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Plant-based fish analogues vs. fish: Assessment of consumer perception, acceptance, and attitudes

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ABSTRACT

Plant-based fish is developed to mimic the taste, texture, and appearance of fish. Despite being the fastest-growing segment in plant-based analogues sales, it remains a niche product due to several hindrances, including sensory and nutritional issues. This study assessed consumer perception, attitudes and acceptance drivers of plant-based canned tuna involving 165 consumers who evaluated for liking and described through the Check-All-That-Apply method five plant-based and three animal-based samples. Consumers' food neophobia level, food related lifestyles and food frequency consumption of a series of plant-based and animal-based products were investigated as potential explanatory variables in drivers of acceptance. Generalised linear models showed that plant-based samples scored very low (<40 VAS score), while animal-based products were well accepted (63.6 – 75.2). Principal Coordinate Analysis revealed that pink colour, tuna/fish flavour, and dryness characterised tuna samples and contributed positively to liking, while unappealing appearance, off-flavour, legume/vegetable flavour, bitterness, gelatinous and gumminess, characterised plant-based samples and contributed negatively to liking. Agglomerative hierarchical analysis identified two consumer clusters differing in liking for plant-based fish analogues. One cluster (27 % of consumers) showed significantly higher liking scores for all plant-based samples, a higher consumption of plant-based analogues and seemed more careful when buying food, both regarding its nutritional composition and its naturalness than the other cluster. This study suggests that the exploitation of plant-based ingredients (textured soy, pea and wheat proteins) affects all sensory dimensions of plant-based canned tuna and highlights the importance of sensory optimisation in the development of plant-based alternatives to meet consumer preferences.

1. Introduction

In recent years, the numerous climate and environmental crises have increasingly underlined the need to redesign food systems (Willett et al., 2019). Various actions are being implemented to respond to this emergency, involving all levels of the food chain, from production to consumption. Consumers could exert a pivotal influence on mitigating environmental strain through their food choices. In particular, adopting vegan and vegetarian diets can reduce environmental impacts regarding GHG emissions (CO_2, CH_4, N_2O), water and land use and biodiversity loss (Scarborough et al., 2023). Nowadays, consumers are increasingly conscious of their food choices and their environmental impact. This awareness is reflected in the growing proportion of the European population (51 % in 2023 compared to 46 % in 2021) reporting to actively reducing meat consumption. The main motivations for this shift are health (47 %), animal welfare (29 %) and environmental concerns (26 %). However, despite these promising trends, many consumers may underestimate their actual meat consumption, as the intake of animal-based foods in Europe remains high, with 16 % and 14 % of the population still consuming meat (poultry, beef, and pork) and fish more than three times a week, respectively (The Smart Protein Project, 2023).

Concerning fish, the average European per capita consumption is 24.74 kg, higher than the world average consumption of 21.07 kg (EUMOFA, 2022). Although fish consumption is promoted for its beneficial effects on health (Chen et al., 2022), this huge demand for fish is associated with unsustainable fishing practices and risks to marine biodiversity loss (OECD, 2022). In this context, increasing attention to environmental issues has led to the development of plant-based fish analogues, that are designed to mimic the taste, aroma, texture and appearance of fish while being nutritionally comparable (Lima et al., 2022;). In Europe, the popularity of these products has grown, as shown by the impressive 326 % increase in the sales value of fish alternatives

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between 2020 and 2022, reaching €43 million (The Good Food Institute Europe, 2022). Although the category of plant-based fish represents only 1 % of the plant-based sector (The Good Food Institute Europe, 2022), the market is expanding with various fish alternatives, such as plant-based fish fingers, fillets, salmon, tuna, sushi, caviar, calamari, prawns, and scampi (Kazir and Livney, 2021). These analogues are made with soy, wheat, legumes (peas, beans, chickpeas, lentils, lupin), rice proteins, algae and vegetables (Nowacka et al., 2023) and contain various other ingredients such as lipids (e.g., seaweed oil, canola oil, sunflower oil), both simple (e.g., potato, rice, and wheat starch) and complex carbohydrates (e.g., seaweed alginate, gum Arabic), micronutrients (e.g., iron, sodium chloride), antioxidants, and antimicrobials (e.g., herbs and spices) (Leonard and Fang, 2023; Lankatillake et al., 2023). Additionally, they include additives such as flavouring agents and seasonings (e.g., sodium chloride, garlic powder, soy sauce) and emulsifying and thickening agents (e.g., wheat flour and starch, gum Arabic, maltodextrin) (Leonard and Fang, 2023). In order to recreate the fibrous gel structure typical of fish, ingredients are processed using various techniques, such as vegetable protein texturisation, 3D and 4D food printing, electrospinning, wet spinning, and directional freezing (Kazir and Livney, 2021; Nowacka et al., 2023). However, the use of these additional ingredients raises doubts about the nutritional equivalence of these products to conventional ones (Nolden and Forde, 2023).

The use of plant-based proteins in meat, dairy, eggs and fish analogues, presents several challenges concerning their appearance, aroma, taste, flavour and texture (Alcorta et al., 2021; Appiani et al., 2023). These challenges often result in products with sensory quality that differs significantly from the animal-based products they aim to replicate (Kerslake et al., 2022; Tso et al., 2020), which can negatively impact their acceptability and consumption (Waehrens et al., 2023; Faber et al., 2024). This underscores the need for sensory optimization, recognising that each sensory dimension plays a unique role within different plant-based categories. For example, plant-based meat requires improvements in appearance and texture, as it currently lacks the elasticity and juiciness of traditional meat products (Appiani et al., 2023). Conversely, dairy analogues face significant sensory challenges related to the aroma of the raw materials and the texture, especially in products like yogurt and cheese (Appiani et al., 2023). On the other hand, there is limited information on the sensory properties and overall acceptance of plant-based fish products (Appiani et al., 2023). To the best of our knowledge, only one study (Katayama and Wilson, 2008) has investigated the sensory properties of a fish analogue made from textured soy and flavoured with powdered seasonings to replicate shrimp flavours. Most of the existing literature focuses on the nutritional composition, chemico-physical characterization and processing techniques of this product category (Kazir and Livney, 2021; Lankatillake et al., 2023; Leonard and Fang, 2023; Tripathi and Agarwal, 2023). In contrast, the few studies that address consumers mainly focus on their expectations of fish analogues (Lanz et al., 2024; Gorman et al., 2023).

Besides sensory characteristics, person-related factors such as socio-demographic characteristics (e.g., gender, age, income), dietary status (e.g., omnivores, flexitarians, vegetarians, and vegans) and psychological traits (e.g., food neophobia) (Giacalone et al., 2022; Tuorila and Hartmann, 2020) play an important role in consumers' acceptance of plant-based foods. Moreover, consumers' attitudes towards food, regarding, for example, health concerns, animal welfare or the naturalness of food are other factors that influence purchasing decisions and acceptability (Saba et al., 2019).

Until now, studies have mainly investigated consumer attitudes towards plant-based meat (Bryant and Sanctorum, 2021; Yeliz et al., 2023) and plant-based milk (McCarthy et al., 2017; Moss et al., 2022), while those towards plant-based fish remain poorly explored (Gorman et al., 2023).

Based on these premises, the primary aim of this research was to assess consumer liking and sensory drivers of plant-based canned tuna alternatives, with the goals of guiding product innovation, addressing the challenge of poor sensory properties in these products and investigating the perceptive and behavioural determinants of products' acceptability as well as their nutritional quality. Plant-based canned tuna was chosen because it is the main fish species consumed in Europe (mainly canned – 3.10 kg/capita), followed by salmon (2.36 kg/capita) and cod (2.11 kg/capita) (EUMOFA, 2022). In Italy, canned tuna is consumed by almost the entire population (96 %) and more than half consume it weekly as a source of protein (ANCIT & Doxa, 2022). Additionally, consumer segmentation was performed to explore possible consumers clusters varying in terms of acceptance. Clusters were characterised for background variables, including socio-demographic and psychological factors (e.g., food neophobia), as well as attitudes toward plant-based fish (e.g., consumption frequency, purchase behaviour), which may act as either drivers or barriers to the consumption of these alternatives. Whether multiple consumer segments emerge, there is potential to tailor different plant-based fish alternatives to these segments or develop new products to align more effectively with the sensory expectations among diverse consumer groups.

2. Materials and methods

2.1. Participants

One-hundred-sixty-five Italian consumers (age range: 18 and 60 years, mean age ± SD: 38 ± 14 years, 48 % women) were involved in the study. Only subjects who liked canned tuna and who followed an omnivorous (diet that includes a wide variety of foods of both animal and plant origin) or flexitarian diet (mainly vegetarian diet that also includes the occasional consumption of meat and/or fish) (Derbyshire, 2017) were included in the study.

All participants received verbal and written information about the study and then gave their written informed consent before participation. Participants were given a reward for their participation. The present study was performed according to the principles established by the Declaration of Helsinki and the protocol was approved by the Ethical Committee of the University of Milan (n. 95/23).

2.2. Food samples

2.2.1. Sample selection

The final set of samples evaluated in the present study was selected through a stepwise process (Liechti et al., 2022) that began with an inventory of the Italian online marketplace, focusing on plant-based products labelled as fish analogues. In order to carry out this inventory, both e-commerce of the major retailers in Northern Italy (Bennet S.p.a., Carrefour S.p.a., Conad S.c., Coop Italia Società cooperativa, Crai Secom S.p.a., Esselunga S.p.a, Grandi magazzini e supermercati il gigante S.p.a., Iper Montebello S.p.a., Pam panorama S.p.a., Famila S.r.l., Iperal supermercati S.p.a., Tigros S.p.a.) and online shops specialized in the retail of vegetarian and vegan products (NaturaSì ShopSì, Macrolibrarsi Golden Books S.r.l., Greenweez Italia S.r.l. società benefit, iVegan S.r.l., Cuore Vegano, Bio salute di Franchetto Fabio, Vegano Bio Chiccoteca S.r.l) were considered (Angelino et al., 2020). A database with a total of 50 fish analogues was created (13 plant-based breaded-fish, 6 canned tuna, 7 sliced salmon or tuna, 5 fish fillets, 5 spreads, 3 caviars, 2 shrimps, 2 fish salads and 7 fish-snacks). The best represented products in terms of brands and availability on the market were plant-based breaded-fish (included in another paper in preparation) and canned tuna.

A pilot test was then carried out involving 8 expert judges (women n = 5) to select and taste the samples identified through the online market inventory (see paragraph 2.3.2.1. for further details). The pilot test allowed the identification of 8 commercial canned tuna samples, including 5 plant-based and 3 animal-based versions. The plant-based samples selection was based on the following criteria: compositional characteristics to ensure diversity in plant-based ingredients (i.e., soy, wheat, pea) and sensory properties across various modalities. Both the most typical variants available on the Italian market such as water-packed and oil-packed canned tuna, as well as a seasoned one (flavoured with lemon and pepper) were chosen. This choice was driven by the well-known issue of off-flavour that plant-based proteins can produce in analogues when lipoxygenases, saponins, aldehydes, and ketones are present (Appiani et al., 2023). These off-flavours are commonly described as "grassy" and "beany" (Leonard and Fang, 2023). Since the use of flavour masking agents is among the most exploited solutions (Shen, 2024), the inclusion of a sample with a protein base similar to the water-packed and oil-packed versions but seasoned with lemon and pepper would have allowed the evaluation of this aspect on the liking of plant-based samples. Moreover, only the sample with an ensured commercial availability on the Italian market were selected and purchased in supermarkets (Esselunga S.p.a) or via a vegan food shop online (Bio salute di Franchetto Fabio). The selected plant-based tuna samples were compared together with three animal origin samples. The criterion for selecting the animal-based samples was to choose the brand that is market leader in Italy and the world's second largest player in the tuna market (GDO News, 2022). Additionally, from an online market research, it emerged that this brand offered formulations with seasonings similar to some of the selected plant-based options (i.e., water-packed, oil-packed, and seasoned with pepper and lemon), which were therefore included to allow comparison.

The list of the 8 samples together with key ingredients and nutritional facts is given in Table 1, specifically: plant-based samples contained carbohydrates and fibre due to the plant-based origin of the protein. Regarding protein content, the plant-based samples seemed to be characterized by lower levels than those of animal origin, except for PBT_PEA (Plant-based tuna made with pea protein), which had similar nutritional values compared to animal products. Moreover, the plant-based samples were enriched with omega-3 fatty acids (DHA+EPA).

For a given brand, all samples were purchased from the same batch and with a similar expiry date. The samples were stored at room temperature (approx. 20 °C), except for one sample (PBT_PEA) which was stored at 4 °C (as indicated on the label) and then removed from the fridge two hours before the tasting session.

2.3. Experimental procedure

Firstly, information concerning participants' age, gender, education level, and dietary habits was collected. To prevent sensory fatigue and ensure participants' concentration, the evaluation of the samples was divided into two phases, separated from the completion of the questionnaires. The evaluation was organized as follows: 1) evaluation of the first four tuna samples (overall liking and Check-All-That-Apply (CATA) questionnaire) (Varela & Ares, 2012); 2) Food Frequency questionnaire; 3) Food Related Lifestyle questionnaire; 4) evaluation of the other four samples (overall liking and CATA questionnaire); 5) Food Neophobia Questionnaire.

Consumers were asked not to smoke, eat or drink anything, except water, at least one hour before the tasting sessions.

Each consumer received approximately 12 g of drained product served at room temperature in a covered small plastic cup coded with three-digit numbers. A spoon was provided for each sample. The order of presentation was randomized and balanced to prevent carry over effects. Being some samples spicy and oiled, consumers were imposed to wait 40 s before tasting the next sample during which, in addition to rinse their mouths with still mineral water (Levissima S.p.A.), they had to eat a piece of Granny Smith apple. This procedure was tested in the pilot test and found to be appropriate to clean the palate after each tasting.

Data acquisition was conducted using Fizz v2.31 software (Biosystèmes, Couternon, France). The evaluations were performed in individual booths under white light and lasted approximately 40 min.

2.3.1. Overall liking evaluation

Participants were instructed to eat a spoonful of each sample and then express their overall liking on a 10 cm linear scale anchored by the extremes "*Extremely disliked*" (rated 0) and "*Extremely liked*" (rated 100) (Lawless and Heymann, 2010; Lim, 2011). After that, consumers were invited to eat another spoonful of the sample to proceed with the sensory description using the Check-all-that-apply (CATA) method.

2.3.2. CATA method

2.3.2.1. Generation of CATA terms. CATA attributes were generated during a pilot test, in which 8 expert judges (5 women) were involved. Each judge was presented with the 8 samples and for each of them, once tasted, he/she was asked to generate a list of attributes considering all sensory modalities: appearance, smell, taste, flavour and texture. A total of 99 terms were generated, of which 29 related to appearance, 28 to aroma, 5 to taste, 21 to flavour and, finally, 16 to texture. The list of terms was finalised by the experimenters by considering the most frequently cited descriptors (terms reported by at least 20 % of the subjects) and the most common word in case of synonyms (Jaeger et al., 2015). In total, 28 descriptors were retained of which 7 related to appearance (*Pink colour, Beige colour, Yellow colour, Pale colour, Brightness, Unappealing appearance, Matt colour*), 8 to odour/flavour (*Odour/Flavour (O/F)_Tuna, O/F_Oil, O/F_Spicy, O/F_Fish, O/F_Lemon, O/F_Legume/vegetable, O/F_Pepper, Off-flavour*), 4 to taste (*Saltiness, Sweetness, Bitterness, Sourness*) and, finally, 9 to texture (*Gumminess, Softness, Fibrousness, Pastiness, Dryness, Moisture, Oiliness, Spiciness, Gelatinous*). The number of attributes selected is in line with previous research suggesting heterogeneity of the descriptors and a list of words ranged between 10–40 to avoid a dilution effect of the responses (Ares and Jaeger, 2015; Jaeger et al., 2015). However, the descriptors were divided by sensory modality in order to maintain consumer focus and increase discriminatory ability (Ares et al., 2013).

2.3.2.2. Check-all-that-apply (CATA) assessment. After overall liking evaluation, consumers were asked to eat a spoonful of the sample and to select any descriptor they found useful to describe it. The position of attributes was randomized using the "to assessor" list order allocation scheme, meaning that attributes were listed in the same order within subject and in a different order between subjects (Meyners and Castura, 2016).

2.3.3. Food frequency questionnaire

Participants completed a food consumption frequency questionnaire (FFQ), inspired by a questionnaire previously used by Michel et al. (2021). The questionnaire consisted of a list of 33 foods, both animal-based and plant-based, and for each one they had to indicate how often they ate it. Different categories of food where chosen: meat products (7 items); plant-based meat analogues (6 items); dairy products (4 items); plant-based dairy analogues (4 items); fish products (5 items); plant-based fish analogues (3 items); Eggs (2 items); plant-based egg analogues (2 items). Answering options were: "never", "rarely (less than once a month)", "1–3 times a month", "1–3 times a week", "4–6 times a week", "once a day", "multiple times a day" (Laureati et al., 2020).

2.3.4. Food related lifestyle (FRL) questionnaire

The Food related lifestyle (FRL) questionnaire comprises 69 items and aims to explain consumer behaviour towards the choice of food (Grunert, 1993). The original FRL has been validated both in Western (Nie and Zepeda, 2011; Scholderer et al., 2004) and Asian populations (Liang, 2014). In the present study, the reduced and validated Italian version was used (Saba et al., 2019). This version consists of 42 items divided into 4 domains subdivided into 14 original factors (sub-scales): 1) ways of shopping (importance of product information, enjoyment from shopping, specialty shops, price criteria, shopping list), 2) quality

Table 1
Characteristics of the samples included in the study.

Type of product	Label	Description	Ingredients	Nutrients per 100 g	Brand
Plant-based samples	*PBT_SOY_Olive*	Plant-based tuna seasoned with olive oil (soy as main protein source)	Textured soy protein (water, soy protein, wheat gluten, salt, soy oil, natural flavours) (56 %), water, olive oil (10 %), flavours, lemon juice concentrate, DHA and EPA rich oil from microalgae Schizochytrium sp.*, antioxidant: tocoferol rich extract.	Energy: 712 kJ/ 176 Kcal Fat: 10 g Of which saturated: 1.4 g Carbohydrates: 4.4 g Of which sugar: 0.3 g Protein: 14 g Fibre: 2.6 g Omega-3 fatty acids: 0.33 g Salt: 1.3 g	Unfished (Prefera Foods S.A.)
	PBT_SOY_Water	Plant-based tuna seasoned with water (soy as main protein source)	Water, textured soy protein (soy protein, wheat gluten, salt, soy oil, natural flavours) (56 %), canola oil, flavours, DHA and EPA rich oil from microalgae Schizochytrium sp.*, antioxidant: tocoferol rich extract; lemon juice concentrate.	Energy: 464 kJ/ 110 Kcal Fat: 3.0 g Of which saturated: 0.2 g Carbohydrates: 4.5 g Of which sugar: 0.1 g Protein: 15 g Fibre: 2.7 g Omega-3 fatty acids: 0.33 g Salt: 1.2 g	Unfished (Prefera Foods S.A.)
	PBT_SOY_Lem&Pep	Plant-based tuna seasoned with lemon & pepper (soy as main protein source)	Textured soy protein (water, soy protein, wheat gluten, soy, soybean oil, natural flavours) (52 %), water, canola oil, linseed oil, spices and seasonings (…)(in variable proportions: paprika, rosemary, coriander, parsley, pepper (0.4 %), onion, garlic, dill, turmeric), sugar, corn flour, starch, lemon peel, lemon juice concentrate (1.3 %), (…)flavours, antioxidant: citric acid, tocoferol rich extract.	Energy: 606 kJ/ 145 Kcal Fat: 6.0 g Of which saturated: 0.5 g Carbohydrates: 6 g Of which sugar: 1.1 g Protein: 14 g Fibre: 2.7 g Omega-3 fatty acids: 0.33 g Salt: 1.8 g	Unfished (Prefera Foods S.A.)
	PBT_PEA	Plant-based tuna (pea as main protein source)	Water, pea protein (18.7 %), rapeseed oil, wheat protein, flavouring, food fibre (citrus), salt.	Energy: 1156 kJ/ 278 Kcal Fat: 19.9 g Of which saturated: 2.3 g Carbohydrates: 1.7 g Of which sugar: 0.03 g Protein: 22.6 g Fibre: 0.7 g Omega-3 fatty acids: 0.8 g Salt: 1.2 g	Garden Gourmet (Nestlè S.p. A)
	PBT_ WHEAT	Plant-based tuna (wheat as main protein source)	Water, wheat protein, wheat flour, sunflower oil, broad bean protein flour, natural flavouring, salt, acidifier: citric acid; vegetables (peppers, onion, tomato, smoked chilli), spices, vegetable powder (onion, garlic, tomato), lovage, glucose syrup, seaweed oil, starch.	Energy: 695 kJ/ 166 Kcal Fat: 7.1 g Of which saturated: 0.5 g Carbohydrates: 6.1 g Of which sugar: 0.1 g Protein: 19 g Fibre: 0.9 g Salt: 1.28 g	Novish (Larco Foods B.V.)
Animal-based samples	TUNA_Olive	Tuna seasoned with Extra Virgin Olive Oil	Tuna, Extra Virgin Olive Oil, Salt	Energy: 1667 kJ/ 403 Kcal Fat: 37 g Of which saturated: 5.6 g Carbohydrates: 0 g	Rio Mare (Bolton Food S.p.A)

(*continued on next page*)

Table 1 (*continued*)

Type of product	Label	Description	Ingredients	Nutrients per 100 g	Brand
				Of which sugar: 0 g Protein: 17 g Salt: 1.1 g	
	TUNA_Water	Tuna seasoned with water	Tuna 85 %, water, salt, natural celery and onion flavouring	Energy: 393 kJ/93 Kcal Fat: 0.5 g Of which saturated: 0.2 g Carbohydrates: 0 g Of which sugar: 0 g Protein: 22 g Salt: 1.1 g	Rio Mare (Bolton Food S.p.A)
	TUNA_Lem&Pep	Tuna seasoned with olive oil with lemon and black pepper	Tuna, Olive Oil, Lemon Juice 1 %, Black Pepper, Salt, Natural Flavourings of Lemon and Pepper	Energy: 1695 kJ/ 410 Kcal Fat: 38 g Of which saturated: 6.2 g Carbohydrates: 0 g Of which sugar: 0 g Protein: 17 g Salt: 1.3 g	Rio Mare (Bolton Food S.p.A)

aspects (health, novelty, organic products, freshness), 3) cooking methods (interest in cooking, looking for new ways, convenience, woman's task), 4) purchasing motives (self-fulfillment in food). Therefore, in total, the questionnaire consisted of 42 items, each measured on a 7-point scale ranging from 1 = "strongly disagree" to 7 = "strongly agree" (Saba et al., 2019; Scholderer et al., 2004).

2.3.5. *Food neophobia questionnaire*

Food neophobia, the reluctance to consume new or unfamiliar foods, was measured using the food neophobia scale (FNS) (Pliner and Hobden, 1992) validated in Italian as described by Laureati et al. (2018). The questionnaire consists of 10 items, 5 related to neophilic and 5 related to neophobic attitudes. For each item, participants were asked to indicate the degree of agreement using a 7-point scale ranging from 1 = "strongly disagree" to 7 = "strongly agree". The answers to the 10 items of the FNS were summed up (after reversing the scores of the neophilic items) to have a food neophobia score ranging from 10 to 70, where higher scores indicate a greater level of food neophobia. Subjects were categorised based on their neophobia score using arbitrary cut-offs (Laureati et al., 2018): Neophilic (FNS score $\leq$ 18), Neutral (18 $<$ FNS score $<$ 36) and Neophobic (FNS score $\geq$ 36).

2.4. *Data analysis*

The XLSTAT-Sensory (version 2023.3.1, Addinsoft, Boston, MA, USA) statistical software package was used for the data analysis. Effects showing a *p*-value of 0.05 or lower were considered significant.

The liking score distribution for each sample was calculated and checked for normality. According to the Shapiro–Wilk test, the distribution deviated from the normal distribution for all samples. However, inspection of the Q–Q plots suggested a normal pattern, and thereby all data were handled as normally distributed (Næs et al., 2010). Liking of the eight samples was analysed by means of generalised linear model (GLM) considering samples (the eight tasted samples), gender (women and men), and age groups (18–30 years, 31–45 years, 46–60 years) and their second-order interactions as factors. Least-squares means (LS-means) and relevant standard errors (SEM) were computed for each factor. When the GLM showed a significant effect ($p \leq 0.05$), the Bonferroni test adjusted for multiple comparison was used for post-hoc analyses.

The CATA data were subjected to Cochran's Q test followed by Sheskin's multiple pairwise comparison tests to assess significant differences among the samples for each sensory attribute (Meyners and Castura, 2016). A frequency table (samples x CATA terms) was created, and Correspondence Analysis (CA) was applied to examine the relationship between the product samples and sensory attributes. Furthermore, principal Coordinate Analysis (PCoA) was used to evaluate the association between the liking scores of the eight tasted canned-tuna samples and their CATA-descriptions ($p < 0.05$).

Agglomerative Hierarchical Clustering (AHC) was performed on the liking data to identify segments of consumers with different liking patterns. Euclidean distances of dissimilarity and Ward's method were used as the agglomeration criterion. A two-cluster solution was retained based on both the dendrogram and the Silhouette index (see Supplementary Figure and Table S1). The segment size obtained was comparable with other studies in the literature with a similar approach (Cardello et al., 2022; Jaeger et al., 2024). The differences in liking between the two clusters were studied by means of two-way ANOVA followed by Bonferroni post-hoc test considering clusters (Cluster 1; Cluster 2), samples (the eight tasted samples), and their interaction as factors. For CATA data, Cochran's Q test and Sheskin's post-hoc test followed by CAs were performed separately for each cluster. In order to better highlight the differences in the perception of the samples by the two clusters, CAs were run separately by sensory dimension (appearance, odour/flavour, taste and texture). For each sensory dimension, the similarity between the sensory spaces obtained from the two clusters was evaluated for both samples and descriptors by computing the regression vector (RV) coefficient between their coordinates (Robert & Escoufier, 1976). The RV was calculated between the first two dimensions of the CA (Perrin and Pages, 2009). The significance of the RV coefficient was tested using a permutation test (Josse, Husson, & Pagès, 2007).

In order to find which sensory attributes were positively or negatively associated with hedonic responses of each cluster (Meyners and Castura, 2016), penalty-lift analysis was performed between CATA attributes and the overall liking. Differences between clusters in terms of gender (women and men), age-class (18–30, 31–45, 46–60) and food neophobia level (Neophilic, Neutral and Neophobic) were assessed by chi-square tests. GLM with Bonferroni post hoc test was used to examine if food consumption behaviour (FFQ) and personal traits (FRL and FNS) varied by cluster.

Reliability of FNS and FRL sub-scales was assessed by calculating Cronbach's α as a measure of internal consistency. The value of 0.60 was set as the lowest acceptable limit for the satisfactory internal consistency of the measure (Mohamad et al., 2015). Adequate internal consistency was found for FNS, whereas for the FRL questionnaire, the subdimension "Novelty" was taken out having reliability lower than 0.60.

3. Results

3.1. Participants' characteristics

Table 2 shows the socio-demographic characteristics, mean consumption for each food category and the mean scores for the Food Related Lifestyles and food neophobia dimensions for both the total sample as well as the two consumer clusters ("PB_Dislikers" and "PB_Neutrals") described in paragraph 3.4. The sample comprised 48 % women with a mean age of 38 years (SD=14; 18–60 years old range). Three age classes were defined: 18–30 years (37 %), 31–45 years (34 %), and 46–60 years (29 %). Most of the population exhibited a medium level of neophobia (46 %). Regarding consumption frequencies, the overall sample appears to be generally aware of and consumes all the investigated categories. Specifically, plant-based products, such as dairy and meat analogues, are reported to be consumed monthly, whereas fish and egg analogues are consumed much less frequently. The mean consumption for each food category and the mean scores for each retained Food Related Lifestyle dimensions are shown in Table 2.

Table 2
Socio-demographic characteristics, mean consumption frequency for each food category and mean scores for the Food Related Lifestyles and Food Neophobia dimensions for the total group of individuals (n = 165) and the two consumer clusters (PB_Dislikers, n = 121; PB_Neutrals, n = 44). Standard deviation is reported in brackets. n.s. = not significant (based on ANOVA or Chi-Square).

Variable	Total (n = 165)		PB_Dislikers (n = 121)	PB_Neutrals (n = 44)	*p-value*
Socio-demographic characteristics	n	%	%	%	
Gender					n.s.
Men	85	52	49	52	
Women	80	48	51	48	
Age class					n.s.
18–30	61	37	39	32	
31–45	56	34	32	39	
46–60	48	29	29	29	
Food neophobia level					n.s.
Mean (SD)	27.6 (11.1)		27.9 (11.1)	26.8 (11.3)	
Low	45	27	26	32	
Medium	76	46	47	43	
High	44	27	27	25	
Food frequency consumption	Mean (SD)		Mean (SD)	Mean (SD)	
Meat products	3.2 (1.1)		3.2 (1.1)	3.2 (1.2)	n.s.
Plant-based meat analogues	2.2 (1.2)		2.1 (1.2)	2.4 (1.3)	0.03
Dairy products	4.2 (1.5)		4.2 (1.5)	4.3 (1.4)	n.s.
Plant-based dairy analogues	2.5 (1.5)		2.4 (1.4)	2.8 (1.4)	0.04
Fish products	3.2 (1.1)		3.2 (1.0)	3.2 (1.1)	n.s.
Plant-based fish analogues	1.8 (1.1)		1.6 (0.9)	2.2 (1.3)	0.001
Eggs	3.3 (1.2)		3.3 (1.2)	3.4 (1.3)	n.s.
Plant-based eggs	1.7 (1.0)		1.6 (0.9)	2.1 (1.2)	0.002
Food-related dimensions					
Ways of shopping					
Importance of product information	5.3 (1.2)		5.2 (1.2)	5.6 (1.0)	0.045
Enjoyment from shopping	5.7 (1.1)		5.6 (1.1)	5.7 (1.1)	n.s.
Speciality shops	4.4 (1.3)		4.3 (1.3)	4.7 (1.1)	n.s.
Price criteria	5.3 (1.2)		5.2 (1.2)	5.5 (1.1)	n.s.
Shopping list	5.1 (1.5)		5.0 (1.5)	5.3 (1.4)	n.s.
Quality aspects					
Health	5.2 (1.2)		5.0 (1.2)	5.5 (1.2)	0.037
Organic products	4.3 (1.3)		4.2 (1.3)	4.5 (1.2)	n.s.
Freshness	5.6 (1.0)		5.6 (1.0)	5.6 (1.1)	n.s.
Cooking methods					
Interest in cooking	5.1 (1.5)		5.1 (1.5)	5.0 (1.4)	n.s.
Looking for new ways	5.3 (1.2)		5.2 (1.3)	5.5 (1.0)	n.s.
Convenience	3.4 (1.4)		3.4 (1.4)	3.4 (1.4)	n.s.
Woman's task	2.1 (1.3)		2.0 (1.4)	2.2 (1.3)	n.s.
Purchasing motives					
Self-fulfilment in food (skill)	5.4 (1.0)		5.3 (1.1)	5.6 (0.9)	n.s.

3.2. Overall liking assessment

The mean liking scores by samples are provided in Fig. 1a. Results from GLM showed a significant effect of the main factors "*Samples*" ($F_{(7,1286)} = 92.96$; $p < 0.0001$). According to the post-hoc test, the three animal-based samples were comparable in terms of liking (TUNA_Lem&Pep: Ls-mean = 65.6 ± 12.0; TUNA_Olive: Ls-mean = 64.9 ± 2.0; TUNA_Water: Ls-mean = 63.4 ± 2.0) and obtained significantly higher scores compared to plant-based ones, which received low ratings (Ls-mean range: 19.8 – 40.4).

The main factor "*Age groups*" was found to have a negligible effect on liking ($F_{(2,1286)} = 4.19$; $p = 0.02$). Overall, younger consumers (18–30 years) showed a higher level of liking (Ls-mean = 45.7 ± 1.13) in comparison to individuals aged 31 to 45 (Ls-mean = 41.6 ± 1.22) and 46 to 60 (Ls-mean = 41.5 ± 1.29), with no statistically significant difference observed between the latter two groups. No other main or interaction effects were found to be significant.

3.3. CATA assessment

Results from the Cochran's Q-test showed that all the selected sensory terms significantly discriminated the canned-tuna samples (all p-values < 0.0001, Supplementary Table S2, S3).

The first and the second dimensions of the symmetric plot obtained from CA accounted for 85.26 % of the variance of data (Fig. 2a). Factor 1 (58.89 %) clearly separated animal-based versus plant-based samples, while Factor 2 (26.38 % explained variance) distinguished the samples (both of animal and plant-based origin) seasoned with olive oil, lemon and pepper from the rest of samples. On the right of Factor 1, animal-plant based samples were described with higher frequency of terms Pink colour, Tuna odour/flavour, Fish odour/flavour, and Dryness. These descriptors were positively correlated with overall liking, as shown by the Principal Coordinate Analysis (Fig. 2b), which links liking to the CATA descriptions, displaying the sensory descriptors that drive samples overall liking. On the other hand, plant-based samples, positioned on the left side of Factor 1, are associated with the terms Unappealing appearance, Pale colour, Legume/vegetable odour/flavour, Off-flavour, Bitterness, Sourness, Gelatinous and Gumminess, all of which negatively impact the liking of these samples (Fig. 2b). The animal-based product seasoned with olive oil, lemon and pepper (upper right panel) was associated with higher frequency of terms Pepper and Lemon odour/flavour and Spiciness. Pepper odour/flavour and Spiciness also characterised the plant-based version of the samples seasoned with lemon and pepper, which was also perceived as sour, yellow and as having a spicy aroma and flavour.

3.4. Identification and characterisation of consumers clusters

Hierarchical cluster analysis identified two consumers segments: cluster 1 consisting of 121 (73 %) consumers and cluster 2 consisting of 44 (27 %) consumers. Mean liking scores by cluster are shown in Fig. 1b. Results from two-way ANOVA performed on overall liking scores showed a significant effect of "*Samples*" ($F_{(7,1304)} = 64.12$, $p < 0.0001$), "*Cluster*" ($F_{(1,1304)} = 235.22$, $p < 0.001$) and the interaction "*Cluster*" * "*Samples*" ($F_{(7,1304)} = 15.01$, $p < 0.0001$). Since the two clusters markedly differed in their liking of plant-based samples, they were named "plant-based samples Dislikers" (PB_Dislikers, 73 %) and "plant-based samples Neutrals" (PB_Neutrals, 27 %).

"PB_Dislikers" showed a marked preference for animal-based samples, rejecting all plant-based ones, whose average liking scores were below 35 (Ls-mean range: 10.4 – 32.9). "PB_Neutrals" showed

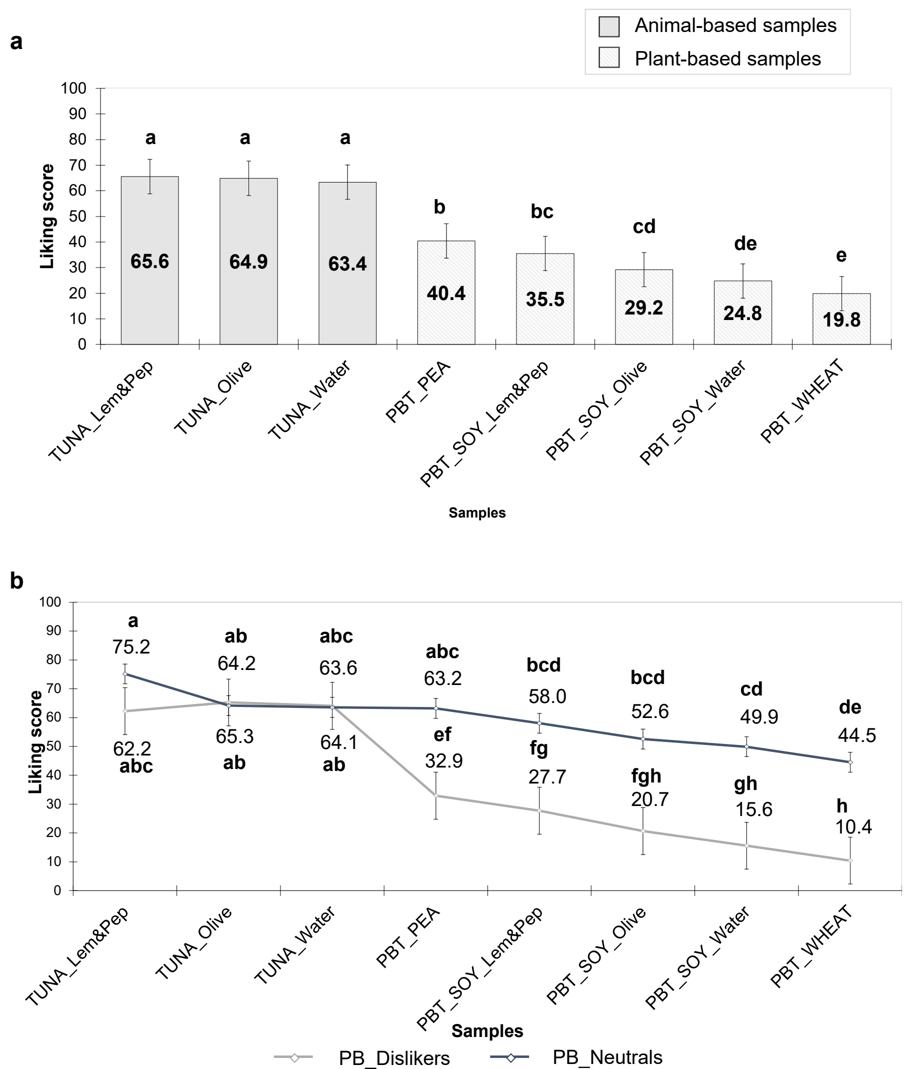

Fig. 1. Liking scores a) for the global average b) for the average of the two clusters (“PB_Dislikers”; “PB_Neutrals”). Error bars represent standard error of the mean (SEM). Different letters indicate significant differences according to Bonferroni post hoc test.

significantly higher liking scores than “PB_Dislikers” for all plant-based samples, although the scores were still close to the average value of 50. Moreover, all plant-based samples but one (PBT_WHEAT), were in general accepted with mean liking score above or corresponding to the middle of the scale (Ls- mean range: 44.5 – 63.2). The two clusters did not differ in liking for animal-based samples.

Fig. 3(a–d) shows the symmetric bi-plots by sensory dimension (appearance, odour/flavour, taste and texture) of the samples based on sensory descriptive analysis for the two consumer segments. The samples and attributes configurations related to appearance (sample configuration: RV = 0.98, $p < 0.0001$; attribute configuration: RV = 0.98, $p < 0.0001$), odour/flavour (sample configuration: RV = 0.91, $p < 0.0001$; attribute configuration: RV = 0.98, $p < 0.0001$) and texture (sample configuration: RV = 0.91, $p < 0.0001$; attribute configuration: RV = 0.94, $p < 0.0001$) from both clusters were highly similar. Interestingly, there were differences, although small, in the configuration of samples according to the taste dimension (sample configuration: RV = 0.76, $p < 0.0001$; attribute configuration: RV = 0.85, $p < 0.0001$). The “PB-Neutrals” cluster perceived the PBT_PEA and PBT_SOY_Olive samples as more similar to the animal-based ones, and the only sample perceived as bitter was the PBT_WHEAT. This is in contrast to the “PB-Dislikers” cluster, which clearly distinguishes the two groups of samples in terms of taste.

In order to investigate the influence of the presence and absence for each CATA attribute on hedonic scale, a penalty-lift analysis was performed separately by cluster. Fig. 4(a–b) reports the liking mean impact plot in which attributes with significant impact ($p < 0.05$) are shown. Firstly, the results of the penalty lift analysis showed that for “PB_Dislikers” cluster, 18 CATA descriptors significantly influenced the mean liking (10 positively, 8 negatively). On the other hand, for “PB_Neutrals” cluster, only 9 descriptors were found to have a significant effect (6 positively, 3 negatively).

For “PB_Dislikers”, Tuna odour/flavour (Mean impact (MI) = + 41.60), Pink colour (MI = + 30.35) and Lemon odour/flavour (MI = + 22.72) were the top three positive drivers. This result aligns with the liking pattern shown by this cluster for the animal-based samples. Off-flavour (MI = – 36.00), Legume/vegetable odour/flavour (MI = – 26.20) and Gumminess (MI = – 25.52) attributes associated with plant-based samples had a negative impact on liking scores.

For “PB_Neutrals”, Tuna odour/flavour (MI = + 20.65), Pink colour (MI = + 13.50) and Softness (MI = + 12.92) attributes had a lower positive overall liking mean impact compared to “PB_Dislikers”. Moreover, the impact of Gumminess (MI = – 13.89) and Legume/vegetable odour/flavour (MI = – 7.27) were less strong than in the “PB_Dislikers” cluster. The penalty of Beige colour was comparable between the two clusters (PB_Dislikers = – 5.73; CL2= – 5.52). Therefore, although

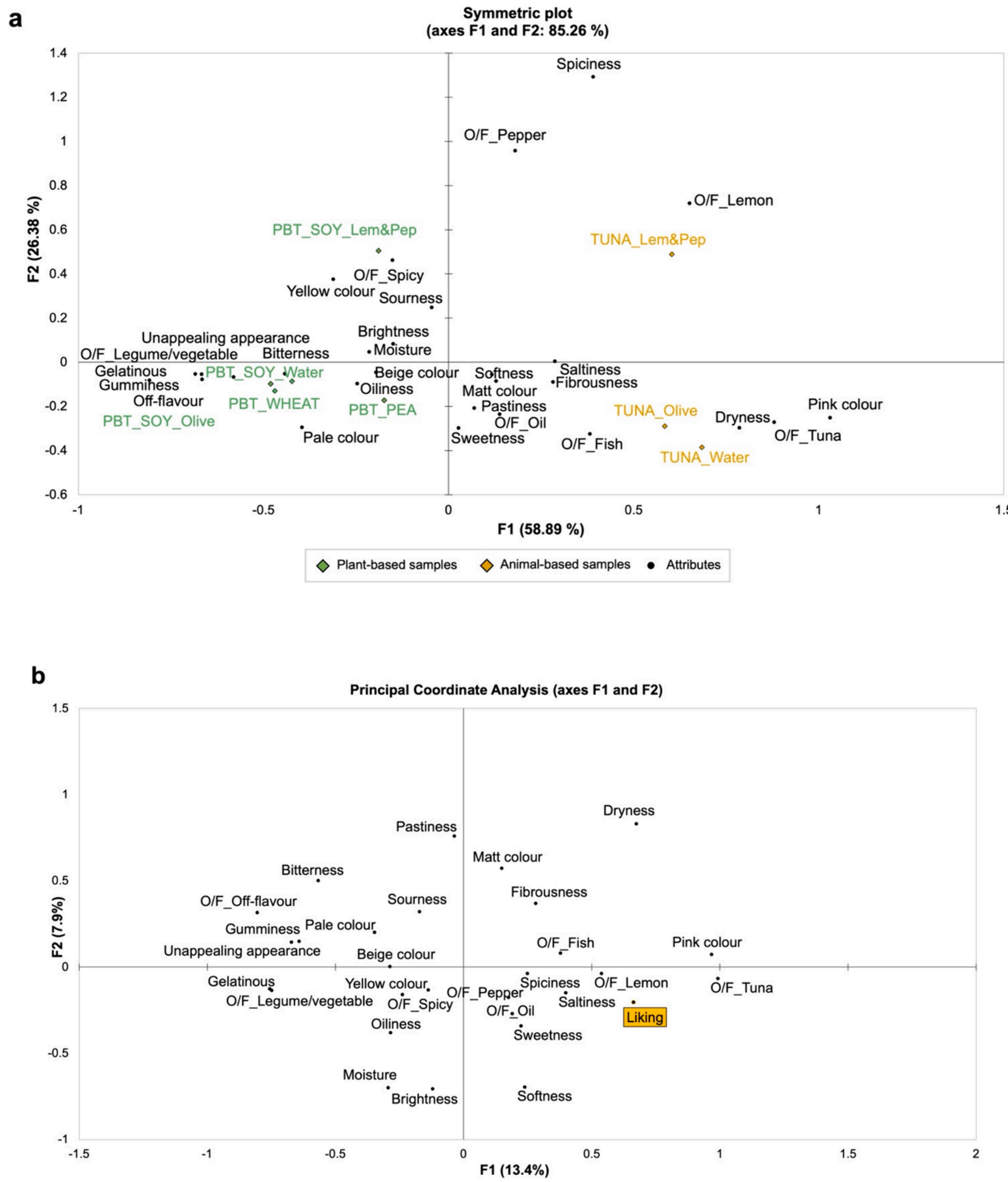

Fig. 2. Correspondence analysis symmetric plot (a) and Principal Coordinate plot (b) based on CATA data of eight canned-tuna samples (O=Odour; F=Flavour).

these terms are associated with plant-based samples, for this cluster their presence did not influence liking to such an extent that they are unacceptable.

To explore more in-depth and better understand the differences in terms of liking, the two clusters were characterized by a series of variables. The socio-demographic characteristics are shown in Table 2. According to χ^2 results, no significant difference between the two clusters was found in terms of gender ($\chi^2 = 0.01$; $p = 0.91$), age class ($\chi^2 = 0.83$; $p = 0.66$) and food neophobia level ($\chi^2 = 0.63$; $p = 0.73$). On the contrary, significant differences were found between the clusters in terms of food consumption. Overall, in "PB_Neutrals" a higher consumption of plant-based meat ($F_{(1,163)} = 4.92$, $p = 0.03$), dairy ($F_{(1,163)} = 4.26$; $p = 0.04$), fish ($F_{(1,163)} = 11.06$; $p = 0.001$) and eggs ($F_{(1,163)} = 9.45$; $p = 0.002$) was observed. In particular, "PB_Neutrals" showed a higher consumption of plant-based steaks ($F_{(1,163)} = 5.54$, $p = 0.02$), cold cuts ($F_{(1,163)} = 10.35$, $p = 0.002$), sliced salmon ($F_{(1,163)} = 9.03$, $p = 0.003$), canned-tuna ($F_{(1,163)} = 10.60$, $p = 0.001$), breaded fish sticks/fillets analogues ($F_{(1,163)} = 8.38$, $p = 0.004$), plant-based eggs ($F_{(1,163)} = 8.75$, $p = 0.004$) and mayonnaise ($F_{(1,163)} = 7.28$; $p = 0.008$).

Moreover, clusters significantly differed in two food related lifestyle related to the "Importance of product information" ($F_{(1,163)} = 4.07$; $p = 0.045$) and "Health" ($F_{(1,163)} = 4.44$; $p = 0.037$). "PB_Neutrals" seemed more careful when buying food, both in regard to its nutritional composition and its naturalness compared to "PB_Dislikers".

4. Discussion

The present study evaluated consumer perception, liking and drivers of acceptance of plant-based canned tuna alternatives, while also exploring potential consumer clusters with different liking patterns. To the best of our knowledge, this is the first study to address this topic by including the actual consumer tasting of the products. Among fish analogues, plant-based canned-tuna could be particularly relevant to sustainable consumption from both economic and environmental perspectives, having the potential to leverage public concerns related to overfished tuna stocks, bycatch issues, and the impact of fishing

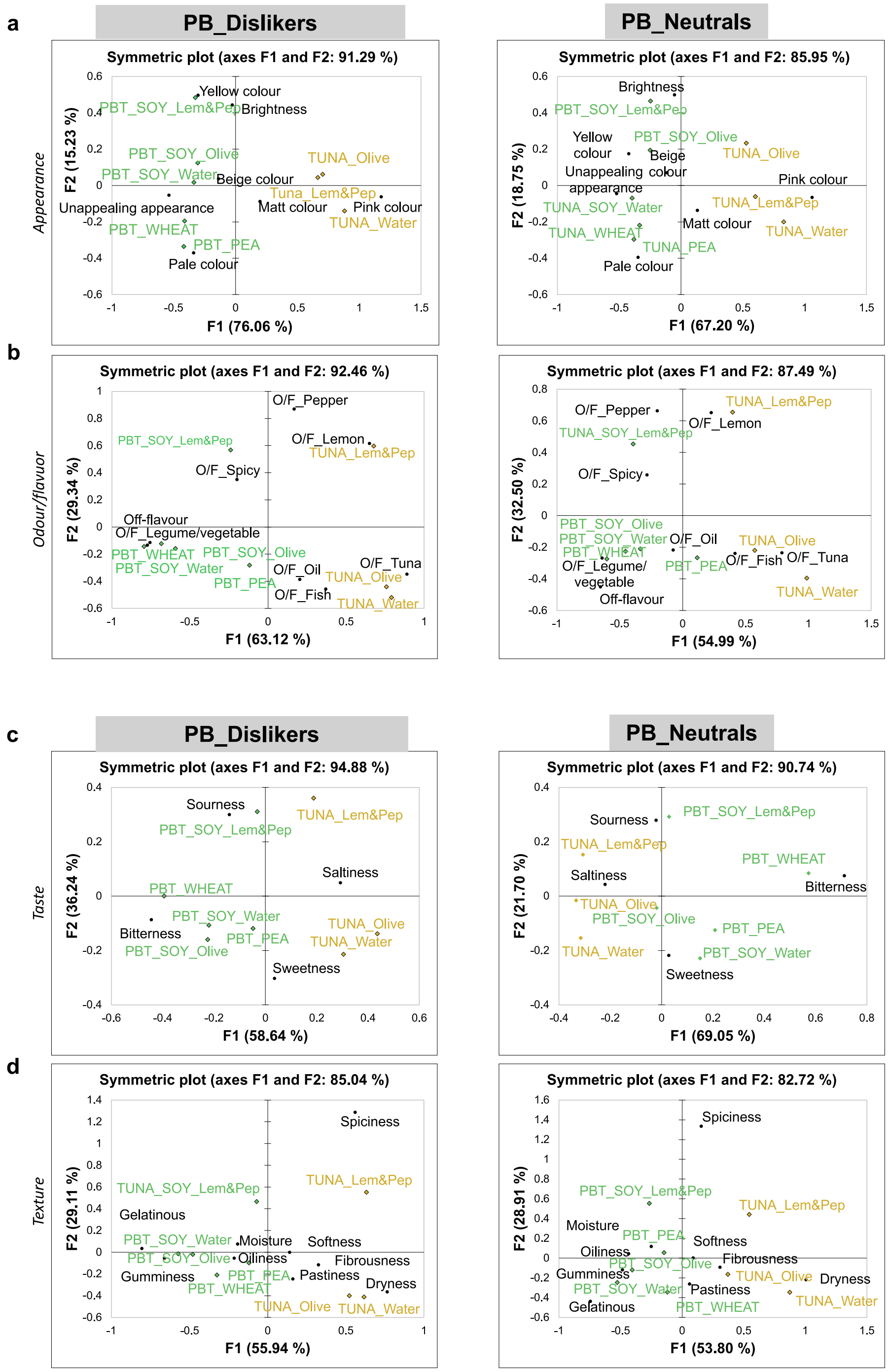

Fig. 3. a–d – Correspondence analysis symmetric plot by sensory dimension (appearance (a), odour/flavour (b), taste (c) and texture (d)) based on CATA descriptions of eight canned-tuna samples of "PB_Dislikers" (n = 121) and "PB_Neutrals" (n = 44) (O=Odour; F=Flavour).

methods on marine ecosystems (Bahri et al., 2021; ISSF, 2021).

4.1. Nutritional quality of plant-based canned tuna analogues

From a nutritional point of view, it is widely recognised that the exploitation of plant-based protein, whatever the selected raw ingredients results in analogues having markedly different nutritional profiles compared to their animal counterparts (Nolden and Forde, 2023; Tso and Forde, 2021). Based on nutritional information provided on product labels, plant-based tuna analogues tested in the present study were nutritionally different from conventional animal products. In contrast to a previous study, which reported a higher protein content in canned tuna analogues compared to the animal-derived version (Leonard and Fang, 2023), the nutritional labels showed a lower protein content in plant-derived foods compared to animal products, as evidenced in other product categories, like meat and dairy analogues (Katidi et al., 2023). Only the sample made from pea protein (PBT_PEA) had a protein content higher than the animal products (22.6 g/100 g vs 17–19 g/100 g). However, their biological quality in terms of essential amino acids should be well assessed since plant-based proteins have a low digestibility and lack certain essential amino acids naturally present in animal proteins (such as leucine, isoleucine, valine, lysine, and methionine) (Ewy et al., 2022). Despite the lower protein content, the canned tuna analogues offer the potential nutritional benefit of

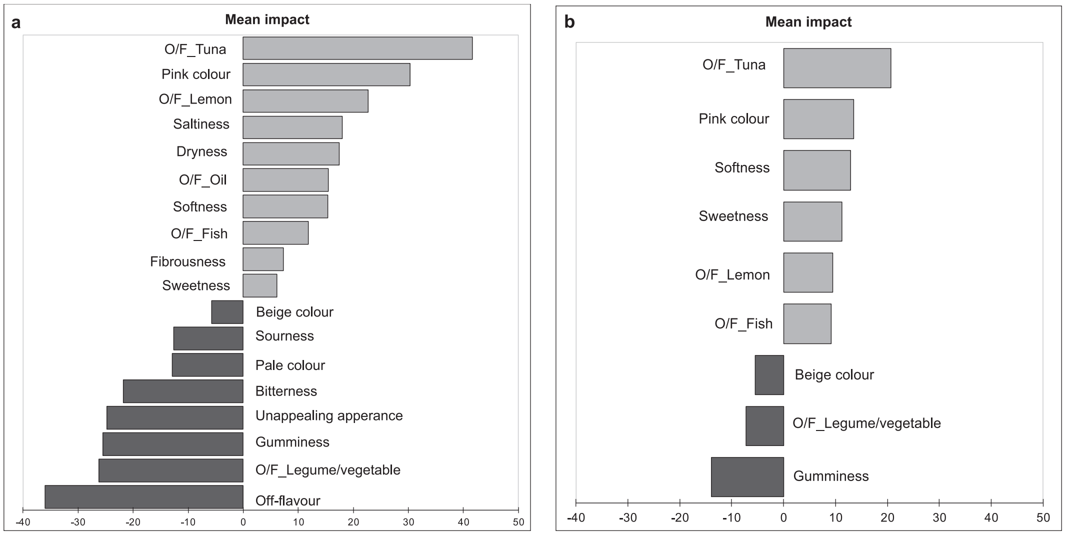

Fig. 4. a–b – Liking mean impact plot representing the impact of sensory descriptors from the CATA list in the overall liking of 8 canned-tuna samples for "PB_Dislikers" (n = 121) (a) and "PB_Neutrals" (n = 44) (b). The dark grey bars to the left of 0 indicate that the attribute's presence was correlated to decreases in overall liking and the light grey bars to the right of 0 indicate that the attribute's presence was correlated to increases in overall liking. Only attributes that resulted in significant increase or decrease in overall liking are present. (O/F=Odour/flavour).

providing dietary fibre and omega-3, such eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), when consumed. Indeed, the naturally occurring carbohydrates in plant-based proteins (Leonard and Fang, 2023; Saffarionpour, 2023) contribute to a significant presence of fibre in these products, while the inclusion of microalgae or seaweed oil in their formulation make them a potential source of omega-3 fatty acids. These particular fatty acids have been associated with promoting cardiovascular and muscular health, as well as preventing obesity and diabetes (Punia et al., 2019). Despite fish being designated as the primary source of these polyunsaturated fatty acids, canned tuna is notably deficient in them (EPA=0.00 g; DHA=0.08 g), as reported in the Food Composition Database for Epidemiological Studies in Italy (Gnagnarella et al., 2022). Although we did not measure omega-3 fatty acids in the tested products, the thermal processes that occur during canning, along with the subsequent storage period, is reported to lead to a significant reduction in the omega-3 fatty acid content of fresh fish (García-Arias et al., 1994; Siriamornpun et al., 2008). This becomes more particularly pivotal when one considers that individuals on vegetarian and vegan diets are often advised to take omega-3 supplements to avoid a potential nutritional deficit (Lane et al., 2021) caused by the absence of fish in their dietary choices.

4.2. *Sensory quality of plant-based canned tuna analogues*

Despite the potential environmental and nutritional advantage associated with the consumption of these products, this study showed that, regardless of the protein source (pea, textured soy protein or wheat flour), all plant-based canned tuna samples were disliked by consumers. This outcome is consistent with the conclusions drawn in prior research on other analogues product categories, such as meat (e.g., Cordelle et al., 2022), cheese (e.g., Falkeisen et al., 2022), milk (e.g., Cardello et al., 2022), and yoghurt (Cardello et al., 2024; Jaeger, Cardello et al., 2023). It should be noted that, as in other studies aimed at optimizing the sensory qualities of these products (e.g., Cardello et al., 2024; Jaeger et al., 2024), plant-based samples were evaluated alongside conventional ones, which could have potentially led to a contrast effect that underestimated the liking of plant-based products. Despite this, the low liking scores observed in the present study, as well as the CATA results, highlight the critical need for significant sensory optimisation. This is confirmed by the fact that during the study, finding the samples was challenging as some products identified through the market inventory were out of production within a short time frame.

Until now, literature has predominantly focused on exploring attitudes towards fish analogues (Lanz et al., 2024) and identifying factors that may influence the willingness to consume these alternatives (Gorman et al., 2023) using questionnaires. Lanz et al. (2024) revealed that consumers exhibit a greater inclination towards plant-based fish, considering it both a preferred option and more environmentally sustainable when contrasted with alternatives like 3D-printed fish and cultured fish. However, despite this apparent interest, concern about sensory characteristics may discourage consumers from trying and incorporating these products into their consumption choices (Gorman et al., 2023).

In the present study, plant-based canned tuna samples were well distinguished in terms of sensory properties from conventional ones, which impacted differently on liking scores. Firstly, tuna analogues were characterised by unattractive appearance due to their beige or yellow colour, which is very different from the traditional pink colour the consumer is used to when consuming this kind of products. Challenges, especially in terms of visual appeal, stem from the often-unnatural appearance of similar products. Furthermore, complications arise due to the susceptibility of plant proteins to alterations during heat treatment (Wannasin et al., 2023).

These analogues were also distinguished by odour of legume/vegetable and off-flavours. The development of off-flavours results mainly from the presence of both volatile (e.g., aldehydes, alcohols, ketones, furans) and non-volatile (e.g., phenolics, saponins, and bitter peptides) compounds (Leonard et al., 2023; Saffarionpour, 2023; Wang et al., 2022), which are also responsible for the bitter taste that characterize plant-based analogues (Appiani et al., 2023).

The present study confirmed that bitter taste also characterizes plant-based canned tuna. Consumers perceived the plant-based samples as bitter and sour, in contrast to the saltiness associated with canned tuna. Interestingly, the animal-based samples were perceived to be saltier than the plant-based versions, although the salt content was comparable to that of analogues products. This might be associated with the umami taste that characterizes fish and is described as savoury (Ninomiya, 2002), contributing to the samples' overall liking. Indeed, it is well known that for both salty and umami there is an innate preference (Ventura and Worobey, 2013). To replicate a fish flavour and to mask off-flavours that affect product liking, flavouring additives or spices may be added to plant-based foods (Fiorentini et al., 2020; Wang et al., 2022).

Finally, alternative samples differed significantly from conventional ones in terms of texture. Currently, there are two technological approaches used to replicate the typical fibrous structure of fish flesh: bottom-up and top-down methods (Lankatillake et al., 2023; Leonard and Fang, 2023; Nowacka et al., 2023). Bottom-up approaches (e.g., electrospinning, wet spinning) involve the creation of individual units that are subsequently joined together using binding agents. In contrast, top-down approaches, such as extrusion and shear cell, involve applying shear forces to protein blends. Although bottom-up methods could produce analogue products that more closely resemble fish meat, they tend to be much more expensive and are therefore less widely used (Lankatillake et al., 2023). In addition to technological processes, specific ingredients also play a crucial role in determining the final texture, such as the incorporation of vegetable oils commonly found in plant-based products. For instance, the products investigated in this study contain canapa, linseed, rapeseed, or sunflower oil which not only enhance the flavour of the product but also act as binding agents, thereby affecting its texture (Younis et al., 2023). However, despite numerous efforts, replicating a texture similar to that of their animal counterparts remains a significant challenge for all categories of plant-based products (Appiani et al., 2023).

The present findings generally emphasize the importance of optimizing the sensory attributes of plant-based tuna to foster wider acceptance. Achieving this goal requires food companies to prioritize the enhancement of product's sensory quality through ingredient formulation and the optimization of technological processes. Among the protein sources evaluated, pea-based options appeared to be the most promising in terms of consumer acceptability. Moreover, the addition of seasonings, such as lemon and pepper, may successfully mask legume and vegetable odours, off-flavours, and mitigate bitterness.

4.3. Clusters identification and characterisation: Drivers of liking, food frequency consumption and food-related lifestyles

Segmenting the whole consumer sample based on liking scores, allowed the identification of distinct liking patterns for plant-based tuna, with the subsequent delineation of two consumer clusters. A non-negligible group of consumers ("PB_Neutrals"; 27 %) was found to score plant-based analogues higher than the results shown on aggregate level, with liking scores exceeding (plant-based samples made of pea or textured soy protein) or being very near the middle of the scale. This result suggests that products made of pea or textured soy protein may have good market potential for a specific segment of consumers. The correspondence analysis conducted on sensory dimensions highlighted a good agreement between the two clusters in the perception and characterisation of samples regarding appearance, odour/flavour, and texture. Nonetheless, different descriptions of the samples emerged between the clusters in terms of taste. The observed difference in taste perception between the two clusters is a potential explanation for their differentiation in terms of liking, as also demonstrated by the penalty lift analysis. These findings align with existing literature indicating that taste/flavour serves as the primary sensory factor influencing liking across various products (Cardello et al., 2022; De Pelsmaeker et al., 2017; Andersen et al., 2019; Moskowitz & Krieger, 1995). For the "PB_Dislikers" cluster, bitter and sour were identified as two descriptors that negatively affected the liking score. Indeed, among all taste sensations, it is well recognised the negative impact that bitterness/sourness and somatosensory sensitivity could have on consumers' food acceptance (Cliceri et al., 2018; Pagliarini et al., 2021). Moreover, individuals with food neophobia tend to be more sensitive to these sensations, particularly when they are at low concentration (Laureati et al., 2018). However, because taste responsiveness was not evaluated in this study, definitive conclusions on this matter cannot be drawn. However, the drivers had a different impact between the two clusters. For "PB_Neutrals", the effect on liking was less severe (either positively or negatively) for all of the sensory attributes.

The characterisation of the two clusters showed no differences in gender, age and food neophobia. This lack of difference, especially in terms of gender, is unexpected given that women are reported to exhibit a higher degree of attention and positive attitudes towards plant-based products compared to men (Appiani et al., 2023; Coucke et al., 2023; Giacalone et al., 2022; Grasso et al., 2019).

Nevertheless, differences in behavioural attitudes and eating habits were highlighted. "PB_Neutrals" were found to eat significantly more frequently plant-based meat, fish and eggs, which may result in a higher acceptance of plant-based products than those who disliked the products ("PB_Dislikers") whose consumption of plant-based analogues was almost negligible. The lack of familiarity is a significant barrier to the consumption of plant-based products (Giacalone et al., 2022; Hoek et al., 2011) since it can also create negative expectations among consumers, leading to a reduction in their acceptability. Conversely, individuals who regularly consume these foods are more likely to accept the sensory attributes of plant-based analogues (Grasso et al., 2022; Michel et al., 2021). Furthermore, consumers who liked plant-based products ("PB_Neutrals") exhibited a greater interest on both label information and the health implications of the products they purchase. Therefore, their attention to product information and health factors can contribute to explaining these liking patterns. However, the effect of information on the acceptance of plant-based foods is still debated in the literature. Gorman et al. (2023) showed that providing information on the health and environmental benefits of plant-based fish can encourage consumers to try and integrate these products into their diet. However, if the sensory quality of the products is low, the information provided does not affect the liking of the products (Jaeger et al., 2023).

4.4. Limitations of the study

Although this research has taken important steps to shed light on what plant-based tuna innovation should focus on, some limitations should be acknowledged. Firstly, this study focused only on five plant-based products available on the Italian market and did not encompass broader markets, thus lacking global representativeness. Furthermore, the number of individuals in the "PB_Neutrals" cluster was relatively small for a consumer study. Finally, although the clusters were characterised based on socio-demographic and behavioural variables, physiological variables, the impact of meal context and consumption moment on the acceptance of plant-based products were not investigated and should be included in future research.

5. Conclusions

Within the framework of increasing consumer demand for plant-based alternatives, this study aimed to evaluate consumer preferences and sensory drivers influencing plant-based canned tuna alternatives. Present findings indicated a general lack of sensory appeal in current plant-based samples, potentially leading to unfavourable attitudes and reluctance to consume them. Key sensory issues were highlighted to suggest more accurate reformulations for product optimization.

Moreover, the consumer segmentation based on liking scores, allowed an interesting identification of distinct liking patterns for plant-based tuna, with the subsequent delineation of a group of consumers found to like plant-based analogues. The two clusters showed relatively consistent agreement regarding sensory distinctions among the products, except for attributes related to taste. This suggests that the disparities observed among the two clusters in this study were not due to varied perceptions of the sensory attributes of the products but were mostly associated with differing preferences, particularly concerning the taste/flavour of the plant-based products, and the impact these attributes had on consumers' liking. In conclusion, this study contributed for the first time to gauging baseline preferences and behaviours towards plant-based canned tuna, as well as to identifying target consumer segments and factors influencing their behaviours.

Ethical statement

Ethical approval for the involvement of human subjects in this study was granted by the Ethical Committee of the University of Milan, Reference number 95/23.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGpt in order to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Marta Appiani: Writing – original draft, Investigation, Formal analysis. **Camilla Cattaneo:** Writing – review & editing, Methodology, Investigation, Formal analysis, Conceptualization. **Monica Laureati:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

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

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2024.105329.

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