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RESEARCH ARTICLE

Consumer sensory profiling and liking of Bolognese-type sauces: how do insect and plant foods really fare against red meat?

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Abstract

Meeting global targets for healthier and more sustainable diets calls for a substantial reduction of meat consumption in Western nations, especially red and processed meat. This requires a transition to the large-scale production, marketing, and adoption of alternative proteins. The current state of development of new plant- and insect-based foods holds good promise, but optimizing their sensory quality to the point where they can satisfactorily replace everyday meat-eating experiences remains a challenge, demanding a more consumer-oriented approach. This study investigated how Portuguese adults (N = 130, 18-40 years old, 50% female, regular meat eaters) perceived the sensory characteristics of seven Bolognese-style pasta sauces – made with 100% red meat (beef and pork), plant (soya beans or peas) or edible insect (house cricket or yellow mealworm larvae) protein – and how this affected their hedonic preferences for these products. Expectedly, the meat-based sauce was generally the most appreciated. Still, consumers liked all products slightly to moderately apart from mealworm mince. Sensory-mediated disgust affected the evaluations of some insect- and plant-based sauces, while others benefitted from formulations that enhanced savouriness and the prototypical attributes of a tomato pasta sauce. Moreover, the disconfirmation of positive sensory-affective judgements of 'meatiness' induced by mince-like texture cues penalized liking. High inter-individual variation in evaluations was observed. Distinct preferences for spiciness, for instance, moderated the effects of meat substitution on product liking, with over half of participants appreciating a mild or a spicy plant-based option more than the typical beef Bolognese. Sociodemographics, Beef Consumption, Healthy Eating Consciousness and Food Disgust Sensitivity were all important predictors of patterns of product liking, pointing out that the type of protein selected is just one of the many factors driving the acceptance of meat substitutes by consumers that can be leveraged by the food industry.

Keywords

check-all-that-apply – consumer preferences – consumer segmentation – meat substitutes – mixed dish

1 Introduction

The transformation of global food systems – to secure the provision and consumption of healthy diets from sustainable production, processing and distribution methods that provide adequate nutrition to all and protect the planet – is underway to meet UN 2030 Sustainable Development Goals (UN, 2015). This transformation implies two major dietary shifts: the reduction of current levels of red and processed meat consumption in middle- and high-income nations and the concomitant increase of the supply of high-quality protein from alternative sources (Willett *et al.*, 2019). Several strategies to reduce red and processed meat intake are available to consumers, from totally excluding these sources of protein from diet (e.g. adopting vegetarianism or veganism) to reducing their portion sizes (e.g. curtailment, hybrid formulations) or eating them less often (e.g. flexitarianism) (Verain, Dagevos and Antonides, 2015). Whatever the strategy adopted, an increase in the consumption of alternative sources of protein is likely to occur as the result of reducing meat intake (Nguyen *et al.*, 2022; Onwezen and Dagevos, 2024).

The functional properties and market potential of an increasing number of alternative protein sources are therefore being investigated, with each set to win the preference of the growing flexitarian consumer segment (Siddiqui *et al.*, 2023). Traditional plant-based proteins (e.g. tofu, seitan, tempeh) remain the most popular and well-accepted meat alternatives in Europe, much given their longstanding presence in the market to cater for the needs of vegetarians and vegans (He *et al.*, 2020). Additionally, recent advances in food technology enabled the development of increasingly sensory appealing meat analogues (e.g. plant-based patties), giving an important boost to the category by penetrating a wider range of consumer groups and consumption settings (Fiorentini, Kinchla and Nolden, 2020). Shares of plant-based meat alternatives in Western markets are still quite modest, however (Giacalone, Clausen and Jaeger, 2022). Meanwhile, the use of insects as source of protein in Western diets is slowly but steadily gaining traction (Boukid, Sogari and Rosell, 2023; Kröger *et al.*, 2022). This development is largely fuelled by the growing realization that the rearing and consumption of edible insects are well-established practices in over 110 countries, and that there are at least 2,000 insect species that can be considered edible (Rumpold and Schlüter, 2013; Van Huis *et al.*, 2013). With several species and food uses already cleared for production and marketing in the European Union, edible insects are increasingly acknowledged as valid and viable sources of protein for future foods that are nutritious and safe to eat (IPIFF, 2024; Smetana *et al.*, 2021). Their more widespread consumption may thus come to play a critical role in shifting from meat-centric diets towards healthier and more sustainable eating patterns (Caparros Megido *et al.*, 2016; van Huis, 2022). Rejection of insect-based meat analogues is quite high among European consumers, nevertheless, being driven by disgust and food neophobia coupled with lack of exposure (Kröger *et al.*, 2022; Ribeiro et al., 2022), as well as by high uncertainly about their taste, adequate modes of preparation and appropriate meal contexts (Deroy, Reade and Spence, 2015; Hamerman, 2016; Shelomi, 2015).

Per capita meat supply reached 230.0 g/day (84.0 kg/year) in Portugal in 2020, with meat representing 21% of the mean daily energy intake (429.0 kcal). This represents over a fourfold excess relative to national dietary recommendations (INE, 2021). Meeting current guidelines for healthy and sustainable diets in this country demands a substantial decrease in meat consumption, particularly of the intake of red and processed meats by adolescents and young adults (IAN-AF, 2017). Yet only one third of Portuguese adults believe that reducing red meat intake will improve their diet (Schmidt *et al.*, 2020) and less than 10% are flexitarians, with the market penetration of plant-based meat substitutes being quite low (Lantern, 2021). Additionally, over three-quarters (79%) are unwilling to adopt entomophagy (Schmidt *et al.*, 2020), with more than half (55%) opposing the rearing of insects for human diet (Truninger *et al.*, 2022). The use of edible insect protein in food formulations seems to have better acceptance, however, especially among males (Florença *et al.*, 2021).

Regardless of the type of alternative protein used, poor evaluations of the sensory quality of meat alternatives consistently stand out as a major reason for their lack of acceptance by consumers (Nguyen *et al.*, 2022; Onwezen *et al.*, 2021; Siddiqui *et al.*, 2023). Manufacturing products with desirable, or at least acceptable appearance, taste and texture remains therefore a major bottleneck for the accomplishment of meat reduction goals (Giacalone, Clausen and Jaeger, 2022; Ribeiro, Pintado and Cunha, 2024). This is particularly the case when the target for research and development activities is set at mimicking meat products as closely as possible, before and after home cooking, to appeal to the mainstream markets of regular meat eaters and flexitarians (Caputo, Sogari and Van Loo, 2023; Grasso *et al.*, 2022; Smetana *et al.*, 2021). Yet, the investigation of the perceived sensory profiles of foods made with alter-

native protein sources and their actual level of liking has been somewhat neglected in favour of understanding the demographic, cognitive and emotional drivers of their consumption. This is rather notorious in the case of edible insect foods (Perez-Santaescolastica *et al.*, 2022) and might *de facto* be hindering the discovery and implementation of viable strategies for promoting their widespread adoption (Deroy, Reade and Spence, 2015; Shelomi, 2015), as well as the much-needed development and optimization of their sensory profiles (Ribeiro, Lima and Cunha, 2024).

This study examined how Portuguese adults perceived the sensory characteristics of seven Bolognese-style pasta sauces – made with 100% red meat (beef and pork), plant (soya beans or peas) or edible insect (house cricket or yellow mealworm larvae) protein – and how this affected their relative liking of products. Importantly, it also assessed the effects of different sources of preference heterogeneity – related both to product technology and individual variation in sociodemographic and psychological traits (Eckl *et al.*, 2021) – on patterns of sensory liking. Studies where consumers assess the sensory quality and overall acceptability of comparable formulations of traditional meat dishes, in which some of the samples contain alternative protein sources, remain remarkably scarce and limited in scope to plant-based options (Cordelle, Redl and Schlich, 2022; Elzerman *et al.*, 2011; Niimi *et al.*, 2022; Spencer *et al.*, 2021). Meanwhile, and to the best of our knowledge, extant research on the sensory evaluation of edible insect foods focuses almost exclusively on individual products like burger patties and sandwiches (Caparros Megido *et al.*, 2016; Neville *et al.*, 2017; Schouteten *et al.*, 2016; Smetana *et al.*, 2021), meatballs (Tan, Verbaan and Stieger, 2017) or pork sausages (Ho *et al.*, 2022a; Neville *et al.*, 2017) where meat is only partially replaced. This is thus the first study of its kind comparing meat-, plant- and insect-based proteins as complementary ingredients of a mixed product intended for the preparation of a homecooked dish. By undertaking a more comprehensive strategy and grounding it in meal practices, we sought to answer extant calls for more sensory-driven and consumer-oriented research supporting the development and marketing of foods made from alternative proteins, with the goal of incorporating them in daily meals to promote the transition to less meat-centric diets (Giacalone, Clausen and Jaeger, 2022; Onwezen and Dagevos, 2024).

2 Materials and methods

Ethical approval

The data herein reported was collected between October and November 2022 to pilot an at-home behavioural intervention seeking to reduce process and red meat consumption among young adults in Portugal by providing alternative (insect- and plant-based) protein sources (ISRCTN53814211). This research was approved by the Ethics Committee of Universidade Católica Portuguesa (ref. CETCH2022-18) on October 10, 2022. All participants provided written informed consent prior to enrolment. This research was conducted ethically in accordance with the World Medical Association Declaration of Helsinki.

Participants

Young adults (18-40 years old) were selected as the study population given that they comprise the segment most likely to consume plant- and insect-based meat alternatives in Western countries (Giacalone, Clausen and Jaeger, 2022; Kröger *et al.*, 2022), including in Portugal (Schmidt *et al.*, 2020). A consumer panel service provider screened and recruited individuals willing to take part in an online questionnaire and a product evaluation session at the sensory analysis laboratory of Universidade Católica Portuguesa, as part of an ongoing academic study on consumer preferences for insect- and plant-based alternatives to red meat, against compensation with a gift voucher of €25 for time spent. To increase the diversity, representativeness (beyond student populations) and impact of consumer studies on the acceptance of alternative protein sources (Mina, Peira and Bonadonna, 2023; Onwezen and Dagevos, 2024), efforts were undertaken to recruit a sizeable, gender-even sample of professionally active individuals who regularly consumed red and processed meats. A total of 132 healthy, non-pregnant, native Portuguese-speaking individuals (124 nationals and six Brazilian residents), reporting no restrictions to the intake of red meat, processed meats, pulses, protein or energy, and no allergies to shellfish or dust mites, were deemed eligible and provided written informed consent to participate.

Online questionnaire

Participants completed a 15-minute online questionnaire administered by Qualtrics CoreXM (Provo, UT, USA) in the week prior to their product evaluation session. The questionnaire began with questions recording participant demographics (herein reported: sex, age, education level and job status), frequency of consump-

tion of different types of meat (herein reported: days per week dinning meals with beef or pork at home) and general sustainable consumption habits (herein not reported). Next, measures of familiarity with entomophagy and emotions associated with this type of consumption were administered; herein reported is the degree of familiarity with edible insects (1 item, 6-point bipolar rating scale, 1 = *Never heard about*; 3 = *Have tried once*; 6 = *Consume regularly*) (Costa *et al.*, 2021). The questionnaire ended with the administration of four psychometric measures of interest:

- Healthy Eating Consciousness (Hartmann, Siegrist and van der Horst, 2013; Schifferstein and Oude Ophuis, 1998);
- Food Neophobia (Pliner and Hobden, 1992);
- Food Disgust Sensitivity (Hartmann and Siegrist, 2018);
- Meat Attachment Index (Graça, Calheiros and Oliveira, 2015) (herein not reported).

Healthy Eating Consciousness (4 items) and Food Neophobia (10 items) measures were previously adapted and validated for Portuguese native speakers (Costa and Simão, 2018; Paupério *et al.*, 2014), being assessed on 5-point Likert-type response scales (1 = *Totally disagree*, 3 = *Neither agree nor disagree*, 5 = *Totally agree*). The Eight-Item Short Version of the Food Disgust Sensitivity Scale (Hartmann and Siegrist, 2018) was translated from English to Portuguese and assessed on 5-point bipolar rating scales (1 = *Not disgusting at all*, 3 = *Somewhat disgusting*, 5 = *Extremely disgusting*). The order of presentation of psychometric/behavioural measures and their items was randomized. Supplementary Table S1 details the psychometric measures analysed in this study.

Study samples and formulation

The category under study was Bolognese-style pasta sauce due to its prototypicality as a red meat recipe and its popularity and acceptability among young Western adults (Niimi *et al.*, 2022). Manipulating meat-centric, familiar recipes high in sensory-liking was shown to facilitate the trial of alternative protein sources (Caparros Megido *et al.*, 2016; Tan, Verbaan and Stieger, 2017). Likewise, incorporating novel proteins in products suitable for consumption as part of a cooked dish – preferably one where the replacement of red meat is less striking or relevant to the enjoyment of the meal – is known to raise their acceptability (Elzerman *et al.*, 2021; Hamerman, 2016; Spencer *et al.*, 2021). Three product formats were selected: ready-made sauces, dry protein spice mixes and minces. This sought to cover a variety of processing technologies, methods and degrees of preparation for consumption, sensory profiles and degrees of similarity to red meat. The inclusion of dry mixes intended specifically to investigate the open question of whether novel protein foods designed to replace the nutritional function of red meat in diets – without necessarily resembling its sensory characteristics closely – perform better, in terms of consumer acceptance, than those purposefully developed to mimic the appearance, flavour and texture of meat in dishes as much as possible (Cordelle, Redl and Schlich, 2022; Roos *et al.*, 2020). Table 1 provides a description of the seven Bolognese-type sauces tested, including the details about protein source, origin, composition and preparation for sensory evaluation.

One reference meat product and three pairs of matching edible insect- and plant-based options were selected for comparative purposes. The meat product was a commercial ready-made sauce prepared according to the traditional Italian Bolognese recipe (i.e. where beef is the main protein source and cured pork belly is added to enhance meat flavour and mouthfeel). Soya beans (dry spice mix, ready-made) and peas (mince) were the principal protein sources in the plant-based sauces. Soya beans and peas are the primary types of non-animal protein used by the food industry in the production of meat alternatives, due to their ability to mimic the sensory properties of cooked meat, particularly flavour and texture, and generally low cost (Giacalone, Clausen and Jaeger, 2022). Commercial offers matching the protein content of either meat- or insect-based products were selected. Both meat- and plant-based products were available at large grocery stores, from where they were acquired.

House cricket (*Acheta domesticus*), in powder (dry spice mix) and frozen ground (ready-made) forms, and yellow mealworm larvae (*Tenebrio molitor*) in powder form (mince) were the main sources of protein in the insect-based sauces. These are among the very few insect species and forms currently authorised for the production and marketing of foods in the European Union under the Novel Food Legislation (IPIFF, 2024). Powder forms are the primary type of protein source present in meat alternatives marketed worldwide (Boukid, Sogari and Rosell, 2023; Mishyna, Chen and Benjamin, 2020), being reputedly also the most popular edible insect ingredient among Western consumers (van Huis, 2022). Studies evaluating the sensory profile and acceptance of insect-based meat alternatives remain rather scarce (Mishyna, Chen and Benjamin, 2020; Ribeiro, Pintado and Cunha, 2024), nevertheless, particularly those examining the effects of

TABLE 1 Description of the Bolognese-type sauces tested in the sensory evaluation study

Sample	Product	Origin	Ingredients	Protein (per 100 g)	Storage and preparation
Beef Bolognese Sauce (*BfBlgn*)	Meat Bolognese Pasta Sauce (400 g)	*Barilla*®, Italian recipe	Tomato pulp 37%, tomato concentrate 15%, beef 9.5%, pork 9.5%, onions, carrots, celery, herbs, oil, salt, pepper	4.2 g	Room temperature, pre-cooked, heat to serving temperature
Soya Spice Mix (*SoyMx*)	Spice Mix for Vegetarian Taco with Soy Protein (65 g)	*Santa Maria*, Tex-Mex recipe, mild heat	Soya protein 58%, onion, cumin, chilli pepper, garlic, oregano, cane sugar, salt, sugar, potato starch, yeast extract, anti-caking agent (silica), acid (citric acid), natural flavouring	44.0 g	Room temperature, mix 100 g thoroughly with 200 ml of water, bring to heat, add 150 g of canned diced tomato and let simmer for approx. 10 minutes
Soya Pasta Sauce (*SoyPast*)	Vegetable Bolognese (320 g)	*Veg in*, chilli recipe, very mild heat	Water, tomato 12%, soya bean protein 8%, onion, tomato concentrate 6%, pepper, wine (contains sulphites), olive oil, soy sauce (water, soya beans, salt, vinegar beetroot), salt, garlic paste (garlic, salt), spices, yeast, paprika, sugar and chilli powder	5.7 g	Room temperature, pre-cooked, heat to serving temperature
Pea Mince (*PeaMnce*)	Plant-based mince (300 g)	*BEYOND MEAT*®	Water, pea protein 16%, rapeseed oil, coconut oil, rice protein, flavouring, cocoa butter, dried yeast, stabiliser (methylcellulose), potato starch, apple extract, salt, potassium salt, maize vinegar, concentrated lemon juice, emulsifier (sunflower lecithin), colour (beetroot red), maltodextrin, pomegranate extract	15.0 g	Cold or frozen storage, crumble and stir-fry in non-stick pre-heated pan for 8 minutes (medium to high heat), add 150 g of canned diced tomato and let simmer for approx. 10 minutes
Cricket Spice Mix (*CrktMx*)	House Cricket (*Acheta domesticus*) Spice Mix (70 g)	Prototype developed by the Skylab (Technical University of Denmark), mild heat	Fresh, dried and ground cricket (*Acheta domesticus*) 50%, tomato powder 17%, garlic, cardamom, coriander, cumin, berbere, oregano, onion, ginger, nutritional yeast, chili powder, paprika, cloves, cinnamon, nutmeg, black pepper, brown sugar	37.7 g	Frozen storage, heat 100 g in an oiled pre-heated pan for 2 minutes (low heat), add 400 ml water and 150 g of canned diced tomato, season with salt and let simmer for approx. 10 minutes

TABLE 1 (Continued)

Sample	Product	Origin	Ingredients	Protein (per 100 g)	Storage and preparation
Cricket Pasta Sauce (*CrktPast*)	House Cricket (*Acheta domesticus*) Umami Paste (150 g)	Prototype developed by Bugging Denmark, mild heat	Fresh, frozen and ground cricket (*Acheta domesticus*) 31%, tomato paste 17%, olive oil, rapeseed oil, shallots, shiitake mushrooms, soy sauce, garlic, balsamic vinegar, anchovies, *Pimente D'Espelette*, black pepper	18.3 g	Frozen storage, pre-cooked, heat to serving temperature
Mealworm Mince (*TnbMnce*)	Yellow Mealworm (*Tenebrio molitor*) larvae mince (150 g)	Prototype developed by the Research Group for Insect Production and Processing (Katholieke Universiteit Leuven)	Yellow Mealworm (*Tenebrio molitor*) 57%, egg white powder 10%, peanut oil, table salt, paprika powder, potato starch, white pepper, freeze dried onions, nutmeg	23.3 g	Frozen storage, pre-cooked, heat 100 g in an oiled, pre-heated pan for 5 minutes (medium heat), add 200 g of canned diced tomato and let simmer for approx. 10 minutes

the incorporation of house cricket protein (Ho *et al.*, 2022a), which further justifies their inclusion in this study. Edible insect products were prototypes developed, batch produced, packaged and labelled by SUS-INCHAIN project partners in EU production facilities approved by the relevant national food authorities. Their formulation contained only the insect species, forms and uses approved as novel food by the European Commission (IPIFF, 2024) and ensured that insect incorporation was, as much as possible, not discernible in end-products, to facilitate trial (Kröger *et al.*, 2022; Onwezen *et al.*, 2021). Prior to this study, each prototype underwent several design and optimization iterations to balance the desired high rate of incorporation of edible insect protein with palatability, flavour complexity and functionality (Roos *et al.*, 2020). Batches of the final formulations were frozen and shipped for sensory evaluation in Portugal together with a signed declaration of conformity. Upon arrival, they were stored in freezing chambers and samples were taken and sent to an ISO 17025 accredited laboratory for assessment of microbial safety compliance. Products and prototypes were consumed within three months of their arrival at the sensory evaluation laboratory.

Sample preparation

Recipes were developed at the Kitchen Lab of Universidade Católica Portuguesa to prepare similar Bolognese-type sauces from two of the insect-based prototypes – the cricket spice mix and the mealworm larvae mince – and two of the plant-based commercial products – the soya spice mix and the pea mince. Spice mixes were prepared by adding water and a commercial tomato product (unseasoned diced tomato preserved in natural tomato juice), whereas minces were stir-fried for a few minutes before adding this product. The mealworm mince was a pre-cooked product, requiring thus only re-heating for consumption (Stoops *et al.*, 2017), whereas the pea mince, according to the manufacturer's instructions, was cooked thoroughly before serving. The remaining products – pre-cooked, tomato-based pasta sauces with red meat, soya or cricket – were just re-heated.

Products requiring preparation were made in the Kitchen Lab within 24 h prior to each sensory evaluation session and held refrigerated (4 °C). At the start of each session, all products were heated to 65 °C and individually portioned (30 g) over a small amount of freshly cooked wheat pasta (commercial spaghetti cooked in water with salt) in small disposable contain-

ers coded with random alphanumeric codes assigned to each preparation and varying across sessions.

Sensory evaluation

Sessions took place at the sensory analysis laboratory of Universidade Católica Portuguesa just before lunch or dinner time, with up to 16 participants attending per session. These were told not eat or drink in the two hours prior; their height and weight were measured upon arrival. Coded samples were presented to participants as Bolognese-type sauces made with meat, plant or edible insect protein on an individual tasting tray; no other information on test products was provided (Figure 1). Participants were instructed to taste each sauce sample *ad libitum*, without and with pasta, and to complete its evaluation before moving to the next. They were informed that pasta was served merely as a side dish to accompany sauces, as in a standard consumption setting, and hence was not under assessment. The order of tasting and evaluation followed a balanced monadic sequential design; water was served with the instruction to clean the palate between tastings.

Participants registered their responses in a dedicated Qualtrics CoreXM (Provo, UT, USA) questionnaire using lab computer devices. Sample overall liking was evaluated first with a standard measure (1 item, 9-point hedonic scale, 1 = *Dislike extremely*; 5 = *Neither like nor dislike*; 9 = *Like extremely*) (Peryam and Pilgrim, 1957). Next, affective assessments of the appearance, flavour and texture of samples were recorded on novel 9-point emoji scales (herein not reported). Participants were then asked to identify the main descriptive and evaluative attributes characterizing each sample by completing a Check-All-That-Apply (CATA) task (Ares *et al.*, 2010) for each sensory dimension assessed. A total of 57 pre-tested CATA terms were included based on relevant area literature (Grasso *et al.*, 2022; Hongsoongnern and Chambers IV, 2008; Niimi *et al.*, 2022; Schouteten *et al.*, 2016) and preliminary descriptive analysis results (Roos *et al.*, 2020) – 18 for appearance, 22 for flavour and 17 for texture (see Supplementary Table S2 for details). The order of presentation of terms in each dimension was randomized across products and participants. An open question invited further commenting on the sample being evaluated upon completion of the CATA task. Participants were thanked and dismissed at the end of sessions without being debriefed on the type of protein contained in each sample, to prevent them from disclosing this to future session attendees. Gift vouchers rewarding participation in the online questionnaire and sensory evaluation were delivered by the consumer panel service provider at a later date.

FIGURE 1 Presentation of samples for sensory evaluation by participants (left to right, back to middle to front row): Beef Bolognese Sauce, Cricket Spice Mix, Soya Spice Mix, Cricket Pasta Sauce, Pea Mince, Mealworm Mince and Soya Pasta Sauce.

Data analysis

Two respondents did not attend a sensory evaluation session, resulting in their exclusion from the study. In the last session, the evaluations of the Cricket Tomato Paste of two other participants were not registered due to a technical error. The missing overall liking ratings were replaced by the median of remaining participants' scores, weighing for gender, education level, frequency of beef consumption and the medians of liking of the other samples. The significance level alpha was set to 5% in all analyses, unless otherwise stated.

Descriptive statistics were estimated for the variables assessed in the online questionnaire and product overall liking ratings. A Related-Samples Friedman's Two-way ANOVA by Ranks and a post hoc analysis with multiple pairwise comparisons applying a Bonferroni correction were conducted to assess the significance of differences in the distributions of ratings between samples. A Principal Component Analysis of ratings (Kaiser–Meyer–Olkin Measure of Sampling Adequacy = 0.662; Bartlett's Test of Sphericity Chi-square (21) = 93.738, $P < 0.001$) with OBLIMIN rotation was performed to identify underlying product-related dimensions of liking. Dimension regression scores subsequently underwent a Two-Step Cluster Analysis (Tkaczynski, 2017) to identify groups of participants with similar patterns of liking. The procedure used first Ward's minimum variance method to hierarchically group entities, followed by the computation of Dunn's

index to identify the final clustering solution. The means of overall liking ratings were compared across clusters by conducting a Welch's One-way ANOVA; Games–Howell post-hoc tests were performed to interpret results. Clusters were further profiled by comparing the distributions of participants' demographic and behavioural characteristics. Differences in the distributions of Sex (1 = Female; 2 = Male), Higher Education (1 = No; 2 = Yes), Beef Dinners [1 = < two per week (Lower); 2 = 2 per week (Average); 3 = > 2 per week (Higher)], Pork Dinners [1 = < two per week (Lower); 2 = ≥ 2 per week (Higher)], Familiarity with Edible Insects [1 = Never heard or tried it (Unfamiliar); 2 = Else (Familiar)] were assessed with Fisher's Exact Test and a post hoc analysis with multiple pairwise comparisons applying a Bonferroni correction. Mean age and BMI were compared by conducting a Welch's One-way ANOVA with Games–Howell post-hoc tests. These analyses were performed with IBM SPSS Statistics (Version 28).

Cochran's Q (Related-Samples One-Way ANOVA for dichotomous variables) and associated post hoc tests with multiple pairwise comparisons using the Sheskin (Critical Difference) procedure were conducted to assess the significance of differences in the proportions of each CATA term attributed to each sample. To identify the main sensory and evaluative characteristics used by participants to describe samples, a contingency table was built to sum CATA term attributions to each sample across participants and carry out a Correspondence Analysis (Meyners, Castura and Carr, 2013). To assess the strength of associations between these characteristics and product liking, a correlation matrix of attributes and overall liking ratings across samples was computed, and a Principal Coordinates Analysis performed on estimated coefficients. A Penalty Analysis (Plaehn, 2012) was finally conducted to uncover the descriptive and evaluative terms with a significant (positive or negative) mean impact on sample liking. This procedure was repeated per cluster of participants to uncover differences in sample profiling associated to patterns of product liking. These analyses were performed with XLSTAT Sensory by Lumivero (Version 2022.4.1.1358; Denver, CO, USA).

A multinomial logistic regression was estimated to model the relationships between participants' mean Healthy Eating Consciousness, Food Neophobia and Food Disgust Sensitivity scores and cluster membership (with the largest cluster as reference class), with and without adjustment for Sex, Education Level and Beef Consumption (with Male, Yes and High as reference classes, respectively). This analysis was conducted with IBM SPSS Statistics (Version 28; Chicago, IL, USA).

Open comments were transcribed and translated to English in full and underwent content analysis. Results were compiled per sample and cluster to aid in the interpretation of associations between the characteristics of participants, the descriptive and evaluative attributes they used to qualify the products being tested and differences in patterns of product liking.

3 Results

Participant characteristics

Table 2 presents the descriptive statistics of the responses to the online questionnaire, thereby offering a summary of the characteristics of participants. Given recruitment quotas, exactly half of participants were women and only about one-third were older than 30 years. The majority (61%) fell in the healthy weight range, albeit a couple of extreme values registered in the highest BMI class (high risk of obesity). Nearly 80% completed a higher education degree (undergraduate, master or PhD) and were employed. Due to screening criteria, participants were regular consumers of red meat dinners at home, with beef or veal being eaten slightly more often (Median = Twice a week) than pork or piglet (Median = Once a week). The majority (ca. 72 %) had heard about edible insects but had never tried them. The distributions of the mean scores of psychometric measures indicate that while a moderate to high level of Healthy Eating Consciousness predominated, participants' levels of Food Neophobia and Food Disgust Sensitivity were generally low.

Product liking

Overall liking ratings (Figure 2) differed significantly between the samples of Bolognese-type pasta sauces evaluated (see Supplementary Table S3 for tabulated values and statistical test results). The median varied between 4.0 (*Dislike slightly*) for Mealworm Mince and 7.0 (*Like moderately*) for Beef Bolognese Sauce, Soya Spice Mix and Pea Mince. Ratings were less dispersed in Beef Bolognese Sauce and Soya Spice Mix than in other samples, indicating higher inter-individual agreement for most liked samples only. Still, ratings of Soya Spice Mix were recorded for the entire range of hedonic scale categories, this being the only sample with (lower) extreme values.

Liking of Mealworm Mince was significantly lower than that of Cricket Pasta Sauce or Cricket Spice Mix.

TABLE 2 Descriptive statistics of online questionnaire responses (N = 130)

Variable	*n*	%
Age (years)		
18-20	2	1.5
21-25	28	21.5
26-30	54	41.5
31-35	36	27.7
36-40	10	7.7
Mean [95% CI] = 29.0 [28.2-29.7]		
Sex		
Female	65	50.0
Male	65	50.0
Body Mass Index (kg/m^2)		
<18.5	2	1.5
18.5-24.9	79	60.8
25.0-29.9	39	30.0
30.0-34.9	4	3.1
35.0-39.9	4	3.1
≥40.0	2	1.5
Mean [95% CI] = 24.5 [23.7-25.3]		
Higher education		
No	27	20.8
Yes	103	79.2
Employment		
Employed	102	78.5
Unemployed	3	2.3
Student	25	19.2
Beef consumption (nr. of dinners at home with beef or veal per week)		
Less than two	61	47.0
Two	35	26.9
Three or more	34	26.1
Pork consumption (nr. of dinners at home with pork or suckling pig per week)		
Less than two	72	55.4
Two	27	20.8
Three or more	31	23.8
Familiarity with Edible Insects		
Never heard about it, or tried it	98	75.4
Have tried it	32	24.6
Healthy Eating Consciousness[1] (4 items, Cronbach's alpha = 0.79)	38	29.2
Lower Quartile = 3.0	29	22.3
Median = 3.5	47	36.2
Upper Quartile = 4.0	16	12.3
Mean [95% CI] = 3.5 [3.3-3.6]		
Food Neophobia[1] (10 items, Cronbach's alpha = 0.89)	33	25.4
Lower Quartile = 1.7	42	32.3

TABLE 2 (Continued)

Variable	*n*	%
Median = 2.2	28	21.5
Upper Quartile = 2.6	27	20.8
Mean [95% CI] = 2.2 [2.1-2.3]		
Food Disgust Sensitivity[2] (8 items, Cronbach's alpha = 0.77)	42	32.3
Lower Quartile = 1.8	33	25.4
Median = 2.1	23	17.7
Upper Quartile = 2.6	32	24.6
Mean [95% CI] = 2.2 [2.1-2.3]		

CI = Confidence Interval. [1]5-point Likert-type scale; 1 = *Totally disagree*; 3 = *Neither agree nor disagree*; 5 = *Totally agree*; higher values indicate higher mean healthy eating consciousness or food neophobia scores. [2]5-point bipolar rating scale (1 = *Not disgusting at all*, 3 = *Somewhat disgusting*, 5 = *Extremely disgusting*); higher ratings indicate higher mean food disgust sensitivity scores.

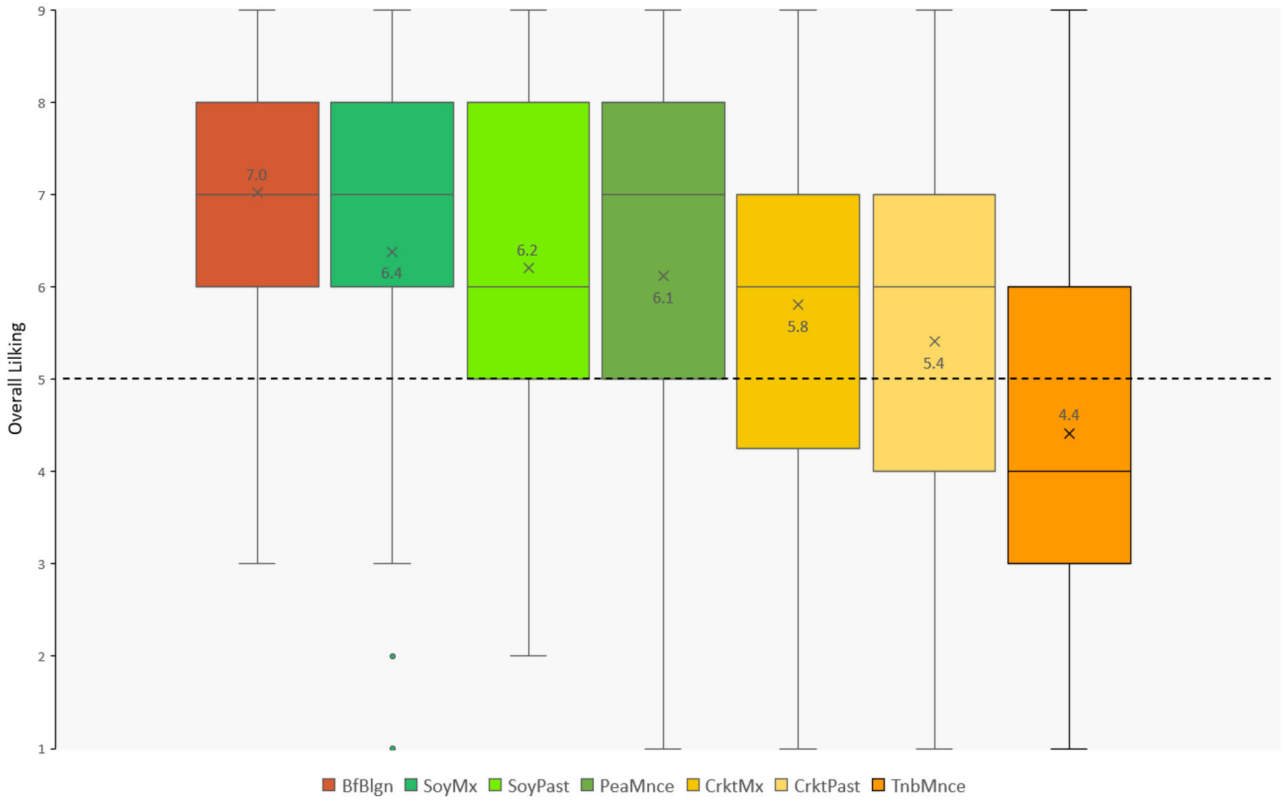

FIGURE 2 Sample overall liking ratings (N = 130). The distribution of ratings differs significantly between samples (Friedman's test, Chi-Square (6) = 152.973, P < 0.001).

Cricket-based samples were however similarly liked. All insect-based sauces were significantly less liked than Beef Bolognese Sauce, particularly Mealworm Mince. The latter was also significantly less liked than all plant-based sauces, as was Cricket Pasta Sauce. Still, liking of Cricket Spice Mix was not significantly different from that of Soya Spice Mix, being also similar to Soya Pasta Sauce and Pea Mince. There were also no significant differences in the liking of plant-based sauces. Finally, Beef Bolognese Sauce was significantly more liked than either Soya Pasta Sauce or Pea Mince, but not Soya Spice Mix. Altogether, the distributions of overall liking ratings indicated that, in addition to sample differences, a high degree of heterogeneity in participants' sensory preferences underlay variations in product evaluation.

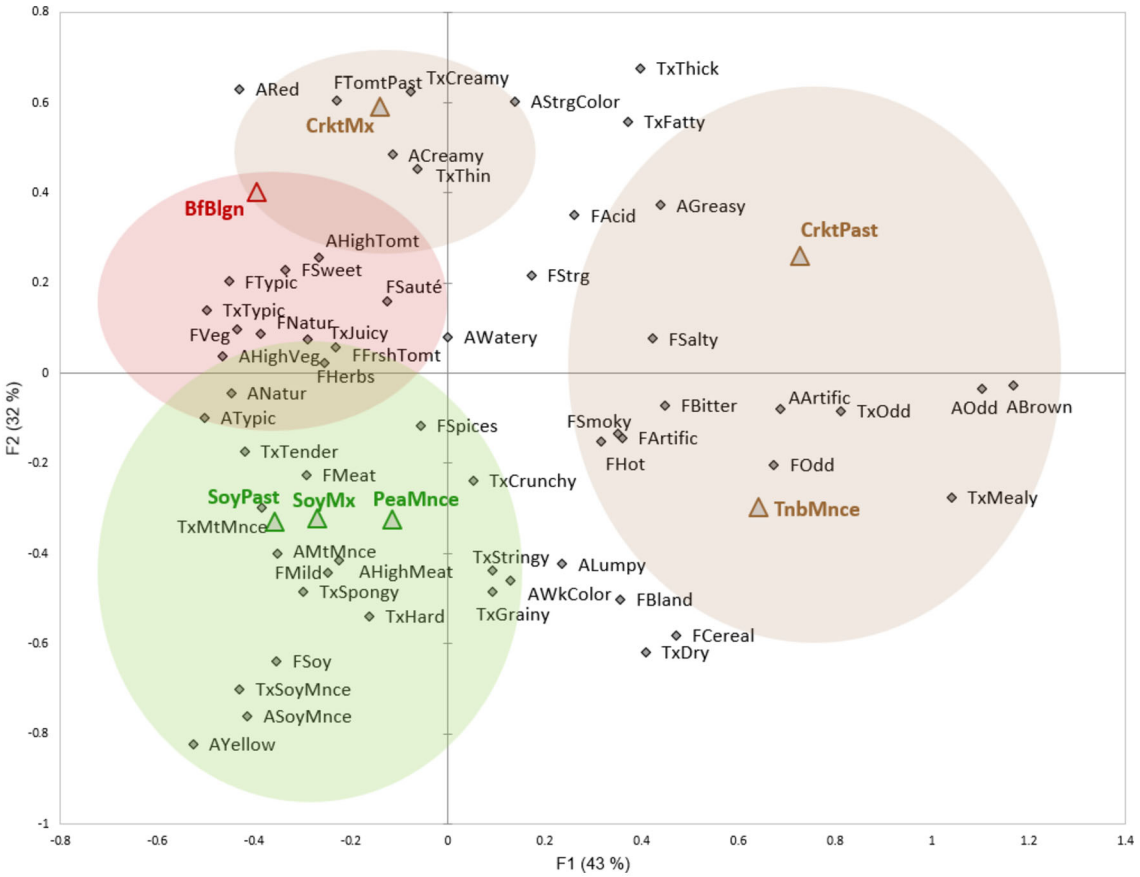

FIGURE 3 CATA terms and sample configuration space obtained by Correspondence Analysis (symmetric plot of first two dimensions: F1, F2) (N = 128).

Descriptive and evaluative attributes of products

The frequencies of elicitation of CATA terms differed significantly from each other across samples (Cochran's Q test, Critical Value Chi-Square (336) = 379.746, Adj. $p < 0.0001$), except in the case of *TxCrunchy* (Adj. $p = 0.087$). The results of multiple pairwise comparisons of attributes between samples are provided in Supplementary Table S4. Figure 3 presents the results of the Correspondence Analysis (sample – CATA term space) undertaken. Six dimensions were extracted, with the two with the highest Eigen value combined explaining 74.8% of total variance.

Both descriptive (related to appearance and flavour) and evaluative (related to naturalness and typicality) terms were strongly associated with the first dimension, thereby greatly discriminating the Cricket Paste and the Mealworm Mince from all other samples. Regarding this dimension, the appearance of these insect-based sauces was most often qualified as 'brown', 'odd' and to some extent also 'artificial'; similarly, their flavour was mainly characterized as 'odd'. On the other hand, both the appearance and the flavour of Cricket Spice Mix and Beef Bolognese Sauce were most often described by terms associated with tomato, namely 'high in tomato' and 'red', and 'tomato paste', respectively. Being 'high in tomato' also characterized the appearance of Soya Spice Mix to some extent, while 'strong colour' discriminated the meat- and cricket-based sauces from plant-based samples and Mealworm Mince. Moreover, both the meat- and soy-based sauces were more often characterized as 'typic' in appearance than all other samples. The flavours of Beef Bolognese Sauce, Pea Mince and, to a lesser extent, Soya Pasta Sauce were likewise much more frequently described as 'natural' than other samples. The terms 'typic' and 'sweet', however, were significantly more often linked to the flavour of Beef Bolognese Sauce than all other samples, with the notable exception of Pea Mince in the latter case.

The terms most closely related to the second dimension were visual and tactile product characteristics linked to perceived texture. Namely, texture CATA terms 'odd', 'mealy', 'grainy' as well as appearance term 'lumpy' strongly discriminated Mealworm mince from other samples, especially Beef Bolognese Sauce and Cricket Spice Mix. An 'odd' texture was also often attributed to Cricket Pasta Sauce, while 'grainy' texture and 'lumpy'

appearance likewise frequently characterized the Soya Spice Mix. On the contrary, these terms were much rarely used to characterize the texture of Beef Bolognese Sauce, which was much more often described as 'typic' in this product than in other sauces. Finally, the texture term 'spongy' was more commonly associated with Pea Mince than with the rest of the samples.

The mouthfeel terms 'creamy' and 'thick' were most often associated to meat- and cricket-based sauces, setting in this respect their texture well apart from that of plant-based sauces and Mealworm Mince. A 'greasy' appearance and 'fatty' mouthfeel were texture terms more commonly used to describe Cricket Pasta Sauce and Beef Bolognese Sauce than Cricket Spice Mix, nonetheless. Importantly, 'meat mince' appearance and texture qualified both meat- and soy-based samples more often than the remainder, especially cricket-based sauces.

Two opposing flavour CATA terms – 'spices' and 'mild' – set the plant-based sauces Soya Spice Mix and Pea Mince apart from each other and the rest of the samples. Other sensory attributes differentiating plant-based sauces from meat- and insect-based samples related to their vegetable composition, i.e., 'high in vegetables' and 'soy mince' appearance, 'soy' flavour and 'soy mince' texture. Noticeably, the term 'strong' was much more often used to characterize the flavour of Soya Spice Mix and cricket-based sauces than all other samples. Conversely, the flavour term 'fresh tomato' was significantly less often attributed to Cricket Pasta Sauce.

Associations of descriptive and evaluative attributes with product liking

The results of the Principal Coordinates Analysis are presented in Figure 4. The scree plot indicated that the two first dimensions were sufficient to interpret the relationships between attributes, and between attributes and overall liking ratings. The first dimension discriminated the set of terms with the strongest positive correlations with overall liking from those with the strongest negative correlations. The former were mainly attributes related to the flavour and texture of both traditional Bolognese recipes and red meat – *FNatur*, *FHerbs*, *FSauté*, *FMeat*, *TxTender*, *TxJuicy* [0.284; 0.250]. These were more often used by participants to describe Beef Bolognese Sauce, all plant-based samples and, to some extent, Cricket Spice Mix. Such overlapping in the perceived sensory profiles of these samples explains the general lack of significant differences observed in their liking (Figure 2). The latter were primarily evaluative terms describing the unusualness, unexpectedness, strangeness or unpleasantness of the sensations experienced while assessing some of the insect-based samples, particularly Mealworm Mince and Cricket Pasta Sauce, as well as their 'unnaturalness' – *FOdd*, *TOdd*, *FBitter*, *AOdd*, *AArtific*, *FArtific*, *TMealy* [–0.533; –0.277].

The second dimension discriminated terms denoting a nuanced perception of the impact of the samples' main ingredients on their sensory profiles. Attributes related to colour (red and more intense from tomato vs yellow and less intense from soya vs brown from cricket paste) and flavour (stronger from tomato paste and spices vs mild from fresh tomato and vegetables vs bland and cereal from soya protein or mealworm flour) were linked to the higher liking of Beef Bolognese and dry spice mixes. Yet, attributes related to texture were detrimental to the appreciation of ready-made sauces and minces (e.g., greasy appearance, fatty and thick mouthfeel related to Cricket Pasta Sauce and its strong, distinct flavour; lumpy appearance, dry, grainy and stringy mouthfeel linked to Mealworm and Pea minces; the spongy, soy-mince, chewy character of plant-based sauces).

Individual preferences underlying patterns of product liking

The Two-Step Cluster Analysis performed on dimension regression scores resulted in a four-cluster solution with fair quality (average silhouette = 0.40) as the most parsimonious model with the best fit, determined by the highest change in Schwarz's Bayesian Criterion from a smaller solution. Figure 5 plots the means [95% CI] of overall liking ratings of samples per cluster of study participants (see Supplementary Table S5 for values and statistical test results). Participants' overall liking of Pea Mince differed widely across clusters, ranging from ratings of 2.0 (*Dislike very much*) in the smallest cluster to 8.0 (*Like very much*) in the second largest one. Overall liking ratings of Cricket Spice Mix and Soya Spice Mix also varied to a fair extent. Meanwhile, overall liking of Mealworm Mince, Cricket Pasta Sauce and Soya Pasta Sauce differed the least. Finally, overall liking of Bolognese Sauce was significantly lower in one of the clusters extracted.

The largest cluster obtained comprised the 30.0% of participants that, on average, not only did not dislike any of the Bolognese-type pasta sauces tested, but also liked most of them moderately to very much. This was therefore also the group with the lowest variation in liking between samples. Consequently, it was named *All Bolognese Likers*. The second largest cluster was similarly big (27.7% of participants) and grouped mostly

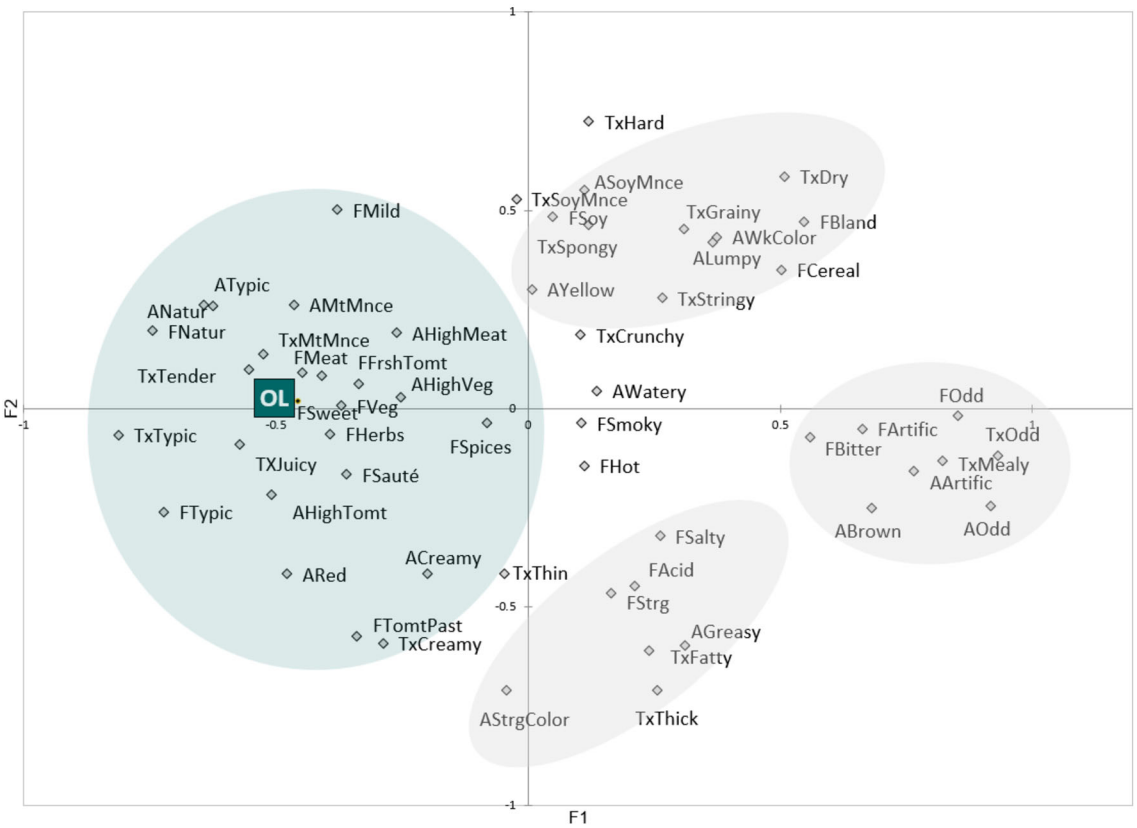

FIGURE 4 CATA terms and overall liking space configuration obtained by Principal Coordinates Analysis (plot of first two dimensions: F1, F2, OL = Overall Liking) (N = 128).

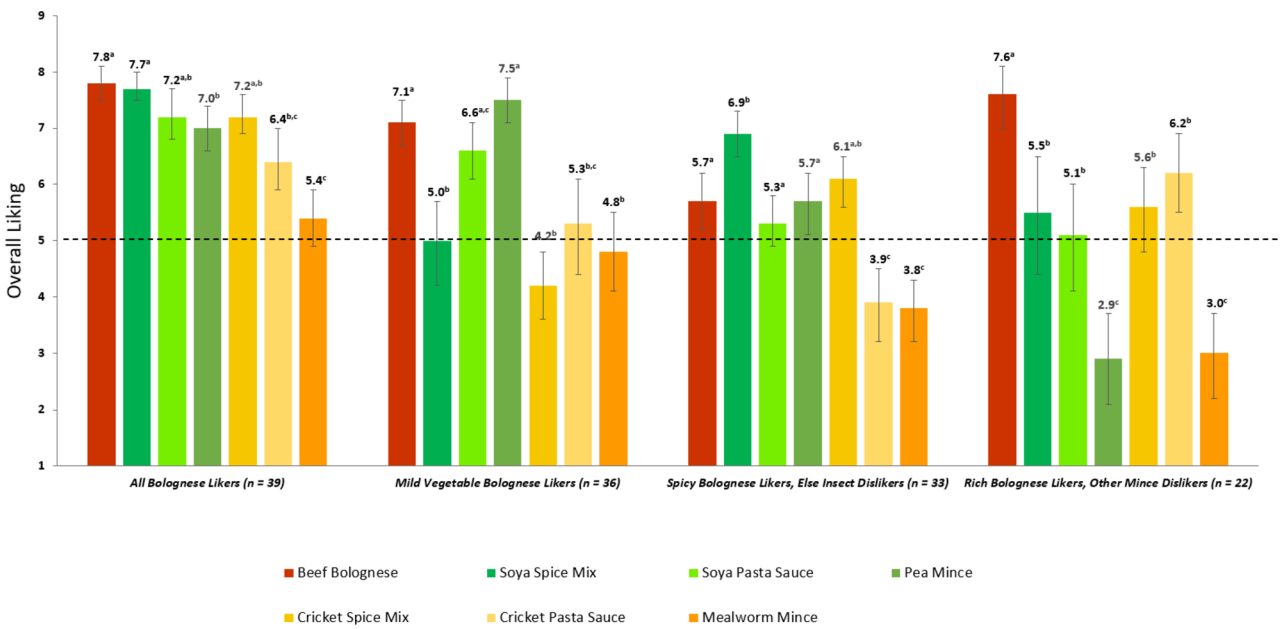

FIGURE 5 Means [95%CI] of overall liking ratings of samples (9-point hedonic scale) per cluster of participants (N = 130). Different lowercase letters in superscript indicate a significant difference ($P < 0.05$) in the means of ratings within clusters.

those individuals that, together with *All Bolognese Likers*, appreciated Pea Mince and Soya Pasta Sauce the most. Contrary to these, however, they disliked (slightly to moderately) both Soya and Cricket Spice mixes. At the same time, they similarly liked other insect-based sauces better than the remaining participants. The second cluster was therefore labelled *Mild Vegetable Bolognese Likers*. The third cluster also encompassed a good

proportion of the participants (25.4%), namely those generally liking both the Soya Spice Mix and the Cricket Spice Mix the most, and the other insect-based sauces as well as Beef Bolognese Sauce the least. Considering these preferences, the third cluster was labelled *Spicy Bolognese Likers*, *Else Insect Dislikers*. Lastly, the fourth and smallest cluster comprised the nearly 16.9% of participants that appreciated both Beef Bolognese Sauce and Cricket Pasta Sauce more than individuals classified in the third cluster, albeit not more than those in the first two clusters. What ended up distinguishing them the most from the remainder was their much higher dislike of the Pea Mince and, to a lesser extent, Mealworm Mince. Bearing this in mind, along with the results of the sensory profiling of samples, the fourth cluster was named *Rich Bolognese Likers*, *Other Mince Dislikers*.

Impact of descriptive and evaluative attributes on product liking per cluster of participants

Figure 6A-D present the descriptive and evaluative attributes with significant mean positive and negative impact on the overall liking of samples in each cluster of participants, identified by Penalty Analysis. These terms are likewise indicated in green and orange, respectively, in Figures 7A-D, which depict the space configurations of CATA terms and overall liking obtained by Principal Coordinates Analysis for each cluster.

All Bolognese Likers had the highest number of attributes with significant impact on overall liking ratings (15) as well as the highest proportion of those being descriptive (87.0%) and having a positive penalty lift (87.0%) (Figure 6A). Sensory terms related to the appearance and texture of red meat mince as well as those linked to the appearance of a tomato sauce had the strongest positive impact on overall liking in this cluster. Attributes prototypically associated to the flavour profile of a Bolognese-style pasta sauce also positively impacted liking, albeit less strongly. All these descriptors were broadly used by *All Bolognese Likers* to describe the sensory qualities of Beef Bolognese, Soya Spice Mix, Soya Pasta Sauce and Cricket Spice Mix. Such overlapping in the perceived sensory profiles of these samples explains the general lack of significant differences in their liking within this cluster. Meanwhile, only two sensory terms had a significant negative penalty lift, both being related to the appearance of samples. The strongest negative impact was registered for appearance term *Brown*, an attribute that strongly discriminated both the profile and the liking of Cricket Pasta Sauce and, to some extent, Mealworm Mince from the rest of the samples. The appearance term *Lumpy* essentially discriminated Pea Mince and Mealworm Mince from other samples. Figure 7A shows three groups of CATA attributes with negative associations with overall liking ratings in this cluster (clockwise): one comprising terms depreciative of the sensory profile of plant-based sauces, another containing terms penalizing the liking of Mealworm Mince and a final grouping terms often used to the describe Cricket Pasta Sauce.

Mild Vegetable Bolognese Likers had the second highest proportion of attributes being descriptive (77.0%) and having a positive penalty lift (69.0%). Terms related to the texture of red meat mince and sauce creaminess had the strongest positive impact on overall liking in this cluster, along with an evaluative descriptor of sauce appearance, *Natural*. Attributes prototypical of a tomato pasta sauce also had a positive impact on liking. On the other hand, the evaluative terms referring to odd flavour and texture had the strongest negative impacts. Noticeably, this was the only cluster where the flavour attribute *Strong* had a significant negative penalty lift. This and several other flavour and mouthfeel attributes penalizing indiscriminately the liking of Soya Spice Mix, Cricket Spice Mix and Cricket Pasta Sauce formed one of three groups of CATA attributes visible in Figure 7B (counterclockwise). A second group comprised descriptive and evaluative terms penalizing Mealworm Mince while a third one contained sensory terms used in this cluster to describe Pea Mince and Soya Pasta Sauce, two of the samples with the highest mean overall liking ratings.

Spicy Bolognese Likers, *Else Insect Dislikers* had the highest proportion of attributes being evaluative (31.0%) and the second highest having a negative penalty lift (38%). This was the only group where an evaluative attribute, characterizing appearance (*Natural*), had the strongest positive impact on liking. After that, appearance attributes characteristic of the main ingredients of a Bolognese-style sauce (*Meat Mince*, *Red*, *High Tomato*) had the highest positive penalty lifts, as well as flavour attributes. Attributes characterizing the texture of meat mince also had a positive impact on liking. Moreover, this was the group where the evaluative terms referring to the oddness of the sensory profile of samples had the strongest negative impact. Along with flavour and mouthfeel terms severely penalizing the appreciation of Mealworm Mince, these formed one of the four groups of CATA attributes visible in Figure 7C. The appearance attribute *Lumpy* and the mouthfeel attribute *Pasty* also exhibited significant negative penalty lifts. The former (clockwise) formed a second

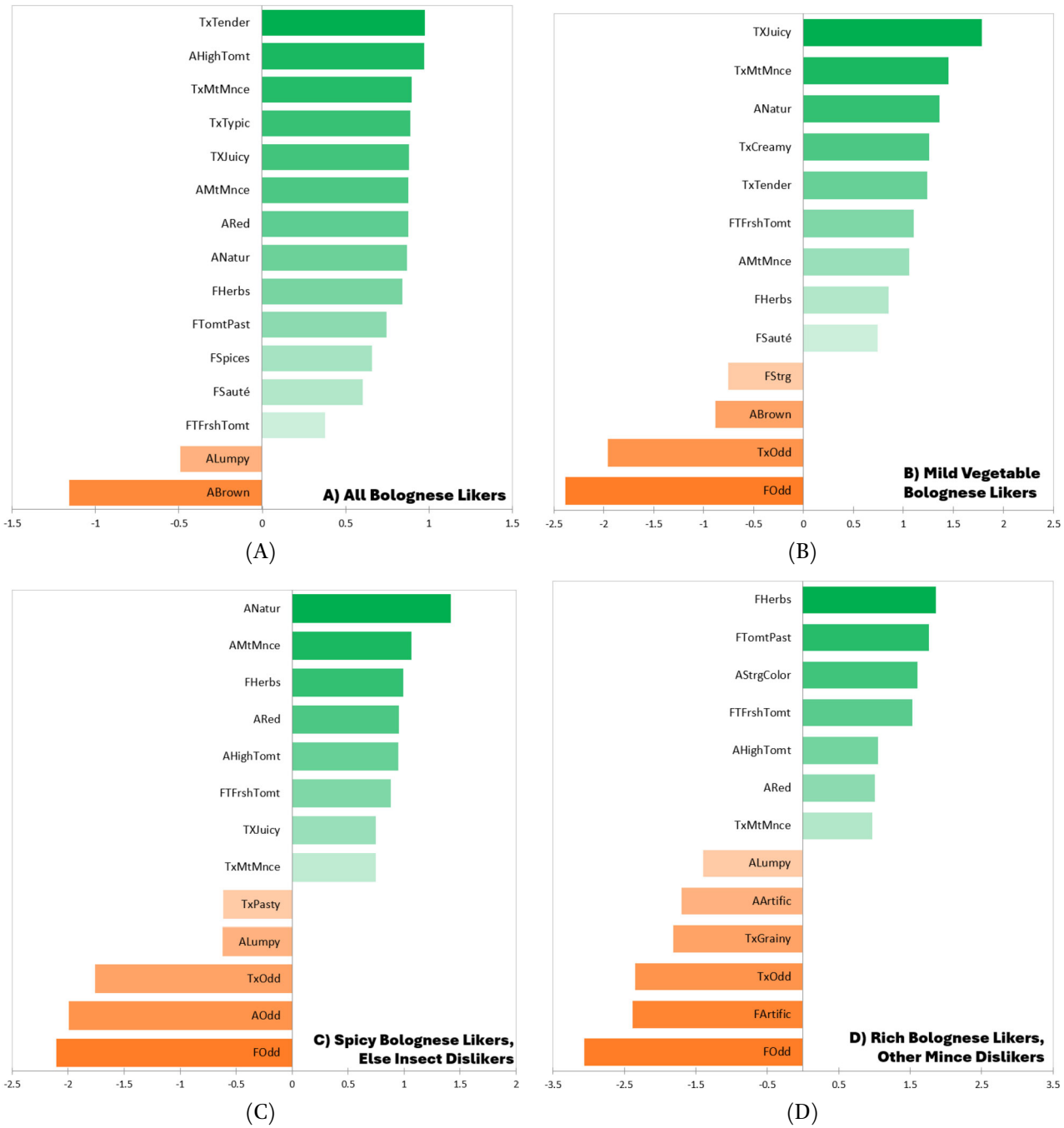

FIGURE 6 (A-D) Positive and negative penalty lifts of CATA terms with significant ($P < 0.05$) mean impact on overall liking per cluster of participants (NA = 39, NB = 36, NC = 33, ND = 22).

group with other sensory descriptors discriminating Pea Mince and, to a lesser extent, Soya Pasta Sauce, from the remaining samples; the latter (counterclockwise) formed a third group along sensory terms used to characterize Cricket Pasta Sauce. A third group contained the sensory attributes used in this cluster to profile the two samples with the highest mean overall liking ratings: Soya Spice Mix and Cricket Spice Mix.

Rich Bolognese Likers, Other Mince Dislikers had the highest proportion of attributes being evaluative (31.0%) and having a negative penalty lift (46%). However, they were the only group where evaluative descriptors did not have positive penalty lifts. They were also the only group where attributes describing flavour were among those with the strongest impact on liking, followed by attributes characterizing colour, particularly its intensity. These attributes were used by the participants in this cluster to describe the sample they preferred the most, Beef Bolognese. Moreover, sensory terms related to the prototypical composition

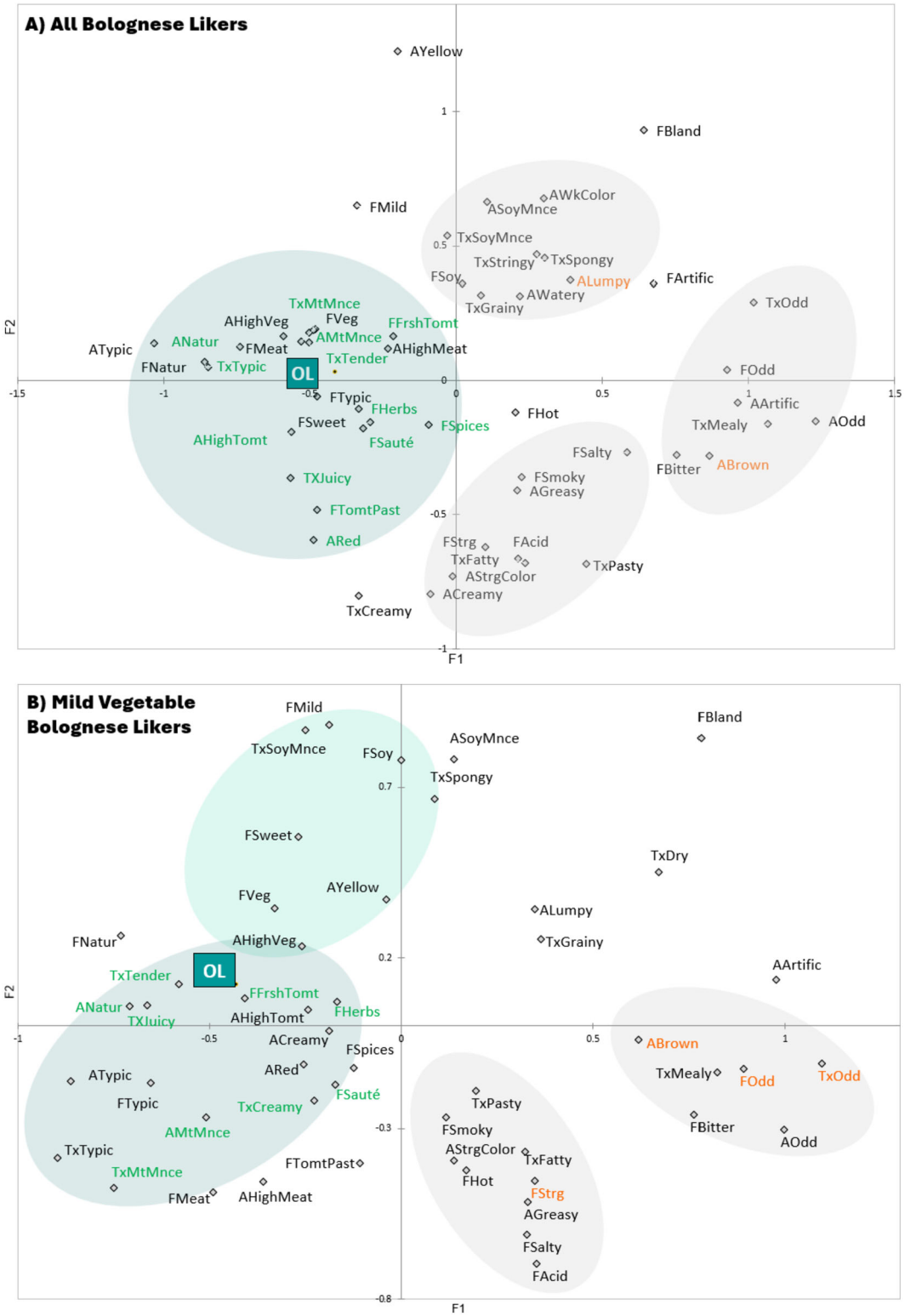

FIGURE 7 (A-D) CATA terms and overall liking space configurations obtained by Principal Coordinates Analysis for each cluster of participants (plot of first two dimensions: F1, F2, OL = Overall Liking) (NA = 39, NB = 36, NC = 33, ND = 22). Green/Orange denotes terms with significant positive/negative mean impact on overall liking.

of a tomato pasta sauce predominated among the attributes with positive penalty lifts, and likely had a positive impact on the appreciation of the second most liked sample, Cricket Pasta Sauce. One attribute referring to meat mince texture also positively impacted on liking, although less strongly. Flavour, texture and appearance sensory descriptors highly detrimental to the appreciation of Pea Mince and Mealworm Mince,

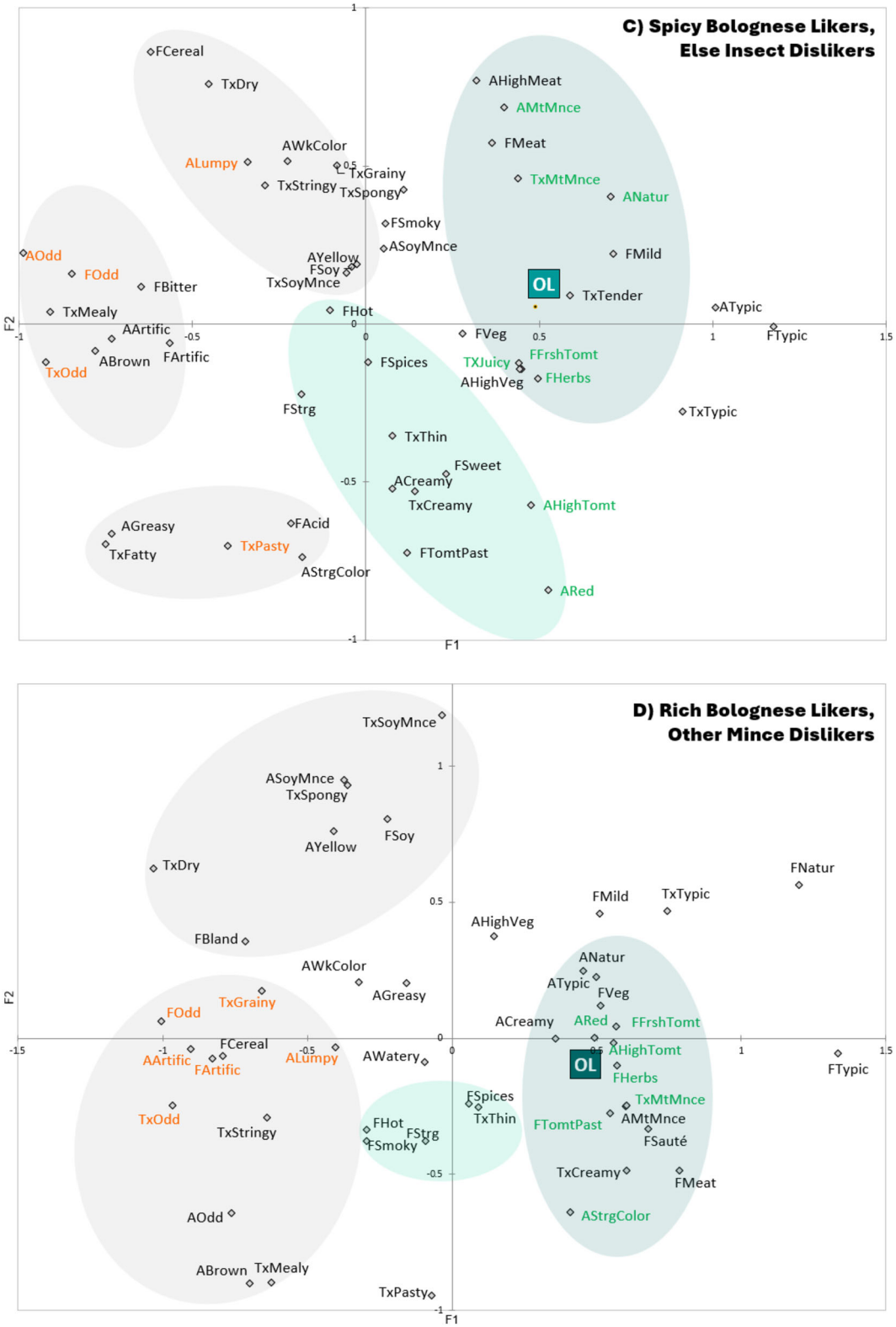

FIGURE 7 (Continued.)

along with evaluative terms referring to their artificial flavour and appearance formed one of the four groups of CATA attributes visible in Figure 7D. A second group (clockwise) comprised descriptive terms penalizing Soya Pasta Sauce and, to a lesser extent, Soya Spice Mix, while a third one (counterclockwise) contained sensory terms used in this cluster to describe Cricket

Spice Mix and Cricket Pasta Sauce, two of the samples with the highest mean overall liking ratings.

Comments per cluster of participants

Over one third of participants (36.7%) commented freely on the products they had evaluated. *All Bolognese Likers* offered only positive comments on the broad set of samples they had appreciated, across all sensory modalities. Positive or neutral (descriptive) remarks were also made specifically about the spices ('curry', 'saffron') and the spicy/hot sensations characterizing the flavour profiles of both sauces made from dry mixes. Opinions were rather more divided, however, on the sensory profile and enjoyment of Pea Mince and Cricket Pasta Sauce. *All Bolognese Likers* readily (and erroneously) identified Pea Mince as being soy-based, but while some acknowledged and liked its mince-like appearance and flavour, others made negative remarks regarding its flavour and texture qualities. Likewise, there seemed to be little agreement on the characterization, intensity and agreeableness of the flavour of Cricket Pasta Sauce, as well as on the pleasantness of its mouthfeel. Agreement was nonetheless high regarding the negative appreciation of Mealworm Mince, particularly in what respected its unappealing appearance and unpleasant flavour profile.

Meanwhile, the positive comments made by *Mild Vegetable Bolognese Likers* were sparse and concentrated on the three samples with the highest mean overall liking in this cluster: Pea Mince, Beef Bolognese Sauce and Soya Pasta Sauce. Remarkably, participants in this group nearly always compared the appearance and flavour of these samples with those of meat, or of meat- versus plant-based sauces, with positive appreciation increasing with similarity to the reference categories as well as with a generic hedonic preference for plant-based meat alternatives. This also applies, to some extent, to the comments made about Soya Spice Mix. Nevertheless, due to judgements of a too intense and rather spicy ('cumin', 'hot') flavour, combined with a grainy texture attributed to soya, comments about this sample were generally negative. Convergence in opinions regarding other (less liked) samples was likewise high, both in terms of lack of appreciation and reasons thereof. Cricket Spice Mix was criticised due to the perception of a rather strong, overpowering tomato/tomato paste flavour and, to a lesser extent, of a chunky, soy-like appearance and texture. Mealworm Mince, albeit praised for its meat-like appearance, was judged to have a rather odd, intense and spicy/hot flavour as well as an unpleasantly grainy, mealy and dry texture. Overconcentrated flavour, odd creaminess and mealy texture were the sensory attributes penalizing appreciations of the Cricket Pasta Sauce, with some members of this cluster remarking on their strong distaste and flat-out rejection of this sample.

Comments by *Spicy Bolognese Likers*, *Else Insect Dislikers* were much more often descriptive than appreciative of the sensory profiles of samples. They focused on the taste and texture of the products being evaluated, particularly on the similarities and differences of the main protein relative to pork or beef, as well as on the flavour profile of the sauces compared to those of traditional Bolognese recipes cooked at home. This comparison is likely to have made some members of this cluster be less appreciative of Beef Bolognese Sauce than Soya Pasta Sauce or Pea Mince, as a few commented to find that sample rather plain and bland in taste, and hence seemed to infer that it did not contain meat. On the other hand, how well plant-based samples were able to mimic the texture of meat appeared to be both acknowledged and appreciated, particularly in the case of Soya Spice Mix. Furthermore, the lack of resemblance of the main protein to either meat or soy appeared to be strongly detrimental of the appreciation of Mealworm Mince and especially of Cricket Pasta Sauce. This was likely the reason why these samples were generally much more disliked in this group than in the remainder. Regarding Mealworm Mince, comments focused on the negative experiences associated to a strange and unfamiliar taste as well as texture. They also often referred to the odd, unnatural and unappealing colour and thick consistency of the Cricket Pasta Sauce. These characteristics prompted aversion to tasting this sample and triggered expectations of poor flavour and texture. Even when such expectations were to some extent disconfirmed, this seemed insufficient to overcome the lack of familiarity of the sensations experienced and the unpleasantness associated to them. Meanwhile, richness and depth of flavour, 'smoky' flavour notes and spicy/hot sensations were attributes qualifying favourably the sauces made from the dry spice mixes. These opinions were likely contributing to the high mean liking ratings of Soya and Cricket Spice Mix registered in this group, particularly when contrasted with the evaluations of *Mild Vegetable Bolognese Likers*.

Comments by *Rich Bolognese Likers*, *Other Mince Dislikers* were predominantly evaluative (rather than descriptive) of the appearance and flavour of samples, particularly of the level of congruence between these modalities. Accordingly, some moderately appreciative

opinions about the flavour of Beef Bolognese Sauce and Cricket Pasta Sauce stemmed from positive disconfirmation of expectations based on initial perceptions of poor appearance (plant-based character, erroneously attributed, and odd colour, respectively). On the other hand, remarks made about Soya Pasta Sauce reflected some disappointment regarding the blandness and lack of appeal of the flavour of this sample in view of its attractive appearance and visual resemblance to a conventional Bolognese sauce. Meanwhile, comments regarding similarity to the prototypical flavour and texture of a Bolognese sauce, or rather the lack of it – namely in what respected sweetness, saltiness and tomato flavour intensity, meat flavour, mild spiciness, herb seasonings and meat/mince texture –, were made indiscriminately about meat-, plant- and insect-based samples. Still, remarks concerning lack of flavour, lack of salt and herb seasoning, strong and atypical flavour, and odd texture were made specifically about Pea Mince, Mealworm Mince and Soya Pasta Sauce, the samples with lower mean liking ratings. Noticeably, the mean ratings of both mince-like samples were significantly lower in this group than in the remainder. Comments per sample and pattern of product liking are provided *verbatim* in Supplementary Table S6.

Individual differences associated to patterns of product liking

There were significant associations between cluster membership and gender as well as level of education. Post-hoc test results indicated that the proportion of males was significantly higher in *Spicy Bolognese Likers*, *Else Insect Dislikers* (73%) than in other clusters (41-44%), while the proportion of participants with higher education (64%) was significantly lower (75-91%). There were nevertheless no significant associations between cluster membership and Beef Consumption, Pork Consumption or Familiarity with Edible Insects. Moreover, the means of age and BMI did not differ significantly between clusters.

Table 3 presents the results of the multinomial logistic regression model predicting cluster membership from Healthy Eating Consciousness, Food Neophobia and Food Disgust Sensitivity, after adjustment for Sex, Education Level and Beef Consumption. The fit between the model containing only the intercept and data improved with the addition of hypothesized predictors [Chi-Square$_{(21,\,N\,=\,130)}$ = 47.18, p < 0.001, Nagelkerke R-Square = 0.33] and relative to the unadjusted model [Chi-Square$_{(21,\,N\,=\,130)}$ = 19.61, p = 0.021, Nagelkerke R-Square = 0.15].

Lower Healthy Eating Consciousness significantly increased participants' likelihood of being *Rich Bolognese Likers*, *Mince Dislikers* instead of *All Bolognese Likers*; similarly, it marginally increased the likelihood of being *Spicy Bolognese Likers*. Meanwhile, no significant association was observed between Food Neophobia and cluster membership. However, higher Food Disgust Sensitivity significantly increased participants' odds of being *Mild Vegetable Bolognese Likers* instead of *All Bolognese Likers*; likewise, it significantly increased their chance of being *Rich Bolognese Likers*, *Mince Dislikers*. There was also a significant association between the frequency of eating beef dinners at home and cluster membership. Namely, being in the average or lower beef consumption frequency categories (compared to being in the highest) decreased participants' chance of being *Mild Vegetable Bolognese Likers* instead of *All Bolognese Likers*. Lastly, having higher education and, to some extent, being female marginally decreased the odds of participants' being *Spicy Bolognese Likers*, *Else Insect Dislikers* instead of *All Bolognese Likers*.

4 Discussion

Nearly all samples were liked slightly to moderately by consumers

Beef Bolognese Sauce and Soya Spice Mix were the samples preferred by most participants. These findings support prior research on the acceptance of reformulations of traditional meat dishes using protein derived from plants and/or fungi (Cordelle, Redl and Schlich, 2022; Elzerman *et al*., 2011; Spencer *et al*., 2021), pointing out that some meat-free recipes may reach levels of liking comparable to their meat-based counterparts and in sizeable consumer segments. Meanwhile, the liking of Cricket Spice Mix was, on average, no different from that of Soya Spice Mix, Pea Mince, or Soya Pasta Sauce, nor of Cricket Pasta Sauce. Studies investigating the acceptance of hybrid burger patties (Caparros Megido *et al*., 2016; Caputo, Sogari and Van Loo, 2023; Grasso *et al*., 2022; Smetana *et al*., 2021) and sausages (Neville *et al*., 2017) found that the partial replacement of red meat with plant and/or insect protein could create products with high levels of consumer liking. Yet, present study findings show that the full replacement of meat by either plant or insect protein can produce a similar outcome, provided, it seems, that an entire mixed dish is reformulated rather than a single meat product or meat component. This lends support to those advocating the reduction of red meat intake pri-

TABLE 3 Associations between participant characteristics and cluster membership (N = 130)

	Mild Vegetable Bolognese Likers (n = 36)			Spicy Bolognese Likers, Else Insect Dislikers (n = 33)			Rich Bolognese Likers, Other Mince Dislikers (n = 22)		
	Beta (SE)	Wald Chi-Square (P-value)	Odds Ratio (95% CI)	Beta (SE)	Wald Chi-Square (P-value)	Odds Ratio (95% CI)	Beta (SE)	Wald Chi-Square (P-value)	Odds Ratio (95% CI)
Intercept	−0.834	0.201	–	1.862	1.065	–	−0.915	0.210	–
	(1.863)	(0.654)		(1.805)	(0.302)		(1.999)	(0.647)	
Healthy Eating	0.001	0.000	1.001	−0.620	2.589	0.538	−0.966	**5.041****	0.380
	(0.393)	(0.997)	(0.463-2.165)	(0.385)	(0.108)	(0.253-1.145)	(0.430)	(0.025)	(0.164-0.884)
Food Neophobia	−0.0456	1.086	0.634	−0.108	0.057	0.898	0.291	0.326	1.337
	(0.437)	(0.297)	(0.269-1.494)	(0.454)	(0.812)	(0.369-2.184)	(0.509)	(0.568)	(0.493-3.627)
Food Disgust	1.097	**5.406****	2.994	0.422	0.786	1.526	1.190	**4.978****	3.288
Sensitivity	(0.472)	(0.020)	(1.188-7.547)	(0.477)	(0.375)	(0.600-3.882)	(0.534)	(0.026)	(1.156-9.357)
Beef Consumption									
Higher (ref.)									
Average	−1.216	**3.070***	0.297	−0.292	0.160	0.747	0.045	0.002	1.046
	(0.694)	(0.080)	(0.076-1.155)	(0.730)	(0.689)	(0.179-3.123)	(0.938)	(0.962)	(0.166-6.579)
Lower	−1.519	**5.929****	0.219	−0.672	0.998	0.511	0.560	0.449	1.751
	(0.624)	(0.015)	(0.064-0.744)	(0.672)	(0.318)	(0.137-1.907)	(0.836)	(0.503)	(0.340-9.003)
Sex									
Male (ref.)									
Female	0.280	0.293	1.323	−0.878	2.674	0.415	0.324	0.308	1.383
	(0.516)	(0.588)	(0.481-3.640)	(0.537)	(0.102)	(0.145-1.191)	(0.584)	(0.579)	(0.440-4.345)
Higher Education									
Yes (ref.)									
No	1.053	2.073	2.866	1.207	**2.992***	3.344	−0.808	0.623	0.446
	(0.731)	(0.150)	(0.684-12.016)	(0.698)	(0.084)	(0.852-13.133)	(1.023)	(0.430)	(0.060-3.312)
Nagelkerke R-square		0.33							
2-log likelihood intercept		307.8							
Chi-square (df = 21, N = 130)		47.18, P-value < 0.001							

SE = Standard Error; CI = Confidence Interval. Reference category for cluster is *All Bolognese Likers*. *P-value < 0.10; **P-value < 0.05.

marily through the integration of alternative protein sources as ingredients in familiar recipes that are part of regular household meals (Elzerman *et al.*, 2021; Maya *et al.*, 2022; Niimi *et al.*, 2022), rather than by increasing the offer of snack-like products.

That novel protein ingredients for cooked dishes should be readily identifiable with conventional meat products (e.g. mince, meatballs, strips) (Spencer, Cienfuegos and Guinard, 2018; Tan *et al.*, 2016), or that they should mimic the sensory characteristics of meat in mixed recipes as close as possible may not always be necessary, nonetheless (Cordelle, Redl and Schlich, 2022; Elzerman *et al.*, 2015). Indeed, participants in this study generally preferred sauces prepared from dry spice mixes (plant- or insect-based) to their ready-made or mince counterparts with a milder flavour, notwithstanding important differences being observed between clusters. This highlights the need to take individual preferences for the type of products and their sensory profiles into account when devising meat-replacement strategies, particularly when catering for consumers who may not necessarily like or want to eat foods that remind them of red meat (Elzerman *et al.*, 2015; Grasso *et al.*, 2022).

An unfavourable sensory profile led to the general dislike of Mealworm Mince

Mealworm Mince was the only sample disliked by most participants, being generally found to have poor appearance ('brown', 'odd', 'artificial', 'lumpy') and texture ('odd', 'mealy', 'grainy'), and to lack naturalness and familiarity. The replacement of meat by edible insect protein in the form of whole insect powder, especially of *T. molitor*, is often rather detrimental to the sensory quality and acceptability of processed foods (Schouteten *et al.*, 2016; Tan, Verbaan and Stieger, 2017), even at modest rates of substitution (~10%) (Choi *et al.*, 2017; Ho *et al.*, 2022b; Smarzyński *et al.*, 2019). In most cases, this type of reformulation results in end-products with poor appearance and texture characteristics (e.g. 'pale', 'brown', 'hard', 'dry', 'granular', 'gritty', 'fibrous, 'mushy'), being therefore generally disliked and rejected by consumers (Ribeiro, Lima and Cunha, 2024; Wallner *et al.*, 2023). The general dislike of Mealworm Mince was further enhanced by the negative evaluation of its flavour (e.g. 'odd', 'artificial'). The heat processing of foods containing whole insect powder can generate distinctive off-odours and flavours – described as 'musty', 'stale', 'bitter', 'mealy' and 'petfood-like' – that considerably lower the acceptance of meat analogues and hybrids. Others, more pleasant, but still rather uncharacteristic of meat, like 'nutty', 'cereal' or 'bread', may also be formed, heightening consumers' perceptions of the oddness or atypicality of products (Perez-Santaescolastica *et al.*, 2022; Ribeiro, Lima and Cunha, 2024). Several of these attributes were mentioned in the open comments about Mealworm Mince, likely because this sample was prepared with whole insect powder.

The addition of other ingredients and seasonings in the formulation of the insect-based mince (Stoops *et al.*, 2017) – to help mask any off-odours and flavours developing when heated (Gonzalez-Estanol *et al.*, 2023; Ho *et al.*, 2022a) – and its inclusion in a popular recipe for testing (Niimi *et al.*, 2022) were therefore not wholly successful in preventing the perception of unfavourable or uncharacteristic sensory qualities in this sample. A similar outcome was observed in a study of the liking of a Bolognese-style pasta sauce made with a mince mixing whole yellow mealworm flour, crushed green spelt grains and beetle bean meal (Wallner *et al.*, 2023). The use of defatted, hydrolysed or fermented insect fractions as ingredient, instead of whole powders, could improve the sensory quality of meat analogues and other insect-based foods further (Grossmann *et al.*, 2021; Ribeiro, Pintado and Cunha, 2024) – thereby increasing their acceptability and potential to replace red meat in human diets (Mishyna, Chen and Benjamin, 2020) – and warrants thus future investigation.

Disconfirmation of sensory-affective judgements of 'meatiness' and typicality affected consumer preferences

Being frequently associated to congruent, meat-related attributes – such as 'meat mince' appearance, and 'tender' and 'meat mince' texture – had a strong positive impact on overall liking ratings across samples. All these attributes were significantly associated to meat- and plant-based samples, but not insect-based ones. Displaying a prototypical texture, even more so than a traditional beef sauce (Figure 1), likely led to a high degree of assimilation of soya-based sauces to an ideal mince reference, thereby raising their liking relative to other samples, particularly in the case of Soya Spice Mix. Moreover, the impact of this first impression did not generally seem to be affected by the accurate identification of their plant origin. As exposure to soya-based products increases in Western markets with the boom of novel meat alternatives (Giacalone, Clausen and Jaeger, 2022), more research should be conducted on how this is affecting consumers' expectations about the texture of mince-like foods, including those made with actual mince. Results can offer important insights

for the sensory optimization of products using other plant sources or edible insect proteins to replace meat, with positive effects on their acceptance. Another meat-related attribute with a significant positive penalty lift, 'juicy', was much more often used by participants to quality the texture of meat- and plant-based sauces than insect-based ones, except for Cricket Spice Mix. Displaying this attribute likely improved both texture and flavour perceptions, being in part responsible for the higher preference of this sample compared to other insect-based sauces. Meanwhile, the frequency of associations of samples with the appearance term 'high meat', and especially with the flavour term 'meaty', was much less often used to qualify insect-based sauces. Yet, neither of these attributes had a significant impact on liking.

Overall, the findings of this study lend support to the contention that improving the appearance and texture of novel meat analogues and hybrids – whether insect- or plant-based – to deliver on expected meat-like qualities, will contribute to improve their liking (Neville *et al.*, 2017). Nevertheless, they also show that any gains in acceptance are likely contingent on matching their appearance and, most important, their gustatory sensory characteristics to at least some of the prototypical attributes of original recipes that are expected and appreciated by consumers. That these attributes must promote assimilation to a meat product, at least in any obvious way, may prove to be less and less necessary, as consumers' expectations of what meat products are, or ought to be – including what role they should play in different meals and meal settings – continue to evolve (Apostolidis and McLeay, 2016; Elzerman *et al.*, 2015). What sensory attributes should ultimately be the focus of refinement in the business of meat alternatives will therefore depend not only on the type of alternative protein being explored but also, and probably more critically, on the hedonic preferences and dietary choices of consumer segments being targeted. Irrespectively, what extant research shows is that these attributes do not necessarily have to be those typifying the experience of eating red meat, in every product and for every person, and that products attempting to imitate this highly idiosyncratic experience, but ultimately falling short of delivering it face a high risk of (sooner or later) being rejected by consumers.

As an example, using fresh frozen house cricket ground to a paste appears to have benefitted both the mouthfeel (creaminess, thickness, fattiness) and flavour (savouriness, concentration, balance) attributes of Cricket Pasta Sauce, thereby contributing to improve its liking relative to Mealworm Mince. Furthermore, by lacking the appearance of a beef mince and tomato sauce, particularly in terms of colour and texture – but still delivering on pleasant, meat-like sensations upon tasting – this sample likely gained from positive disconfirmation effects, reaching thus a much higher preference than Mealworm Mince in two clusters of participants – *Bolognese Likers* and *Rich Bolognese Likers*, *Mince Dislikers*. Cricket Pasta Sauce probably also benefitted from the negative disconfirmation effects penalizing the liking of samples with high visual resemblance (mince-like) to a traditional Bolognese sauce, but decisively non-meat qualities of flavour (e.g. bland, mild, weak) and texture (e.g. mealy, chunky, thin). These included not only Mealworm Mince, but also Pea Mince and Soya Pasta Sauce. These findings lend support to previous research showing that perceived incongruences between the anticipated and experienced sensory characteristics of plant-based pasta sauces, following from their presentation as Bolognese-style products, can result in disconfirmation effects and thereby motivate dislike (Niimi *et al.*, 2022).

Such effects contributed furthermore to explain the idiosyncratic preference of *Rich Bolognese Likers*, *Mince Dislikers* for either cricket-based sample over any plant-based sauce. Judging by their CATA evaluations, open comments and significantly higher mean overall liking of Beef Bolognese Sauce, their hedonic preferences were primarily driven by differences in the perceived savouriness (i.e. saltiness, tomato umami, spiciness, herbs) and richness (i.e. concentration, strong colour, energy density, thickness) of the sauces. These appeared to be the key sensory dimensions conferring more, or less similarity to the sensation of eating a prototypical meat Bolognese recipe among this group of participants, rather than appearance or texture. A study of the liking of hybrid beef burgers and sausage analogues – made with textured soya, mycoprotein, insect protein or pulses – compared to commercial meat-only products, found that the groups of consumers with a higher preference for the latter exhibited an equally higher positive penalty for the flavour attribute 'meaty' on overall liking, and had the lowest level of acceptance of plant-based alternatives (Neville *et al.*, 2017).

Overall, present findings suggest that the disconfirmation of sensory-affective expectations (Costa and Monteiro, 2018), particularly of the flavour and texture qualities inferred from appearance – in terms of both their pleasantness and similarity to red meat – can affect consumer preferences for meat alternatives, potentially lending an edge to certain insect-based

products over plant-based ones in some consumer segments. Avoiding resembling and hence being categorized as a mince-product, as was the case of Cricket Pasta Sauce, could further this advantage (Grasso *et al.*, 2022). This underscores the role played by formulation and processing in delivering enjoyable eating experiences from alternative protein foods, irrespectively of the origin of the protein (Tan, Verbaan and Stieger, 2017), not the least by shaping the expectations of consumers about how these products will perform against meat in terms of flavour and texture (Spencer and Guinard, 2018).

Sensory-mediated disgust decreased liking of some insect- and plant-based sauces

Several participants commented negatively on feeling the lingering presence of small, hard particles in the mouth after tasting Mealworm Mince or Cricket Pasta Sauce, with a few attributing this to pieces of 'shell', i.e. insect exoskeleton, being perceptible in these samples. Accordingly, texture terms 'odd', 'grainy' and 'mealy' had negative impact on overall liking ratings across samples (Figure 7A-D), affecting especially these two insect-based sauces. Similar results were found in previous studies of the sensory liking of edible insect foods (Ribeiro, Lima and Cunha, 2024), namely of products with (processed or unprocessed) house cricket (Barton, Richardson and McSweeney, 2020; Sogari, Menozzi and Mora, 2018). Grinding insects to smaller particles addresses this flaw that intensifies their distaste and consequently lowers their acceptance as an alternative source of protein (Deroy, Reade and Spence, 2015). At the same time, however, it increases particle surface area, which contributes to exacerbate off-flavours and the umami taste of house cricket products along with other processing parameters (Ribeiro, Pintado and Cunha, 2024). Determining optimal particle size in insect-based foods calls for further sensory research (Wendin, Olsson and Langton, 2019).

Much like in their descriptions of Mealworm Mince, participants also often characterized the appearance of Cricket Pasta Sauce as 'brown', 'odd' and 'artificial', as opposed to 'red', 'typic' and 'natural'. They likewise described its flavour and texture as 'odd'. Altogether, these were the CATA attributes with the strongest negative impact on liking (Figure 6A-D). Intense, pervasive and persistent sensations of aversive colour, odour, gustatory or texture qualities in foods trigger emotional responses of disgust in humans, particularly when they cannot be readily attributed to a known and appropriate origin (Tuorila and Hartmann, 2020). Disgust responses were shown to mediate the effects of anticipated and/or experienced aversive textural properties on liking and intake (Martins and Pliner, 2006), for instance, with this psychological process being more likely to impact the acceptance of unfamiliar foods of animal origin than familiar foods or those with plant origin (Dovey *et al.*, 2012; Gumussoy and Rogers, 2023). Accordingly, several participants referred to Cricket Pasta Sauce as having a "weird", "rather suspicious" and "funky" colour, a "strong", "bitter", "funny" and "unfamiliar" taste, as well as a "funny", "very weird" and "mealy" texture of undiscernible origin. These perceptions were exacerbated by the lingering presence of "hard particles" or "pieces" in the mouth, the origin of which some participants remarked they could not identify, while others putatively attributed to edible insects. Irrespectively, the resulting sensation was overall described as rather unpleasant or downright aversive. The same type of unfavourable remarks, especially concerning texture, were made about Mealworm Mince.

Lack of exposure to entomophagy and moderate to high levels of food neophobia are believed to be critical barriers to the acceptance of insect-based foods by European adults (Piha *et al.*, 2018; Sogari, Menozzi and Mora, 2019; Verbeke, 2015), including the Portuguese (Ribeiro *et al.*, 2022). Present findings indicate that addressing these obstacles by creating opportunities for their trial and repeated exposure, as it is often recommended (Kröger *et al.*, 2022), might be premature if these products are not yet rid of sensory cues that might induce their disgust and consequent rejection. They also suggest that making sure that edible insects are not seen (Caparros Megido *et al.*, 2016) will not be enough if they can otherwise be felt or tasted, or even just imagined (Naranjo-Guevara, Stroh and Floto-Stammen, 2023). Finally, the question remains of whether offers with high sensory appeal may succeed in overthrowing the prevalent disgust responses primed by the ideation of ingesting insects, as this seems to override even pleasant tasting experiences and curb subsequent intake of edible insect foods (Gumussoy and Rogers, 2023; Hamerman, 2016).

However, present findings also support the contention that disgust elicited by sensory cues, particularly those linked to texture, is by no means exclusive of insect-based foods and may also hinder the acceptance of plant-based meat alternatives (Bryant *et al.*, 2019; Martins and Pliner, 2005; Neville *et al.*, 2017). Indeed, participants remarked experiencing both texture- and flavour-based induced disgust reactions to Pea Mince, a contemporary, plant-based meat analogue

designed to mimic the sensory profile of a beef mince closely and already present in the market for some years (Giacalone, Clausen and Jaeger, 2022). Namely, the texture of Pea Mince was significantly more often described as 'spongy' than that of other samples, while being significantly less often qualified as 'typic'. These characteristics had a negative impact on the liking of this sample, particularly among *Rich Bolognese Likers*, *Other Mince Dislikers* (Figure 7D). Moreover, several participants commented that this mince felt "too spongy", "grainy", "chewie", "dry" or "hard", despite looking rather like beef mince. Meanwhile, others remarked that, despite it having a pleasanter ('sweet') flavour than some other samples, this was still unmistakably a plant-based Bolognese sauce and not the traditional meat-based one. Others yet described it as having a "cloying" or "nauseating" flavour that became apparent after repeated tastings and deterred from further consumption. Altogether, these results suggest that a deeper understanding of the sensory-affective processes driving disgust towards alternative protein foods is required.

Prototypical ingredient cues raised liking some insect- and plant-based sauces

Extant research found that associations to CATA terms describing red colour and the flavours of herbs, fresh tomatoes, tomato purée and spices increased liking of Bolognese sauces made from beef, soya bean protein, mycoprotein, oat or whole yellow mealworm powder indiscriminately, while associations to brown colour and lumpy or mushy texture reduced their acceptance (Niimi *et al.*, 2022; Wallner *et al.*, 2023). Moreover, they uncovered that sample liking was largely driven by appearance and flavour attributes unrelated to the inclusion of red meat in the recipes, i.e. those delivered by adding ingredients like tomato paste, fresh tomatoes, onions, carrots, mushrooms, herbs and spices, and applying cooking techniques like sautéing. In addition, they uncovered that the strength of the associations of these attributes typically did not differ significantly with the sauce being evaluated.

Comparable results were obtained by the present study. CATA terms 'tomato paste' and 'fresh tomato', for instance, had a strong positive impact on overall liking across samples and clusters, being most often used to describe the flavour of Beef Bolognese Sauce and Cricket Spice Mix. Likewise, the flavour attribute 'herbs' was most often employed to characterize these samples as well as the two sauces prepared from soya bean products. The term 'sauté' was moreover associated to both these products as well as to Soya Pasta Sauce and Cricket Pasta Sauce. Another important driver of liking, a 'natural' appearance, was meanwhile often applied to describe all samples except Cricket Pasta Sauce and Mealworm Mince (Figure 6A-D). Noticeably, the term 'typic' was significantly more often used to characterize the flavour of Beef Bolognese Sauce than any other sample; however, it had no significant impact on liking. Altogether, these findings confirm that some colour and flavour cues are indeed prototypical of a Bolognese-style sauce and hence essential to its liking; however, these do not necessarily require the incorporation of meat in formulations.

Distinct preferences for spiciness moderated the effects of replacing red meat with plant or edible insect protein on product liking

Manipulating the savouriness (saltiness, umami, spiciness) of a meat-centric product to modulate its flavour profile to the sensory preferences of different groups of consumers (Guinard *et al.*, 2016; Spencer *et al.*, 2021) demonstrated also in this study to be an effective means of improving the liking of a dish made with an alternative (plant or insect) protein source. Participants generally liked Cricket Pasta Sauce more than Mealworm Mince in large part due to its savouriness and concentration. Namely, *Mild Vegetable Bolognese Likers* and *Rich Bolognese Likers*, *Other Mince Dislikers* liked it also more than Cricket Spice Mix, albeit possibly for different reasons. In turn, both Soya Spice Mix and Cricket Spice Mix were much more liked than their plant- and insect-based counterparts, respectively, by both *All Bolognese Likers* and *Spicy Bolognese Likers*, *Else Insect Dislikers*. Again, flavour concentration and savouriness, especially spiciness, seemed to largely drive preferences. Several members of these two clusters commented appreciatively on the distinctive spicy notes and intense piquancy characterizing the taste of Soya Spice Mix. In the case of Spicy Bolognese Likers, flavour attributes 'hot', 'spices' and 'strong' had important positive associations with overall liking ratings (Figure 6C), determining their higher preference for the samples prepared from either dry spice mix.

Meanwhile, CATA appearance terms 'red', 'hight tomato' and 'strong colour', as well the flavour term 'tomato paste' were significantly more often used to describe Soya Spice Mix and Cricket Spice Mix than other samples. These were all attributes with significant positive penalty lifts on liking overall and across clusters, probably due to their assimilation to some of the prototypical sensory characteristics of a generic tomato sauce (Bendini *et al.*, 2017; Niimi *et al.*, 2022).

Remarkably, Cricket Spice Mix was able to avert most of the sensory-induced disgust responses that affected the liking of other insect-based samples. By showing that novel Bolognese-style sauces with an insect protein can be liked as much as their plant- or even meat-based counterparts by non-negligible consumer segments, this study expands prior work on the acceptance of reformulations of popular meat-centric dishes with alternative protein sources (Cordelle, Redl and Schlich, 2022; Elzerman *et al*., 2011; Spencer *et al*., 2021).

Altogether, these findings lend support to strategies that leverage culinary arts' knowledge, in addition to food technology and sensory evaluation expertise, to create meat-free or meat-less meals with high hedonic appeal even for regular red meat consumers (Cordelle, Redl and Schlich, 2022; Spencer *et al*., 2021). But notably, they demonstrate that such approaches need not to be limited to plant-based ingredients, partial meat replacement or a single flavour profile for outcomes to be well accepted. At the same time, they underscore the need to diversify and customize offers to match the idiosyncratic sensory and dietary preferences of different consumer segments.

Sociodemographics, Healthy Eating Consciousness and Beef Consumption predicted patterns of product liking

Present findings point out that the modulation of the oro-sensory attributes of plant-based meat alternatives, particularly along the bland/mild – spicy/hot dimensions, affects their degree of assimilation to a meat-based reference and thereby their liking *vis-à-vis* meat products. However, they also show that this process is moderated by individual differences in gender, level of education and magnitude of concern with eating healthily, being also affected by how these differences impact familiarity with, and general preference for eating plant-based protein. Prior research noted the existence of stronger preferences for spicy/hot foods, spiciness and trigeminal heat in males than females (Alley and Burroughs, 1991; Spencer *et al*., 2021). Other studies uncovered a higher prevalence of this kind of sensory preference in individuals less concerned with healthy eating and/or from lower socioeconomic strata than in other adult populations (Ma *et al*., 2018; Spencer and Guinard, 2018). The characteristics of participants grouped under *Spicy Bolognese Likers*, *Else Insect Dislikers* (Table 3) are in line with these findings. In one study (Fasanelli *et al*., 2020), significant gender effects were observed among young adults asked to imagine eating a dish with edible insects, with males anticipating 'spiciness' to be more perceptible in this type of meal than females. Yet, they also expected 'spiciness' to be the least disturbing gustatory sensation to be experienced more often than them. This did not happen with other sensory dimensions, like 'bitterness', 'greasiness-unctuosity' or 'persistence', for instance. These findings help explain why acknowledging and appreciating the markedly spicy/hot flavour of the sauces prepared from dry spice mixes shaped the preferences of *Spicy Bolognese Likers*, *Else Insect Dislikers* to a large extent. Namely, they shed light onto why this segment ended up preferring a plant-based Bolognese sauce to the traditional meat-based recipe, as well as one insect-based sample much other than the others.

Young adult females and individuals with higher education are generally more concerned with leading a healthy diet than, respectively, males and those less educated, being also more likely to curb red meat intake and increase the consumption of plant-based meals (Graça, Godinho and Truninger, 2019; Siegrist and Hartmann, 2019). Their familiarity with and liking of plant-based meat analogues tend thus to be higher than those of the general population (Nguyen *et al*., 2022; Onwezen *et al*., 2021). A strong preference for Bolognese-style sauces with a mild, only lightly seasoned flavour profile, combined with a similar liking of meat- and plant-based recipes, but not insect-based ones, set *Mild Vegetable Bolognese Likers* apart from other participants, with their comments revealing high familiarity and at least a moderate level of liking of plant-based meat options. Studies conducted with consumers from Northern European countries, or the United States find plant-based hybrids to be significantly better accepted than 100% pea or soya protein burgers (Caputo, Sogari and Van Loo, 2023; Grasso *et al*., 2022; Neville *et al*., 2017; Schouteten *et al*., 2016; Smetana *et al*., 2021). This somewhat contrasts with the findings of this study, where except for a minority grouped under *Rich Bolognese Likers*, *Other Mince Dislikers*, participants did not significantly prefer the meat reference to plant-based sauces (Supplementary Table S5). One other study found no significant differences in preference rankings between 100% or 75% beef burgers and a 100% pea protein burger under blind-tasting conditions, with the equivalent soy protein burger ranking the highest (Sogari *et al*., 2023). Meanwhile, a higher consumption of beef dinners at home significantly raised the odds of participants belonging to *Mild Vegetable Bolognese Likers* rather than *All Bolognese Likers*, but not *Spicy Bolognese Likers*, *Else Insect Dislikers* or *Rich Bolognese Likers*, *Other Mince Dislikers*. This is somewhat contrary to what is suggested by prior work

(Niimi *et al*., 2022; Verbeke, 2015). The existence of 'true' flexitarian consumer segments – characterized by high levels of consumption and liking of both meat and meat-free products – was nevertheless found in a broad study of the acceptability of red meat hybrids and analogues (Neville *et al*., 2017).

Food Disgust Sensitivity but not Familiarity with Edible Insects or Food Neophobia predicted patterns of product liking

A high propensity to experience and be bothered by disgust reactions, and a high sensitivity to one or more sensory modalities associated to eating (e.g. oral tactile sensitivity, taste/aroma sensitivity) may lower acceptance of foods deemed to be unfamiliar (Coulthard, Aldridge and Fox, 2022). Similar effects can help interpret the links between Food Disgust Sensitivity and patterns of product liking found in this study. High Food-Domain Disgust Sensitivity (Haidt, McCauley and Rozin, 1994) can co-occur with frequency of consumption of red meat (Fessler *et al*., 2003), which could explain why both variables were significant predictors of membership in *Mild Vegetable Bolognese Likers*. Males, on the other hand, tend to score lower on this trait than females (Kocabas and Sanlier, 2024), which could explain why it was not a significant predictor of membership in *Spicy Bolognese Likers*, *Else Insect Dislikers*. Meanwhile, a strong preference for the traditional meat-based sauce led *Rich Bolognese Likers*, *Other Mince Dislikers* to flat-out reject meat-free minces with strongly atypical and unpleasant texture attributes that induced aversion.

Neither Familiarity with Entomophagy nor Food Neophobia were significant predictors of the patterns of product liking uncovered. Research shows that Food Disgust Sensitivity can predict intention to consume edible insect products independently of Food Neophobia (La Barbera *et al*., 2018; Russell and Knott, 2021), as well as their anticipated (Gumussoy *et al*., 2021) or actual consumption (Ammann, Hartmann and Siegrist, 2018). It is relevant to note that most participants in this study had hear about entomophagy and did not self-report as food neophobic.

Limitations

Aside from constraints imposed by study design, other aspects of this work may have limited the results herein presented. Evidence on expectation disconfirmation effects was indirect only; future studies should investigate the role played by these effects in the acceptance of meat alternatives. In hindsight, a clearer picture of consumers' sensory evaluations and the role they played in determining product preferences could have been attained by asking participants to assess and describe the odour of samples prior to tasting. Likewise, asking them to judge samples on additional attributes (or on the same attributes over time), or making open comments mandatory could have generated further important insights. The recruitment and participation of additional study subjects, as well as the investigation of other relevant individual differences (e.g. familiarity with plant-based meat alternatives), stimuli (e.g. meat hybrids, different types of dishes, other meat products, varying portion sizes) and consumption settings (e.g. natural consumption, repeated exposures, with provision of product information) would likely have strengthened present study contributions. To this respect, see for instance Grasso *et al*. (2022), Cordelle, Redl and Schlich (2022), Neville *et al*. (2017), Spencer and Guinard (2018) or Spencer *et al*. (2021). These limitations were mainly imposed by practical constraints, not the least the desire to minimize participant burden. Yet, they underscore the importance of diversifying the cultural background of consumer samples and their representativeness in future research on perceptions and acceptance of alternative protein sources, as well as the cuisine, ingredients, processing, recipes, sensory profiles and modalities being tested (Spencer, Cienfuegos and Guinard, 2018).

5 Conclusions

The results of descriptive and affective sensory evaluation by a panel of young, meat-eating Portuguese adults showed that product formulation and processing technology, along with differences in sensory preferences and sociodemographic, behavioural and psychological traits were linked to large variations in the sensory profiles and hedonic preferences for seven Bolognese-styles sauces – made with 100% red meat (beef and pork), plant (soya beans or peas) or edible insect (house cricket or yellow mealworm larvae) protein. This demonstrates that the type of alternative protein used is only one of several factors influencing the perceived sensory properties of reformulations of familiar meat-centric products and, consequently, their relative liking by consumers. Although red meat consumers generally recognise and reward the sensory profile of meat-centric formulations, there are still important individual differences affecting their judgements of the different proteins presented as their substitutes in a

meal, such as idiosyncratic flavour preferences, varying sensitivities to sensory food cues, food attitudes and dietary choices (Eckl *et al.*, 2021). By taking these differences more into account, manufacturers of plant-based foods that succeed in mimicking well the appearance and texture of mince can increase their acceptance and secure a more definitive stronghold in the market for non-meat options in Europe (Apostolidis and McLeay, 2016). This approach may also deliver good results for edible insect foods, particularly house cricket products where the natural savouriness and juiciness of insect fractions is underscored and balanced by both adequate formulation and processing. Nevertheless, much improvement of their sensory quality is still needed before they can become an equally or even more viable alternative to meat than plant-based products (Ribeiro, Lima and Cunha, 2024). In this context, the mitigation of any disgust-inducing sensory cues, including in the packaging and communication of products (Naranjo-Guevara, Stroh and Floto-Stammen, 2023), is key and should anticipate any attempts to improve consumer acceptance by promoting their exposure. Replicating meat flavour might not be essential, though, nor replacing meat only partially, if these products are included in fitting mixed dishes that reproduce other prototypical aspects of the flavour of traditional recipes well. A crucial challenge remains in how these requirements can be met without increasing the already spiralling consumption of ultra-processed foods (Cordelle, Redl and Schlich, 2022) or trading off against healthier or more sustainable food consumption behaviours (Verain, Dagevos and Antonides, 2015).

Supplementary material

Supplementary material is available online at: https://doi.org/10.6084/m9.figshare.27232395

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Author contributions

A.I.A. Costa and M.P.J. Monteiro designed the sensory evaluation study. All authors except B.F. Faria designed the online questionnaire. A.I.A. Costa, M.J.P. Monteiro and B.F. Faria collected data and analysed and interpreted the results. A.I.A. Costa took the lead in writing the manuscript. All authors provided feedback on findings and/or commented on the manuscript.

Conflict of interest

The authors have no conflict of interest to declare.

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