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RESEARCH ARTICLE

Insect-based dinner products for meat substitution in ordinary diets: Developing the quality criteria and experimental products for consumer interventions

C. Maya[1]*, *R. Flore*[2], *Y. Sun*[2], *A.I.A. Costa*[3], *L.M. Cunha*[4], *C. Rocha*[5], *M.J.P. Monteiro*[6], *A. Osimani*[7], *L. Aquilanti*[7], *M. Van Der Borght*[8], *D. Vandeweyer*[8], *I.E. Chiriac*[9], *M. Peters*[10], *J. Rukov*[11] *and N. Roos*[1]

[1]Department of Nutrition, Exercise and Sports (NEXS), University of Copenhagen, Frederiksberg C, Denmark; [2]Skylab, Technical University of Denmark (DTU), Kongens Lyngby, Denmark; [3]CATÓLICA-LISBON School of Business and Economics, Universidade Católica Portuguesa, Palma de Cima, 1649-023 Lisboa, Portugal; [4]GreenUPorto/Inov4Agro, DGAOT, Faculdade de Ciências, Universidade do Porto, Rua da Agrária, 747, 4485-646 Vila do Conde, Portugal; [5]Sense Test, Lda, Rua Zeferino Costa, 341, 4400-345 Vila Nova de Gaia, Portugal; [6]Escola Superior de Biotecnologia, Universidade Católica Portuguesa, Rua Diogo Botelho, 1327, 4169-005 Porto, Portugal; [7]Dipartimento di Scienze Agrarie, Alimentari ed Ambientali, Università Politecnica delle Marche, via Brecce Bianche, 60131 Ancona, Italy; [8]Geel Campus, Department of Microbial and Molecular Systems (M²S), Research Group for Insect Production and Processing (IPandP), KU Leuven, Geel, Belgium; [9]LEITAT, Terrassa, Spain; [10]New Generation Nutrition (NGN), Den Bosch, The Netherlands; [11]Bugging Denmark, Otto Busses Vej, 2450 Copenhagen SV, Denmark; *casma@nexs.ku.dk

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Abstract

The growing environmental impact of livestock farming has emphasised the need for more sustainable diets with lower meat consumption, identifying insects as a potential alternative protein source. The Sustainable Insect Chain (SUSINCHAIN) project aimed to incorporate six new insect protein products into regular dinner meals, aiming to replace 20% of meat protein through a six-week dietary intervention in Denmark and Portugal, namely a randomised controlled study targeting families with children and young and childless couples respectively. This paper presents the process undertaken by project partners to develop the specifications and establish the quality criteria for the six study products. Quality criteria focused on the immediate appeal and sensory properties of edible insects as food ingredients, particularly taste, texture, and appearance to promote acceptability. Initial sensory evaluations of product prototypes provided essential feedback for improvement. The development of insect-based food products, including those mimicking traditional meat products, highlighted the significance of sensory quality and consumer perception in product acceptance. Non-meat mimicking items had high sensory appeal, but were not perceived as meat replacements, typically being later added as side dishes or supplements by intervention participants. Balancing insect protein content with sensory appeal presented challenges, highlighting the need to consider portion sizes and presentation. Overall, animal meat protein replacement in dinner meals using insect-based foods requires an integrated approach that combines innovative product development, ongoing quality assessments, and a deep understanding of consumer preferences, crucial for market acceptance and adoption.

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Keywords

alternative proteins – edible insects – novel proteins – product development

1 Introduction

Negative effects of livestock rearing, like emissions from deforestation, enteric fermentation, and manure, have drawn attention to the dire need for more sustainable diets (FAO, 2020; IPCC, 2023). Notably, meat is the most burdensome food regarding greenhouse gas emissions, making it the primary focus for protein replacement initiatives in an effort for a more sustainable dietary transition. The EAT-Lancet Commission (Willett *et al.*, 2019) highlighted the benefits of reduced meat consumption in diets. Such diets, when balanced with appropriate fruit, vegetable, and caloric intake, can halve diet-related greenhouse gas emissions and caloric intake, and reduce premature mortality by 20% (FAO and WHO, 2019). Addressing meat reduction requires sustainable protein alternatives that meet the needs of the human diet.

While the use of insects in food products has received substantial attention in the past decade, its introduction to the European market has largely been for snack foods (chips, bars, candy) rather than foods incorporating into main meals which is traditionally when meat is consumed in larger quantities. Edible insects should be made available to consumers to substitute meat in main meals. To establish the consumption of edible insects as a viable alternative to meat among European consumers on the course of adoption of more environmentally sustainable diets, edible insect foods need to transition from being mere niche snack products to becoming de facto main meal components (Kinyuru and Ndung'u, 2024; Maya *et al.*, 2024). Consumers have diverse motivations and approaches to changing their diets, so catering to consumers characterized as early adopters is important to establish a market for novel food products (Ho *et al.*, 2022). Early adopters of novel food products have been identified to be motivated by initial curiosity, sustainability, health, and variety in diet, while moving from sporadic tasting to regular repeated consumption is influenced by factors like availability, price, taste, and how the products fits into the dietary patterns (House, 2016). Providing insect-based foods that meet the expectations of early adopters in terms of taste and dietary fit is a crucial first step for integrating insect-based foods into regular diets.

SUSINCHAIN was a collaborative project among European institutions and enterprises that aimed to overcome technical and market barriers to enable sustainable large-scale production and consumption of insect proteins in Europe (Veldkamp *et al.*, 2022, 2024). Part of the SUSINCHAIN project was dedicated to developing experimental dinner products that would enable consumers to integrate insect protein into their regular diets and thereby have the potential to replace meat in more sustainable dietary patterns for European consumers. The experimental products were subsequently tested by families through a six-week intervention with the purpose of assessing their actual intake and how they contributed to replace meat in main meals and thereby decrease total meat consumption. Families in Denmark and Portugal were invited to participate in a six-week intervention by consenting to receive the experimental insect-based products suited for replacing meat in three dinner meals per week. In Denmark, the intervention focused on families with young children aged 8 to 10 (Maya *et al.*, 2022) and in Portugal, the intervention focused on young couples without children (Costa *et al.*, 2024). Results from the interventions in Denmark and Portugal on the intakes of insect products, replacement of meat and consumers perceptions of the products are available from Roos *et al.* (2023), Maya *et al.* (2024), and de Almeida Costa *et al.* (2024).

The insect-based dinner products were developed in the context of a premature commercial market for insect products in Europe. Therefore, it was necessary to develop and produce experimental insect products within the project to be able to conduct the planned consumer interventions. The initial step of the product development process was to define which quality criteria the insect-based dinner products should meet to ensure that products were not promptly rejected due to poor quality and, most importantly, that they were relevant and acceptable alternatives to meat, thereby allowing the assessment of the uptake of insect-based dinner meals in ordinary diets in its place. Detailing this process showcases both the challenges and opportunities involved in translating novel food concepts into viable solutions within the context of sustainable protein alternatives.

This paper describes the process of establishing the quality criteria for the insect-based dinner products

tested, designed to be relevant for consumer introduction within a food basket of six experimental insect-based products suited to serve as alternatives to meat as a primary protein source in ordinary family dinner meals.

2 Methods

Workshop for defining product quality criteria

The quality criteria to be met by the insect-based dinner products were defined as an internal reference among the SUSINCHAIN partners, in order to set a shared standard for the final specifications of the six experimental food products. These had to jointly represent the menu for a diverse food basket for three weekly family dinners over a six-week intervention period. The internal reference for quality standards was formulated through a combination of industry experience with specific products and edible insects, published studies, and sensory feedback throughout the product development process. The quality criteria were ultimately established following a three-day workshop (January 22-24, 2020) hosted by chef and food innovator Roberto Flore (Skylab, Technical University of Denmark (DTU), Kongens Lyngby, Denmark). The full workshop program combined the presentation of product prototypes, with hands-on work on creating dishes and recipes with prototypes in DTU food innovation kitchen, followed by tastings, inspirational talks by invited experts, and group sessions to compile the quality criteria to be met for the final products. The full workshop program is included as Supplementary Table S1.

The task of developing the insect-based products was divided among six project partners, each responsible for the independent development and production of one experimental product. Food developers were identified during the early phases of implementation of the SUSINCHAIN project and represented private companies as well as academic institutions. Private companies were New Generation Nutrition (NGN), from the Netherlands, Bugging Denmark, and LEITAT Technological Center, from Spain. Academic institutions were the Università Politecnica delle Marche (UNIVPM), Italy, KU Leuven (KUL), Belgium and the DTU, Denmark. The workshop also included project partners responsible for sensory evaluation (SenseTest, Portugal) and the implementation of the family interventions in Denmark (University of Copenhagen) and Portugal (SenseTest and Universidade Católica Portuguesa, Portugal), as well as for food safety (Wageningen University and Research, The Netherlands).

Assessing insect food prototypes and establishing criteria for final products

Prior to the workshop, each of the six food developers produced a prototype of the insect product to be tested. These prototypes were taken as baseline for product development and for defining the quality criteria to be met by the final products. The only requirements set for them were that they contained edible insects as ingredient and were suitable for inclusion in a main meal (i.e., not being a snack product like protein bars or sweets). Prototypes were shipped to DTU, where they were evaluated by ten trained sensory panellists. The panellists were not familiar with edible insect food but were informed that the products contained edible insects as an ingredient. The sensory evaluation described the sensorial qualities of the prototypes in four dimensions: Appearance, smell, taste and texture. The results of the panel evaluation were presented at the workshop to participants by the responsible scientist at the sensory lab and the sensory panel representative. Table 1 lists the prototypes assessed and provides examples of the negative descriptive characteristics noted by the sensory panel, which subsequently guided product reformulation by project partners.

Reformulation of prototype products

The workshop was the offset of a process of reformulation of the product prototypes in order to reach the final products presented to consumers in the family interventions. The level of reformulation undertaken varied between the products.

Initial sensory evaluation

Products reformulated following their initial assessment at the workshop were shipped to SenseTest (Porto, Portugal) for sensory profiling by consumer panels, to support the food developers in reaching acceptable sensory quality. Details on the various tests are can be found in Barbosa *et al.* (2025), Costa *et al.* (2024), Rocha *et al.* (2025) and SUSINCHAIN (2023a). Decisions regarding quality improvements were made in consultation with the responsible project partners leading the family intervention.

At SenseTest, several consumer studies were conducted to support food developers to reformulate their prototypes and meet the criteria set for sensory quality:

Mealworm mince (KUL): Overall liking and open comments from 100 consumers about a minced meat

TABLE 1 Six edible insect food prototypes and examples of the negative comments made about them by a trained sensory panel

Prototype	Appearance	Flavour	Texture
Falafel made with cricket (*Acheta domesticus*)	Looks like dried figs	Reheated meat, 'Stable'	Massive, crumble when you bite
Bolognese made with cricket (*Acheta domesticus*)	Too blended	Sourish, umami	Pieces stick to teeth
Mealworm (*Tenebrio molitor*)/pork sausage	Looks reheated	Mild, bacon chips	No sense of skin, dry
Mince made with lesser mealworm (*Alphitobius diaperinus*)	Does not look like meat, white dots	'Stable' (cow), bitter, like straw	Crumble as bread, not cohesive
Bread bun made with cricket (*Acheta domesticus*)	Black spots, like dry bread	Dry bread, 'Stable', chicken liver	Crumbly
Mince made with mealworm (*Tenebrio molitor*)	Incohesive, looks cooked, not fried	Taco mix, nutmeg, not meat-like	Have to chew, like quinoa

analogue prepared from yellow mealworms (*T. molitor*) added to a tomato/vegetable sauce.

Sausage (LEITAT): Overall liking and open comments about boiled vs. grilled sausages, with or without bratwurst sauce, containing lesser mealworm (*A. diaperinus*)/cricket (*A. domesticus*) both by samples of 60 consumers.

Crispbread (UNIVPM): Overall liking and Check-All-That-Apply (CATA) (Ares *et al.*, 2010) of seven formulations of a flatbread with cricket (*A. domesticus*) or yellow mealworm (*T. molitor*) flour and herbs by 50 and 100 consumers, respectively.

Falafel (NGN): Overall liking and open comments about a formulation of frozen, ready to eat falafel containing lesser mealworm (*Alphitobius diaperinus*) by 100 consumers.

Chili-tomato paste (BD): Overall liking and open comments about two formulations of a cricket (*A. domesticus*) and tomato umami paste, presented either as a topping on cooked pasta or as a spread on bread or toast, by 100 consumers.

Spice mix (DTU): Overall liking and open comments about a cricket (*A. domesticus*) spicy flour mix intended for the preparation of dhal, an Indian style dish, by 100 consumers.

The crispbread, spice mix and falafel products received additional feedback for improvement based on sensory evaluations conducted during school classroom interventions in Denmark (Maya *et al.*, 2023).

3 Results and discussion

The internal quality criteria for the final insect-based dinner products are presented in the following sections. Products meeting the criteria were scheduled to be produced in batches sufficient for the distribution to families participating in the forthcoming intervention in Denmark and Portugal (Figure 1).

Criterion 1. Insect protein content

The products should incorporate enough insect protein to provide the amount necessary to replace meat as a main protein source in a dinner. The SUSINCHAIN family interventions set as target the replacement of 20% meat protein with insect protein, on a weekly basis.

The insect protein content in a dinner serving was defined based on available data for typical meat consumption in Denmark and Portugal, using national dietary survey data. Calculations for Denmark were based on data from the latest national dietary survey (Pedersen *et al.*, 2015). The mean consumption of red meat was 134 g per adult a day. Accordingly, the average weekly meat consumption amounted to 938 g, or 187.6 g of animal protein. The weekly meat protein intake was divided by 14 meals (weekly lunch and dinner) and equal to 13.4 g of meat protein per meal. Calculations for Portugal were based on data from a national dietary survey in 2015–2016 (Lopes *et al.*, 2017). Average meat consumption was 104.4 g per adult per day, which equals to weekly consumption of 730.8 g or 146.2 g of meat protein. Accordingly, the average intake in lunch and dinner meals was set to 10.4 g of meat protein per meal.

To achieve the target of 20% replacement of meat protein on a weekly basis, the products should fully

FIGURE 1 Selected six edible insect foods tested in the consumer interventions in Denmark and Portugal. The crispbread (bottom left) was kept under refrigeration prior to delivery; all others were stored frozen.

replace meat protein in three dinner meals per week. The insect products should be developed in order to incorporate the amount of insect protein corresponding to the estimated amounts of meat protein in average dinner meals in a dinner serving, as above outlined.

Justification: Insects as meat replacement in dinner meals

The 20% target was considered sufficient to explore whether the introduction of insect-based foods in ordinary diets could contribute to a substantial reduction in meat intake, and thereby contribute to reduce the climate impacts of the total diet. The intervention was designed under the assumption that the majority of meat protein is typically consumed during main meals (i.e., lunch and dinner).

The amounts of insect to be incorporated in a dinner serving to obtain the targeted insect protein intake would depend on the protein content of the insects used, which varied by species and processing. Published values for protein for house crickets (*Acheta domesticus*) ranged from 55–71% dry matter (DM) (Rumpold and Schlüter, 2013), for mealworms (*Tenebrio molitor*) 47–49% DM, and 58–65% DM in lesser mealworms (*Alphitobius diaperinus*) (Rumbos *et al.*, 2019). These values are generally based on crude protein, being determined by nitrogen converted to protein by the standard factor 6.25. In SUSINCHAIN, protein content was estimated by food developers based on the composition of products, and insect ingredient supplier information. Moreover, samples were analytically tested for protein content using a 6.25 nitrogen conversion factor in a certified laboratory. The food developers estimated the amount of insect needed to provide the targeted amount of insect protein, and then designed the product to incorporate this amount into a serving suited for a dinner serving.

Criterion 2: Sensory quality

Considering the sensory profiles of edible insects as ingredients in foods, quality criteria were set to ensure the development of acceptable intervention products for the participating families. The products were required to have immediate appeal and taste, texture, and appearance should be acceptable in the context of the suggested serving in a dinner meal.

Justification: Importance of sensory properties

Sensory properties vary widely across edible insect species; moreover, their method of incorporation into foods and processing can greatly impact acceptability (Borges *et al.*, 2022). The process of developing SUSINCHAIN's final products also highlighted the importance of the choice of insect species and of minification, both influencing taste and texture.

Cunha and Ribeiro (2019) discussed the importance of the sensory characteristics of edible insects in foods,

while Ribeiro *et al.* (2024) presented a thorough characterisation of the sensory properties of edible insects and of the foods containing them, showing that there is still a long way to guarantee higher consumer acceptance and liking. Some of the negative characteristics identified are dry, mealy, grainy texture, unpleasant flavour and odour, existence of off-flavours and prolonged aftertaste (Ribeiro *et al.*, 2024). Processes such as the defatting of freeze-dried crickets and the microwave-drying or defatting mealworms can have a positive impact, improving liking scores and acceptability by masking negative odours and flavours (Ribeiro *et al.*, 2019, 2022b, 2024). Meanwhile, the addition of edible insects as powders can also alter the moisture, flavours, colour and texture of enriched breads, which will then require further development to become acceptable to consumers (González *et al.*, 2019).

Taste

Crickets have been used to fortify staple foods such as bread products, rice, tortillas and protein powders (Barton *et al.*, 2020; Bawa *et al.*, 2020; Homann *et al.*, 2017; Luna *et al.*, 2021; Osimani *et al.*, 2018; Tao *et al.*, 2017). Lesser mealworms have been used in wheat bread (Kowalski *et al.*, 2022a), commercially-available protein bars and crispbreads (Erhard *et al.*, 2023) and explored as a potential ingredient for meat analogues, like burgers (Kornher *et al.*, 2019). Mealworms have been used to fortify pates and crisps (Wendin *et al.*, 2021) and as an ingredient in breads (Kowalski *et al.*, 2022a,b). Roncolini *et al.* (2019) describes that mealworm is characterised by a sweet, nutty flavour and nutty, cocoa smell and have higher acceptability in breads than cricket powder. Other studies that explored the effects of adding mealworm to frankfurters and chips found acceptability at lower levels of inclusion (Choi *et al.*, 2017; Petrescu-Mag *et al.*, 2022). Thus, balancing the flavour of insects with the protein requirements is of utmost importance.

Insect foods are usually associated with salty or savoury flavours (Detilleux *et al.*, 2021), which fits with the aim to use in dinner meals. Savoury, or umami, is seen as more appropriate, preferred, and expected to taste better than sweet insect food products, likely due to a preconception of insects as a meat substitute (Tan *et al.*, 2015, 2016, 2017). However, using dried powdered insects can result in an overpowering umami flavour due to the extensive surface area of the insects coming in contact with the mouth (SUSINCHAIN, 2023b). The products should have an optimized particle size to reduce overpowering umami, lessening the intensity of the flavour and creating a more balanced food. This optimization could be achieved by adjusting minification processes to control particle size distribution. Further research can identify specific particle size ranges that improve taste.

Texture

It is crucial that the texture and mouthfeel of foods are appealing to the consumer. Aversive textures and sensations can trigger food disgust (Martins and Pliner, 2006) and result in the immediate rejection of foods products. Insect ingredients can change the textural properties of meat-like products (Borges *et al.*, 2022; Starowicz *et al.*, 2022), like hardness, chewiness and integrity, with this being particularly relevant to the mince and sausage intervention products. In bakery products, such as the crispbread intervention product, the inclusion of insect flours can increase nutritional value, but may result in reduced springiness, chewiness, and cohesiveness due to the absence of gluten (Borges *et al.*, 2022; Çabuk, 2021). Additionally, the acceptance of insect-based foods increases with finer particle size through the minification (i.e., grinding or mincing) of insects (Wendin and Nyberg, 2021), as large particle size can lead to a higher perception of coarseness (Wendin *et al.*, 2019).

The product development processes undertaken by SUSINCHAIN partners highlighted the importance of the choice of insect species and minification, which influenced both taste and texture. A significant challenge in creating the mealworm mince used in the intervention was adjusting the level of reduction of the exoskeleton fragments to minimize negative impacts on mouthfeel. This was addressed by implementing an optimal grinding procedure to render these fragments imperceptible (SUSINCHAIN, 2023b).

Appearance

Like texture, the appearance of insect-based foods should match consumer expectations, drawing reference from similar, non-insect products already available in the market.

Final edible insect foods were intended to be as similar to conventionally available foods as possible, in order to facilitate their acceptance by intervention families. The visual appeal of uncooked products, for those foods requiring further cooking at home, and of prepared ones was considered. Namely, products were not to contain whole insects or visible insect parts; insect traces in final products should be fully masked.

Numerous studies have shown that 'invisible' insects promote food acceptability (Dagevos and Taufik, 2023;

Naranjo-Guevara *et al.*, 2021; Tan *et al.*, 2016). This is line with the results of SUSINCHAIN's products sensory evaluations showing that traces of unprocessed insects were perceived as unfamiliar. The preference for edible insects to be invisibly, or 'stealthily', incorporated into familiar products like burger patties, breads, and pastas over whole, unprocessed insects is recommended as a promising strategy to increase acceptability (Dagevos, 2021; Dagevos and Taufik, 2023; Kusch and Fiebelkorn, 2019; Ribeiro *et al.*, 2022a; van Huis *et al.*, 2021). This strategy should be implemented in compliance with food labelling regulations to ensure that consumers are adequately informed and provided with transparent information about product contents.

Criterion 3. Presentation, packaging and labelling

The insect products were either ready-to-eat or semi-ready products that required some, but minimal, preparation prior to consumption. Intervention participants were provided with instructions for heating them, when applicable, as well as with recipes for preparation and serving, in the form of a recipe book designed for each intervention location (Denmark or Portugal). Recipes books offered different preparation and serving options for each of the six edible insect foods tested, in order to inspire participants to vary their dinner meals over the six weeks of intervention. Equivalent recipes were provided to the control group receiving the plant-based foods.

A standard label template was used for the edible insect foods. Product names and language were adjusted for the Danish and Portuguese interventions. Labelling included the ingredients list, basic nutritional information, allergen information, and storage instructions. Plant-based products were sourced from commercially available offers, with their packaging being altered to cover their brand name.

Justification: The influence of packaging on new foods

Packaging of the edible insect foods prioritized quality preservation, practicality in use and product communication. The insect-based foods tested were manufactured and packaged in batches according to the portion sizes required for the interventions. The packaging design and product presentation was not developed for commercial products, which instead were supplemented with the appropriate portion sizes, storage instructions and relevant nutritional information. The interventions did not investigate the impact of the packaging on product perception. Future studies on edible insect foods should assess the influence of packaging and labelling on a positive eating experience, by highlighting positive sensory characteristics of the food, using enticing product images and providing preparation instructions and meal recipes that enhance palatability (SUSINCHAIN, 2023c).

TABLE 2 Microbial standards applied to the developed edible insect food products

Parameter	Set limit
Escherichia coli	<50 cfu/g
Bacillus cereus	<5000 cfu/g
Presence of *Salmonella* spp.	Not detected
Yeasts and moulds	<5000 cfu/g
Listeria monocytogenes	<100 cfu/g
Staphylococcus aureus	<100 cfu/g
Aerobic Plate Count 30 °C	<1 000 000 cfu/g

Criterion 4. Food safety

To ensure that test foods were safe for consumption, the final products were produced following the latest general safety standards for food, General Food Law Regulation (EC) No 178/2002, and hygiene regulations, Regulation (EC) No 853/2004. Producers followed guidelines for Hazard Analysis and Critical Control Points (HACCP). Products were tested for microbiological safety prior to distribution and routinely throughout storage. Table 2 describes the microbial standards, which were based on existing industry guidelines for similar food products, set by the project team and applied. Each study site was responsible for monitoring the food safety of their distributed products by ensuring timely microbial testing and addressing any issues with spoilage. Any products that exceeded the set limits were discarded.

Perspectives: The final six edible insect food products

The six products presented in Table 3 were selected following iterative reformulation and sensory testing, based on their ability to meet the internal quality criteria described earlier in the manuscript. These criteria included sufficient insect protein content to contribute to the target meat replacement, acceptable sensory quality (taste, texture, and appearance), and suitability for incorporation into familiar dinner meals. Each edible insect dinner product represented a distinct approach using a variety of insect species and product formats to reflect realistic consumer options.

TABLE 3 The final edible insect dinner products developed to meet the quality criteria for the family interventions in Denmark and Portugal

Product	Insect species	Total protein content	Serving sizes	Developer	Description	Product image	Serving example from recipe book, Denmark
Falafel	Lesser mealworm (*Alphitobius diaperinus*)	11 g protein/100 g	Denmark: 199/144 g Portugal: 125 g	New Generation Nutrition (NGN), Netherlands	A deep-fried falafel made with blanched lesser mealworm. The product should be reheated before portion.		
Crispbread	House cricket (*Acheta domesticus*)	17 g protein/100 g	Denmark: 149/108 g Portugal: 120 g	Università Politecnica delle Marche (UNIVPM), Italy	A ready-to-eat crispy bread made with cricket flour and can be eaten with preferred toppings.		
Mealworm mince	Mealworm (*Tenebrio molitor*)	23 g protein/100 g	Denmark: 93/68 g Portugal: 75 g	KU Leuven, Belgium	A mealworm mince similar to fried ground beef. The product is pre-cooked but should be reheated.		
Chili-tomato paste	House cricket (*Acheta domesticus*)	18 g protein/100 g	Denmark: 97/70 g Portugal: 75 g	Bugging Denmark, Denmark	A paste made with ground crickets. It is pre-cooked but should be prepared with the dish.		
Sausage	House cricket/lesser mealworm (*Acheta domesticus* and *Alphitobius diaperinus*)	13 g protein/100 g	Denmark: 107/78 g Portugal: 87.5 g	LEITAT, Spain	A sausage made with cricket and lesser mealworm powder. It should be heated before consuming.		

TABLE 3 (Continued)

Product	Insect species	Total protein content	Serving sizes	Developer	Description	Product image	Serving example from recipe book, Denmark
Spice mix	House cricket (*Acheta domesticus*)	38 g protein/100 g	Denmark: 43/31 g Portugal: 35 g	Skylab, Technical University of Denmark (DTU), Denmark	A seasoning made with ground cricket and designed to be cooked with a dish.		

In Denmark, portion sizes were set to include 13.4 g of insect protein for adults and 9.7 g for children, respectively. The servings for Denmark are given for adults/children, respectively. In Portugal, portion sizes for adults were set to include 10.4 g of insect protein.

Development insights: Insect protein content and consumer acceptance

The target for insect protein content in the final products was set to achieve a 20% reduction in the meat intake, based on dietary data from Denmark and Portugal (Maya *et al.*, 2022). Achieving this target posed some challenges to food product developers, as incorporating the required quantities of insects sometimes negatively impacted the appearance, taste, or texture of the products. During development, reformulation was required to balance nutritional goals with consumer-acceptable portion sizes. This highlighted the importance of designing insect-based products that fit within culturally relevant meals while still contributing meaningfully to protein intake.

Given that edible insect foods are new to European consumers, maintaining their high sensory quality is crucial for market acceptance. Rigorous testing with trained sensory and consumer panels is recommended. Developers relied on structured sensory evaluations to guide formulation, and products were prepared alongside practical guidance for meal preparation.

Development insights: Types of insect-based products for meat replacement

Food developers could pursue two distinct approaches for the development of the edible insect products: either mimic traditional meat products, such as the sausages and mealworm mince, or develop original products for new types of dinner meals, like the chili-tomato paste and spice mix. These latter products were not intended to mimic meat directly but aimed to contribute umami sensory appeal and complement familiar dishes. Understanding how product format influences perceived role in the meal was a key consideration during development. Even when non-meat mimicking products achieve high sensory quality, they may not be perceived as a central protein component like traditional meat or its direct substitutes. Therefore, when developing edible insect foods, it is important to consider not only their sensory quality and their ability to mimic meat, but also their positioning and the role they are likely to play in a meal. These factors are critical to ensuring that insect-based foods can support dietary change and promote more sustainable eating practices.

Development insights: Instructing and supporting the consumers

Insect-based foods are novel and unfamiliar to most European consumers. As part of product readiness, developers prioritized consumer guidance. Preparation

instructions and culturally relevant meal recipes were included alongside the products to support their integration into regular family dinner meals.

4 Conclusion

Edible insect foods to incorporate in dinner meals are novel to food innovators and consumers. This study presented the approach of establishing internal standards for prototypes, to be met before final products are exposed to consumers. The quality criteria specified the nutritional composition, namely the amount of edible insect protein required to consider a product relevant as a meat replacement in dinner meals, the levels of acceptable sensory quality for taste, texture, and appearance, and the food safety standards to be met. Meeting the required amounts of insects in dinner servings challenged the food innovators to adjust and reformulate products. It became evident that the integration of insect-based intervention foods into European diets requires a multifaceted approach. It requires not just innovative product development and thorough sensory optimisation but also continuing quality assessments, attention to consumer habits, and an understanding of what consumers consider meat replacements. These approaches are crucial for promoting the acceptance and adoption of insect-based food products as an integrated part of future more sustainable diets in Europe.

Supplementary materials

Data is available on https://doi.org/10.1163/23524588-bja10276 under Supplementary Materials.

Conflict of interest

The authors declare no conflict of interest.

Ethical statement

The family interventions for which the products described were used were approved by the Danish National Committee on Health Research Ethics (H-21070172) and by the Ethics Committee of Universidade Católica Portuguesa (ref. CETCH2022-18), and were registered on ClinicalTrials.gov (registration number NCT05156853) and on the International Standard Randomised Controlled Trial Number registry (registration number ISRCTN53814211).

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