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Research report

Introducing menus of three weekly insect- or plant-based dinner meals slightly reduced meat consumption in Danish families: Results of a randomized intervention study

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ABSTRACT

The environmental concerns associated with excess meat consumption have emphasized the need for sustainable alternatives. Edible insects offer a promising alternative due to their environmental efficiency and nutritious profile, but their widespread adoption in Western diets remains a challenge. The objective of the study was to investigate the impact of exposing families (parents and children) to insect-based or plant-based dinner menus on dietary pattern, meat intake, and protein intake over a six-week intervention period. The study was a two-arm randomized equivalence trial comparing an insect-based menu to a plant-based control. Families received either an insect or plant-based menu to replace meat in dinner meals three times a week for six weeks, aiming to replace 20% of their meat protein intake. Dietary changes were assessed through dietary registrations and daily questionnaires. Both adults and children maintained their estimated daily total protein intake, while reducing daily meat protein intake. Neither group met the 20% weekly meat replacement goal. In the insect-based menu group, adults and children reached an average 5.5% and 2.3% weekly meat replacement, respectively. In the plant-based menu group, adults and children replaced 9.0% and 4.3%, respectively. Meat attachment had an effect on meat protein intake. The menus slightly reduced meat protein intake. The weekly frequency of meat meals slightly declined, but portions remained the same. By enhancing insect and plant-based food quality and understanding consumer behavior, insect- and plant-based products have the potential to be a complementary alternative in a sustainable dietary transition without sacrificing nutrition.

Clinical trial registry: ClinicalTrials.gov: NCT05156853; clinicaltrials. gov/study/NCT05156853.

1. Introduction

Shifting human diets away from their current reliance on meat towards higher intakes of plant and insect protein in the future can benefit the environment by reducing greenhouse gas emissions and the conversion of forests and grasslands into pasture (Eshel et al., 2019; Halloran et al., 2016; Smetana et al., 2021). Despite the numerous studies advocating for the reduction of especially red and processed meat consumption, beliefs that associate (red) meat eating with proper nutrition, good health, and identity generally remain strong (Caso et al., 2023).

Global consumption of meat is estimated to increase by 14% by 2030, driven by increasing wealth and population (OECD/FAO, 2022). In the Nordic countries (Denmark, Sweden, Norway, and Finland), consumption emissions are above average for high-income nations, with animal products contributing to approximately 65–75% of these emissions (Wood et al., 2019). Moreover, the national identity is intrinsically linked to red meat consumption and is therefore a strong predictor of intentions to eat red meat (Randers & Thøgersen, 2023). To promote more climate-friendly diets, Danish dietary guidelines are now recommending a weekly meat consumption of maximum 350 g per adult (Fødevarestyrelsen, 2021). Various strategies exist for consumers to reduce meat consumption and replace protein intake, including curtailment, decreasing the frequency of meat consumption, or completely eliminating meat-based products from their diet (Siddiqui

Abbreviations: Department of Nutrition Exercise and Sports, (NEXS); European Union, (EU); Last observation carried forward, (LOCF); Meat Attachment Questionnaire, (MAQ); Physical activity level, (PAL); Sustainable Insect Chain, (SUSINCHAIN).

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et al., 2022). These strategies can be aided by incorporating alternative protein sources such as plant-based foods and edible insects (Onwezen et al., 2021).

Over the past decade, European consumers have been increasingly exposed to the idea of edible insects as a sustainable alternative protein source, especially since 2018, when some farmed species and their products finally earned coverage by the European Union (EU) Novel Food legislative framework (Belluco et al., 2017; Mancini et al., 2022). In parallel, the potential of edible insects as a viable source of human nutrition has emerged as a prominent and widely discussed topic in recent years due to their lower resource requirements compared to traditional livestock protein sources (Halloran et al., 2016), and their high-quality, digestible protein content (Jensen et al., 2019; Malla et al., 2022) and other potentially beneficial bioactive compounds like chitin (Oonincx & Finke, 2021; Stull & Weir, 2023; van Huis et al., 2021). However, to significantly contribute to the reduction of meat consumption and work towards the widespread adoption of more environmentally sustainable diets, edible insects must overcome their current status of niche products – as “adventurous snack foods” or “oddity protein bars” –, and secure their place in the regular diets of a broader audience, namely at the family dinner table (House, 2016).

Introducing a new protein source to western diets is complex. New risks associated with foodborne pathogens or allergens may emerge, requiring adequate assessment, the establishment of treatment methods and even a reevaluation of the legislative framework. On the other hand, the successful development of a new food production process requires a substantial investment of time and resources, as well as extensive research and development efforts to overcome technical barriers and improve quality along the value chain, from farm to fork. Furthermore, the design and implementation of effective communication activities is key for introducing novel protein sources to the public and help overcome any pre-existing negative attitudes or biases that may work against their acceptance (Looy et al., 2014). Even so, once a product has been introduced to the market, its adoption by consumers as a regular dietary protein source, particularly for family meals, remains highly uncertain, suggesting the need for continuous marketing investments and upkeep.

The EU insect sector has experienced significant growth, driven by increased academic interest, market expansion, and positive legislative assessments (Mancini et al., 2022; van Huis, 2023). To support this budding enterprise, the EU-funded project Sustainable Insect Chain (SUSINCHAIN 2019–2023) gathered more than 30 private sector and public partners to jointly address obstacles throughout the insect chain (Veldkamp et al., 2022), including investigating the integration of edible insects into regular diets by developing insect-based food products tailored to appeal to early adopters in Europe (Maya et al., 2022).

Regardless of the increasing interest and availability of edible insects, there are strong barriers to their successful incorporation into the diet, primarily relating to acceptability and their ability to integrate into everyday meals and diets. Some psychosocial barriers include food neophobia, food disgust sensitivity, and meat attachment. Lower neophobia scores are typically associated with a greater willingness to consume insects, and vice versa (Gere et al., 2017; van Huis & Rumpold, 2023). The appearance of insects can trigger food neophobia, with higher neophobic reactions observed towards whole insects than processed ones (Ruby et al., 2015). Several studies show that food disgust sensitivity also strongly influences the willingness to consume and acceptance of edible insects (Ammann et al., 2018; Hartmann & Siegrist, 2018; La Barbera et al., 2018; McClements, 2023; Ruby & Rozin, 2019; Tuorila & Hartmann, 2020). Meat attachment has been shown to impact dietary preferences (Graça et al., 2015). Individuals with weaker meat attachment are more willing to reduce meat consumption and adopt alternatives such as edible insects, while those with stronger meat attachment often consume more meat and are less likely to limit its intake (Circus & Robison, 2018; Dagevos, 2021; Verbeke, 2015). Moreover, insects as a food ingredient, particularly in higher percentages, can result in unfamiliar quality, poorer organoleptic properties, and reduced acceptance (Castro Delgado et al., 2020; González et al., 2019; Ho et al., 2022; Ribeiro et al., 2019). Various intervention strategies, including educational sessions and repeated exposure, can contribute to overcome these barriers (Chow et al., 2021; Erhard et al., 2023; Kinyuru et al., 2021; Maya et al., 2023; Tan et al., 2015; Woolf et al., 2021) and support food innovation to meet consumer preferences and expectations.

However, many of these interventions have focused on singular or short-term exposure to edible insects, which does not adequately assess their long-term acceptance as a regular protein option in everyday meals. This aspect is significant since, in order for edible insects to contribute significantly to sustainability and become a viable protein source in the human diet, they must have the capacity to substitute a substantial portion of meat protein.

Many acceptance studies focus on adult consumers and have identified barriers and promising strategies to address them. Introducing children to edible insects and insect-based foods can be a great tool for promoting environmental awareness and cultivating sustainable eating habits from an early age (Rumpold & van Huis, 2021).

As described in Maya et al. (2022), these challenges aren’t unique to insect-based foods. Dietary patterns may shift due to the introduction of any novel food, including plant-based options (Graça et al., 2019). Thus, a plant-based menu was established as a control to determine whether the observed effects stemmed from the protein source or because of the introduction of new foods.

Therefore, the objective of this study is to investigate the impact of exposing families (parents and children) to insect-based or plant-based dinner menus on dietary pattern, meat intake, and protein intake over a six-week intervention period.

2. Methods

2.1. Study design

The study protocol, detailed in Maya et al. (2022), entailed a two-arm randomized equivalence intervention trial. An insect-based menu arm served as the experimental exposure, while the plant-based menu arm served as the control to identify if the effects of the intervention differ from other alternative protein sources. The research was conducted by the Department of Nutrition, Exercise and Sports (NEXS) at the University of Copenhagen.

2.2. Participants

Recruitment ran from August 2022 to April 2023. Relevant families were identified from the Copenhagen metropolitan area through the Danish Civil Registration System. Families with two custody holders and a child aged 8–10 registered to live in the same address received an invitation letter through the public e-mail ‘e-boks.’ Responding families were pre-screened in a telephone interview. Following an information meeting, consents were given by one adult and one child in each family to be enrolled as study participants.

In general, to be eligible, interested persons had to be healthy, consume meat for dinner at least five days a week, and be willing to eat both insect-based and plant-based foods. Although the study had an overall low risk, participants were advised that rare cases of severe allergic reactions, including anaphylactic shock, have been documented from edible insects. Participants who were participating in other clinical studies, had food or dust mite allergies or intolerances, adhered to one or more restricted diets (e.g., veganism, gluten-free, keto, vegetarianism), used protein supplements, or had gastrointestinal, kidney, liver, or chronic inflammation disorders (excluding obesity) were not eligible to participate. Detailed eligibility criteria are available in Maya et al. (2022).

Throughout the study, participating families were provided with insect- or plant-based menus to replace meat in dinners three times a week for six weeks, which was designed to replace 20% of their weekly meat protein intake. The final visit served as the study's conclusion, formally closing out participants from the study.

2.3. Intervention menu

Each menu consisted of six food items meeting specified criteria for protein content, defined in order to consider the products as meat replacement in ordinary dinner meals. The products for adults were designed to contain 13.4 g of insect protein and the products for children were designed to contain 9.7 g of insect protein. The insect-based menus entailed six different intervention-specific products, each developed and produced by one SUSINCHAIN project partner (Maya et al., 2022): chili-tomato paste (*Acheta domesticus*), crispbread (*A. domesticus*), falafel (*Alphitobius diaperinus*), minced meat (*Tenebrio molitor*), spice mix (*A. domesticus*), and sausages (*A. domesticus and A. diaperinus*). Plant-based menus included comparable products currently commercialized in Denmark to closely match the insect-based menu in appearance, function, and protein content for serving sizes. These products were ready-to-heat Bolognese sauce with lentils, crispbread topped with seeds, frozen chickpea-based falafel, frozen soy-based minced meat, soy-based taco mix, and frozen pea-based sausages.

Development of the insect-based products was carried out by SUSINCHAIN project partners Bugging Denmark (Copenhagen, Denmark), Marche Polytechnic University (Ancona, Italy), New Generation Nutrition (Den Bosch, Netherlands), KU Leuven (Leuven, Belgium), the Technical University of Denmark (Lyngby, Denmark), LEITAT (Barcelona, Spain). Preliminary sensory testing was conducted by Sense Test (Vila Nova de Gaia, Portugal).

Throughout the intervention period, participants visited NEXS four times. During the first three visits, participants received two weeks' worth of their assigned dinner meals for the two participants (one adult and one child). Additional portions were offered on request, to allow the families to prepare the intervention dinners to the whole family when desired.

2.4. Measurements

Household characteristics and anthropometric measures were collected at the beginning of the study at NEXS. Before randomization, participants were instructed to complete online questionnaires on food neophobia (Damsbo-Svendsen et al., 2017; Pliner, 1994; Pliner & Hobden, 1992), food disgust sensitivity (Hartmann & Siegrist, 2018), and exposure to edible insects (Rozin et al., 2014). Additionally, adults were assigned the meat attachment questionnaire (Graça et al., 2015).

Participating adults completed the Food Neophobia Scale (Pliner & Hobden, 1992) while children utilized the Food Neophobia Test Tool (Damsbo-Svendsen et al., 2017; Pliner, 1994). Means scores were collected using a 7-point Likert scale, where higher values signified higher food neophobia. Adults and children used a modified version of the 8-item Food Disgust Scale (FDS- short) (Hartmann & Siegrist, 2018) with 4 additional questions pertaining specifically to insects (Rozin et al., 2014). The additional questions were assigned regardless of randomization. Means scores were collected for each questionnaire using a 7-point Likert scale, where higher values signified higher food disgust sensitivity. Due to the nature of its questions, only the participating adults were administered the meat attachment questionnaire (MAQ) (Graça et al., 2015). Mean scores were collected for each questionnaire item using a 7-point Likert scale, with higher values indicating a greater level of attachment to meat. Finally, all participants were asked if they have had previous exposure to insects and their answers recorded dichotomously.

Furthermore, all participants were asked to complete baseline and endline 4-day dietary registrations using the MyFood24 dietary software (myfood24.org). The intervention foods were added to the MyFood24 food composition database.

Throughout the intervention, participants also received a daily link to a questionnaire to record whether they had consumed the test food, meat for dinner, and the amount consumed. If participants reported consuming a meat dinner meal that day, consumption was recorded using a scale ranging from 1 ("I have eaten much more meat than usual") to 5 ("I have eaten much less meat than I usually do"). If participants reported consuming an intervention product on the daily questionnaire, they were further asked to indicate the amount consumed using a scale ranging from 0 ("Tasted, but no further consumption") to 1 ("The entire portion was eaten").

Lastly, food acceptability and feedback questionnaires were administered at the first and last exposure for two products within their assigned menu. Participants who completed the intervention were assigned an end-of-study questionnaire. Participants rated 'overall assessment' using a 7-point scale where 1 = extremely bad and 7 = extremely good. Questionnaires and the 4-day dietary registration were completed at home.

2.5. Outcomes

The primary outcome was the replacement of dietary meat protein with protein from the intervention foods, which were measured by changes in the intake of meat protein over the 6-week intervention period and the measures for replacement by the intervention products. The secondary outcome was change in the sensory evaluation of the intervention foods, which were measured by changes in the sensory parameters for liking of the intervention foods during first and last exposures.

2.6. Sample size and statistical methods

A sample size of 78 paired participants (78 adults and 78 children) was based on $\alpha = 0.05$, $\beta = 0.80$, and an assumed $\sigma = 7$. The goal was to recruit 80 paired participants. Participants were analyzed according to the intervention menu they were randomized to.

Baseline and endline protein consumption was determined from the 4-day dietary registration done through MyFood24. Total protein intake was determined from all food sources. Meat protein content was exclusively calculated based on foods or dishes predominantly composed of meat (i.e. a steak, chicken breast, meatballs), but excluded seafood.

Primary analysis was done using a linear mixed model with fixed effects for intervention menu, time, gender, body weight (kg), disgust, disgust towards insects, neophobia, meat attachment, an interaction for time and menu, and a repeated measure for time assessment points (baseline and endline). Separate models were ran for adults and children. To explore whether disgust towards insect had more of an effect on those allocated to the insect-based diet, the model was re-run split by diet. A binary logistic regression was used to investigate the effect of intervention menu on drop out. This calculation used the adult dataset, as those who dropped out also withdrew the child's participation. For the daily questionnaires, last observation carried forward (LOCF) was used for missing self-reported meal count data points. Responses were translated into proportions and mean values were calculated for the 6-week intervention. Descriptive statistics were used for the results of the food acceptability and feedback questionnaire.

2.7. Ethical approvals

This study was approved by the Danish National Committee on Health Research Ethics (H-21070172). This trial was registered on ClinicalTrials.gov (registration number: NCT05156853).

3. Results

Fig. 1 shows the recruitment and flow of the intervention study.

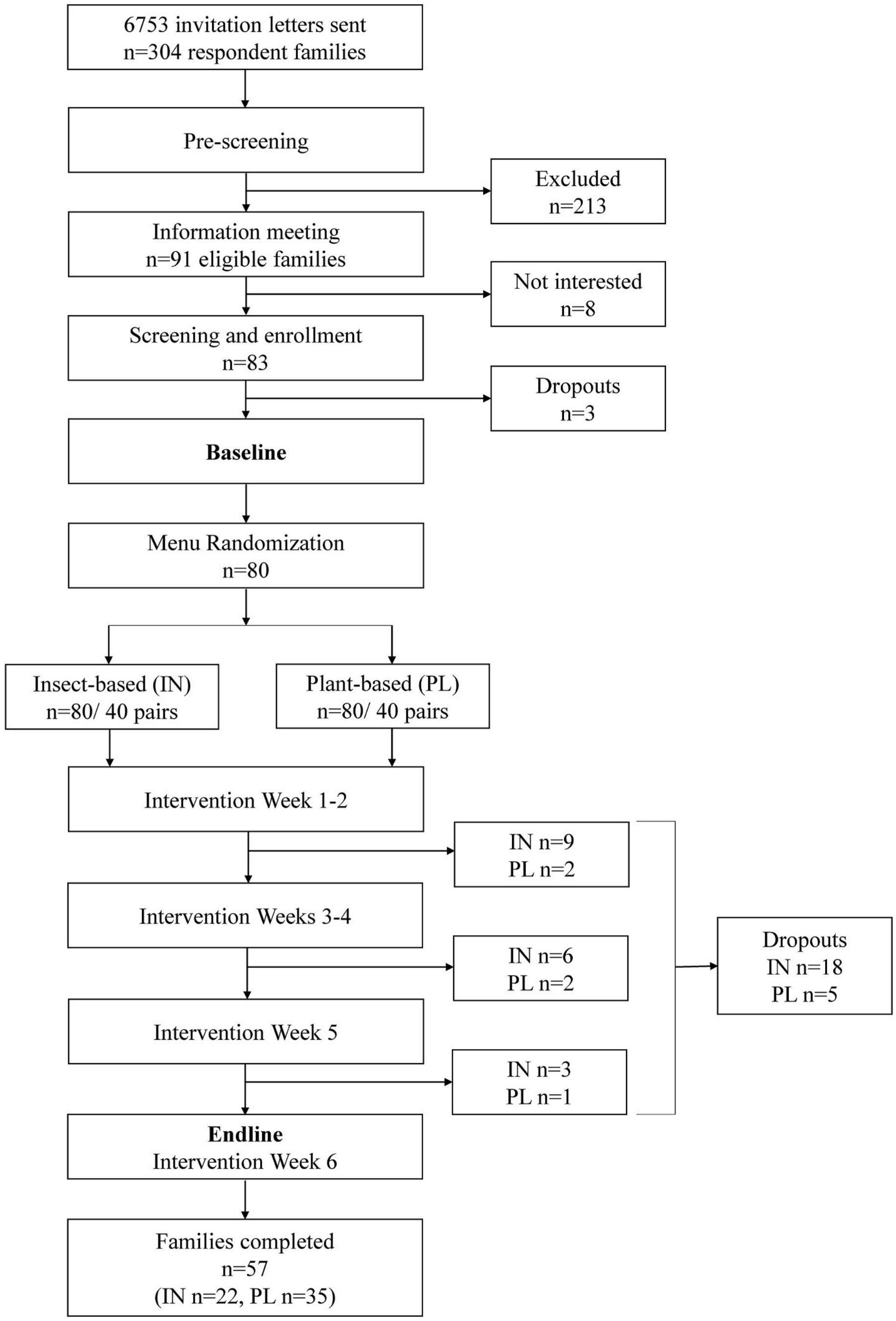


Fig. 1. Flow chart of the study.

After receiving contact information for potentially eligible families, 6753 recruitment letters were distributed in batches of 500–1000 to locations identified by zip codes and 304 responses were received. Screening continued until the target amount of 80 families were enrolled in the intervention. Randomization resulted in 40 families being allocated to the insect-based menu and 40 families to the plant-based menu. A total of 57 families, or 114 individuals, completed the 6-week intervention. More families randomized to the plant-based menu (n = 35) completed the intervention than those in the insect-based menu. Eleven families dropped out specifically due to disliking the intervention foods.

3.1. Participants

Baseline characteristics are shown in Table 1. All participants had some level of post high school education, with the majority having a graduate degree. In general, adults presented low food neophobia, low food disgust sensitivity and disgust towards insects, and moderate meat attachment. Children displayed low food neophobia and low disgust towards insects, but moderately high food disgust sensitivity. The majority of participants had tried edible insects before the study. Specifically, having 'tried insects on a few occasions' categorized the largest share of adults (51%) and children (38%). Some adults (28%) and children (27%) had 'never tried edible insects' prior to the study.

3.2. Energy intake

Table 2 shows the average total energy intake as well as the percent energy for protein, carbohydrates, and fat. A physical activity level

Table 1
Baseline characteristics of enrolled participants.

	Insect-based menu (IN) (n = 40)		Plant-based menu (PL) (n = 40)	
	Adult	Child	Adult	Child
Age, *years (SD)*				
Female	43.6 (3.3)	9.5 (0.8)	43.2 (4.4)	9.8 (0.8)
Male	43.4 (4.9)	9.6 (0.7)	44.1 (3.3)	9.5 (0.9)
Gender, *n* (%)				
Female	21 (52.5)	16 (40.0)	23 (57.5)	20 (50.0)
Male	19 (47.5)	24 (60.0)	17 (42.5)	20 (50.0)
Country of origin, *n* (%)				
Denmark	35 (87.5)	37 (92.5)	37 (92.5)	39 (97.5)
Other	5 (12.5)	3 (7.5)	3 (7.5)	1 (2.5)
Weight, *kg* (SD)				
Female	69.8 (13.5)	32.2 (6.6)	67.9 (12.2)	32.5 (6.8)
Male	81.7 (13.4)	33.4 (4.7)	88.0 (14.2)	33.0 (6.0)
BMI, kg/m^2 (SD)				
Female	25.2 (5.8)	16.4 (2.4)	23.3 (3.9)	16.7 (2.5)
Male	25.1 (3.5)	16.5 (1.5)	25.9 (4.2)	16.6 (1.9)
Years of education post high school				
<3	3 (7.5)	–	4 (4.0)	–
3-4	15 (37.5)	–	9 (22.5)	–
>4	22 (55.0)	–	27 (67.5)	–
Psychosocial variables, *score* (SD)				
Neophobia [a]	2.2 (0.7)	2.8 (1.0)	2.2 (0.7)	2.9 (0.8)
Food disgust [b]	3.6 (0.8)	5.1 (0.9)	3.7 (1.0)	5.0 (1.0)
Insect disgust [c]	3.0 (1.2)	2.5 (1.3)	3.0 (1.2)	2.3 (1.3)
Meat attachment [d]	4.1 (0.9)	–	4.1 (0.8)	–

[a] Mean scores of 7-point scale (1 = Strongly agree; 7 = Strongly disagree) Food Neophobia Scale (Pliner & Hobden, 1992) for adults and the Food Neophobia Test Tool (Damsbo-Svendsen et al., 2017; Pliner, 1994) for children.
[b] Mean scores of 7-point scale (1 = Not disgusting at all; 7 = Extremely disgusting) Food Disgust Scale (FDS- short) (Hartmann & Siegrist, 2018).
[c] Mean scores of 7-point scale (1 = Not disgusting at all; 7 = Extremely disgusting) Disgust Towards Insects (Rozin et al., 2014).
[d] Mean scores of 7-point scale (1 = Strongly agree; 7 = Strongly disagree) Meat Attachment Questionnaire (Graça et al., 2015).

(PAL) of 1.4 was used for the estimated energy requirements of adults and children.

Energy intake remained similar prior to and at the end of the intervention. At baseline, adults reported consuming 77% (±20%) of their estimated energy requirement. Adults completing the study reported consuming around 79% (±22%) at endline. Children reported consuming about 87% (±18%) of their estimated energy requirement at baseline and 85% (±18%) at endline.

3.3. Change in meat protein

Baseline dietary registrations indicated that an average of 36% (min 8% to max 66%) of protein intake originated from meat-based sources among participating adults. For children, meat contributed to 37% (min 8% to max 81%) of the overall protein consumption.

For each of the adult and children datasets, a total of 137 observations were available for analysis: 80 from baseline and 57 from endline. Results from the linear mixed model are shown in Table 3.

At baseline and endline, adults maintained their estimated daily total protein intake ($p = 0.548$), but reduced their estimated daily meat protein consumption by 9.7 g at endline ($p = 0.003$). Menu assignment did not have a significant effect on estimated difference on daily total protein intake ($p = 0.118$) or daily meat protein intake ($p = 0.154$). There was no interaction effect between menu and time on estimated daily total protein intake ($p = 0.698$) and estimated daily meat protein intake ($p = 0.594$).

After adjusting for body weight, females consumed an estimated 17.4 g/day less total protein ($p = 0.005$) and an estimated 9.9 g/day less meat protein ($p = 0.004$) than males.

Meat attachment was the only psychosocial variable that had a significant estimated effect, which suggested that for every unit increase in meat attachment there was an associated increase of 7.1 g/day in total protein intake ($p = 0.019$) and 3.7 g/day in meat protein intake ($p = 0.023$).

Children also maintained their estimated total daily protein intake ($p = 0.193$) and reduced their estimated daily meat protein consumption by 4.1 g ($p = 0.030$).

Similar to adults, female children consumed an estimated 7.3 g/day less total protein ($p < 0.021$) and an estimated 5.3 g/day less meat protein ($p = 0.025$) than male children.

Unlike adults, children with higher levels of food disgust sensitivity showed an associated significant decrease in estimated total protein intake. Specifically, for every unit increase in disgust, there was an estimated decrease of 3.5 g/day in total protein intake ($p = 0.043$). Estimated daily meat protein intake was not affected by food disgust sensitivity ($p = 0.336$).

Given the expectation that disgust towards insects would have a greater impact on those allocated to the insect-based menu, the model was re-run by intervention diet. Disgust towards insects did not affect estimated daily meat protein intake for adults ($p = 0.062$) and children ($p = 0.057$) following the insect-based menu.

Total protein intake and meat protein replacement by intervention foods from the dietary registrations are shown in Table 4. Adults and children following both menus did not reach the 20% weekly meat replacement goal. Adults in the insect-based menu group demonstrated an average weekly meat replacement of 5.5%, while those in the plant-based menu group had an average weekly meat replacement of 9.0%. Among children, the insect-based menu group showed an average weekly meat replacement of 2.3%, while the plant-based menu group had an average weekly meat replacement of 4.3%.

Table 2
Energy intake by 4-days dietary registration at baseline and endline [a].

		Adults				Children			
	n	Total energy kcal [b]	Protein E%	Carb E%	Fat E%	Total energy kcal [b]	Protein E%	Carb E%	Fat E%
Baseline									
Total	80	2005 (559)	16.8 (2.5)	46.0 (5.8)	37.2 (5.4)	1705 (346)	15.0 (2.1)	51.0 (5.3)	34.0 (5.2)
Endline									
Total	57	2063 (593)	15.8 (2.8)	47.0 (4.9)	37.2 (5.0)	1674 (375)	14.5 (2.3)	52.0 (5.1)	33.5 (4.6)
Insect	22	1934 (612)	15.5 (3.1)	47.3 (5.2)	37.2 (5.1)	1686 (340)	13.8 (2.1)	53.2 (4.4)	33.0 (4.0)
Plant	35	2144 (566)	15.9 (2.7)	46.8 (4.7)	37.3 (5.0)	1666 (394)	15.0 (2.3)	51.2 (5.3)	33.8 (5.0)

Note: Carb = Carbohydrate.
[a] Values are reported as mean (SD).
[b] Total energy content from foods was calculated using (Carbohydrates × 4 kcal/g) + (Protein × 4 kcal/g) + (Fat × 9 kcal/g).

Table 3
Estimated differences and effects [b].

	Adults [c]				Children [c]			
	Total Protein		Meat Protein		Total Protein		Meat Protein	
	Estimated difference	p-value	Estimated difference	p-value	Estimated difference	p-value	Estimated difference	p-value
Menu Difference IN to PL	−10.8 (−24.4; 2.8)	0.118	−5.8 (−13.8; 2.2)	0.154	−5.2 (−12.7; 2.4)	0.175	−2.9 (−8.4; 2.7)	0.307
Time Difference BL to EL	−2.7 (−11.6; 6.2)	0.548	−9.7 (−15.8; 3.5)	0.003[a]	−3.1 (−7.8; 1.6)	0.193	−4.1 (−7.9; 0.4)	0.030[a]
Menu[a]Time	2.7 (−11.2; 16.7)	0.698	2.6 (−6.9; 12.0)	0.594	1.9 (−5.6; 9.3)	0.617	1.7 (−4.1; 7.6)	0.560
Gender Difference F to M	−17.4 (−29.4;-5.3)	0.005[a]	−9.9 (−16.5;-3.4)	0.004[a]	−7.3 (−13.5;-1.1)	0.021[a]	−5.3 (−10.0;-0.7)	0.025[a]
	Estimated effects	p-value	Estimated effects	p-value	Estimated effects	p-value	Estimated effects	p-value
Body weight (kg)	0.0 (−0.4; 0.4)	0.809	0.2 (−0.1; 0.4)	0.161	0.2 (−0.3; 0.7)	0.425	0.2 (−0.1; 0.6)	0.221
Disgust	0.7 (−5.0; 6.5)	0.804	1.4 (−1.8; 4.5)	0.380	−3.5 (−6.8;-0.1)	0.043[a]	−1.2 (−3.7; 1.3)	0.336
Disgust towards insects	−2.0 (−6.8; 2.8)	0.401	1.7 (−0.9; 4.3)	0.194	−1.4 (−3.9; 1.1)	0.271	−0.2 (−2.1; 1.7)	0.835
Neophobia	0.4 (−6.8; 7.6)	0.909	1.0 (−2.9; 4.9)	0.605	1.5 (−2.1; 5.2)	0.400	0.0 (−2.7; 2.8)	0.977
Meat attachment	7.1 (1.2; 13.0)	0.019[a]	3.7 (0.5; 6.9)	0.023[a]	–	–	–	–

Note: IN= Insect-based menu, PL = plant-based menu, BL = baseline, EL = endline, F = female, M = male. Linear mixed model with fixed effects for intervention menu, time, gender, body weight (kg), disgust, disgust towards insects, neophobia, meat attachment, an interaction for time and menu, and a repeated measure for time assessment points.
[a] Denotes significant difference.
[b] Primary outcome.
[c] Total available observations n = 137, BL = 80, EL = 57. Values are reported as estimate of effects (95% confidence interval).

Table 4
Protein intake and calculated weekly meat replacement from 4-day dietary registrations at baseline and endline. [a,d].

	Adults				Children			
	Total protein (g/d)	Meat protein (g/d)	Intervention protein (g/d) [b]	Weekly Meat Replacement (%) [b,c]	Total protein (g/d)	Meat protein (g/d)	Intervention protein (g/d) [b]	Weekly Meat Replacement (%) [b,c]
Insect								
Baseline	79.1 (56.5; 104.8)	28.9 (13.8; 48.1)	–	–	60.5 (46.7; 80.9)	20.4 (11.0; 37.1)	–	–
Endline	73.5 (43.0; 113.0)	15.7 (5.3; 48.2)	4.6 (0.0; 13.8)	5.5 (0.0; 32.2)	55.0 (41.6; 78.9)	17.4 (8.1; 33.1)	1.8 (0.0; 5.9)	2.3 (0.0; 12.4)
Plant								
Baseline	81.4 (54.2; 126.3)	28.8 (13.0; 65.6)	–	–	65.9 (45.7; 84.8)	22.7 (6.1; 36.5)	–	–
Endline	82.6 (51.2; 119.1)	19.3 (5.6; 46.0)	5.6 (0.0; 13.1)	9.0 (0.0; 23.7)	62.8 (38.6; 85.3)	16.1 (5.8; 35.3)	2.4 (0.0; 5.3)	4.3 (0.0; 15.5)

[a] Median (10th percentile; 90th percentile) unless otherwise noted.
[b] Total n = 57; Insect-based menu n = 22; Plant-based menu n = 35.
[c] Median percent. Calculated by 3 x (endline intervention protein x 100)/(baseline meat protein x 7).
[d] Primary outcome.

3.4. Dinner counts and serving sizes

Meals with meat and the intervention foods were recorded. The calculated proportion of serving interprets the self-recorded portion size consumed during the reported meal. Results are depicted in Fig. 2.

Adults in the insect- and plant-based menus consumed an average of 2.8 and 3.0 meat meals per week, with a slight decrease of 0.5 and 0.7 meat meals throughout the intervention period, respectively. Both groups had a proportion of serving result of 1.0, indicating participating adults consumed “about the same amount of meat as [they] usually do.”

Although the intervention was designed to replace meat meals 3 times a week, the average weekly meals with the intervention proteins were 2.0 and 2.3 for the insect- and plant-based menus, respectively. Those following the insect-based menu consumed about half of the designated food portion (proportion of 0.5) while those following the plant-based menu ate more than half of the portion, but not the entire portion (proportion of 0.8).

Children followed similar eating patterns as adults. The insect- and plant-based menu groups consumed an average of 2.9 and 3.1 meat meals per week, with a reduction of 0.4 and 0.7 meals throughout the intervention period, respectively. Children also consumed the same portion size of meat as usual.

The children also did not consume the target 3 intervention meals per week, instead consuming 2.0 and 2.3 for the insect-based and plant-based menus, respectively. Both menu groups only consumed about half the portion designated for children.

Note: PL = plant-based menu, IN = insect-based menu, Prop = proportion. Primary y-axis (left) represents the average weekly meals of the intervention products and meat meals. Secondary y-axis (right) represents the portion sizes of the meal consumed (measured with proportions) where the intervention proportions mean 0.0 = “Did not like/eat the dish,” 0.1 = “Tasted the dish,” 0.25 = “Ate much less than half the portion,” 0.33 = “Ate less than half the portion,” 0.5 = “about half the portion” 0.67 = “Ate more than half the portion,” 0.8 = “Ate much more than half the portion,” 1.0 = “Ate the whole portion” and the meat meal proportions mean 1.5 = “I have eaten much more meat than usual,” 1.25 = “I have eaten more meat than usual,” 1.0 = “I have eaten about the same amount of meat as I usually do,” 0.75 = “I have eaten less meat than usual,” and 0.5 = “I have eaten much less meat than usual.” Error bars indicate standard error.

3.5. Food acceptability

Table 5 shows the ‘overall assessment’ scores of the intervention products. The plant-based products were rated more favorably than the insect-based products by adults. Children rated the plant-based products higher than the insect-based products, with the exception of the insect-based sausage (first exposure), the insect-based mince, and the insect

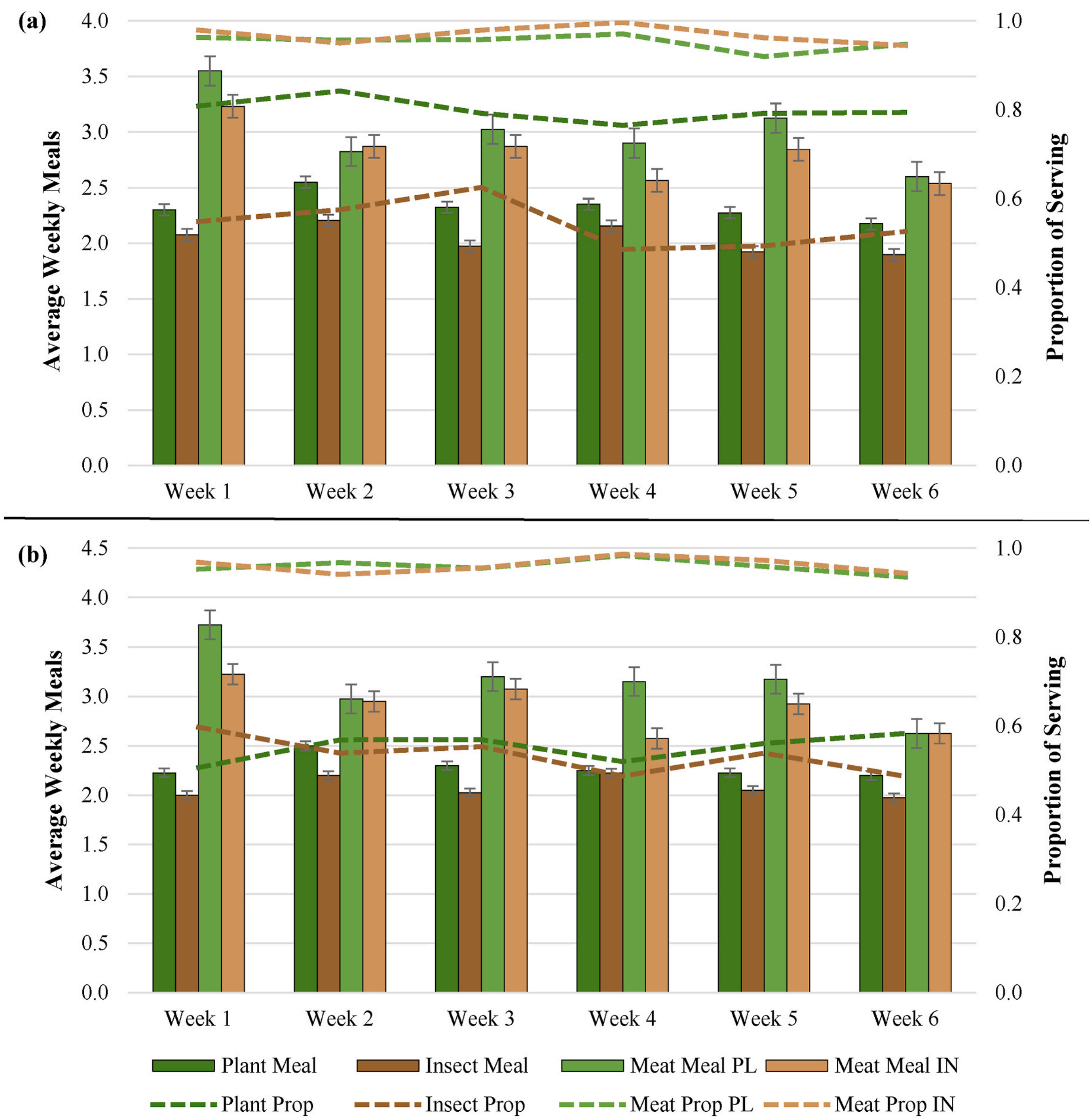


Fig. 2. Change in weekly meals and portion sizes throughout intervention period from daily questionnaires for (a) adults and (b) children.

crispbread (last exposure).

3.6. *End-of-study questionnaire*

Fig. 3 shows the results from the end-of-study questionnaire distributed to adults completing the intervention. Overall, the majority of completing participants had satisfied outlooks following the intervention, agreeing (i.e., slightly agree and above) with statements that reflect a positive impact.

In general, the majority of participants who completed the intervention expressed optimistic attitudes, as suggested by their agreement (i.e., "slightly agree" or higher) with statements reflecting a positive outlook. The plant-based menu received higher positive outlooks compared to the insect-based menu, with the exception of "the experiment has positively changed my view of sustainable food," which indicated a slightly higher percentage of 55% for the insect-based menu and 52% for the plant-based menu.

4. Discussion

4.1. *Participant demographics*

From the start of the study, psychosocial factors indicated that participants were inherently disposed to be receptive towards alternative protein meals.

First, the majority (children and adults) had been tried edible insects before. In recent years, edible insects have gained increased awareness and recognition for their environmental and nutritional benefits. This heightened awareness can be attributed, in part, to the endorsement from the Food and Agriculture Organization (van Huis et al., 2013) and the International Platform of Insects for Food and Feed (IPIFF, 2018), as well as efforts from companies, and academia, which have explored several strategies to increase consumer acceptability. Since 2015, the Danish Veterinary and Food Administration has provided temporary guidelines for food producers for the legal use of certain insect species (Fødevarestyrelsen, 2019). This period of transition, leading up to the full legal coverage by the EU Novel Food legislation, has facilitated increased exposure to consumers. Repeated exposure and strategies to

Table 5
Scores for 'overall assessment' of insect- and plant-based intervention products averaged for adults and children completing the assessment [a].

Product	Adults [b]			Children [b]		
	n	First exposure	Last exposure	*n*	First exposure	Last exposure
Crispbread						
Insect	8	4.6 (0.5)	4.3 (1.4)	7	4.0 (1.6)	4.6 (1.6)
Plant	9	5.9 (0.8)	5.9 (1.2)	9	4.4 (1.7)	4.4 (2.1)
Spice Mix						
Insect	6	4.3 (1.2)	4.2 (0.8)	6	4.3 (2.0)	3.8 (1.5)
Plant	10	5.5 (0.9)	5.5 (1.0)	11	5.0 (1.1)	4.6 (1.6)
Paste						
Insect	8	4.5 (0.5)	4.1 (1.1)	9	3.9 (1.2)	4.1 (1.1)
Plant	10	5.1 (1.0)	4.9 (1.2)	11	5.0 (1.8)	5.4 (1.5)
Mince						
Insect	6	4.2 (0.8)	4.3 (1.4)	6	5.8 (1.1)	5.8 (1.2)
Plant	10	5.2 (0.9)	5.2 (0.9)	9	5.3 (1.6)	5.4 (1.5)
Sausage						
Insect	3	3.7 (1.5)	3.0 (1.7)	4	4.3 (2.4)	2.5 (1.9)
Plant	8	4.8 (0.7)	3.3 (1.6)	7	4.0 (1.9)	3.4 (2.2)
Falafel						
Insect	8	5.1 (1.1)	4.1 (1.5)	7	4.3 (1.7)	3.4 (1.5)
Plant	12	5.6 (0.8)	5.7 (0.9)	10	5.3 (1.5)	5.0 (1.4)

[a] Secondary outcome.
[b] Scores are written as mean (SD) calculated using a 7-point scale where 1 = extremely bad and 7 = extremely good.

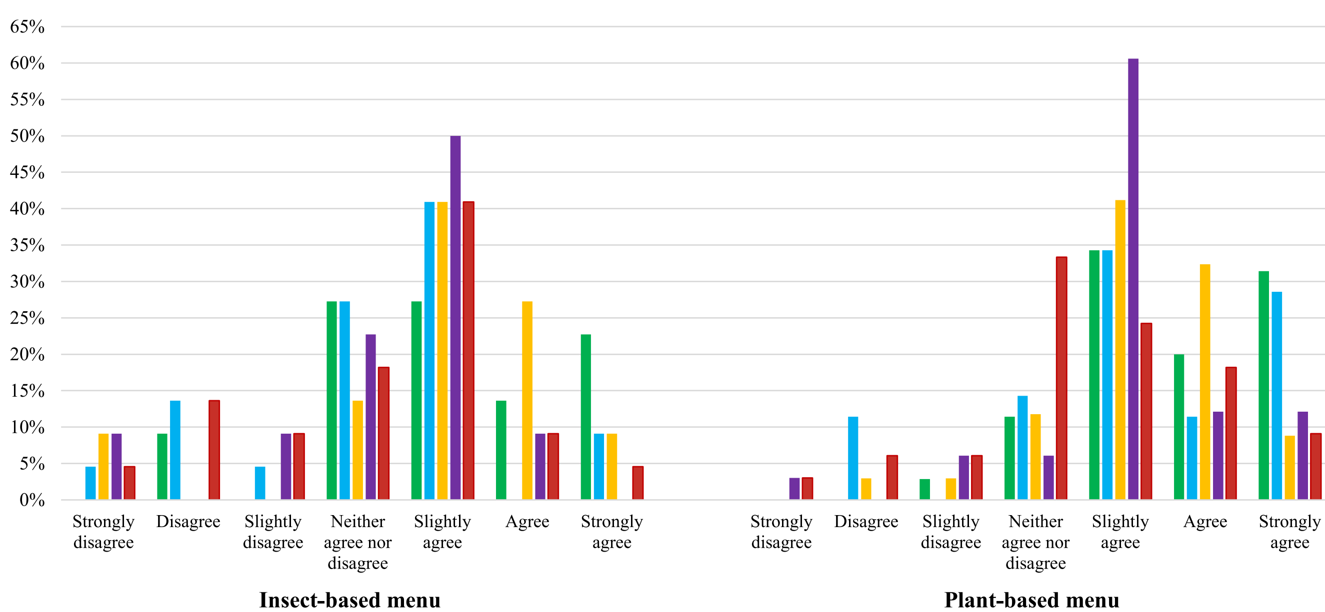
increase the consumers acceptance of insects like information and educational sessions have shown to be a promising methods to expose consumers to edible insects and increase acceptance (Deroy et al., 2015; Marquis, 2023; Sogari et al., 2019). This study, along with the findings of Maya et al. (2023) and Erhard et al. (2023) focusing on Danish children, indicates that prior exposure to insect consumption has become more prevalent. House (2016) discussed the need to shift research from forecasting acceptance to engaging with actual insect consumption. We suggest this becomes increasingly relevant in populations where some familiarity with edible insects is expected. Being aware of sustainability issues can also influence a consumer's tolerability of insect ingredients. Tang and Chung (2023) found that priming with a sustainable eating framework resulted in less sensitivity to the flavor and concentration of mealworm powder in a protein shake, though the long-term effect of such priming is unknown.

Second, participating adults and children had relatively low food neophobia. While the invitations were sent to all families defined by demographic criteria, it was expected that more adventurous food consumers would be attracted to the study and respond to the invitation. In one study, Verbeke (2015) found that food neophobia was a key factor influencing the adoption of insects as a meat substitute, with early adopters displaying lower food neophobia scores being more likely to make the switch.

Third, disgust is often associated with insects in Western cultures and plays another major role in accepting edible insects (Bisconsin-Júnior et al., 2022; Cunha & Ribeiro, 2019; La Barbera et al., 2018; Verbeke, 2015). The adult participants had low food disgust sensitivity and reported even less disgust towards insects. Although children had moderately high food disgust sensitivity, they still displayed low disgust towards insects, similarly to the adults. Those who experience significant fear or disgust towards insects were not expected to respond to the invitation, given their awareness to the random assignment of the intervention menu. As described by Gumussoy and Rogers (2023), people do not 'want' to eat disgust-inducing foods, even if they are tasty, suggesting that those with lower disgust sensitivity may be more willing to accept insect-based foods. For those allocated to the insect-based menu, disgust towards insects did not have statistically significant effect on estimated daily meat protein intake, but the borderline values indicate that insect-disgust score could be further explored as a useful indicator for predicting consumer's meat replacement when exposed to insect products.

When it came to recruiting, a major strength of the study was utilizing the Danish civil registration system to distribute invitations to all relevant families in a given location identified by zip codes. Despite the broad catchment for the invitations sent directly to all relevant families, we observed notable uniformity in demographics of the responders. This consistency suggests an established profile for potential high-chance adopters of edible insects in Copenhagen—higher education, low food neophobia, low disgust sensitivity, and little disgust towards insects.

Meat attachment was the only psychosocial variable that had an



Note: ■ I am more open to trying new and different types of alternative proteins. ■ I will eat alternative proteins as part of my normal diet after the trial. ■ I want to talk to my friends and family about alternative proteins. ■ I will eat more sustainably after the experiment. ■ The experiment has positively changed my view of sustainable food.

Fig. 3. Results of select questions asked post-intervention to adult participants.

effect on meat protein intake. Participants with stronger meat attachment were associated with more daily meat protein intake, but their willingness to take part in the study suggests some awareness of the potential benefits of replacing meat with insect- or plant-based protein. Given that our inclusion criteria was frequent meat consumption, it is reasonable to expect a moderate level of meat attachment among the participants, as opposed to those with already reduced meat intake (i.e., flexitarians or vegetarians). Among our study's participants, some may have exhibited traits of optimistic bias, possibly underestimating their attachment to meat and overestimating their ability to change (Miles & Scaife, 2003) – a concept which may be especially relevant to those who dropped out in the study. However, those who did not drop out can be grouped as "conscious optimists," which refers to those who were hopeful and proactive about making sustainable dietary changes while acknowledging the personal challenges of shifting their meat protein intake and meal habits. While this term is related to the concept of optimism bias, we use the term "conscious optimist" to offer a more nuanced understanding and differentiate those who remained committed to the intervention. This characterization is further supported by baseline meat protein intake; on average, participants consumed less than 350 g of red meat per week, the maximum amount recommended by the latest Nordic Nutrition Recommendations for health and environmental reasons (Blomhoff et al., 2023). Moreover, the majority of participants maintained optimistic attitudes at the end of the study, even if they did not particularly enjoy the intervention foods or faced challenges in replacing meat throughout the intervention.

As highlighted by (Menozzi et al., 2017), attitude can shape intentions, in this context, the intention to consume insect-based foods. Their study found significant correlations between the belief that consuming products containing insect flour has positive health and environmental effects, with both attitudes and intention. These observations aligns with our own study's participants, who also expressed positive attitudes towards the beneficial impacts of incorporating either insect- and plant-based foods into their diets at the end of the study.

4.2. Dietary intake

The Nordic Nutrition Requirements (Blomhoff et al., 2023) reports the total energy requirement is 11.3 MJ/day (approximately 2700 kcal/day) for males and 9 MJ/day (approximately 2150 kcal/day) for females using a PAL of 1.6. Even with a lower PAL of 1.4, both adults and children reported falling short of their estimated energy requirements by around 20%. Energy intake was likely underreported. Whether intentional or not, dietary registrations have historically underreported energy intake (Macdiarmid & Blundell, 1998), and the observed assumed underreporting is within the expected margin.

For the methodology applied using the Danish version of the software MyFood24, a validation study conducted by Koch et al. (2021) found no significant difference in mean energy intake was observed between the MyFood24 software and weighed dietary records. Both approaches underestimated protein intake; specifically, those using MyFood24 reported a protein intake approximately 10% lower than its biomarker. These discrepancies were similar to those that have been reported in other studies and with other dietary assessment tools (Freedman et al., 2014; Koch et al., 2021; Park et al., 2018).

4.3. Consumption and meat replacement

The participants following the insect-based menu replaced 5.5% of meat protein, while plant-based menu replaced around 9.0%. While both of the intervention menus did not reach the 20% weekly meat replacement goal set for the design of the intervention menus. The selection of an arbitrary value meat replacement was a necessary step in order to develop the insect-based products. Insect protein per meal was decided based on the latest national consumption survey in Denmark (Pedersen et al., 2015). The target of 13.4 and 9.7 g of insect protein per meal for the three weekly servings was set to reach a weekly 20% meat replacement was considered an ambitious goal, and challenged the food innovators.

It is important to acknowledge the impact even one meatless meal can have especially with those who are still habitual meat eaters. Substituting one weekly dinner meal to be meatless can reduce environmental impact over time (Ernstoff et al., 2019; Gerbens-Leenes et al., 2013), as well as lead to manageable behavioral changes. However, through modeling various dietary changes across 140 countries, introducing a meatless day yielded minimal impact; replacing meat with low-impact animal foods, including insects, offered a climate impact reduction potential on par with adopting vegan diets (Kim et al., 2020).

The intervention menu had a statistically significant effect on drop out ($p = 0.002$). The odds of dropping out was higher for the insect-based menu compared to the plant-based menu. Those following the insect-based menu had 5.7 times the odds of dropping out compared to the plant-based menu.

Lack of adherence to the diet may have been affected by a combination of introducing a novel food ingredient with known effects to the sensorial properties of the food. Opting for a lower content of insect protein could have resulted in products that would have been easier to integrate into the everyday diet. This suspicion becomes apparent when comparing some of the products. The insect-based mince and sausages did not have large portion sizes, but were rated lower by adults. On the other hand, the crispbread and falafels received favorable ratings, but required larger portions to meet the target protein intake, which was often unmet.

Providing that the participants were habitual meat eaters with moderate meat attachment, the results provide insight to the approach that can be taken for these demographics. Participants consumed 2.0 insect-based meals per week, falling short of the target 3 meals. This suggests that less frequent alternative protein meals may be a more reasonable starting point to lead to a higher and more significant reduction in meat. Such meals can also serve as a complementary alternative in a sustainable dietary transition. While we observed a decrease in the frequency of meat meals among participants, the portion sizes remained unchanged.

4.4. Eating patterns of children

Children, especially when they are younger and more dependent, are influenced by their parents' dietary preferences and habits, including those related to meat consumption (Patrick & Nicklas, 2005; Robinson et al., 2015). The meal count results indicated that children mirrored the meat-eating habits of adults. For the acceptability and overall liking of each of the products, the children showed a stronger preference for intervention foods resembling familiar, or "kid-friendly," dishes such as mince and falafel.

Interestingly, food disgust sensitivity had an impact on children's total protein intake, but it did not affect their meat protein intake. Evidence indicates a strong genetic impact on children's appetite traits, with protein foods like meat displaying a notable genetic influence on sensory acceptance, while other foods, with subtler genetic effects, often require repeated exposure for acceptance (Harris, 2008; Scaglioni et al., 2011).

When targeting a reduction in children's meat protein intake, prioritizing the palatability of more sustainable alternatives is essential to promote acceptability.

4.5. Product feedback

The ratings for intervention foods varied. Both intervention menus had items that were not well-received, but the insect-based menu were seemingly less well accepted overall. Notably, both the insect- and plant-based sausages received lower 'overall assessment' scores, likely stemming from texture issues related to uneven fat distribution, a challenge often observed in meat analogues (Cavalheiro et al., 2023). The familiarity of sausage sets specific taste and texture expectations; if these are not met, there is potential for dislike, regardless of whether the novel product is insect- or plant-based. When it comes to edible insects, taste plays an important role in their acceptance (Zielińska et al., 2020). The insect-based crispbread, resembling regular crackers in appearance, also followed this trend, though changes in texture and aftertaste became apparent over time. The plant-based crispbread and falafel received positive scores upon first exposure, likely due to their existing presence in Danish supermarkets.

For certain products, the 'overall assessment' ratings varied from the first to the last exposure. For instance, scores by children for the insect crispbread increased, possibly suggesting growing acceptance over time, similar to findings by Homann et al. (2017). Decreased scores might result from a decline in quality, monotony, or challenges in adapting to the product.

Disgust is more associated with reduced food wanting than novelty; therefore, careful attention should be given to the tastes and textures of insect-based foods to promote their acceptance (Gumussoy & Rogers, 2023).

This highlights the need to explore the sensory attributes of insect-based foods, particularly in terms of texture and taste, to better understand consumer preferences and aversions, especially when these foods mimic familiar meat substitutes. Additionally, investigating factors that contribute to increased acceptance over time, such as repeated exposure in long-term studies and gradual adaptation, can provide valuable insights for product development in the industry.

4.6. Limitations

The project timeline was interrupted by the COVID-19 pandemic, which severely limited the time that could be taken to run additional sensory tests and conduct product improvements. Results gathered from a Danish population may differ from those of other countries and cultures, so generalizations should be made with caution. We recognize that a direct comparison between the insect-based foods developed within the project and the plant-based foods offered by established companies may not be entirely equitable. Participants in this study were largely open to the idea of insects as food, so generalizations to other consumers should be made with caution. Future research should address these limitations to better support the development of sustainable foods that appeal to consumers and promote dietary changes.

5. Conclusion

Insect-based foods replaced approximately 5.5% of meat protein, while plant-based foods replaced around 9.0% in adult consumers with habitual meat consumption and moderate meat attachment. The majority of individuals exhibited low levels of food neophobia and disgust sensitivity towards food and insects, alongside a "conscious optimist" outlook, demonstrating the significance of these traits in fostering willingness to reduce meat protein intake. Children were influenced by the dietary pattern of adults, but may benefit from more palatable foods. The frequency of meat meals declined, but portions remained the same. Incorporating dinner meals with insect- or plant-based proteins can be a complementary option for reducing meat intake in a sustainable dietary transition. By optimizing the quality of insect- and plant-based foods and understanding the behavior of those willing to adopt these alternatives, we can promote a sustainable dietary shift without compromising nutrition.

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Data sharing

Data described in the manuscript, code book, and analytic code will not be made available because it was not stipulated in our initial ethical approval, and we did not obtain explicit consent from the participants for this purpose.

CRediT authorship contribution statement

C. Maya: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **D.E. Wilderspin:** Data curation, Project administration, Writing – review & editing, Investigation. **A.I.A. Costa:** Conceptualization, Methodology, Writing – review & editing. **L.M. Cunha:** Conceptualization, Methodology, Writing – review & editing. **N. Roos:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare no conflict of interest.

Data availability

The authors do not have permission to share data.

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