussion). Despite the latter, DCE is arguably one of the most popular methods used in food choice literature (Caputo & Scarpa, 2022). Consequently, we conducted an online DCE in Chile about mussel purchasing decision-making, interviewing over 2,000 mussels' consumers. We chose the Chilean mussel as the product of interest given its popularity and economic relevance. It is one of the most important export industries in Chile, even leading the prices in the European mussel market (Avdelas et al., 2021; Salazar & Dresdner, 2022).

Consumers' valuation for certified depuration has not been extensively researched, even considering how extended its use is to reduce the number of microorganisms in seafood. Previous research has found consistent evidence of a premium for eco-labelled seafood (Bronnmann et al., 2023; Smetana et al., 2022; Vitale et al., 2017), but we did not find any study on depuration technologies. Nevertheless, we could expect that consumers will have a positive WTP for risk reduction technologies in food products, as in previous research (Mørkbak et al., 2012). Then, our first research hypothesis (H1) is that consumers value depuration as a technology to reduce MP from mussels. Besides, the literature using information treatments on food purchasing decision-making shows that, in general, if these information treatments are positively framed (e.g., nutritional and health benefits claims; see Ballco and Gracia (2022) for a review), then a WTP premium is expected (although it is not always the case (Steinhauser & Hamm, 2018)). In our case, we presented information about potential adverse health and environmental effects, which is not common in the literature. Regarding the magnitude effect order, previous evidence showed that health-related information generates a higher premium than environmental-related information (Vecchio et al., 2016). Consequently, we expected that the WTP for depuration varies across information treatments; specifically, the WTP in the control group will be the lowest, followed by the ENV treatment, then the HEA treatment, and the highest WTP for depuration certification should be found in the HEA-ENV treatment (H2). Moreover, these information treatments could affect the consumption itself. For instance, some labels or certifications, such as the "clean label" (Asioli et al., 2017), activate the avoidance and prevention motivation, and we hypothesize that a risk reduction technology such as depuration will trigger the same motivation in a fraction of seafood consumers. Then, our H3 says that information treatments increase the probability of choosing a no-purchase alternative as a preventive behavior, following the same order as the WTP for certified depuration. Finally, recent literature suggested that people perceive MP as riskier for the environment than for human health (King, 2022; Soares et al., 2021). However, we extended this analysis by exploring whether information treatments could affect this perception. Hence, we hypothesized that information treatments affect the perceived riskiness of MP on human health and the environment, but the effect will be higher for riskiness on human health (H4).

The remainder of the article proceeds as follows: In the background section, we described the relevance of MP pollution, its links with food products, and the related literature using SP methods. Next, we described the DCE design, survey procedure, and how we planed to analyze the resulting data. The results section was divided into three sub-sections pertaining to the main outcomes: WTP, no-purchase probability, and riskiness perception of MP pollution. We then discussed the results, comparing them with related literature and highlighting the main takeaways from our study. We finalized the article with the conclusions, policy suggestions, main limitations, and recommendations for further research.

2. Background

2.1. Microplastics pollution and food products

Plastic is a waterproof, durable, safe, resistant to biodegradation, and cheap material ubiquitous in our daily activities due to these characteristics (Horton et al., 2017). Although their usefulness, these characteristics also make plastic a persistent environmental pollutant. Moreover, since the study of Thompson et al. (2004), who showed that "microscopic plastic fragments" are widespread in the ocean, the literature has put explosive attention on exploring how the different sizes, shapes, and compositions of these fragments could impact the environment (Rochman, 2018). MP have been found in isolated areas like the Scilly Islands (Nel et al., 2020), Mount Everest (Napper et al., 2020), Marianas Trench (Peng et al., 2018), or even the Arctic Sea (Obbard et al., 2014). Recently, the literature has intensively investigated some sources or actions that could increase human exposure to MP. For instance, using take-out containers (Du et al., 2020), drinking beer (Liebezeit & Liebezeit, 2014) or bottled water (Nacaratte et al., 2023), consuming seafood (Smith et al., 2018), milk (Kutralam-Muniasamy et al., 2020), and many others (Pham et al., 2023).

To provide a quantitative glimpse of the problem, Cox et al. (2019) estimate that the American's annual MP intake ranges from 74,000 to 121,000 particles considering ingestion and inhalation, but these estimates can be just a lower bound of the actual consumption. Other authors, such as Hernandez et al. (2019), found that a single plastic teabag exposed to a brewery temperature (95°) can release close to 12 billion microplastic particles into the cup of tea. Besides, a single garment can remove over 1,900 fibers per wash (Browne et al., 2011), or, including the detergent used, a 5 kg wash load could release over 6 million fibres (De Falco et al., 2018). This wide range of values shows a relevant challenge of MP pollution research: the lack of standardized data collection methods that could ensure comparability across studies (Ding et al., 2022; Smith et al., 2018). This barrier has its own implications in economic analyses, hindering attempts at cost-benefit analysis.

Now, specifically in seafood, there is vast evidence of MP particles in the organisms of marine species of the whole food chain, covering from plankton (Cole et al., 2013) to whales (Besseling et al., 2015), and this ubiquitous presence is not limited to farmed species but also the natural ones (Garcia et al., 2021). Then, human exposure to MP pollution through the ingestion of seafood is unsurprising. However, the presence of MP in seafood does not necessarily imply a risk. It will depend on the exposure concentrations and the plastic additives or chemical components (Smith et al., 2018). The heterogeneity between measures of MP in marine species has been summarized in comprehensive reviews where the reader can further explore the topic (Khanjani et al., 2023; Kibria et al., 2022; Lusher et al., 2017; Smith et al., 2018).

Therefore, as the evidence of MP contamination across species is robust, researchers have been investigating how to adapt technology or generate new ones to prevent, reduce, or remove MP pollution in food products. A strand of the literature has focused on reducing MP pollution from the source by improving wastewater treatment plant technologies (Iyare et al., 2020), while other literature has focused on removing MP from natural water (Pan et al., 2022). We will focus on depuration, an existing technology that consists of depositing the mussels in a tank with clean seawater and letting them clear their intestinal contents through filtering activity. This process is mainly used to eliminate microorganisms, but not other pollutants such as heavy metals, because scientific evidence shows it is not entirely effective (Anacleto et al., 2015; Lee et al., 2008). However, recent literature has found that depuration is able to eliminate a significant amount of MP from mussels, although more research is still in progress (Birnstiel et al., 2019; Fernández & Albentosa, 2019; Li et al., 2021). Except for Anacleto et al. (2014), depuration technology in seafood and how consumers value it has been scarcely discussed in the literature.

2.2. Stated preferences, plastic pollution, and seafood

Recently, SP methods have been used to capture preferences for different dimensions of the plastic life cycle. A relevant strand of this literature has investigated consumers' preferences for more sustainable plastics (Polyportis et al., 2022; Ruf et al., 2022), which is limited to the consumption phase of the plastic life cycle. However, specific literature about preferences for improving the end-of-life of plastic materials or tackling the consequences of plastic and MP pollution is still scarce. Regarding MP pollution, Choi and Lee (2018) conducted a Contingent Valuation (CV) study in South Korea, where they estimated a yearly WTP of US$ 2.59 for some policies to reduce MP in the ocean. Similarly, Borriello and Rose (2022) conducted a DCE in Australia about hypothetical management programs to reduce MP in the ocean. The average WTP between individuals ranged between US$ 36 and US$ 107 per year. Using the same data, Borriello (2023) analyzed specific policies that could lead to a slight improvement (WTP US$ 46) or a large improvement (WTP US$ 116) from the described status quo. Following the same concept, Khedr et al. (2023) conducted a multi-country study to estimate the WTP for plastic and MP removal from the marine environment. They estimated a monthly WTP for implementing policies to accomplish the Marine Strategy Framework Directive for reducing marine litter at the EU scale that varied from € 20.4 in Greece to € 53.8 in Sweden. In non-marine-related topics, King (2022) carried out two CV studies to estimate preferences for research into the long-term effects of MP on human health and the environment and for upgrading the filtering systems of wastewater treatment plants to decrease the release of MP in the environment. The annual WTP per household was £53.37, and £88.43 respectiveley. Other studies have estimated the WTP for reducing plastic pollution as a more general concept in different geographical regions, such as Galapagos Islands (Zambrano-Monserrate & Ruano, 2020), Svalbard (Abate et al., 2020), Indonesia (Tyllianakis & Ferrini, 2021), North Western Hawaiian Islands (Meginnis et al., 2022), China (Han et al., 2023), the US, and the UK (Börger et al., 2023).

SP methods have been widely used to explore consumer preferences for diverse food products (Caputo & Scarpa, 2022; Lizin et al., 2022). Regarding seafood, comprehensive reviews summarize the current knowledge (Cantillo et al., 2020; Maesano et al., 2020; Saidi et al., 2022; Vitale et al., 2017). More specifically, our article lies within the literature linking pollution and preferences for food products. This literature has investigated consumer preferences under food security concerns such as food poisoning (Henson, 1996), pesticides (Florax et al., 2005), genetic modification (Onyango et al., 2006), food processing (Asioli et al., 2017) or food irradiation (Caputo, 2020). Nonetheless, as far as we know, the only study investigating the nexus between consumer preferences and plastic or MP pollution in food products is Moon et al. (2023), who conducted a CV study to elicit consumers' WTP for a fillet of salmon with a lower number of MP particles. This article focused on comparing Western and East Asian cultures in terms of consumer preferences for seafood by including cultural and attitudinal factors. However, it did not specify the mechanism for microplastic mitigation nor contextualize microplastics as an emerging pollutant and its impact on human health or the environment.

3. Material and methods

3.1. Survey and discrete choice experiment design

We designed a DCE as part of a comprehensive survey on mussel consumption, integrating a between-subjects information treatment in the DCE contextualization. This treatment introduced four survey formats, distinguished solely by informative additional paragraph providing information on the potential health and/or environmental effects of MP. The survey was structured into three sections. In the first section, we gathered respondents' general sociodemographic data, consumption patterns, and their prior knowledge and riskiness perceptions of MP. Following this, in section two, we introduced and conducted the DCE alongside debriefing questions. The third section included a survey module adapted from Cavatorta and Schröder (2019) to measure ambiguity preferences. This data is not included in the present article.

The DCE encompassed four attributes: Mussel's format, certified depuration efficiency, producer size, and price per 250 g of mussel's meat (see Table 1). We included mussel's format because it is the initial consumer-facing attribute in mussel purchasing decisions. We chose fresh, frozen, and canned mussels since they are the main varieties available in the market, and the literature has shown their relevance for consumers (Ponce et al., 2022). The inclusion of depuration efficiency

Table 1
Discrete Choice Experiment attributes.

Attributes	Levels
Mussel's format	Fresh Frozen Canned
Certified depuration efficiency	90 %, 50 %, 25 %, and no depuration
Producers size	Small mussel farmers or large-scale mussel farmers
Price (US$ for 250 g mussels' meat)	$1.875, $2.5, $3.125, $3.75, $4.375 and $5

stems from its potential role in reducing MP presence in seafood. In Chile, depuration is mandatory when the *Escherichia coli* bacteria exceeds the 4,600 Most Probable Number (MPN) for each 100 g of mussel meat in 90 % of the sample. Therefore, it is likely that most mussels with MP are not taken to depuration centers because they have low levels of *Escherichia coli* bacteria. The efficiency levels, 25 % and 50 % were based on depuration trials conducted by Birnstiel et al. (2019) while the 90 % was chosen to resemble the standard use for the *Escherichia coli* bacteria. Furthermore, the Chilean mussel industry comprises small rural producers and large-scale farmers (San Martin et al., 2020). We hypothesized that consumers were more inclined towards supporting small-scale producers due to pollution issues surrounding the aquaculture industry (Chávez et al., 2019). Lastly, we included a price attribute that comprised six levels obtained from actual market prices.

Consumers were presented with three alternatives: two for purchasing mussels with varying attribute levels, and one for not purchasing. We introduced the non-purchase alternative to account for the potential avoidance of seafood consumption resulting from information treatments (H3). Then, we used a Bayesian D-optimal design to reduce the cognitive burden implied in showing many combinations of attributes and levels (choice situations) (Hensher et al., 2005). This process resulted in six blocks of four choice situations each. Consumers faced choice situations similar to figure A1 presented in appendix A. Prior to presenting the choice situations, we contextualized the DCE by providing information about mussels, their filter-feeding mechanism, and how this characteristic was related to MP pollution. Additionally, we offered detailed descriptions of MP, their widespread presence, and their potential removal via depuration technology. The complete text is available in appendix B.

The difference in each treatment group consisted of additional information about the potential effects of MP on human health (HEA), the environment (ENV), or a combination of both (HEA-ENV). We also included a control group (CONTROL) receiving no additional information. The information presented in HEA and ENV treatments was presented as follows, while the HEA-ENV information was included in appendix B:

HEA: "*Scientific studies have reported that microplastics are present in various foods and our stool, lungs, colon, or even blood. The presence of microplastics in our bodies can potentially cause negative health effects. For example, they could lead to:*

- o *Neurotoxicity: Toxic substances affect the normal activity of the nervous system.*
- o *Oxidative stress: Imbalance between free radicals and antioxidants, which can damage different cellular molecules and structures.*
- o *Immunotoxicity: Adverse effects on the structure or function of the immune system.*

However, many of these studies have been conducted under conditions that do not reflect a realistic exposure to microplastics, so there is still uncertainty about the actual effects on human health.".

ENV: "*Scientific studies have reported that microplastics can cause a variety of potential effects on the environment.*

For instance, microplastics in the soil can affect the growth or biomass of different plants, such as wheat, rice, broad beans, and lettuce, among others. In addition, the presence of microplastics can also change some soil properties (for instance, accelerating soil water evaporation) or affect soil fauna (earthworms who ingest microplastics may suffer weight loss or a decreased growth rate). In the marine environment, microplastics can be consumed by fishes, crustaceans, molluscs, among other organisms. This voluntary or involuntary ingestion can cause a decrease in nutrient uptake and a reduction in feeding activity because of false satiety.

There are several other potential effects of microplastics on the environment, but we only intended to mention a few."

Finally, a relevant concern in SP studies is whether respondents behaved consistently as they were in a real purchasing situation. We implemented standard strategies to mitigate this potential hypothetical bias. Specifically, we included a cheap talk paragraph before presenting the choice sets, asked about how certain their answers were in the DCE and whether they thought the experiment would be policy consequential. These questions will be used in the robustness analyses included in appendix C.

3.2. Data collection

We conducted an online DCE to 2,026 Chilean seafood consumers between April and June 2023. The survey was tested in a pilot survey in February 2023, where we interviewed 139 consumers, and its results were used to optimize survey flow and improve the question framing. We used the opt-in online panel of consumers provided by the specialized firm OpinandoOnline.[1] The respondents were adults older than 18 years old who have consumed mussels in the past six months. The Institutional research ethics committee of Universidad del Desarrollo, Chile approved the survey's final version.

To increase the quality of our data, we gathered response-time information and dropped observations representing the 5th percentile of the left and right tails of the distribution. We also took out from the sample some observations reporting unfeasible values (e.g., respondents reporting that they pay, on average, over US$ 100 for the mussels they consume). Then, the final full sample had 1,826 consumers; the control sample had 451, the environment treatment sample had 454, the health treatment sample had 472, and the last treatment had 449 consumers. Table 2 shows the descriptive statistics by treatment group and the results of means equality chi-square tests.

Table 2 shows that each subgroup is very similar in sociodemographic terms, signaling the successful treatment randomization process. The p-values of the means equality chi-square tests support this. The null hypothesis is mean equality across treatments, and we cannot reject this hypothesis in any of the demographic variables. The average respondent in the sample was around 43 years old, and the sample was composed of more women (70 %) than men. Chile is a long country that we divided into four zones, where the metropolitan area is the most populated and represents around 60 % of our sample. Regarding educational level, most respondents stated that they had completed secondary (39 %) or tertiary (52 %) education. Finally, the average household comprised 3.6 members, 44 % of respondents ensured that mussels were consumed at least once every two weeks, and around 48 % of consumers mentioned having heard about MP before the survey.

3.3. Econometric modeling

Under the Random Utility Maximisation framework, we can derive statistical models that assume a utility-maximizing behavior by the decision-maker. The indirect utility function for individual n in decision occasion t, given that they have chosen alternative j, is denoted by U_{njt}, and they will always choose alternative j if $U_{njt} > U_{nit}$ with $j \neq i$. However, the researcher can only observe some x_{njt} attributes of the different alternatives and specific characteristics of the individuals (e.g., sociodemographic characteristics). Since the researcher is unable to observe the full utility, we can say that the individual's indirect utility is composed of an observed component V_{njt} and an unobserved component ε_{njt}.

$$\mathbf{U_{njt}} = \mathbf{V_{njt}} + \varepsilon_{\mathbf{njt}} \tag{1}$$

[1] https://www.opinandoonline.com/.

Table 2
Descriptive statistics by treatment group.

	Full sample	CONTROL	ENV	HEA	HEA-ENV	
	Mean(Std dev)	Mean(Std dev)	Mean(Std dev)	Mean(Std dev)	Mean(Std dev)	P-values
Age	43.42(13.32)	43.08(13.37)	42.49(12.44)	43.72(13.90)	44.37(13.49)	0.1543
Gender (1 = Male)	0.30(0.46)	0.28(0.45)	0.26(0.44)	0.32(0.47)	0.33(0.47)	0.0821
Northern Zone (1 = Belong this zone)	0.07(0.25)	0.06(0.29)	0.08(0.27)	0.07(0.26)	0.07(0.25)	0.6273
Metropolitan Zone (1 = Belong this zone)	0.58(0.49)	0.60(0.49)	0.61(0.49)	0.56(0.50)	0.55(0.50)	0.2213
Central Zone (1 = Belong this zone)	0.18(0.38)	0.18(0.38)	0.15(0.36)	0.19(0.39)	0.20(0.40)	0.2245
Southern Zone (1 = Belong this zone)	0.18(0.38)	0.17(0.38)	0.17(0.37)	0.18(0.39)	0.19(0.39)	0.6897
Primary Education	0.10(0.30)	0.09(0.28)	0.10(0.30)	0.11(0.31)	0.09(0.29)	0.6589
Secondary Education	0.39(0.49)	0.38(0.49)	0.39(0.49)	0.40(0.49)	0.37(0.48)	0.8387
Tertiary Education	0.52(0.50)	0.53(0.50)	0.51(0.50)	0.49(0.5)	0.54(0.50)	0.4913
Household Size	3.61(1.47)	3.64(1.49)	3.67(1.50)	3.63(1.48)	3.51(1.44)	0.3759
Frequent Consumer (1 = Yes)	0.44(.050)	0.45(0.50)	0.45(0.50)	0.44(0.50)	0.44(0.50)	0.9804
Previous knowledge about microplastics (1 = Yes)	0.48(0.50)	0.47(0.50)	0.45(0.50)	0.48(0.50)	0.44(0.50)	0.8777
Observations	1,826	451	454	472	449	

The last column contains p-values from mean equality chi-square test across treatments. Std dev = Standard deviation. CONTROL = Control group. ENV = Microplastics environmental effects information treatment subsample. HEA = Microplastics human health effects information treatment subsample. HEA-ENV = Microplastics human health and environmental effects information treatment subsample.

The joint density of ε_{njt} is assumed i.i.d. extreme value distributed. This means that the probability of choosing alternative j over alternative i by individual n in the choice situation t can be written as:

$$P(U_{njt} > U_{nit}) = \frac{e^{V_{njt}}}{\sum_I e^{V_{nit}}} \tag{2}$$

Then, assuming V_{njt} is linear-in-parameters and vector β_{kn} contains the parameters of the effect of the k non-monetary attributes, and θ_j is the effect of the monetary attribute on the utility, we have:

$$V_{njt} = ASC_{no-purchase} + \beta_{1n}Frozen_{njt} + \beta_{2n}Canned_{njt} + \beta_{3n}Dep\_25_{njt} + \beta_{4n}Dep\_50_{njt} + \beta_{5n}Dep\_90_{njt} + \beta_{6n}Small\_scale_{njt} + \theta_n Price_{njt} \tag{3}$$

Where $ASC_{no-purchase}$ represents the alternative-specific constant for the no-purchase alternative. Note that for the format attributes, we keep the fresh format as the baseline so that we can identify the effects of *Frozen* and *Canned* formats. In depuration, the baseline was 0 % of depuration efficiency (*Dep_0*), and large-scale producers in the producer's size attribute. We are interested in capturing unobserved taste heterogeneity between individuals, then we estimate a Mixed Logit model (MXL). This model allows the parameter to follow a distribution function *g(.)* (e.g., normal distribution), which will be defined by the researcher. However, this specification poses limitations when estimating the WTP. For instance, the WTP is usually calculated as the ratio of a non-monetary attribute parameter and the monetary attribute parameter, then, the resulting WTP can take excessively large values as the denominator is allowed to take very low values. Then, we reparametrize equation (3) to obtain equation (4) which is the utility in the WTP-space (Scarpa et al., 2008), where $\gamma_{kn} = \beta_{kn}/\theta_n$ which is the WTP for each k non-monetary attribute presented in the DCE.

$$V_{njt} = ASC + \theta_{njt}[\gamma_{1n}Frozen_{njt} + \gamma_{2n}Canned_{njt} + \gamma_{3n}Dep\_25_{njt} + \gamma_{4n}Dep\_50_{njt} + \gamma_{5n}Dep\_90_{njt} + \gamma_{6n}Small\_scale_{njt} - Price_{njt}] + \varepsilon_{njt} \tag{4}$$

This specification is useful as gives us directly the scale-free parameters of WTP distribution for each attribute, which eases interpretation and WTP-related hypotheses testing (Mariel et al., 2021). In this study, we assume that non-monetary parameters follow a normal distribution, while the price parameter follows a log-normal distribution. Then, we estimate the MXL model by maximum simulated likelihood with 500 MLHS draws and using R package Apollo (Hess & Palma, 2019).

Table 3
Mixed logit estimations in WTP-space by treatment group.

	Full sample MXL1	CONTROL MXL2	ENV MXL3	HEA MXL4	HEA-ENV MXL5
Mean					
ASC – No purchase	−3.39 (0.16)***	−3.13 (0.28)***	−3.41 (0.35)***	−3.33 (0.32)***	−3.46 (0.38)***
Format: Frozen	0.07 (0.09)	0.73 (0.14)***	1.12 (0.05)***	1.83 (0.02)***	0.00 (0.14)
Format: Canned	−0.26 (0.12)*	−0.22 (0.22)	−0.59 (0.25)**	−0.57 (0.10)***	−0.47 (0.29)
Depuration: 25 %	0.57 (0.12)***	0.90 (0.14)***	1.19 (0.16)***	−1.75 (0.04)***	0.35 (0.17)*
Depuration: 50 %	2.72 (0.07)***	2.60 (0.06)***	3.42 (0.17)***	3.99 (0.04)***	2.85 (0.11)***
Depuration: 90 %	4.14 (0.12)***	3.90 (0.17)***	4.72 (0.27)***	6.07 (0.06)***	4.11 (0.26)***
Producer: Small-scale	0.72 (0.12)***	0.78 (0.11)***	1.15 (0.18)***	0.37 (0.05)***	0.08 (0.14)
Price	−0.66 (0.09)***	−0.86 (0.19)***	−0.97 (0.24)***	−1.50 (0.46)***	−0.53 (0.17)***
Standard Deviation					
Format: Frozen	3.75 (0.19)***	3.56 (0.10)***	5.97 (0.58)***	9.64 (0.06)***	2.87 (0.23)***
Format: Canned	3.58 (0.24)***	2.96 (0.10)***	5.25 (0.49)***	7.83 (0.12)***	3.09 (0.47)***
Depuration: 25 %	1.99 (0.10)***	1.00 (0.08)***	0.44 (0.11)***	3.86 (0.05)***	0.96 (0.12)***
Depuration: 50 %	2.59 (0.13)***	2.78 (0.14)***	2.76 (0.28)***	3.94 (0.08)***	2.12 (0.21)***
Depuration: 90 %	3.20 (0.21)***	2.48 (0.15)***	3.68 (0.31)***	6.06 (0.08)***	3.77 (0.68)***
Producer: Small-scale	1.73 (0.08)***	1.92 (0.07)***	1.09 (0.09)***	4.44 (0.07)***	2.54 (0.34)***
Price	1.67 (0.15)***	1.96 (0.39)***	2.07 (0.30)***	3.60 (0.67)***	1.62 (0.23)***
Observations	7304	1804	1816	1888	1796
Log Likelihood convergence	−6376.73	−1584.81	−1558.26	−1625.61	−1588.59

***p < 0.001; **p < 0.01; *p < 0.05 Standard Errors in parentheses; ASC = Alternative Specific Constant. WTPs are in US$ 2023. MXL = Mixed logit model. CONTROL = Control group. ENV = Microplastics environmental effects information treatment subsample. HEA = Microplastics human health effects information treatment subsample. HEA-ENV = Microplastics human health and environmental effects information treatment subsample.

4. Results

In Table 3, we present the results of the MXL model for the full sample (MXL1) and each treatment (MXL2, MXL3, MXL4, and MXL5) and discuss WTP parameter statistical significance and their differences in statistical terms across treatments. Next, we will show the alternative's choice probabilities by treatment and test whether they are statistically different from each other. Finally, we explore whether the perceived riskiness of MP for human health and the environment varies across treatments.

4.1. Mixed logit estimations

The second column of Table 3 presents the results of a pooled model. Most parameters were statistically significant and showed the expected signs. That is, the ASC for the no-purchase alternative was always statistically significant and with a negative sign, which means that choosing the no-purchase alternative reports lower average utility across respondents. The frozen format was not statistically significant, but the canned format presented a negative WTP compared with the fresh one. The depuration attribute was statistically significant and with a positive sign, reflecting that consumers consider the depuration efficiency certification as a positive attribute. Small-scale producers' attribute was statistically significant, with a positive sign showing that consumers, on average, prefer mussels produced by small-scale producers instead of large-scale producers. Lastly, the price parameter was always statistically significant and with a negative sign.

As we estimate the models in WTP space, each attribute's parameters can be interpreted as marginal WTP (in US$ 2023). To test whether the differences in WTP across treatments were statistically significant, we calculated the z-tests for mean differences between WTP. Regarding the format attribute, the WTP was positive for frozen and negative for canned, although they were not statistically significant in every model. The frozen format increased from US$ 0.73 in the CONTROL group to US$ 1.83 in the health information treatment (z-test = -7.9, p-value = 0.000), which means a 151 % increase in consumer valuation for the attribute. Conversely, the canned format was not statistically significant in the CONTROL group nor the HEA-ENV treatment, but the WTP was negative under ENV and HEA (although not statistically different from each other), which means that they need to be compensated (e.g., discount) to be willing to consume mussels in this format. Regarding the producer's size, the ENV and HEA treatments generated different effects. The ENV treatment increased the WTP from US$ 0.78 to US$ 1.15 (z-test = -1.7, p-value = 0.086), but the HEA treatment decreased it to US$ 0.37 (z-test = 3.4, p-value = 0.001), while this parameter was not statistically significant in the joint information treatment. The full results of the mean difference tests are in appendix D.

In the case of depuration, the first relevant result is the monotonically increasing WTP as the depuration efficiency increases. Next, the WTP for the highest level of certified depuration was US$ 3.90 in the CONTROL group, and it increased to US$ 4.72 in ENV treatment (z-test = -2.6, p-value = 0.010) and to US$ 6.07 in HEA treatment (z-test = -12.2, p-value = 0.000), which implies a price premium for 90 % of depuration efficiency of 21 % in ENV and 56 % in HEA. Surprisingly, the WTP in the HEA-ENV group was lower than the WTP in ENV and HEA, and it was not statistically significant to the CONTROL group (z-test = -0.7, p-value = 0.502). This pattern is similar for 50 % of depuration efficiency, but it changes in the 25 % of depuration; the WTP turns negative in HEA treatment. From this, we could argue that consumers see the depuration as unnecessary when the effectivity is low or that they prefer to avoid consumption and would need a positive monetary benefit to accept the risk implied in its consumption.

Lastly, all attributes show a large unobserved preferences heterogeneity, which is captured by the standard deviation parameters. We estimated the respondent-specific WTP for each attribute across treatments to explore this heterogeneity. Figure 1 shows the WTP distribution across respondents.

Here, we can highlight that treatments generate changes in skewness and kurtosis of WTP distributions. For instance, in format attributes, CONTROL and HEA-ENV treatments present a leptokurtic distribution around zero. In contrast, ENV and HEA treatments show a more platykurtic distribution over positive and negative WTP values. In the case of depuration, for 25 % efficiency, the ENV treatment generates a concentration over the mean WTP (around US$ 1.2), while the HEA treatment generates a large dispersion in WTP values. In certified efficiency of 50 %, the WTP dispersion is very similar across treatments, but all the means are statistically different between them (Table D1). In 90 % of certified depuration, the information treatments generate higher dispersion in WTP values versus the control sample. Moreover, the HEA-ENV distribution is positively skewed, while the HEA distribution is negatively skewed. In fact, the density of WTP around zero is highest in HEA-ENV treatment. Regarding the WTP for small-scale producers, the ENV treatment generates a relevant impact on the kurtosis of the WTP, while the other subsamples have more dispersed WTP values. Lastly, a main takeaway from this figure (and that can be inferred from standard deviation parameters in Table 3) is that HEA treatment generates a larger variance in WTP distributions compared to the other treatments.

4.2. Predicted choice probabilities

In this section, we calculated the predicted choice probabilities for each alternative at the observation level (equation (2) and then averaged them to obtain an average predicted choice probability, which is presented in Table 4. After that, in the lower panel of Table 4, we presented the result of the mean differences z-test between each treatment.

The predicted probability of choosing alternative no-purchase in the CONTROL group was around 13.6 %, which decreased to 11.3 % under ENV treatment (change of −17.4 %) but increased to 14.2 % in HEA treatment (an increase of 4 %). Unlike the estimated WTPs, the HEA-ENV treatment generated the highest impact on no-purchase alternative probability. The joint information treatment increased the probability of non-purchasing mussels by 22.8 %.

4.3. Microplastics riskiness perceptions

We asked whether consumers had heard about MP before the survey, and to those who answered positively (between 44–48 % depending on the subsample), we showed a risk scale between not dangerous at all (=1) and extremely dangerous (=10) to score how dangerous are MP for human health and the environment. After the DCE, we repeated these questions, asking them to consider the information they had read in the survey. In Table 5, we summarized the effect of information treatments on perceived riskiness.

Before the DCE, consumers perceived MP as more dangerous for the environment than for human health; however, health risk scores changed after the DCE and information treatments. For instance, the average risk score in the control sample was 8.77 for health and this increased by 2.6 % after the DCE, even without any additional information, just the standard contextualization information offered in all samples, but the environment risk score did not statistically change. Then, in the treated samples, the health risk score increased by 5.8 % in ENV, 5.7 % in HEA, and 5.6 % in HEA-ENV. In contrast, the riskiness of MP for the environment did not generate a change in risk scores large enough to reject the null hypothesis of equal means with a 95 % confidence level. Therefore, even considering these changes, consumers kept perceiving MP as more dangerous for the environment than for human health.

Finally, in appendix C, we conducted additional analyses to explore how consumer preferences changed when we focused on those consumers with a high certainty in their answers, those who strongly believed that the DCE results would be policy consequential, and those who had heard before about MP. In general, these additional analyses

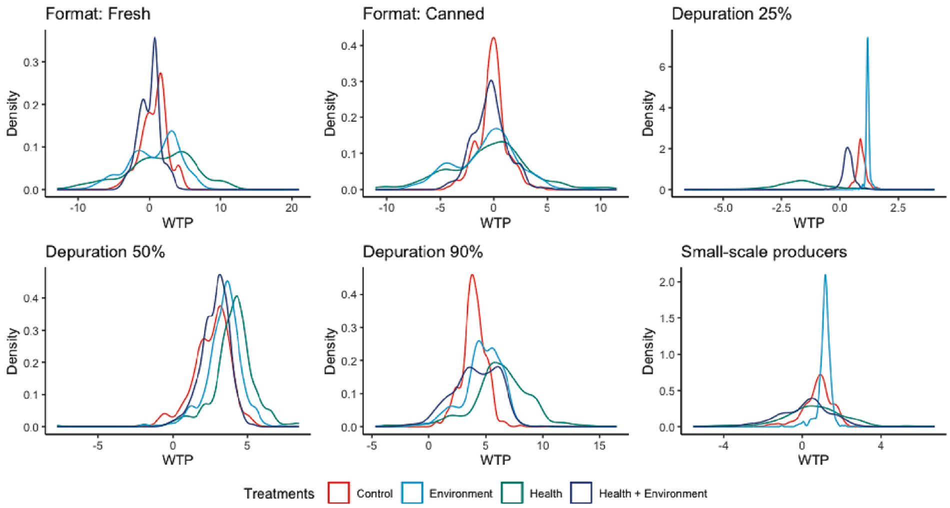

Figure 1. Distribution of respondents' specific WTP for each attribute. WTP: Willingness to pay.

Table 4
Average predicted probability for no-purchase alternative and Z-test for the difference in their means.

	CONTROL MXL2	ENV MXL3	HEA MXL4	HEA-ENV MXL5
Predicted probability of no-purchase alternative	0.1364(0.0693)	0.1127(0.0681)	0.1419(0.0586)	0.1675(0.0705)
Z-statistics and P-values				
	CONTROL	**ENV**	**HEA**	**HEA-ENV**
CONTROL	–	13.05 (0.000)	−3.03 (0.003)	−16.87 (0.000)
ENV		–	−27.75 (0.000)	−47.79 (0.000)
HEA			–	–23.85 (0.000)
HEA-ENV				–

Upper panel: standard deviations of predicted probabilities in parentheses. Lower panel: P-values in parentheses. MXL = Mixed logit model. CONTROL = Control group. ENV = Microplastics environmental effects information treatment subsample. HEA = Microplastics human health effects information treatment subsample. HEA-ENV = Microplastics human health and environmental effects information treatment subsample.

showed that our main results were robust. For instance, we confirmed that HEA-ENV treatment pushed down WTP for depuration. Some differences included changes in WTP for the format attribute and more conservative WTP for certified depuration, including that WTP for depuration 25 % in HEA treatment passed from negative to small positive values. Interestingly, consumers with previous knowledge about MP strongly prefer fresh mussels instead of frozen or canned formats.

5. Discussion

In this article, we studied consumers' preferences for technology to reduce the amount of MP in mussels. Moreover, we showed that information about the potential effects of MP on human health and the environment are relevant drivers boosting their mussels' attributes valuation, but also could generate that some consumers avoid mussels' consumption and increase their riskiness perception about MP pollution. The fact that further information about the potential effects of MP was

Table 5
Average risk scores between treatments before and after the discrete choice experiment and Z-test for the difference in their means.

Treatment		Mean value	Z-test mean difference = 0. (P-value)
CONTROL	Health – Before	8.77	−3.03(0.002)
	Health – After	9.00	
	Environment – Before	9.29	1.32(0.188)
	Environment – After	9.20	
ENV	Health – Before	8.57	−6.33(0.000)
	Health – After	9.07	
	Environment – Before	9.06	−1.78(0.075)
	Environment – After	9.20	
HEA	Health – Before	8.48	−6.15(0.000)
	Health – After	8.96	
	Environment – Before	9.28	1.85(0.065)
	Environment – After	9.17	
HEA-ENV	Health – Before	8.62	−6.40(0.000)
	Health – After	9.10	
	Environment – Before	9.19	−0.45(0.651)
	Environment – After	9.22	

CONTROL = Control group. ENV = Microplastics environmental effects information treatment subsample. HEA = Microplastics human health effects information treatment subsample. HEA-ENV = Microplastics human health and environmental effects information treatment subsample.

relevant for consumers has implications for the policy design. As the awareness of MP pollution increases and new evidence of its impacts emerges, consumers' preferences for mitigation technologies and strategies could sharply increase. Hence, policymakers could consider this price premium in the cost-benefit analysis of new technological regulations. This information could also be useful for producers to evaluate new investments in depuration technology.

Specifically, we found that most presented attributes were statistically significant and with the theoretically expected sign. Analyzing the results from the full sample, we found that the WTP for frozen mussels was not statistically different from that for fresh mussels, but the WTP for the canned format was negative compared to the fresh format. The relationship between formats is in line with Ponce et al. (2022), who found that the frozen format is preferred over fresh and various canned formats. This result could be linked to the perception that different formats imply different production methods. For instance, Boccia et al. (2023) found that traditionally processed jams are preferred over industrially processed.

Our main results, regarding the technology attribute, are that respondents have strong preferences for higher levels of certified depuration. To the best of our knowledge, the only article discussing preferences for depuration in seafood is Anacleto et al. (2014), who associate depuration certificate to clams quality perception and find that it is not the most relevant quality criteria for most consumers, but it is particularly important for older consumers. Unlike their study, we focused on the food security role of depuration and its capacity to eliminate MP from mussels. Additionally, we relate the depuration attribute result with literature that has explored preferences for certification in mussels; for instance, Brayden et al. (2018) found that US consumers are willing to pay a premium of around US$ 0.70 for mussels certified as organic. More broadly, there is robust evidence of WTP premium for eco-labelled seafood (Bronnmann et al., 2023; Smetana et al., 2022; Vitale et al., 2017). We extended the evidence to a type of certification scarcely analyzed in previous literature.

Furthermore, the information treatments strengthened the previous findings but also added some puzzling results. First, we found that depuration 90 % was valued with a premium of around US$ 4 (considering full model and CONTROL treatment), which was between 50 % and 100 % of the actual market price of 250 g of mussel's meat that fluctuates around US$ 2 and US$ 4. Hence, this premium increased by 21 % under the ENV treatment and 56 % under the HEA treatment, implying that consumers were willing to pay twice or even thrice for certified depurated mussels if they were aware of the impact that MP could have on human health or the environment. Compared to other literature using information treatments in food products, our estimated WTPs were large. Nevertheless, this behavior was expected since our treatments triggered a precautionary behavior instead of highlighting product characteristics. For instance, Bi et al. (2016) found that communicating the nutritional benefits of consuming seafood could increase their WTP between 6 % and 17 %, and Vecchio et al. (2016) estimated an increase of 36 % in the WTP for functional yogurt when an additional health claim is included. Similarly, Tian et al. (2022) found that health and environmental information could increase WTP for seaweed noodles (14 %), and farm-raised clams (6 %) but not for farm-raised oysters.[2] Focusing on environmental information, Michel and Begho (2023) found that information about the environmental benefits of insect-based food could reduce their price penalties between 15 % and 35 %.

Although we showed that information about the potential health and environmental impacts of MP pollution increases the WTP for the depuration attribute, the joint information treatment did not. This was against our initial expectations, as we thought it should be the treatment reporting the highest WTP. Two findings could help us to understand this result. First, HEA-ENV treatment increased the probability of no-purchase by 22.8 %. Second, as we saw in figure 1, the density of WTPs around zero was also higher in this treatment. Then, having information about the potential environmental and health effects of MP pollution pushed consumers to not consume instead of paying more for certified depuration. In fact, at the end of the survey, we offered an open space for comments, and many respondents mentioned that they would purchase mussels if they had the security of not consuming microplastics at all (efficiency 100 %). An alternative explanation could be that crowding with information about potential risks may undermine consumers' WTP. In a field experiment in Korea, Chung et al. (2024) found that when calorie labelling and daily intake recommendations were presented together, they canceled out the information effect. Another puzzling result was the negative WTP for 25 % depuration in the HEA treatment. However, in our robustness analyses, it turned out to be positive but small. Therefore, we believe that this dissonant result is explained by the larger variance in WTP distributions generated by the HEA treatment.[3]

Another relevant result is the effect of information treatments on the probability of choosing the no-purchase alternative. We found a significant change in this probability from 13.64 % in the CONTROL group to 16.75 % in the HEA-ENV treatment, which implied an increase of 22.8 % in the probability of choosing not to purchase mussels when consumers were informed of the health and environmental risks altogether. We argue that depuration certification partially activated the avoidance and prevention motivation in consumption decisions (Asioli et al., 2017), and then the information treatments boosted this activation by increasing the proportion of consumers preferring not to consume mussels. Although consumption avoidance was rational under an uncertain pollution scenario, it could hinder efforts to promote seafood as a vital component of the future food supply.

The last result is the impact of information on consumers' MP riskiness perception. To avoid potential priming, we only asked these questions to those who stated they had heard about MP before the survey (48 %). The initial average risk scores were around 8.6 for human health and 9.2 for the environment, but after the DCE, they increased to 9.0 on average for human health and remained similar for the environment. We also showed that information treatments doubled the increase in risk scores that the DCE generated (CONTROL group). The 48 % of awareness about MP pollution in Chile was relatively low compared to other countries, such as 80 % in Germany (Kramm et al., 2022) or 62 % in India (Dowarah et al., 2022), but higher than the 26 % reported for China (Deng et al., 2020). Regarding riskiness perceptions, Soares et al. (2021) and King (2022) studies also found that people perceive MP as more risky for the environment than for themselves, which is intriguing and deserves more research. Borriello et al. (2022) found that the negative attitudes towards MP that emerged from environmental concerns are stronger than those that emerged from human health concerns, arguing that this finding can be explained because effects on human health have not been scientifically proven yet.

Although recent articles have provided economic valuations for MP reduction policies, most settings are quite different, complicating any comparison. The closest study is Moon et al. (2023), who found a price premium for MP-safer salmon between 150 % and 222 % depending on the country, and these premiums were on the same scale as the premium for depuration certification found in our study.

[2] This article offers results for seafood raised in four US states, but we only refer to the results of those locally raised in Connecticut.

[3] Following an anonymous reviewer suggestion, we estimated depuration parameters under different distribution assumptions. Qualitative results maintain, and depuration 25% can be positive when using other distributions but still normal distribution generates more conservative and coherent results. These additional analyses are available upon request.

6. Conclusions and policy implications

While this article was written, diverse initiatives and investigations aimed to propose policy frameworks aimed at reducing plastic pollution in multiple dimensions. The most notable initiative is the United Nations Treaty on Plastic Pollution, where 180 countries agreed to develop a legally binding instrument to be launched by 2025. Meanwhile, researchers have proposed reviews and recommendations of different policies to address various aspects of plastic pollution (Alpizar et al., 2020; Tessnow-von Wysocki & Le Billon, 2019). This policy design needs, for instance, quantitative measures to conduct a cost-benefit analysis. In this matter, we provided novel evidence of the consumer's WTP for technology to reduce the MP content in seafood.

Furthermore, consumers' valuation of depuration technology has implications for food labelling. Labels are crucial in reducing information asymmetries, subsidizing search costs, and facilitating market segmentation or product differentiation (Bonroy & Constantatos, 2015). Consequently, this positive premium might lead to changes in the seafood market. The extent of these changes will be incremental as new regulations and scientific knowledge about MP emerge. This research also contributes to the literature on health claims and food choices, providing a case study for a geographically under-researched zone (7 out of 125 studies have been conducted in Latin America, none in Chile (Ballco & Gracia, 2022)).

The direct impacts of these MP particles on human health and the environment are still largely unknown, and further research is needed. We do not have enough evidence to accurately state how hazardous MP are. Nevertheless, we should –at least- think and propose environmental policies to precautionary deal with the sources, transport, and fate of MP in the environment. Moreover, as Vuori and Ollikainen (2022) pointed out, when the evidence about the impacts of MP on human health becomes clear and robust, we could use valuation methodologies such as disability-adjusted life years to generate better economic measures for a cost-benefit analysis of technologies or policies aimed to reduce the MP pollution. In the meantime, welfare measures, as reported here, can be useful to validate further investment in research and development related to MP pollution mitigation measures.

Besides standard policies such as subsidies for research, innovation, and adaptation of technologies to limit the presence of MP in food products, Smith et al. (2018) suggested the identification of low-risk species, production methods or geographical regions, and seafood processing and cooking methods as mechanisms to mitigate the ingestion of MP. Moreover, focused taxes or bans could also be essential. Some countries have already imposed bans on microbeads and MP used in cosmetic products (Anagnosti et al., 2021), but greater efforts are needed.

Implementing depuration certification, as with other sustainability-related food labels, could face challenges such as the increasing competition between different food labels, uncertainty about the external validity of case-specific results, or lack of well-established evidence about the risks of MP and the efficiency of depuration technology (Asioli et al., 2020). These challenges could compromise the efficiency of depuration certification in reducing the concern about MP in seafood, potentially hindering the future demand for these food products.

Finally, we used an opt-in panel survey, limiting our capacity to extend our conclusions to the entire Chilean population. Although recent studies have found that economic valuations using probabilistic and non-probabilistic samples may provide similar WTP estimates (Sandstrom-Mistry et al., 2023) , this finding is case-specific, and so the results of our study should be used considering this limitation. Another relevant limitation is that we did not consider a certified depuration of 100 % because there is no research achieving that depuration level at the time of the survey. Likely, some respondents would only consume mussels with 100 % depuration efficiency certification, and, as that level was not available in our design, they chose the no-purchase alternative. The investigation of consumers' preferences for the total avoidance of MP in food products using innovative and feasible technologies is an obvious area for future research. Other future research directions include conducting similar analyses with other food products and, once new technologies are fully developed, complementing them with real/non-hypothetical DCE and by a sensory experiment to test whether knowing about the presence of MP in food products can alter perceived taste. Moreover, complementary techniques such as visual attention (Ballco et al., 2019; Van Loo et al., 2015) or hybrid choice modelling (Fantechi et al., 2022) could be implemented to obtain a better insight into the mechanism behind the effect of information on consumer preferences for pollution-reducing technology in food products. Finally, we always tried to be cautious about using the term 'potential' before any claim about effects on human health or the environment. However, as new evidence confirms these effects, an interesting future study would be to repeat the analysis with scientifically confirmed risks (and be more specific about the risks because different framing of health claims may have different consumers' responses (Van Kleef et al., 2005)) and test the differences from this relatively uncertain framing.

CRediT authorship contribution statement

Manuel Barrientos: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Felipe Vásquez Lavín:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Roberto D. Ponce Oliva:** Writing – review & editing, Validation, Supervision, Project administration. **Rodolfo M. Nayga:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Stefan Gelcich:** Writing – review & editing, Validation, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Felipe Vasquez reports financial support was provided by National Agency for Research and Development. Manuel Barrientos reports financial support was provided by Horizon Europe. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper].

Data availability

Data will be made available on request.

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Appendix A

	ALTERNATIVE A	ALTERNATIVE B	ALTERNATIVE C – Do not purchase
MUSSELS FORMAT	FRESH 	FROZEN 	-
DEPURATION CERTIFICATION	NO - 0% EFFICIENCY	YES - 90% EFFICIENCY	-
PRODUCERS	SMALL-SCALE MUSSEL FARMERS	LARGE-SCALE MUSSEL FARMERS	-
PRICE (250gr mussels' meat)	$1.500 CLP (US$ 1.875)	$2.500 CLP (US$ 3.125)	$0 CLP

Figure A1. Choice situation example.

Appendix B

"A mussel is a shellfish produced in various parts of the country **[**Figure B1**]**. In Chile, the major mussel's production comes from farming areas where producers hang mussels' seeds in long rows that they then feed, fatten, and when they reach maturity, extract and sell in the market **[**Figure B2**]**.

Mussels are **filter feeders**, i.e., they pass water through a filtering structure and capture suspended particulate matter (including food) **[**Figure B3**]**. Moreover, this feeding mechanism causes the mussels to accumulate substances (e.g., chemicals) in their organisms (a process known as **bioaccumulation**). Due to this characteristic, mussels are used as **bioindicators**, as they can indicate the pollutants concentrations in the areas they inhabit. In recent years, mussels have been proposed as bioindicators for the presence of **microplastics**.

Microplastics are small plastic particles with a size between 5 mm–0.1 µm (between the size of an ant and the width of a human hair, approximately) that are present everywhere. Microplastics can be classified as primary (if they are intentionally created and incorporated into daily products) or secondary (if they are released from larger plastics).

Microplastics can be found in various food products such as sugar, honey, table salt, beer, or bottled water. There is also evidence of their presence in meat or seafood products. Specifically, there is wide evidence of their presence in mussels. This is due to the filtration and bioaccumulation process described above.

[TREATMENT IS HERE]

A procedure that can be used to remove microplastics and other pollutants particles from mussels is through depuration. Depuration involves keeping live mussels in pools with filtered seawater in order to reduce the pollution they contain. Scientific studies show that depuration helps to reduce a significant percentage of the microplastics in mussels.

However, the depuration standard in the country is mainly related to the presence of *Escherichia coli* bacteria. That is, there may be mussels with microplastics that are not taken to depuration centers because they have low (or very high) levels of *Escherichia coli* bacteria. Therefore, we are interested in knowing their preferences for mussels that have undergone a certified depuration period that ensures a lower percentage of microplastics or other pollutants.".

The information treatment combining health and environmental pieces of information was presented as follow:

HEA-ENV: "*Scientific studies have reported that microplastics can cause various potential effects on the environment and human health.*

For instance, microplastics in the soil can affect the growth or biomass of different plants, such as wheat, rice, broad beans, and lettuce, among others. In addition, Microplastics can also change some soil properties (for instance, accelerating soil water evaporation) or affect soil fauna (earthworms who ingest microplastics may suffer weight loss or a decreased growth rate). In the marine environment, microplastics can be consumed by fishes, crustaceans, molluscs, among other organisms. This voluntary or involuntary ingestion can cause a decrease in nutrient uptake and a reduction in feeding activity because of false satiety.

Regarding humans, different studies have reported that microplastics are present in a variety of foods products and also in our stool, lungs, colon, or even *blood. The presence of microplastics in our bodies can potentially cause negative health effects. For example, they could lead to:*

- o *Neurotoxicity: Toxic substances affect the normal activity of the nervous system.*
- o *Oxidative stress: Imbalance between free radicals and antioxidants, which can damage different cellular molecules and structures.*
- o *Immunotoxicity: Adverse effects on the structure or function of the immune system.*

However, many of these studies have been conducted under conditions that do not reflect a realistic exposure to microplastics, so there is still uncertainty about the actual effects on human health.".

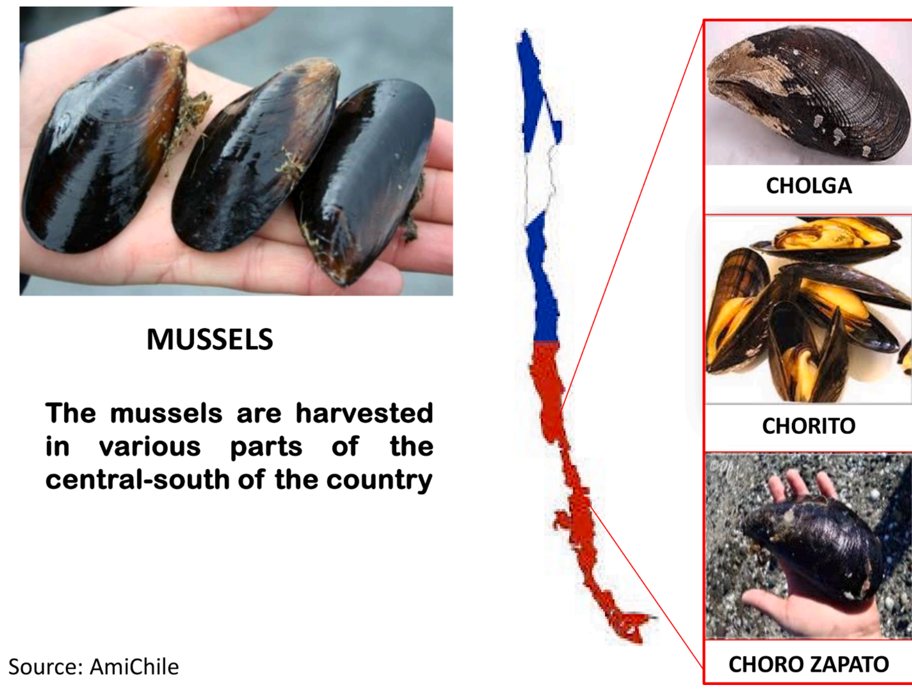

Figure B1. Note: "Cholga", "Chorito", and "Choro Zapato" are different types of mussels.

Figure B2. XXXX

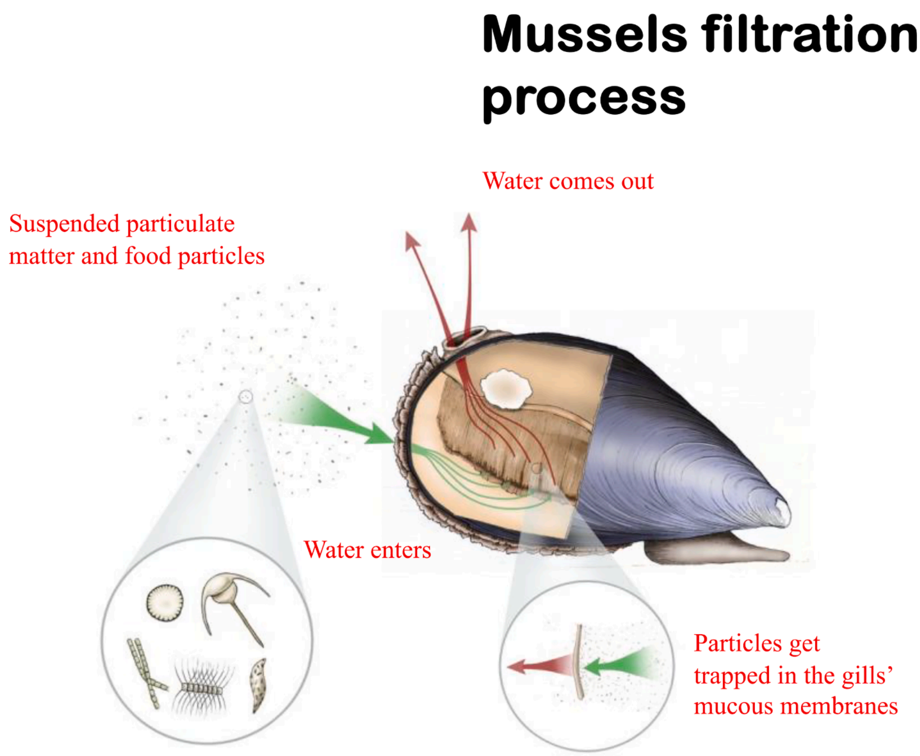

Figure B3. Image source: Kimberly Andrews, "Filter-feeding in a mussel," 2013. Accessed via https://www.kimberly-andrews.com/filter-feeding-in-a-mussel.html

Appendix C

Table C1
Mixed logit estimations in WTP-space by treatment group for certainty 60 % or higher.

	Full sample MXL1	CONTROL MXL2	ENV MXL3	HEA MXL4	HEA-ENV MXL5
Mean					
ASC − No purchase	−3.60 (0.19)***	−3.18 (0.28)***	−3.81 (0.39)***	−3.46 (0.35)***	−3.36 (0.36)***
Format: Frozen	−0.21 (0.10)*	0.26 (0.13)*	−0.90 (0.07)***	0.37 (0.15)**	0.13 (0.47)
Format: Canned	−0.67 (0.22)***	−0.05 (0.23)	−1.53 (0.35)***	−0.71 (0.24)***	0.42 (0.26)
Depuration: 25 %	0.90 (0.11)***	1.00 (0.13)***	1.16 (0.19)***	0.51 (0.34)***	0.24 (0.19)
Depuration: 50 %	2.95 (0.08)***	2.73 (0.15)***	2.99 (0.10)***	3.50 (0.30)***	2.72 (0.12)***
Depuration: 90 %	4.15 (0.13)***	3.73 (0.15)***	4.71 (0.37)***	5.41 (0.29)***	3.43 (0.17)***
Producer: Small-scale	0.45 (0.12)***	0.46 (0.10)***	0.85 (0.14)***	0.80 (0.30)***	−0.05 (0.10)
Price	−0.66 (0.11)***	−0.77 (0.18)***	−0.93 (0.19)***	−0.80 (0.17)***	−0.52 (0.20)***
Standard Deviation					
Format: Frozen	3.01 (0.10)***	3.09 (0.15)***	3.23 (0.22)***	4.80 (0.55)***	2.17 (0.23)***
Format: Canned	2.80 (0.16)***	1.97 (0.21)***	4.36 (0.30)***	4.93 (0.63)***	2.66 (0.31)***
Depuration: 25 %	0.35 (0.07)***	0.80 (0.14)***	0.60 (0.09)***	3.28 (0.37)***	1.26 (0.17)***
Depuration: 50 %	2.30 (0.15)***	2.38 (0.19)***	1.33 (0.08)***	1.84 (0.43)***	1.74 (0.12)***
Depuration: 90 %	3.02 (0.15)***	2.19 (0.19)***	3.68 (0.29)***	3.02 (0.34)***	2.15 (0.77)***
Producer: Small-scale	2.17 (0.11)***	1.18 (0.11)***	0.52 (0.12)***	1.69 (0.32)***	2.48 (0.26)***
Price	1.74 (0.13)***	1.77 (0.31)***	1.85 (0.26)***	1.64 (0.30)***	1.66 (0.34)***
Observations	6692	1680	1652	1724	1636
Log Likelihood convergence	−5805.31	−1476.87	−1398.14	−1450.43	−1445.66

***p < 0.001; **p < 0.01; *p < 0.05 Standard Errors in parentheses; ASC = Alternative Specific Constant. WTPs are in US$ 2023. MXL = Mixed logit model. CONTROL = Control group. ENV = Microplastics environmental effects information treatment subsample. HEA = Microplastics human health effects information treatment subsample. HEA-ENV = Microplastics human health and environmental effects information treatment subsample.

Table C2
Mixed logit estimations in WTP-space by treatment group for perceived policy consequentiality 60 % or higher.

	Full sample MXL1	CONTROL MXL2	ENV MXL3	HEA MXL4	HEA-ENV MXL5
Mean					
ASC − No purchase	−3.41 (0.18)***	−2.93 (0.27)***	−3.89 (0.52)***	−3.85 (0.44)***	−3.70 (0.51)***
Format: Frozen	0.20 (0.30)	0.37 (0.20)***	0.36 (0.12)***	−0.23 (0.04)***	0.10 (0.13)

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Table C2 (*continued*)

	Full sample MXL1	CONTROL MXL2	ENV MXL3	HEA MXL4	HEA-ENV MXL5
Format: Canned	−0.48 (0.27)*	−0.13 (0.36)	−0.55 (0.24)*	−0.69 (0.15)***	0.40 (0.19)
Depuration: 25 %	1.01 (0.20)***	1.18 (0.19)***	1.18 (0.12)***	0.83 (0.24)***	0.25 (0.37)
Depuration: 50 %	3.16 (0.16)***	2.74 (0.05)***	3.16 (0.16)***	4.31 (0.11)***	2.85 (0.28)***
Depuration: 90 %	4.50 (0.21)***	4.47 (0.24)***	4.42 (0.18)***	5.60 (0.19)***	3.12 (0.37)***
Producer: Small-scale	0.73 (0.25)**	0.75 (0.18)***	1.24 (0.06)***	0.82 (0.09)***	0.52 (0.22)**
Price	−0.73 (0.10)***	−1.12 (0.26)***	−0.82 (0.25)***	−0.73 (0.20)***	−0.26 (0.20)
Standard Deviation					
Format: Frozen	4.10 (0.37)***	3.35 (0.24)***	5.30 (0.29)***	4.60 (0.15)***	1.97 (0.22)***
Format: Canned	3.43 (0.39)***	2.69 (0.28)***	4.31 (0.24)***	5.00 (0.22)***	2.38 (0.32)***
Depuration: 25 %	0.80 (0.17)***	0.11 (0.64)	0.24 (0.10)**	2.84 (0.27)***	1.58 (0.28)***
Depuration: 50 %	2.53 (0.42)***	2.26 (0.13)***	2.57 (0.19)***	3.12 (0.15)***	1.47 (0.24)***
Depuration: 90 %	3.22 (0.31)***	2.73 (0.40)***	3.89 (0.23)***	4.33 (0.17)***	1.90 (0.20)***
Producer: Small-scale	1.93 (0.30)***	1.85 (0.16)***	1.22 (0.03)***	1.63 (0.09)***	2.41 (0.24)***
Price	1.65 (0.11)***	2.18 (0.30)***	2.04 (0.33)***	2.11 (0.36)***	1.39 (0.48)**
Observations	5864	1456	1488	1544	1376
Log Likelihood convergence	−5034.53	−1275.66	−1251.76	−1283.95	−1194.28

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$ Standard Errors in parentheses; ASC = Alternative Specific Constant. WTPs are in US$ 2023. MXL = Mixed logit model. CONTROL = Control group. ENV = Microplastics environmental effects information treatment subsample. HEA = Microplastics human health effects information treatment subsample. HEA-ENV = Microplastics human health and environmental effects information treatment subsample.

Table C3
Mixed logit estimations in WTP-space by treatment group for consumers with previous knowledge about microplastics.

	Full sample MXL1	CONTROL MXL2	ENV MXL3	HEA MXL4	HEA-ENV MXL5
Mean					
ASC − No purchase	−3.20 (0.27)***	−2.91 (0.37)***	−4.28 (0.71)***	−3.75 (0.51)***	−2.97 (0.)***
Format: Frozen	−0.06 (0.09)	−0.54 (0.06)***	−0.62 (0.08)***	−0.01 (0.01)***	0.07 (0.19)
Format: Canned	−0.54 (0.14)***	−0.59 (0.08)***	−0.72 (0.16)***	−0.83 (0.31)**	0.15 (0.27)
Depuration: 25 %	0.79 (0.11)***	1.24 (0.13)***	1.89 (0.12)***	0.52 (0.14)***	0.26 (0.78)
Depuration: 50 %	3.08 (0.20)***	3.13 (0.17)***	3.95 (0.08)***	3.79 (0.15)***	2.94 (0.30)***
Depuration: 90 %	4.53 (0.23)***	5.03 (0.43)***	5.88 (0.16)***	4.89 (0.10)***	3.50 (0.55)***
Producer: Small-scale	0.44 (0.27)*	1.01 (0.06)***	0.28 (0.10)**	1.02 (0.09)***	0.38 (0.20)*
Price	−0.67 (0.14)***	−1.30 (0.49)**	−0.35 (0.24)	−0.40 (0.28)	−0.49 (0.22)*
Standard Deviation					
Format: Frozen	2.74 (0.56)***	3.66 (0.09)***	3.69 (0.14)***	2.93 (0.14)***	2.26 (0.32)***
Format: Canned	3.03 (0.38)***	2.71 (0.19)***	3.04 (0.13)***	3.11 (0.24)***	2.02 (0.43)***
Depuration: 25 %	2.01 (0.21)***	0.89 (0.08)	1.88 (0.07)**	2.32 (0.13)***	2.14 (0.98)*
Depuration: 50 %	2.26 (0.25)***	2.01 (0.18)***	2.91 (0.10)***	2.20 (0.14)***	1.17 (0.38)**
Depuration: 90 %	3.53 (0.50)***	3.97 (0.13)***	3.99 (0.13)***	2.52 (0.08)***	1.98 (0.56)***
Producer: Small-scale	1.99 (0.18)***	3.71 (0.16)***	2.90 (0.10)***	2.53 (0.13)***	2.09 (0.35)***
Price	1.90 (0.39)***	2.57 (0.84)***	2.03 (0.37)***	2.01 (0.28)***	1.41 (0.33)***
Observations	3488	852	896	900	840
Log Likelihood convergence	−3063.35	−757.35	−751.46	−765.69	−748.63

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$ Standard Errors in parentheses; ASC = Alternative Specific Constant. WTPs are in US$ 2023. MXL = Mixed logit model. CONTROL = Control group. ENV = Microplastics environmental effects information treatment subsample. HEA = Microplastics human health effects information treatment subsample. HEA-ENV = Microplastics human health and environmental effects information treatment subsample.

Appendix D

Table D1
Z-test for mean WTP differences between treatments.

	CONTROL x ENV	CONTROL x HEA	CONTROL x HEA-ENV	ENV x HEA	ENV x HEA-ENV	HEA x HEA-ENV
Mean						
ASC − No purchase	0.641	0.471	0.716	0.183	0.094	0.273
	(0.522)	(0.638)	(0.474)	(0.855)	(0.925)	(0.785)
Format: Frozen	−2.691	−7.894	3.635	13.747	7.346	12.495
	(0.007)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Format: Canned	1.128	1.493	0.685	0.063	−0.318	−0.341
	(0.259)	(0.135)	(0.493)	(0.950)	(0.750)	(0.733)
Depuration: 25 %	−1.392	18.450	2.529	−17.785	3.633	−12.237
	(0.164)	(0.000)	(0.011)	(0.000)	(0.000)	(0.000)
Depuration: 50 %	−4.529	−19.756	−2.122	3.188	2.808	9.950
	(0.000)	(0.000)	(0.034)	(0.001)	(0.005)	(0.000)
Depuration: 90 %	−2.575	−12.199	−0.671	4.805	1.615	7.216
	(0.010)	(0.000)	(0.502)	(0.000)	(0.106)	(0.000)
Producer: Small-scale	−1.715	3.386	3.836	−4.138	4.591	1.859
	(0.086)	(0.001)	(0.000)	(0.000)	(0.000)	(0.063)
Price	0.370	1.303	−1.261	−1.025	−1.467	−1.981
	(0.711)	(0.193)	(0.207)	(0.305)	(0.142)	(0.048)

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Table D1 (*continued*)

	CONTROL x ENV	CONTROL x HEA	CONTROL x HEA-ENV	ENV x HEA	ENV x HEA-ENV	HEA x HEA-ENV
Standard Deviation						
Format: Frozen	−4.069	−49.972	2.772	6.261	4.958	28.809
	(0.000)	(0.000)	(0.006)	(0.000)	(0.000)	(0.000)
Format: Canned	−4.561	−31.714	−0.257	5.092	3.181	9.785
	(0.000)	(0.000)	(0.797)	(0.000)	(0.001)	(0.000)
Depuration: 25 %	−4.047	−55.461	−0.238	34.966	3.111	37.143
	(0.000)	(0.000)	(0.812)	(0.000)	(0.002)	(0.000)
Depuration: 50 %	0.083	−7.259	2.658	4.118	1.845	8.179
	(0.934)	(0.000)	(0.008)	(0.000)	(0.065)	(0.000)
Depuration: 90 %	−3.528	−21.187	−1.860	7.468	−0.117	3.362
	(0.000)	(0.000)	(0.063)	(0.000)	(0.907)	(0.001)
Producer: Small-scale	25.060	−23.876	−1.787	46.070	−10.365	5.502
	(0.000)	(0.000)	(0.074)	(0.000)	(0.000)	(0.000)
Price	−0.232	−2.123	0.745	2.095	1.211	2.813
	(0.816)	(0.034)	(0.456)	(0.036)	(0.226)	(0.005)

P-values are in parentheses. CONTROL = Control group. ENV = Microplastics environmental effects information treatment subsample. HEA = Microplastics human health effects information treatment subsample. HEA-ENV = Microplastics human health and environmental effects information treatment subsample.

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