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Improving Food Security through Entomophagy: Can Behavioural Interventions Influence Consumer Preference for Edible Insects?

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Abstract: Compared with meats, edible insects taste just as good, are equally or even more nutritious, and have a significantly smaller environmental footprint. However, the adoption of entomophagy is still limited, particularly in Western countries. Considering the environmental benefits of entomophagy and its potential contribution to food security, it is important to understand factors that can influence the willingness to try edible insects as meat substitutes, and policy tools that can encourage the adoption of entomophagy. This research conducts online experiments to test the effect of a wide range of personal traits and a behavioural intervention combining social norm nudges and information boosts. Our findings suggest that behavioural interventions are cost-effective tools to promote the adoption of entomophagy; consumers can be nudged and educated on the basis of the environmental consequences of their individual food choices and are receptive to adopting entomophagy as a sustainable alternative to animal protein.

Keywords: heuristics; behavioural biases; sustainability; conservation; food policy

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1. Introduction

Climate change, food production, and human health share a vicious relationship; food production contributes to climate change which endangers human health, while exacerbating food insecurity in many parts of the world and directly contributing to the spread of infectious diseases [1]. As the global population continues to increase, expected to reach 9.7 billion by 2050 [2], the impacts of the meat industry pose a growing threat to our natural environment as well as food security. Meat production comes with a host of serious repercussions such as acid rain, climate change due to greenhouse gas emissions (GHGs), deforestation, soil erosion, desertification, loss of plant biodiversity, and water pollution [3,4]. With global meat consumption forecasted to increase by 75% from 2017 to 2050, when 465 million tonnes of meat are predicted to be consumed annually [4,5], developing alternative protein sources is crucial for a future of food production that is sustainable and secure [4,6,7].

Entomophagy, the practice of eating insects as food, has recently been receiving more widespread recognition along with growing public interest in adopting more sustainable diets [8]. Entomophagy is not a recent concept; for millennia, a variety of insects have been a part of people's regular diets as a food naturally high in protein and micronutrients [9]. In Asia, Africa, and Latin America, over two billion people consume insects regularly [10], with approximately 2000 species recorded to have been consumed globally [11]. For example, up to 50% of dietary protein consumed in Central Africa is sourced from insects; similarly, an increasing demand for edible insects in Thailand has led to an industrial shift from collection from the wild to construction of mass-rearing facilities [9].

Although meat consumption in developing countries has been increasing fast, per capita meat consumption in developed countries is much higher, especially in North America (see Figure 6.6 in [12]). However, Western countries have been largely reluctant to adopt edible insects as human food. Insects are commonly associated with uncleanliness in many Western cultures, and most consumers are opposed to their consumption [13]. Such preconceptions are implanted through food neophobia, i.e., the fear of eating unfamiliar foods, and a culture that views insects as pests and a marker of filth when associated with food. Additionally, while there is some research on profiling consumers that are more accepting of entomophagy in European countries such as Belgium, Italy, and Portugal [14–18], there is limited research involving controlled experiments testing interventions to improve consumers' attitude towards entomophagy.

To better understand how entomophagy may be more accepted by Western societies, our research asked two questions. First, what are the factors that can influence consumers' willingness to try edible insects? We will consider the knowledge of and attitude towards entomophagy, environmental consciousness, and demographic factors as suggested in existing literature. Data will be collected from the U.S., one of the largest emitters of CO_2 from agricultural production in the world, where empirical evidence on the acceptance of entomophagy is lacking. Second, do behavioural interventions increase the willingness to try edible insects as meat substitutes? Behavioural insights have been applied in environmental studies extensively in the last decades and have proved to be both effective and cost-efficient [19,20]. Some popular behavioural tools, such as nudges, have been applied to encourage healthy food choices as well [21]. Also, past studies indicate people's food choices can be changed through increasing exposure to edible insects, decreasing food neophobia, and altering attitudes to entomophagy [13,14]. Therefore, we design a behavioural intervention that combines social norm nudges and information boosts, and test if this treatment could significantly improve the willingness to try edible insects as a sustainable meat alternative, specifically for consumers in the United States.

Our analytical framework and hypotheses are tested by conducting an online experiment with participants from New York City, U.S., recruited through Amazon MTurk. Empirical findings suggest that not only consumers' demographic characteristics and existing knowledge and attitudes of entomophagy can affect their willingness to try edible insects, but also behavioural interventions are a cost-efficient way to encourage the adoption of entomophagy amongst a non-negligible effect size. Consumers in Western countries are ready to be educated on the environmental consequences of their individual food choices and are receptive to adopting entomophagy as a sustainable alternative to animal protein.

The rest of the paper is organised as follows. A systematic and critical review of related literature is given in Section 2. Data and methods are presented in Section 3, followed by discussions on empirical findings in Section 4. The final section gives policy implications and conclusions.

2. Literature Review

2.1. Environmental Benefits of Entomophagy

The environmental benefits of substituting meat protein with edible insects have been demonstrated in past studies on entomophagy [4,6,7,10,22,23]. The environmental advantages of insect farming can be categorised into four areas: high feed conversion efficiency, decreased land use, reduced water use, and lower GHGs.

Traditional meat production is highly inefficient; accounting for grazing pastures and land used to grow livestock feed, livestock is responsible for 77% of farming land worldwide while producing only 18% of the world's calories [24]. Land use of mealworms, a common edible insect, is much lower than that of chicken (130 to 185% higher), pork (157 to 249% higher) and beef (689 to 1312% higher) [23]. Similarly, the water usage of insect production is much less than that of traditional livestock. A comparison of litres of water needed per gram of protein found that insects need 56 times less water than beef, 28.5 times less than pork, and 17 times less than chicken [25]. The FAO stated that agriculture is responsible for 70% of global freshwater withdrawals [26]. While the most direct form of water usage from livestock is feed production, the consequences of water pollution cannot be understated. In the U.S., the livestock sector produces 55% of total freshwater erosion in addition to pollution by pesticides (37% of total pesticide-produced pollution) and antibiotics (50% of total antibiotic-produced pollution) [27].

Compared to that of mealworms, the global warming potentials (GWPs) per kilogram of edible protein of chicken (32 to 167% higher), pork (51 to 287% higher), and beef (452 to 1151% higher) are much greater. In comparison, for 1 kg of edible insects compared to the same amount of meat from ruminants such as beef, insects produce up to 100 times less GHGs [28]. Evidently, compared to beef, cattle, and chicken, insects have the smallest overall carbon footprint and are a protein source much more suitable for climate change mitigation. Entomophagy presents a sustainable strategy to decreasing the environmental harm of people's food choices; research found that if meat consumption was halved and replaced with insects, this alone would free up approximately 1680 million hectares of land, equivalent to 70 times the size of the United Kingdom [10].

2.2. Improving Food Security through Entomophagy

With more than two billion people worldwide that are malnourished, global hunger is a serious challenge that is expected to worsen as population growth coupled with climate change undermine the planet's ability to fulfil the nutritional needs of the human population [29]. Furthermore, protein deficiency is a longstanding issue that disproportionately affects low-income people worldwide [8]. Entomophagy could be a potential component of the planet's strategy to resolving the global climate crisis.

While nutritional composition varies by insect species, data from 236 edible insect species demonstrated that they sufficiently fulfil humans' requirements for energy, protein, amino acids, lipids, and several minerals and vitamins; in particular, insects contain a high iron and zinc content compared to ruminant meats, especially valuable in improving the issue of malnutrition in developing countries, which experience significant levels of zinc and iron deficiencies [11,30,31].

In comparison to Ready-to-Use Therapeutic Food (RUTF) such as milk powder that must be imported and is rarely locally available in malnourished communities, insects can be reared directly at the country where relief is needed. Particularly in regions where cultivation of vertebrate livestock is infeasible or unaffordable, edible insects are less resource-intensive and more resistant to drought and disease than more traditional livestock [8]. Consequently, entomophagy presents both a low-cost and efficient method of improving livelihoods and regular diets among vulnerable people [11]. There is precedent of substantial production systems used to produce insects for biological control, the technology of which could be applied to develop systems to produce edible insects on a large scale without much difficulty [32].

However, consumers in Western societies are generally detached from the immediate and severe need for nutritional security in other parts of the world. More than seven times the grain directly eaten by the entire U.S. population is used as feed for livestock just in America [33]. By 1997, 85% of the world's grain supply was being produced and imported for livestock feed in industrialised nations [34]. It is unrealistic to assume that food insecurity in less-developed countries is simply a distribution problem [7]. If we do not alter our food choices and choose to continue to ingest meat at the current rate, by 2050 we will need to have increased meat production by 73% to feed the potential population of 9.7 billion, an impossibly dangerous feat considering the environmental consequences [29]. Appealing to Western consumers' environmental consciousness and improving their awareness of the potential for entomophagy may be an effective strategy to sensitise the benefits of eating insects as a substitute for meat, providing a direct and personal connection between consumer action and environmental impact through food choices.

2.3. Factors Influencing the Willingness to Try Entomophagy

The current literature has contrasting results on the subject of Western countries' attitudes towards consuming insects. For example, a study in Belgium in 2011 found that there was little to no acceptance in eating insects as a protein food source, with a mere 5% of the sample being willing to eat insect protein [35]. In contrast, 19.3% of a sample of 368 Belgian meat consumers were willing to adopt insects as a "foodstuff" and while this is not the majority, it revealed that there was a portion of the consumer population that expressed readiness towards entomophagy [14].

The differences in the findings regarding people's attitudes on entomophagy in Western countries can be attributed to a few potential factors. First, past studies with results wherein the majority of participants expressed aversion to edible insects did not include tasting sessions and subjects formed their opinions based solely on non-experimental information such as emotions, memories, or self-purported knowledge [35,36]. Megido, Gierts, Blecker, Brostaux, Haubruge, Alabi and Francis [17] identified knowledge of entomophagy and prior experience as two major factors affecting subjects' acceptance of insect-based food products. Therefore, consumer knowledge and experience construct significantly impacted general attitudes towards insect-based food, consistent with previous theories in consumer research [18].

Second, general attitudes were found to be a strong indicator and key factor of participants' willingness to buy edible insects, reflecting Northern and Central European participants' lack of exposure to insects as a novel food [18]. For instance, Verbeke's research identified food neophobia and meat-related attitudes as influencers for the willingness to try entomophagy for people in Belgium [16]; Florenca, Correia, Costa and Guine [16] found that food products containing processed insects had a greater chance of being accepted compared to whole insects, which aligned with consumers' attitudes to traditional animal meats.

The current literature also illustrates the effects of environmental consciousness on people's food choices. Consideration of environmental impact is one of the key determinants of consumer acceptance of novel foods [37]. While there is limited research in this area, a few studies indicated that motivation towards sustainable food consumption was a notable influence on people's adoption of edible [11,14,38]. While Mancini et al. [39] inferred that a seminar on edible insects mitigated feelings of disgust, this research did not have a control group to ensure whether the change was caused by the intervention; additionally, the seminar was a combination of the ecological, health, and gastronomic aspects of entomophagy, making it difficult to conclude that the results were a direct result of environmental information [39]. Further investigation is needed along this promising line of research.

Past studies also identified a wide range of demographic factors that affect Western consumers' willingness to try entomophagy, such as gender, age, and occupation. For example, males are more likely to try edible insects [17], older people are less willing to adopt entomophagy [14], and people's field of occupation was found to be a factor in people's willingness to buy [16]. Following the practice in the literature, we include these factors in our empirical investigation as well.

2.4. Behavioural Interventions in Environmental Studies

In recent years behavioural interventions—interventions that are neither monetarily incentivising nor legally/regulatorily coercive—have been extensively applied in environmental studies. Several recent meta-analyses and systematic review of the literature demonstrate the scope and potential of this line of research. Palm-Forster et al. [40] surveyed applications of nine behavioural tools (messenger, incentives, norms, defaults, salience, priming, affect, commitment, and ego) in the design of evidence-based, cost-effective agri-environmental programs to mitigate environmental damages and promote the supply of environmental benefits from agricultural landscapes. Khanna, Baiocchi, Callaghan, Creutzig, Guias, Haddaway, Hirth, Javaid, Koch, Laukemper, Loschel, Dominguez and Minx [20] and Buckley [41] contrasted the effect of both behavioural interventions and monetary incentives in reducing energy consumption and CO_2 emissions in residential buildings. They not only confirmed the positive effect of both monetary and non-monetary interventions on reducing the energy consumption of households, but also highlighted the potential benefits of deploying the right combinations of interventions. The most comprehensive review on this topic to date is Nisa, Belanger, Schumpe and Faller [19], which covers six aspects of household activities that contribute to climate changes (i.e., energy, car use, water, food waste, meet, and recycling) and five groups of behavioural interventions (i.e., information, social comparison, engagement, appeals, and nudges). By analysing 144 estimates from 83 randomised controlled trails, they concluded that although the effect is statistically significant, the effect size is small with no evidence of sustained positive effects once the intervention ends. Their findings highlight the importance of combing different behavioural interventions, the use of the two most effective behavioural stimuli (i.e., nudges and social comparisons), and the study of the long-term effect of behavioural interventions in future research.

To better understand and choose among the wide range of behavioural tools for environmental studies, it is helpful to classify these behavioural interventions into two broad categories: nudges and boosts. Nudges [42] leverage behavioural heuristics in the design of choice architecture to induce desirable actions for both the individual and the society, such as using green electricity defaults to increase the uptake of renewable energy [43]. Boosts [44], on the other hand, focus on changing existing behavioural heuristics or establishing new ones to support environmentally friendly actions, such as providing home energy report with personalised energy use feedback and energy conservation information to encourage energy savings [45]. In other words, nudges are manipulating tools, while boosts empower people. Generally speaking, nudges are easier and quick to implement, but the effects tend to be short-lived; boosts require more time and resources to affect behaviours, but tend to remain effective for a longer term because "they have become routinised and have instilled a lasting competence in the user" [46] (pp. 1106).

Both types of behavioural interventions have also been applied to the food industry to reduce carbon footprint and encourage sustainable consumption behaviours. For example, green nudges have been found to be effective in promoting sustainable practices along the food supply chain, such as encouraging farmers to participate in pro-environmental schemes, choosing plant-based dishes when eating out, and reducing food waste [47]. In their review of 23 studies between 2011 and 2019, Abrahamse [48] summarised the positive effect of five behavioural interventions (i.e., nudges, carbon and environmental labels, information provision, visual prompts, and social norms) in encouraging sustainable food choices such as local and organic food consumption, reducing meat and dairy intake, and reducing food wastes. Recognising the potential of behavioural interventions in food policy designs, they call for further behavioural investigations with the consideration of possible moderators and mediators (such as attitude and beliefs) and long-term effect measurements of behavioural interventions.

Existing evidence indicates that both nudges and boosts are effective in encouraging positive actions in environmental protection and conservation in general, and, in particular, sustainable food consumption. Yet the effects vary significantly among studies. For example, boosts are effective only when combined with nudges in energy saving experiments in Monaco [49], while video information boosts outperform nudges in increasing acceptance of recycled water in the US [50]. Therefore, the effectiveness of behavioural interventions is context-specific, and subject to the influence of many possible moderators and mediators such as environmental consciousness (see, for example, [49]). Our literature review reveals that, although the potential of behavioural intervention in increasing the acceptance of entomophagy is significant, there are limited studies in this research stream. Our research sets off to fill this gap in the literature. An analytical framework is developed in the next section based on the literature summarised above.

3. Analytical Framework

Taking stock from existing literature, we develop an analytical framework by combining Ajzen's Theory of Planned Behaviour (TPB) theory and the model developed by [51].

Ajzen's Theory of Planned Behaviour (TPB) states that an individual's actions can be determined by behavioural intention, influenced by socio-cognitive factors including attitude towards the behaviour in question and subjective norms [52,53]. Conversely, the individual's intention, which indicates the subjective possibility of a specific action, can be used as a measurement for said behaviour [54]. Purchase intention of green consumer household products was found to be significantly correlated with willingness to pay, environmental consciousness, and attitude toward the behaviour, among others [55]. Situated in Ajzen's theory, this current experiment evaluated subjects' willingness to try edible insects through collecting data on purported intention of actually practising insect consumption.

The overarching purpose of this research is to test whether environmental consciousness and behavioural intervention could invoke a significant improvement in a subject's willingness to try edible insects (*WTT* hereafter). Applying TPB, the results regarding participants' intentions were interpreted as predictors of the actual likelihood of behavioural change in food consumption, specifically substituting meat with insects. This motivation was supported by current literature that found an increase in environmental consciousness to be positive and significant for choosing environmentally-conscious products [53,56–58]. Behavioural intention can be determined by the general attitude towards a subject, which when applied to the research was tightly related to people's stated *WTT* [18].

We then proceed to use [51] general framework of societal and biological factors influencing the behaviour of societies that decide the shift from entomophobic to entomophilic to determine the explanatory variables in our study. Svanberg and Berggren's [51] model consists of four dimensions: legal and regulatory environment, societal influence, insects knowledge, and biological and social factors of individuals (see Figure 1 in [51]). We omitted the legal and regulatory dimension because our study focuses on cross-sectional analysis within a homogenous legal and regulatory environment (i.e., the New York City), and modified the other three aspects according to the nature of the objects and subjects in our study.

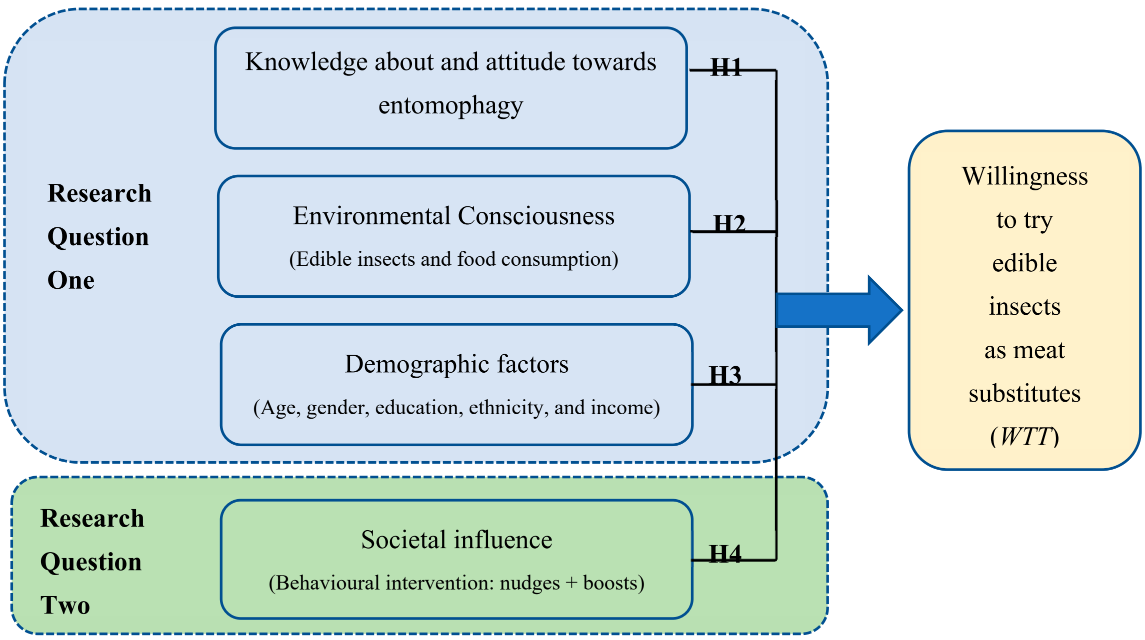


Figure 1. Analytical Framework.

In the societal influence dimension, Svanberg and Berggren considered government, commercial interests and social influence (including tradition). We include a behavioural intervention that combines information boosts and social norm nudges in this dimension. Because entomophagy is a relatively new concept to the target respondents in our study (i.e., New York City), the influence should be imposed by providing information on the benefits and positive aspects of entomophagy, especially regarding environmental conservation and food security. The framework in Grune-Yanoff et al. [59] also suggests that boosts should be considered because the acceptance of entomophagy depends on agent motivation (i.e., respondents will not act subconsciously when choosing edible insects as meat substitutes) and teachability (i.e., via the provision of information). Meanwhile, environmental protection and sustainability have become social norms, of which the nudging effect cannot be overlooked. In response to the call for combining behavioural tools in the literature, we include design text messages and infographics on the environmental and societal benefits of entomophagy in this dimension of the framework. The effect of these behavioural interventions will be tested by comparing the reported *WTT* between the control and the treatment groups.

Next, we divide environmental consciousness in three levels: specific to edible insects, food consumption, and general environmental attitude regarding the relationship between nature and human beings. Environmental consciousness is a rather broad and vague concept for the general public. If not finely defined and explicitly framed, respondents will likely choose answers that they believe to be (politically) correct, instead of providing genuine answers to the questions. This research design will enhance our understanding of the heterogenous effects of environmental consciousness on *WTT*.

Finally, we use a measure of food neophobia to capture the knowledge about and attitude towards entomophagy. A wide range of demographic factors are also included in the framework to control for the variations of personal traits among respondents. The relationship between *WTT* and its determinants are shown in Figure 1. The factors to be used to answer the two research questions are also illustrated by dividing the four groups of determinants into two boxes. Taking stock of existing literature, a total of four hypotheses are derived from the analytical framework as follows.

Hypothesis 1. (H1). *Knowledge about and attitude towards entomophagy affect WTT.*

Hypothesis 2. (H2). *Environmental consciousness and WTT are positively associated.*

Hypothesis 3. (H3). *Demographic factors affects WTT.*

Hypothesis 4. (H4). *Environmental information nudges improves WTT.*

4. Experiment Design and Implementation

4.1. Experiment Design

An experiment was conducted via a questionnaire survey that consists of a combination of original, adapted, and extracted questions on subjects that past studies on consumer preferences regarding edible insects have found to be influential [14–18]. Following Cicatiello, De Rosa, Franco and Lacetera [15], the questionnaire was divided into three parts: food purchasing behaviours and environmental awareness, attitude towards entomophagy, and subject demography.

The first section on food purchasing and environmental awareness began by asking respondents to score their agreement on a 7-point Likert scale for the statement: "Animal protein is a part of my regular diet (meat, milk and dairy, eggs, fish, etc.)". This question was to assess whether or not the subject was a consumer of meat/animal products.

Next, food neophobia was measured on a 7-point Likert scale with four statements selected from the food neophobia scale by Pliner and Hobden [60] and used by Verbeke [14] which were: "I am constantly sampling new and different foods", "I don't trust new foods", "If I don't know what is in a food, I won't try it", and "I will eat almost anything" [14,60].

Then, the subject's environmental awareness when making food choices was measured on a 7-point Likert scale with the statement: "When I buy foods, I try to consider how my use of them will affect the environment". Similarly, the subject's environmental consciousness in general consumption was assessed using the statement: "I buy eco-friendly (e.g., organic, local, free-range, etc.) products on a regular basis". Lastly, general environmental attitude was measured by three items sourced from DeChano [61] and Hiramatsu et al. [62]. The three statements were selected for being phrased negatively to account for acquiescence bias, or "yes-bias" which conditions participants to be more likely to agree with a given statement separate from the statement's content, particularly in the context of environmental consciousness [62]. The items were: "Humans have the right to modify the natural environment to suit their needs", "The balance of nature is strong enough to cope with the impacts of modern industrial nations", and "Individual action will not improve the environment" [61,62].

In the second section, respondents were randomly allocated in either a control or treatment group. Both groups were asked questions about their prior familiarity with edible insects on a 7-point Likert scale and their willingness to try entomophagy was assessed by scoring three statements on a 7-point Likert scale: (1) "I would try at least one of these products if it was available in the grocery store I was shopping at" alongside six examples of food product concepts containing insects that were designed by a gastronomist based on focus group discussions (sourced from [18]), (2) "If there was edible insect-based foods for sale in regular grocery stores, I would buy it" and (3) "I would be willing to try edible insects as a substitute for meat". About half of the respondents were randomly allocated to a treatment before answering the question about their willingness to try entomophagy. The treatment group was exposed to a behavioural intervention that combines information boosts and social norm nudges. The control group proceeded with the rest of the survey without being exposed to this treatment.

The behavioural intervention consisted of two parts. First, a brief introduction on the concept of edible insects, facts and figures on the rate of increase of global meat consumption, data on the annual amount of GHGs generated by livestock production, and the statement that "A global transition towards low-meat diets may reduce the costs of climate change mitigation by as much as 50 percent in 2050" [63]. This is the information 'boost' part of the behavioural intervention. Second, the text concluded with "You can help save our planet with your food choices", following prior literature suggesting that reminding consumers about the capability of an individual to make a difference can effectively encourage pro-environmental behaviour [64]. The information provided was selected to represent environmental impact on a global scale, following research that people were more prone to pro-environmental behaviour when environmental issues were framed on the global rather than local level [65]. This is the nudge (i.e., social norm) part of the behavioural intervention.

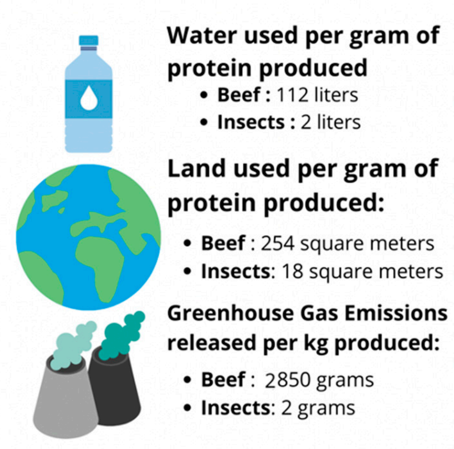
For the entire treatment group, five lines of texts (Table 1) and two infographics were provided (Figure 2): one original image compared water usage, land usage, and GHG emissions between beef and insects, while the other (sourced from [66]) compared the amount of feed required to produce 1 kg of animal weight between beef, pork, poultry, and insects (adopted from [66,67]). We built in a two-minute timer for this part of the questionnaire and required the respondents to check a box next to each message/infographic before proceeding to the next question.

The third and last part of the questionnaire analysed the subject's demography, asking particular questions that were shown to be influential factors in consumer preferences in past studies. The characteristics asked were age, education, gender, ethnicity, and annual income.

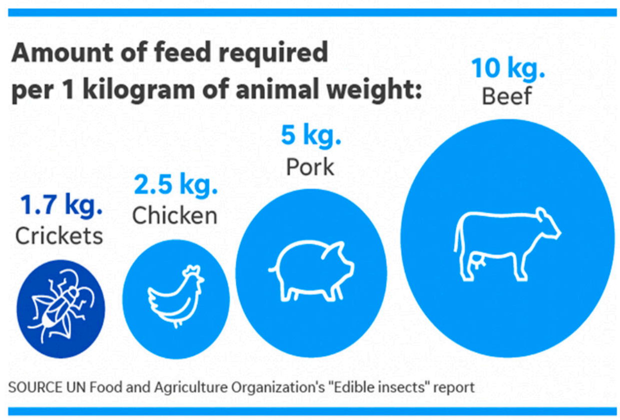
Finally, we conducted a pilot survey for 15 people and through feedback adjusted the time duration of the treatment, corrected textual errors, and clarified terms that were overly technical. Ethical approval was obtained from the Research Committee of the Department of Land Economy, University of Cambridge.

Table 1. Text messages displayed to the treatment group.

No.	Text Message
1	Edible insects are insect species that are used for human consumption, whole or as an ingredient in processed food products such as burger patties, pasta, or snacks. While edible insects have been a traditional part of people's diets in other countries for millennia, the United States is recently being introduced to edible insects as a sustainable alternative to traditional meat.
2	Global meat production has nearly quadrupled during the past half-century with a 380% increase from 71 million tons over 240 million tons. This trend is expected to continue to 465 million tons of meat consumed in 2050. Livestock production generated 3 million tons of carbon dioxide in 2018, equal to 80% of the total GHG emissions of the global agriculture industry.
3	The consequences of meat production include acidification, climate change due to GHGs, deforestation, soil erosion, desertification, loss of plant biodiversity, and water pollution.
4	The world's cattle alone consume a quantity of food equal to the caloric needs for 8.7 billion people—more than the entire human population on earth (PETA).
5	You can help save our planet with your food choices.



(**a**) Infographic 1



(**b**) Infographic 2

Figure 2. Infographics provided in treatment regarding environmental impact of proteins.

4.2. Sample and Data Collection

Cross-sectional data were collected from a sample of 393 adults (18 years and older) in the state of New York, United States, during June and July 2021. The U.S. is the fourth largest emitter of CO_2 from agricultural production at a total of 360 million tonnes per year [68] and the greatest consumer of annual meat consumption per capita among OECD countries with the average citizen eating 99 kg of meat annually [69]. Consequently, for entomophagy to produce significant progress towards climate change mitigation, it is critical to conduct research on people's attitude towards entomophagy in other Western countries, specifically the U.S., aside from European nations. We chose the state of New York as our test ground because we hypothesised that it was more likely for residents in large metropolitan areas to adopt innovative ideas and unconventional products.

The experiment was conducted at Amazon MTurk, which is a widely used online panel data platform for online survey and experiments [70,71]. Under the assumptions of a 95% confidence interval and a margin of error of 5%, the minimum sample size was estimated to be 385. (We calculate the target sample size by using the sample size calculator from Qualtrics.com, which is one of the largest online survey and experiment platforms. Our questionnaire was designed at this platform and later distributed via MTurk. The calculation is based on an estimated population size of ten million. Details can be found at https://www.qualtrics.com/blog/calculating-sample-size/, accessed on 27 February 2022.) Our sample size of 393 meets this criterion. A total of 198 valid responses were collected in the control group, and 195 in the treatment group. The small difference in size between groups is predicted to be random and not of serious concern as the profile of the two groups are largely similar (see Table 2). The data collection portion of the survey consisted of 14 Likert-scale questions and 6 demographic questions. The participants' incentive to complete the survey was a small monetary reward. The average duration of the survey was 4 min and 32 s, and each survey cost $1.40 USD.

Table 2. Demographic statistics of sample (%).

Variable	Values	Whole Sample (n = 393)	Control Group (n = 198)	Treatment Group (n = 195)
Gender	Female	48.85	50.00	47.69
	Male	48.09	46.97	49.23
	Non-binary	2.29	2.53	2.05
	Transgender	0.51	0.51	0.51
	Other	0.25	0.00	0.51
Age (years)	18–24	12.21	11.62	12.82
	25–34	41.48	44.95	37.95
	35–44	25.19	23.23	27.18
	45–54	11.96	11.62	12.31
	55+	9.16	8.59	9.74
Education	Elementary/Primary	1.02	2.02	0.00
	High School/Secondary	14.76	15.66	13.85
	Post-secondary/College	84.22	82.32	86.15
Ethnicity	Asian-Pacific Islander	13.23	12.12	14.36
	Black/African American	9.16	8.59	9.74
	Hispanic/Latino	7.89	8.08	7.69
	Native American/Alaskan Native	1.78	1.52	2.05
	White/Caucasian	63.87	65.66	62.05
	Multiracial/Biracial	3.31	3.54	3.08
	Other	0.76	0.51	1.03
Income ($)	0	2.29	3.03	1.54
	1–9999	10.18	10.10	10.26
	10,000–24,999	10.69	13.13	8.21
	25,000–49,999	23.92	25.25	22.56
	50,000–74,999	28.24	22.22	34.36
	75,000–99,999	10.18	12.12	8.21
	100,000–149,999	6.36	6.57	6.15
	150,000+	3.82	3.03	4.62
	Prefer not to answer	4.33	4.55	4.10

The demographic features of the total sample, the control subgroup, and the treatment subgroup are presented in Table 2. As these factors could potentially bias the study's results, independent samples t-tests were conducted for all demographic variables of the sample to ensure that the variation between control and treatment groups was insignificant; the p-values for age (0.50), education (0.15), income (0.37), gender (0.53), and ethnicity (0.47) were all greater than 0.05, confirming the null hypothesis that both groups had equal means for all demographic factors. Our sample consists of young and educated individuals from a large metropolitan area, who are more likely to adopt innovative ideas and unconventional products. As a result, our sample is representative of the target population—residents of developed countries where resistance to entomophagy is more common. This ensures the external validity of the study.

4.3. Statistical Methods

A subject's willingness to try edible insects (*WTT*) was identified as the dependent variable. The responses to the corresponding survey question were re-coded as a discrete "yes" or "no" binary decision; the Likert-scale answers "strongly agree", "agree", and "somewhat agree" were analysed as a "yes" and the rest as a "no". Following the practice in the literature, we adopted a dichotomous segmentation for a product that is infrequently purchased and/or there is a strong attitude toward the product, both of which apply to edible insects in Western countries [14,15].

The discrete decision was modelled using a binary logistic regression model following Cicatiello, De Rosa, Franco and Lacetera [15] and Verbeke [14]. The binary dependent response *WTT* is a function of K explanatory variables, denoted x_{ki}, where $k = 1, \ldots, K$ for the individual i ($i = 1, \ldots, n$). Besides the demographic factors listed in Table 1, we also include six more explanatory variables that are generated from the experiments: *Meat* (animal protein consumption), *AvgNeo* (average score of food neophobia), *Envfood* (environmental consideration in food choices), *Envcon* (tendency to purchase eco-friendly in daily consumption), *AvgEnv* (awareness of human impact on the natural environment), and *Exp* (familiarity with entomophagy). Thus, the purpose of the logistic regression was to analyse the relationship between the explanatory variables and the dependent variable, the willingness to eat insects. The probability of success is written as $p_i = P(WTT_i = 1 \mid \mathbf{X})$, where $\mathbf{X}$ is the matrix of all independent variables considered. The relationship can be written as:

$$WTT_i = \beta_0 + \sum_{k=1}^{K} \beta_k x_{ik} + \gamma Teatment_i + \varepsilon_i \quad (1)$$

where $Teatment_i = 1$ if individual i is from the treatment group, and zero otherwise. $\beta_0, \beta_1, \ldots, \beta_k$ were the coefficients that capture the effect of the explanatory variables that were to be estimated. γ measures the effect of the information nudges that we implemented in the experiment. Specifically, we use the estimates of βs to answer the first research question, and the estimate of γ to answer the second research question.

5. Empirical Findings

5.1. Descriptive Statistics

In Table 3 we report the mean responses to questions in parts I & II of the questionnaire, as well as variables that we generated based on these questions. The average value of *WTT* indicates that 51% of the respondents in the treatment group would be willing to try entomophagy, whereas 41% of the control group answered as such. Past studies reported lower scores: Cicatiello, De Rosa, Franco and Lacetera [15] found 31% to be willing; Vanhonacker, Van Loo, Gellynck and Verbeke [35] found 5% to be willing; and Verbeke [14] found 19% to be "willing or ready" to adopt edible insects as a meat alternative. This could be due to a few reasons: the increased interest that entomophagy has received in the past few years following the aforementioned studies, the development of insect-incorporated food products rather than whole insects, and the food culture in New York, which is characterised by an innovative restaurant scene and may be less traditional than other less urbanised areas.

Table 3. Mean responses to questions in parts I & II of the questionnaire.

Variable Name	Question or Definition	Whole Sample (n = 393)	Control Group (n = 198)	Treatment Group (n = 195)	*t*-Test Statistics (*p*-Value)
Neo1	I am constantly sampling new and different foods. (R)	3.24	3.32	3.16	1.07 (0.28)
Neo2	I don't trust new foods.	3.03	2.92	3.13	−1.42 (0.16)
Neo3	If I don't know what is in a food, I won't try it.	3.91	3.84	3.98	−0.76 (0.45)
Neo4	I will eat almost anything. (R)	4.02	4.02	4.03	−0.09 (0.93)
Neoscore	$= \frac{(Neo1+Neo2+Neo3+Neo4)}{4}$	3.55	3.53	3.58	−0.41 (0.68)
Envfood	When I buy foods, I try to consider how my use of them will affect the environment.	4.03	3.97	4.09	−0.69 (0.49)
Envcon	I buy eco-friendly (e.g., organic, local, free-range, etc.) products on a regular basis.	4.30	4.18	4.42	−1.33 (0.18)
Env1	Humans have the right to modify the natural environment to suit their needs. (R)	4.15	4.18	4.11	0.45 (0.65)
Env2	The balance of nature is strong enough to cope with the impacts of modern industrial nations. (R)	4.62	4.67	4.56	0.61 (0.54)
Env3	The so-called ecological crisis facing humankind has been greatly exaggerated. (R)	5.12	5.24	4.99	1.34 (0.18)
Envgen	$= \frac{Env1+Env2+Env3}{3}$	4.87	4.96	4.78	1.07 (0.28)
Exp	How familiar are you with the concept of eating insect-based foods?	5.02	5.22	4.82	2.58 (0.01)
Meat	Animal protein is a part of my regular diet (meat, milk and dairy, eggs, fish, etc.).	5.93	5.83	6.02	−1.23 (0.22)
Will1	I would try at least one of these products if it was available in the grocery store I was shopping at.	3.69	3.50	3.88	−1.87 (0.06)
Will2	If there was edible insect-based foods for sale in regular grocery stores, I would buy it.	3.38	3.24	3.53	−1.58 (0.11)
Will3	I would be willing to try edible insects as a substitute for meat.	3.56	3.44	3.68	−1.23 (0.22)
WTT	$= 1$ if $\frac{Will1+Will2+Will3}{3} > 4$, and 0 otherwise.	0.46	0.41	0.51	−1.97 (0.05)

Note: (R) means the original answers were reverse-coded. For example, if someone chose 6 (Agree) in question "I am constantly sampling new and different foods", it was coded as 2 for variable Neo1, which serves as a measurement of the level of neophobia. We include reverse-coded questions to reduce acquiescence bias, or "yes-bias" which conditions participants to be more likely to agree with a given statement separate from the statement's content, particularly in the context of environmental consciousness. All questions were measured on a 7-point Likert scale.

The data stated that approximately three-quarters (74.3%) of subjects were familiar with entomophagy (i.e., *Exp* = 5, 6, or 7), a higher statistic compared to research in Portugal [16%; 16], Belgium [39%; 17], and Italy [5%; 15]. Perhaps the innovative and ethnically diverse food culture of New York could be one explanation; however, the questionnaire did not specify whether subjects' experience included actual consumption of insects, which might have produced a lower statistic. We also noted that there are more respondents who are familiar with the concept of eating insect-based foods in the control group, i.e., 77.73% in the control group versus 70.77% in the treatment group. The difference in the mean responses to the *Exp* question is significant at the 1% level. This is a result of the random allocation of respondents in the two groups. As shown in the last column in Table 3, this is the only factor that is significantly different between the two groups.

We conducted two independent samples t tests on the mean score of *WTT* between the control and treatment groups, and found the difference is significant at the 5% level (p-value = 0.0493). This is a preliminary result indicating the positive effect of the environmental information nudge. However, due to the difference in familiarity with the concept of eating insect-based foods between the treatment and the control group, albeit small in size (i.e., 5.22−4.82 = 0.40 points), we proceed to estimate a logistic regression model to control for the heterogeneity among respondents.

5.2. Logistic Regression Results

We estimated four logistic models as reported in Table 4. Model 1 consists of an intercept term and the treatment indicator only. The coefficient estimate of *Treatment* is 0.40 and significant, which is consistent with the t-test result reported above. The negative and significant intercept estimate of −0.39 suggests an underlying bias against entomophagy. This is the baseline model in our logistic regression analysis, with which alternative models are compared and assessed.

Table 4. Coefficient estimates and diagnostics binary logistic regression estimating.

Variables and Diagnostic Test Statistics	Model 1	Model 2	Model 3	Model 4	
	Coef.	Coef.	Coef.	Coef.	Odds Ratio
Intercept	−0.39 ***	0.44	6.04	−1.16	
Treatment	0.40 *	0.59 **	0.68 ***	0.68 ***	1.97
Neoscore		−0.55 ***	−0.59 ***	−0.59 ***	0.55
Envfood		0.21 **	0.23 **	0.20 **	1.22
Envcon		0.18 *	0.20 *	0.18 *	1.19
Envgen		−0.24 ***	−0.23 **	−0.25 ***	0.78
Exp		0.30 ***	0.35 ***	0.32 ***	1.37
Meat		0.11	0.13		
BinGen (=1 if male)		0.59 **		0.65 ***	1.92
Age		−0.20 *			
Education		−0.38			
BinEth (=1 if white)		−0.07			
Income		−0.09			
Gend1 (=1 if Female)			−18.21		
Gend2 (=1 if Male)			−17.46		
Gend3 (=1 if Non-binary)			−17.58		
Gend4 (=1 if Transgender)			−28.21		
Aged1 (=1 if 18–24 years old)			0.88		
Aged2 (=1 if 25–34 years old)			1.35 ***		
Aged3 (=1 if 35–44 years old)			0.87 *		
Aged4 (=1 if 45–54 years old)			1.02 *		
Edud1 (=1 if Elementary/Primary)			−9.37		
Edud2 (=1 if High School/Secondary)			0.51		
Ethd1 (=1 if Asian-Pacific Islander)			8.67		
Ethd2 (=1 if Black/African American)			8.92		
Ethd3 (=1 if Hispanic/Latino)			9.40		
Ethd4 (=1 if Native American/Alaskan Native)			27.77		
Ethd5 (=1 if White/Caucasian)			8.96		
Ethd6 (=1 if Multiracial/Biracial)			8.21		
Incd1 (=1 if income is 0)			1.97 *		
Incd2 (=1 if income is 1–9999)			0.34		
Incd3 (=1 if income is 10,000–24,999)			0.67		
Incd4 (=1 if income is 25,000–49,999)			−0.16		
Incd5 (=1 if income is 50,000–74,999)			−0.26		
Incd6 (=1 if income is 75,000–99,999)			−0.47		
Incd7 (=1 if income is 100,000–149,999)			0.45		
Incd8 (=1 if income is 150,000+)			−0.37		
Aged2 (=1 if 25–34 years old)				0.45 *	1.57
Lowincome (=1 if income <10,000)				0.77 ***	2.16
AIC	541.47	460.22	461.11	453.03	
SC	549.42	511.88	588.27	492.77	
Wald Statistics	3.84 *	73.13 ***	78.52 ***	73.30 ***	

Note: *** p-value < 1%, ** p-value < 5%, and * p-value < 10%.

We then proceed to add all control variables in the baseline model. Model 2 includes all independent variables reported in Tables 2 and 3. We also transformed the gender and ethnical background variables into two binary variables, i.e., *BinGen* (=1 if male) and *BinEth* (=1 if white), respectively. Model fitting statistics (AIC, BC, and Wald test statistics) suggest that Model 2 is a significant improvement over Model 1. The intercept term is not significant anymore, suggesting that New York City residents do not have any underlying tendency either against or in favour of entomophagy. The treatment effect has increased by nearly 50% (i.e., from 0.40 to 0.59) and became more statistically significant. Overall, the data strongly aligned with past studies, suggesting that the influential factors impacting acceptance of entomophagy in the United States were comparable to that of European countries. For example, for *Envfood*, the importance people attach to the environmental impact of food choices, our data indicated a significant and positive impact on *WTT*, the size of which was 1.24 (odds ratio), which aligned with Verbeke [14], wherein the size of the effect was 1.71. Similarly, the effect of gender ($\hat{\beta}_{BinGen} = 0.59$ with an add ratio of 1.80) resonated with findings from Verbeke [14], Cicatiello, De Rosa, Franco and Lacetera [15], Piha, Pohjanheimo, Lahteenmaki-Uutela, Kreckova and Otterbring [18], Megido, Gierts, Blecker, Brostaux, Haubruge, Alabi and Francis [17], and Florenca, Correia, Costa and Guine [16], which all indicated that men were more likely to try entomophagy than others. The effects of age, ethnical background and income, however, are either insignificant or small. This might be caused by using these categorial variables as numerical ones in Model 2. Consequently, we constructed groups of dummy variables corresponding to the categories included in these variables, and estimated Model 3.

Model 3 does not offer much improvement over Model 2, as suggested by the model fitting statistics. However, it does suggest that certain age and income groups have significant impact on *WTT*. We generated two dummy variables (i.e., *Age2* and *Lowincome*) accordingly to capture the preference of the 25–34 years old group and low-income group. We also omitted animal protein consumption measurement (*Meat*), education (*Education* or *Edud1* & *Edud2*), and ethnical background (*BinEth* or *Ethd1*–*Ethd6*) which are not significant in both Model 2 and Model 3. The resultant Model 4 contains significant independent variables only. This is the final model to test the four hypotheses developed in Section 3. The following discussions are based on the coefficient estimates and odd rations of Model 4, as reported in the last two columns in Table 4.

To test Hypothesis 1, knowledge about and attitude towards entomophagy affect *WTT*, we look at the coefficient estimate of *Neoscore* and *Exp*. The coefficient estimate of *Neoscore* is −0.59 and significant at the 1% level. This suggests that people with higher levels of neophobia are less likely to try edible insects as meat substitutes. *Exp*, or prior experience with entomophagy, has a positive influence on *WTT*. This was also seen in the results of Verbeke [14], Piha, Pohjanheimo, Lahteenmaki-Uutela, Kreckova and Otterbring [18], and Megido, Gierts, Blecker, Brostaux, Haubruge, Alabi and Francis [17]. Both coefficient estimates support Hypothesis 1.

Hypothesis 2 predicts that environmental consciousness and *WTT* are positively associated. This hypothesis is tested by using three measurements of environmental attitudes regarding food choice (*Envfood*), daily consumption (*Envcon*), and relationship between human and nature (*Avgenv*), respectively. The effect size and statistical significance of *Envfood* and *Envcon* are similar and consistent in Models 2 through 4. Specifically, respondents who are more environmentally conscious in their food choices and daily consumption are approximately 20% more likely to try edible insects (i.e., odds ratio equal 1.22 and 1.19, respectively). The effect of general environmental consciousness (*Avgenv*), on the other hand, is negative and significant. This seemingly unintuitive finding could be a result of the influence of vegetarians in our sample, who would likely have high *Avgenv* scores and also would be highly averse to consuming insects as they are in fact animals. This supposition is supported by the positive relationship that consumption of animal protein (*Meat*) has with willingness to try insects (*WTT*). More importantly, our findings highlight the importance of fine-tuned measurements of environmental consciousness in behavioural studies. As environmental consciousness is a rather broad and vague concept for the public, general questions such as those used in the measurement of *Avgenv* might attract automatic and politically correct answers in surveys and interviews, and consequently undermine the validity and reliability of the measurements. Context-specific measurements, such as *Envfood* and *Evncon*, are found to be more robust to such issues, and provide support to Hypothesis 2.

Demographic factors, such as gender, age, and income, also have significant impacts on *WTT*. As stated above, male respondents were found to be more willing to adopt entomophagy than other genders, which is a common finding in the literature. While we do not have enough data to fully explain this phenomenon, researchers have suggested possible reasons such as the impact of women's association of insects with uncleanliness due to household activities [15], that males have a more adventurous taste or find insects less disgusting than others [14], and that men are less neophobic (averse to new foods) overall and more adventurous in food choices than others [17]. Younger subjects (i.e., the 25–34 years old group) demonstrated higher *WTT*, which is similar to the results in Verbeke [14]. The influence of age could also be associated with a variety of factors, such as less mature or ingrained food preferences, more experience with a larger variety of ethnic foods apart, or less concern for the safety requirements of unfamiliar foods. We also found that the low-income group (<$10,000) is much more likely to adopt entomophagy, with an odds ratio of 2.16 which is the largest among all variables considered in Model 4. Unfortunately, income has rarely been considered in previous studies, and we have little empirical evidence to benchmark our findings with. The effect of income should be further investigated by in future studies.

Finally, Hypothesis 4 is tested by using the coefficient estimate of *Treatment*. The coefficient loading is consistent across Models 2 through 4. It is positive and significant at the 1% level, with the second largest odds ratio (i.e., 1.97) among all independent variables considered. The findings suggest a robust, strong, and positive effect of behavioural intervention on the willingness to try edible insects as meat substitutes. The cost-effective nudge-boost combination increased the *WTT* by as much as 97% in our experiment. Behavioural interventions have great potential in encouraging environmentally sustainable food choices in terms of entomophagy.

In summary, our empirical findings provide support to all four hypotheses derived from our analytical framework. This leads to some important policy implications as discussed in the next section.

6. Policy Implications

Faced with undeniable evidence that shows the environmental harm of livestock consumption and given an alternative that researchers affirm taste just as good, is equally or even more nutritious, and has a significantly smaller environmental footprint, why ever not try entomophagy? People's aversion to edible insects, which reflects a complex combination of internal and external factors, is a major barrier in reaping the benefits that entomophagy can provide for our food infrastructure and global nutritional needs. While there has been some research on profiling inherent characteristics of consumers more accepting of entomophagy, this current study was the first controlled experiment to test behavioural interventions, in the form of environmental nudges and boosts, that could generate a significant change in improving people's attitude towards edible insects.

Findings from this study are particularly relevant to policymakers in designing incentives for effective adoption of sustainable food alternatives in developed countries. Although the effectiveness of behavioural interventions in environment policies has been studied extensively, the application of behavioural insights in food policy is still at an early stage. More empirical investigations are needed to verify whether behavioural interventions are effective and practical measures to encourage sustainable food production and consumption decisions. Our study is the first behavioural investigation of entomophagy acceptance by combining both nudges and boosts in experimental designs. We find that the provision of environmental impact information and hints of social responsibility could improve people's willingness to try edible insects. The introduction of edible insects through an environmental lens had the capacity to help realise entomophagy's potential as a sustainable meat alternative. The temporally short duration of the treatment implied that environmental boosts and nudges may be transferred and adapted to meet the needs of a real-life setting, perhaps on the menu of a restaurant, a paragraph on a textbook, a fleeting public service announcement, among others. This is supported by past research that found an intervention of a climate-friendly choice label before choosing a dish at a food service establishment led to more purchases of climate-friendlier meals while showing no decrease in customer satisfaction [72]. Similarly, Potter et al. [73]'s literature review found that 60 out of 76 interventions using ecolabel on food and drink products reported a positive effect on pro-environmental behaviour.

More importantly, the effect size of our behavioural intervention is larger than most of the other factors considered in our model as well as in existing studies. This experiment adds to literature that suggests the potential that behavioural sights in real-life food consumption settings have to alter people's choices. Therefore, our study provides valuable insight not only for those interested in expanding entomophagy as a sustainable protein alternative, but also for policymakers looking for cost-efficient tools to promote environmentally sustainable food choices. The potential of behavioural policy interventions should be explored not only in food security decisions, but also in other closely related sustainability studies, such as food safety and biodiversity.

7. Conclusions

We develop an analytical framework to model the relationship between the willingness to try edible insects as meat substitutes and its determinants. The model is empirically tested by using data from New York City via the Amazon MTurk platform. Our findings from the U.S. are strongly aligned with most of the findings in past studies conducted in European countries. As this is, to the best of our knowledge, the first study to investigate the impact of internal and demographic factors on people's acceptance of entomophagy in the U.S., the results may provide a more thorough understanding of consumers' reception of edible insects in Western countries.

This research strongly suggests that consumers in Western countries are ready to be educated on the environmental consequences of their individual food choices and are receptive to adopting entomophagy as a sustainable alternative to animal protein. To fully realise the environmental benefits of entomophagy and its potential contribution to food security, there are at least four future research directions that are worth exploring.

First, cultural path-dependency is an important factor in food choice decisions. The effectiveness of policy interventions towards entomophagy might vary significantly by cultural type. Therefore, expanding this study's geography to other parts of the world would improve the generalisability of the experimental results and test the potential moderating effect of cultural background; more conservative or less urbanised regions may express higher rejection of entomophagy than subjects from New York.

Second, it is important to investigate the gap between stated environmental intention and behaviour. Studies assessing consumers' decisions to actually taste insect-based products in either an experimental or real-life setting would provide a more realistic estimation of the possibility of wider entomophagy adoption. Future studies should also compare the effectiveness of different types of behavioural interventions, such as data visualisation, textual information, environmental labelling, and celebrity endorsement, in terms of encouraging people to act upon their expressed willingness to try entomophagy.

Finally, and most importantly, the effect size of behavioural interventions should be further explored by comprehensive cost-benefit analysis. This is a crucial step to assess the real impacts of behavioural policy tools in promoting sustainable food choices in terms of entomophagy. This is also a challenging undertaking. Although the general consensus is that behavioural interventions are cost-effective, measuring and comparing the environmental costs of traditional meats and edible insects are by no means straightforward. Factors such as the quality and quantity of water sources, geographic and meteorological conditions, and socioeconomic features of local areas should be considered; costs and benefits should be assessed in both relative and absolute terms, with a focus on long-term, sustainable impacts. Our study is one of the early attempts to push food security research along this promising direction. The behavioural interventions considered in our study require low administration and financial resources to implement, with considerable effect size. This result should be further verified and explored by using data from other parts of the world and especially by using evidence from the field.

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