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Consumer segments less or more willing to adopt foods with microalgae proteins

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ABSTRACT

The use of microalgae proteins as an alternative protein source in the European food market is becoming increasingly important. Despite their potential, these foods are still relatively unknown to European consumers. Therefore, it is crucial for their successful market introduction to explore consumer awareness, perception and willingness to try them. The objectives of this study were to identify factors shaping willingness to try and consumer segments likely to adopt foods with microalgae proteins. Data were collected via a quantitative online survey (N = 3027) in five European countries: the Netherlands, Germany, Hungary, Spain, and Italy. First, binary logistic regression showed that a flexitarian diet, general health interest, food neophobia, and environmental concern significantly shaped willingness to try foods with microalgae proteins. Second, factor analysis identified two dimensions of consumers' perceptions about foods with microalgae proteins: credence attributes related and experience attributes related. Third, these perception constructs were used alongside willingness to try in a two-stage segmentation analysis to identify consumer segments willing to adopt foods with microalgae proteins. The analysis yielded four segments, "Enthusiast", "Cautiously curious", "Undecided", and "Uninterested". Finally, the segments were profiled in terms of sociodemographic characteristics, attitudes and perceptions by means of a multinomial logistic regression (n = 2957). Consumers with a higher general health interest, stronger environmental concern, and greater interest in information about foods with microalgae proteins were more likely to be part of segments with a higher willingness to try and more favorable perceptions. Consumers with higher levels of food (technology) neophobia, were more likely to be part of segments with a lower willingness to try and less favorable perceptions. This study has shown that segmentation proves useful to identify and profile consumers who would be less or more likely to adopt foods with microalgae proteins and enables more effective tailoring of marketing and further research efforts.

1. Introduction

1.1. The need for sustainable protein sources

The demand for alternative sources of protein is driven by several factors, including the need to sustainably meet the nutritional needs of the growing population. Animal protein production is increasingly described as unsustainable (Poore & Nemecek, 2018) and exclusive reliance on animal protein sources may not be a viable strategy to meet the nutritional needs of the growing global population in the coming years (Capper, 2020). These concerns stem from several factors, e.g., first, deforestation due to livestock production and the resulting CO_2 emissions (Poore & Nemecek, 2018). Livestock itself is also responsible for emissions that account for 11% to 17% of global greenhouse gas emissions, with CH_4, NH_2, and CO_2 being the main gasses (Blaustein-Rejto & Gambino, 2023). Lastly, the significant agricultural resources required to feed animals have become a major point of dispute (Aiking, 2014).

In general, the demand from consumers for more environmentally friendly foods has risen in Europe over the last couple of years (Aschemann-Witzel et al., 2021; Tuorila & Hartmann, 2020), especially for alternative meat products (Ettinger, 2022). In 2021, 30% of the population in ten European countries reported being flexitarians, while 3% were pescatarian, 5% vegetarian, and 2% vegan (Perez-Cueto et al.,

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2022). In some countries such as the Netherlands and Belgium, the share of flexitarians has even been reported to amount up to 40% (Dagevos & Verbeke, 2022). Although these numbers reflect a notable presence of non-omnivore dietary preferences, they are still relatively low when contrasted with the 60% majority of omnivores.

Sometimes meat alternatives are perceived as less environmentally friendly compared to meat (Hartmann et al., 2022). One could argue that consumers are more interested in food characteristics other than sustainability per se, such as taste, price, healthiness, etc. (Onwezen & Bartels, 2011; Sautron et al., 2015). Nevertheless, in the study by Holter (2023), 69% of Europeans indicated they would choose a climate friendlier food item rather than a cheaper option.

1.2. Challenges for transition to more sustainable diets

Although consumers may say they want more environmentally friendly foods, their actual buying behaviour often differs substantially from their intention. This could be due to the various challenges associated with sustainable diets in the context of meat consumption. Cultural inertia can hinder the adoption of sustainable options, such as reluctance to eat specific alternatives such as insects despite their low environmental impact and good nutritional benefits (Varela et al., 2022). Another hurdle is the trade-off between ethical principles and personal taste preferences, as some people find it difficult to part with familiar but less sustainable foods. In this sense, it can be challenging for consumers to give up their meat consumption habits, despite all the above reasons that a diet high in meat consumption is less sustainable. The affordability and availability of sustainable foods can also be a barrier, as they may come with a higher cost and limited accessibility (Jones, 2017). Anticipated sensory experiences and food neophobia may also be potential barriers to the adoption of sustainable foods, as people may be hesitant to consume new food products that offer better sustainability (Monneuse et al., 2008) which has already been shown as the different tastes and textures of animal versus plant proteins may present difficulties for individuals accustomed to eating animal proteins (Nolden & Forde, 2023). Lastly, a lack of comprehensive information and awareness about alternative protein sources may prevent consumers from incorporating them into their daily diets (Varela et al., 2022).

Food manufacturers seek to respond to consumer demands for more sustainable foods. Food companies all along the food chain, from farms to processed food companies, are now striving for more sustainable production through a variety of methods, such as more environmentally friendly farming practises (Nicholls et al., 2020) and the usage of alternative and more sustainable ingredients, e.g. alternative proteins instead of meat proteins (Kumar et al., 2023). Switching to vegetarian products is another progressive approach (Poore & Nemecek, 2018). Effective communication plays an important role, and the use of tools such as eco-labels, taxes, or subsidies can reflect environmental costs and convey commitment to sustainability (Springmann et al., 2017). In this regard, it is also important for companies to work with governments to overcome hurdles such as consumer perceptions of sustainable food and jointly develop a strategy to help consumers recognize and adopt a more sustainable diet (Miller et al., 2021).

1.3. Micro- and macroalgae

The overarching term “algae” is often used to encompass both microalgae and macroalgae (Boukid & Castellari, 2021; Matos et al., 2022; Onwezen et al., 2021). Yet, it is important to recognize their different compositions and uses in foods, as well as the fact that the differences between microalgae and macroalgae may not be clear to some consumers. Microalgae are microscopic, unicellular freshwater or marine organisms, which include cyanobacteria, and do not require high land use (Boukid & Castellari, 2021), in contrast to macroalgae, which are macroscopic, multicellular, and marine in nature (Biloria & Thakkar, 2020). Polysaccharides from macroalgae have been used extensively in foods as thickening and gelling agents (Peñalver et al., 2020). Proteins from macroalgae have also been used albeit to a lesser extent to fortify foods (’O Brien et al., 2022). The protein content of macroalgae ranges from 8 to 47 % of dry weight, depending on the species (’O Brien et al., 2022) whereas microalgae have a protein content of 30 to 80 % of the total mass (Janssen et al., 2022). Extraction and drying methods for microalgae proteins have become easier and cheaper in recent years, which has made microalgae more attractive as a source of alternative proteins. In addition, microalgae proteins offer many advantages, including their low land and water requirements, their ability to grow in saltwater environments (Becker, 2007), and a balanced amino acid profile that supports human nutrition (Chronakis & Madsen, 2011). Microalgae can be used to improve the nutritional quality of conventional foods, which in turn could serve as a supplement to meet the energy and nutrient needs of the growing world population or specific population groups (Villaró et al., 2021).

1.4. Microalgae as an emerging protein source

Although macroalgae are currently more prevalent in Europe, the focus of this study is on microalgae, which are gaining attention in Europe (Strodt, 2022). This primarily concerns Spirulina, scientifically known as Arthrospira, which has already established itself as a sustainable protein source (Morelli, 2023). Several European research projects such as ProFuture and NextGenProteins are focusing on the production of new foods with microalgae proteins. However, compared to established alternative protein sources such as soy and peas, the market for foods with microalgae proteins is still in its early stages. This may be primarily because foods with microalgae are as yet more expensive than conventional foods (Van der Stricht et al., 2023). Another reason could be that dietary preferences, habits, and attitudes are different in Europe compared to outside of Europe, as this has already been shown for other new food products (Guerrero et al., 2009). The level of awareness of foods with microalgae proteins in the European Union is described as moderate, with about half of consumers having no experience with them according to the study by Roßmann and Rösch (2020). Awareness levels vary across countries. For example, Spirulina is a more well-known food ingredient among French consumers than among German and Dutch consumers (Grahl et al., 2018).

1.5. Awareness and willingness to try foods with microalgae proteins

The addition of microalgae proteins to foods may impact consumers’ willingness to try them, and familiarity with the food may play a crucial role. According to Hartmann and Siegrist (2017), a positive experience with a familiar product with an unknown protein source can lead to an increased willingness to consume it. Familiarity with Spirulina has also been shown to increase overall acceptance of foods with microalgae (Torrico et al., 2019). However, the effect of familiarity can vary depending on the food product. For example, studies have shown that the acceptability of bread with microalgae is similar to that of conventional bread (Cox et al., 2011; Khemiri et al., 2020). This suggests that familiarity alone may not be sufficient to increase willingness to accept foods with microalgae proteins. It is therefore important to understand the relationship between familiarity and willingness to purchase these foods. In addition to familiarity, other factors are also crucial for the willingness to consume foods with microalgae proteins and for the purchase decision. These other factors include e.g., consumer perceptions of novel food technologies, focusing on perceived safety, risks and benefits (Cardello et al., 2007). The limited research on consumer perceptions of microalgae proteins suggests that risk perception may not be a major issue, as these proteins are perceived to be safe, nutritious and environmentally sustainable according to Lafarga et al. (2021). Nevertheless, it is not clear whether such perceptions are indeed favourable across all consumer segments.

Consumers’ intentions to eat foods with microalgae proteins may

also be influenced by environmental concerns (Vermeir & Verbeke, 2008), health awareness (Verbeke, 2006) and knowledge about microalgae (Lafarga et al., 2021). Consumers' intentions may vary according to their individual dietary philosophies, similar to the case of insect-based foods (Elorinne et al., 2019). Demographic characteristics have also proven their importance. However, contradictory results still exist in this regard. For example, a higher level of education in Germany has been shown to have a negative influence on attitudes toward microalgae as a food (Weinrich & Elshiewy, 2023), while another study in Norway showed that consumers with a university degree were more positive toward eating foods with "algae" than those with a lower educational degree (Gustavsen & Rautenberger, 2023). Inconsistent results were also found for age. No significant differences were found regarding age in purchase intention and willingness to pay (Maehle & Skjeret, 2022). Another study showed that attitudes toward microalgae as a food in France first increased and then decreased with increasing age (Weinrich & Elshiewy, 2023). However, it has also been reported that older age negatively influences the likelihood of trying "algae" foods, while lower age positively influences the likelihood (Gustavsen & Rautenberger, 2023). In addition, it has been shown that women in Germany and the Netherlands have more positive attitudes toward foods with microalgae (Weinrich & Elshiewy, 2023), while Weinrich and Gassler (2021) showed that German men would pay more for food alternatives with "algae". Reasons for these differences in the impact of socio-demographic characteristics on consumers' attitudes and willingness to try food mentioned in the literature could be related to the less specific mention of the type of "algae" and the proportion of "algae" in the foods. In addition, country-specific differences may also be the reason, as most studies were conducted in a limited number of European countries, usually only one to three per study.

Dietary preferences and other nutrition-related attitudes may also influence attitudes and willingness to try foods containing microalgae proteins. For example, it has been shown that consumers with a healthy diet are more interested in microalgae (Weickert et al., 2021) and that foods with microalgae are more popular among vegetarians and vegans (Weinrich & Elshiewy, 2019). In addition, it has been reported that individuals with diets rich in meat are less likely to consume foods with macroalgae (de Boer et al., 2013). Furthermore, environmental concern has been shown to be an important factor in sustainable behaviours and attitudes toward sustainable products (Birch et al., 2019; Pagiaslis & Krontalis, 2014). As Garcia-Segovia et al. (2020) pointed out, food neophobia plays a crucial role in the acceptance of novel foods. Eventual aversion to new food experiences has been associated with a lower willingness to consume innovative products, including those derived from insects, as reported by Verbeke (2015). In line with this, Michel et al. (2021) reported that consumers' ratings of algae-infused burgers were indeed influenced by food neophobia.

To facilitate market uptake of microalgae proteins, it is critical to understand which consumer segments are likely to adopt these foods. Segmentation is only relevant if it is possible and meaningful to identify homogeneous subgroups in an otherwise heterogeneous population, which may be based on country differences but also on consumer opinions, attitudes, interests and behaviours. Market segmentation is essential to understand the factors affecting the consumption of foods with microalgae proteins in Europe, taking into account not only the diversity of dietary culture across countries but also differences in socio-demographics and attitudes. Segmentation should be based on relevant variables that influence the acceptance of foods with microalgae proteins, such as the aforementioned perceptions and willingness to try. Once market segments are identified, further characterisation by examining socio-demographic characteristics, attitudes and interests is required to allow for an effective targeting of segments (Armstrong et al., 2014).

1.6. Objectives of the study

This study aims to identify consumer segments for foods with microalgae proteins by focusing on two key aspects of consumer evaluation: consumer perceptions and willingness to try. To accomplish this goal, the study will first perform a binary logistic regression to determine the differences between consumers who are willing to try foods with microalgae proteins and those who are not. From this analysis, the influential factors with statistical significance will be identified, which will subsequently be used in multinomial logistic regression analysis to profile consumer segments. An exploratory factor analysis will be conducted to identify dimensions of attributes that shape consumer perceptions of foods with microalgae proteins. A segmentation analysis will then be conducted on consumers' perceptions of foods with microalgae proteins and their willingness to try these products as segmentation variables. The resulting consumer segments are characterized by socio-demographic, attitudinal and perception variables using multinomial logistic regression. Consumer perceptions, based on attributes not included in the segmentation variable, and their interest in information about these products are determined for each segment. Recommendations will be given to increase consumer acceptance at the end of this paper. The information gained will also be invaluable in formulating effective marketing strategies.

2. Material and methods

2.1. Study design and sampling

This study was part of the ProFuture (Proteins of the Future) project (https://www.pro-future.eu), funded by the European Union's Horizon 2020, which aims to increase the production of microalgae and promote the use of microalgae proteins as sustainable food and feed ingredients. Ethics approval for the study was granted by the Belgian Ethics Committee of Ghent University Hospital (reference: BC-10402, August 2021).

An online survey was conducted in November 2021 with the aim of reaching at least 600 respondents in Germany, the Netherlands, Spain, Italy and Hungary (total sample N = 3027), selected on the basis of their geographical distribution and different dietary habits. Respondents were recruited using probabilistic sampling from the proprietary online access panel of a professional market research company. The raw data were cleaned by removing the responses of those respondents who did not complete the entire questionnaire, as well as the "speeders," i.e., respondents who completed the questionnaire faster than 0.4 times the median time it took all respondents to complete the questionnaire. The speeders were 6.4 % of the total sample. With these two conditions, a total sample of 3027 of the initial 3233 respondents who took part in the study was reached. Respondents were aged between 18 and 75 years and were responsible for household food purchases. To obtain representative national samples, selection criteria for gender, age and region were used that matched the population distributions in each country, and stratified random sampling was used based on these demographic factors. The data collected were coded in a non-identifiable format and processed anonymously. Data collection was closely monitored to meet predefined conditions.

2.2. Measurement of segmentation variables

Perceptions of food were asked as "I think foods with added microalgae proteins are …?" for fifteen attributes on five-point bipolar interval scales (e.g., "Unnatural" vs. "Natural"). The selection of these attributes was based on information about microalgae retrained from websites of producers of microalgae and foods with microalgae proteins (Allmicroalgae, n.d.; Alver, 2021; Viva Maris, 2021) and discussed within the ProFuture project consortium.

Willingness to try foods with microalgae proteins was assessed with

one of two items, depending on whether respondents had previously tried foods with microalgae proteins. The statement "If proteins from microalgae were added to foods, I would be willing to try them" was asked to those who had never tried foods with microalgae proteins before the study, and respondents who had already eaten these products were asked "I would eat food products with microalgae proteins again". Both questions were answered on a five-point interval scale from "strongly disagree" (1) to "strongly agree" (5). This question was based on research of Grasso et al. (2019).

2.3. Characterising variables

The type of diet followed by the respondents was determined by the following question "Are you currently following any dietary regime?" with the response options: "no special diet", "flexitarian", "pescatarian", "vegetarian" or "vegan". The responses "pescatarian", "vegetarian" and "vegan" were combined for further analysis into one group referred to as 'non-meat eaters' since these groups accounted individually for very small proportions of the sample. General health interest (GHI) was determined using seven statements on a five-point interval scale from "strongly disagree" (1) to "strongly agree" (5), preceded by the question "To what extent do you agree with the following statements about your attitude towards food and health?" ($\alpha = 0.80$) according to Tóth et al. (2020) based on the original scale of Roininen et al. (1999).

Before any specific questions about microalgae, information regarding microalgae and their production process was provided to the survey participants (Appendix A).

Differences in consumers' perceptions and willingness to try foods with microalgae proteins were assessed using three established psychometric scales: the Food Neophobia Scale (FNS), the Food Technology Neophobia Scale (FTNS) and the Environmental Concern (EC) scale. These instruments provided a systematic and standardised method to assess individuals' perceptions and feelings towards the studied foods with microalgae proteins. Short versions of the FNS with six items (e.g., "I do not trust new foods.") ($\alpha = 0.69$) (Ritchey et al., 2003) and the FTNS with four items (e.g., "New food technologies reduce the natural quality of food.") were used ($\alpha = 0.80$) (Verbeke, 2015). EC was examined using six items measuring the new environmental paradigm (e.g., "Plants and animals exist primarily for human use.") ($\alpha = 0.70$) (Bostrom et al., 2006).

Familiarity with foods with microalgae proteins was assessed with the question "Before taking this survey, had you ever heard of foods containing proteins from microalgae?". The five response options were based on previous research (e.g. "Yes, I have heard of these products and have already tried them.") (Verbeke, 2015).

The information consumers would like to receive about foods with microalgae proteins was determined by eleven items (e.g. health and nutritional risk) on a scale from "Not interested" (1) to "Extremely interested" (5). The items were determined using input from microalgae producers (Allmicroalgae, n.d.; Alver, 2021; Viva Maris, 2021).

The socio-demographic and personal characteristics gender, age, perceived household financial situation, highest educational attainment, height and weight were collected. The categories reported for monthly household net income were based on household net income in the five countries in 2020–2021 (Eurostat, 2021; World Population Review, 2021). The International Standard Classification of Education was used to combine the educational levels between the five countries (UNESCO, 2012). These were later reduced to two categories as follows: 1) Below bachelor's degree; 2) Bachelor's degree or higher.

2.4. Statistical analyses and modelling

Data analyses were conducted using the statistical software SPSS, version 28.0.1.0 (IBM Corp., 2021). Statistical analyses in this study used both parametric and non-parametric methods to examine differences in awareness and perception of foods with microalgae proteins. Chi-square was used to detect significant associations between categorical variables. Mann-Whitney U-tests were used to compare the distribution of ranks between two independent groups, while Kruskal-Wallis tests were used for comparisons between more than two groups unless otherwise stated. Two-way Friedman analysis of variance of ranks was used to assess the significance of differences when comparing scores within a group of respondents. Although non-parametric tests were used, the mean is also reported as a descriptive statistic as it provides a more intuitive representation of the data.

After the descriptive results regarding familiarity, perception and willingness to try foods with microalgae proteins, an exploratory factor analysis (EFA) was performed to determine (a) possible dimensions in the perception of foods with microalgae proteins. The internal reliability of the extracted factors was checked using Cronbach's alpha. Then, the scores on the items within the factors that best described perception were aggregated.

2.4.1. Segmentation

A two-stage segmentation analysis was conducted to group respondents according to their willingness to try foods with microalgae proteins and their perception of these foods. First, respondents were divided into pre-segments using hierarchical segmentation. A set of solutions was obtained, and the optimal number of segments was selected based on the change in the agglomeration coefficient. This is also known as the Elbow method (Kodinariya & Makwana, 2013). K-Means segmentation was then performed using the number of segments determined by the hierarchical segmentation. Four segments based on respondents' willingness to try foods with microalgae proteins, their credence attribute perceptions and experience attribute perceptions, were identified as described in Section 3.5.

2.4.2. Binary logistic regression

To analyse the determinants of respondents' willingness to try foods with microalgae proteins, this variable was operationalized as a single dependent variable across the total sample. Willingness to try foods with microalgae proteins was analysed as a discrete (yes/no) decision (Verbeke, 2015; Verbeke et al., 2021) by specifying the response categories 'Strongly agree' and 'Agree' as a 'Yes' (57.0%), and the other response categories (i.e. 'Neither disagree nor agree', 'Disagree' and 'Strongly disagree' as a 'No' (43.0%). This treatment of the dependent variable implies that the analysis concentrates on consumers who showed early interest in foods with microalgae proteins during its initial development. This, combined with the segmentation analysis, enables us to explore the characteristics of early adopters as opposed to those who have doubts or reject the concept.

To model this dichotomous decision, and given the skewed distribution of the response, a binary logistic regression model was used (Verbeke, 2015; Verbeke et al., 2021). For each respondent i, the binary response y_i is defined as one when a latent continuous variable z_i exceeds zero, and y_i is zero otherwise:

$$\begin{cases} y_i = 1 \ if \ z_i > 0 \\ y_i = 0 \ if \ z_i \leq 0 \end{cases}$$

The latent metric and continuous variable zi is specified by a regression model where x_{ki} represent $k = 1$ through K explanatory variables explaining the willingness to foods with microalgae proteins for respondent i with β_k as the coefficient that indicates the effect of x_{ki} on z_i, and where ε_i represents the stochastic error term for respondent i, namely:

$$z_i = \beta_0 + \sum_{k=1}^{K} \beta_k x_{ki} + \varepsilon_i$$

The explanatory variables included demographic (i.e., country of residence, gender and age), socioeconomic (education level, perceived

financial situation), health characteristics (dietary status and BMI) and attitudes (i.e., GHI, FNS, FTNS, and EC). For the previously mentioned variables, the following groups were used respectively as baseline category as they were the most selected options: Germany, male, bachelors' or higher degree, get by alright as concerns financial situation, normal BMI and no dietary restrictions were set as the reference category. Age, GHI, FNS, FTNS and EC were entered as a continuous variables.

The transformation of y_i that creates zi is the logistic function. Hence, the relationship between the probability pi of an observation of y_i assuming the value of one and the values of the explanatory variables x_k is written as:

$$p_i = prob(y_i = 1) = \frac{e^{z_i}}{1 + e^{z_i}} = \frac{e^{\beta_0 \sum_{k=1}^{K} \beta_k x_{ki}}}{1 + e^{\beta_0 \sum_{k=1}^{K} \beta_k x_{ki}}} \quad or$$

$$\log\left(\frac{pi}{1 - pi}\right) = z_i = \beta_0 + \sum_{k=1}^{K} \beta_k x_{ki} + \varepsilon_i$$

The complete empirical specification of z_i with the explanatory variables mentioned before is given by:

$$\begin{aligned} \text{MicroAlgae}_i = {} & \beta_0 + \beta_1 \text{Country}_i + \beta_2 \text{Gender}_i + \beta_3 Age \\ & + \beta_4 \text{BachOrHigher}_i + \beta_5 \text{ManagingWell}_i + \beta_6 \text{FinDiff}_i \\ & + \beta_7 \text{Underweight}_i + \beta_8 \text{Overweight}_i + \beta_9 \text{Obese}_i \\ & + \beta_{10} \text{Flexi}_i + \beta_{11} \text{NoMeat}_i + \beta_{12} \text{GHI}_i + \beta_{13} \text{FNS}_i \\ & + \beta_{14} \text{FTNS}_i + \beta_{15} \text{EC}_i + \varepsilon_i \end{aligned}$$

Regression coefficients were estimated using maximum likelihood estimation and are presented with Wald χ2-statistics and as odds ratios, i.e. the exponentiated logistic regression coefficients or the ratio between the probability that a person is willing to try foods with microalgae proteins.

Respondents who indicated 'Other/ prefer not to answer' in response to the gender question were excluded (n = 9), as their group size was extremely small compared to the other gender categories. Respondents who chose not to provide information on their length and/or weight (n = 2), as well as those who did not disclose their perceived financial situation (n = 56), were also excluded. These exclusions were made to meet the assumptions required for the logistic regression analyses. After these exclusions, a sample of 2960 respondents was taken into account when performing the binary logistic regression, and further on also the multinomial logistic regression.

Assumptions for logistic regression analysis were tested (Field, 2013). On the basis of the standardized residuals, less than 3% of cases had absolute values above 2 (2.6%) and less than 1% of cases above 2.5 (0.2%). Nevertheless, there were three cases with a value of the standardized residuals greater than 3 (0.1%) that could therefore be potential outliers. The logistic regression model was tested on the sample after removing these three potential outliers (n = 2957). There was no evidence of multicollinearity problems (all bivariate correlation coefficients were less than 0.6).

An initial estimation was obtained using backward stepwise regression with a final sample of 2957 respondents. Based on this, variables entered but not retained in the model because they were not significant, were: education (dichotomous); BMI (dummies for four BMI categories); gender (dichotomous); and "I think foods with microalgae are cheap – expensive" (continuous), age (continuous) and household income (dummies for three income categories).

2.4.3. Multinomial logistic regression

Multinomial logistic regression analysis was used to analyze the differences in demographic and socioeconomic characteristics, and attitudes among the four identified segments based on willingness to try and perception of foods with microalgae proteins. The dependent variable was segment membership. The "Uninterested" segment was selected as the reference category to see how the other segments differentiate from the group of consumers with the lowest willingness to try and the least favorable perception. Observations were independent because all respondents were divided into separate segments and assigned to one segment only, thus avoiding overlap.

3. Results

3.1. Survey sample

The study included a total of 3027 respondents from the Netherlands, Germany, Hungary, Spain and Italy. The characteristics of the sample are shown in Table 1. Almost half of the respondents were male (49.0%) and the other half were female (50.7%). The mean age of the respondents was 46.32 ± 15.15 years. In terms of dietary habits, the majority of respondents reported having no special diet (65.7%), followed by a flexitarian diet (29.1%). In terms of perceived financial situation, 41.8% of respondents reported "getting by all right", i.e. making ends meet. The majority of respondents obtained an educational degree lower than bachelors' (65.7%). The sample was representative of the adult population in each of the countries studied in terms of gender, age and region.

3.2. Familiarity and perception of foods with microalgae proteins

About half of the total sample reported never having heard of foods with microalgae proteins before the study (51.9%). Only 14.1 % of respondents reported having already tried these products.

Respondents perceived foods with microalgae proteins as being innovative, sustainable, healthy, natural and expensive (Fig. 1). For the other attributes, respondents reacted rather neutral, e.g. respondents did neither find foods with microalgae proteins unsafe nor safe, and neither difficult to find nor easy to find. 53.5% of the sample (N = 3027) (strongly) agreed with the statement that foods with microalgae proteins are 'natural'. Only 26.1% (strongly) perceived foods with microalgae proteins as being 'unprocessed'.

The majority of respondents agreed that foods with microalgae proteins are high in protein (60.8%), suitable for vegans or vegetarians (58.8%), rich in nutrients (55.9%), rich in vitamins and minerals (51.7%) and rich in fiber (46.4%) (Fig. 2). Responses to the other statements regarding the nutrient content of foods with microalgae proteins were rather neutral and reflecting a lack of agreement or disagreement, or uncertainty. Almost 40% of the respondents (strongly) disagreed that these products provide value for money.

3.3. Willingness to try foods with microalgae proteins

Willingness to try foods with microalgae proteins was based on willingness to try foods with microalgae proteins for the first time and willingness to eat these foods again for those who had already tried them. The mean willingness to try was higher for respondents (n = 426) that already tried foods with microalgae proteins (3.65 ± 1.08) compared to respondents (n = 2601) who never tried these foods (3.53 ± 1.14).

Table 2 presents the results of the binary logistic regression model along with the estimated logistic regression coefficients (β), standard errors (S.E.), Wald χ2 -statistics, significance levels, odds ratios (Exp(β)) and goodness-of-fit statistics in the first columns. The remaining columns present the outcomes of the multinomial logistic regression analysis showing the differences among the four segments.

Initially, the analysis did not reveal any significant country-based distinctions between respondents willing to try foods with microalgae proteins and those who were not willing to try these foods. Flexitarians were 1.56 times more willing to try foods with microalgae proteins compared to consumers that do not follow a specific diet. A one-point

Table 1
Socio-demographic characteristics of the total sample (N = 3027) in percentages per country for the Netherlands (n = 604) Germany (n = 611), Hungary (n = 606), Spain (n = 603) and Italy (n = 603).

		Total	the Netherlands	Germany	Hungary	Spain	Italy
Gender	Female	50.7	50.0	50.1	52.8	49.8	50.9
	Male	49.0	50.0	49.1	47.2	50.1	48.6
	Other	0.3	0.0	0.8	0.0	0.2	0.5
Age	18–29	9.6	10.6	10.1	9.2	9.1	9.1
	30–39	16.3	18.0	14.6	16.3	17.1	15.6
	40–49	20.0	16.7	15.7	23.8	23.4	20.6
	50–59	21.3	20.9	21.8	21.1	20.9	21.9
	60–65	17.4	18.2	19.0	16.2	16.3	17.4
	66–75	15.3	15.6	18.8	13.4	13.3	15.4
Diet	No restrictions	65.7	64.9	62.0	74.4	68.7	58.7
	Flexitarian	29.1	28.8	31.3	22.3	27.0	36.3
	Non-meat eaters	5.2	6.3	6.7	3.3	4.3	5.0
Perceived financial situation (n = 2971)	Managing well	34.1	43.2	46.2	18.0	18.4	44.4
	Getting by alright	41.8	41.4	34.4	44.6	51.2	37.6
	Financial difficulties	22.3	13.2	18.0	35.5	28.4	16.3
Education level	Below bachelor's	65.7	63.9	74.5	89.1	42.5	58.2
	Bachelor's or higher	34.3	36.1	25.5	10.9	57.5	41.8

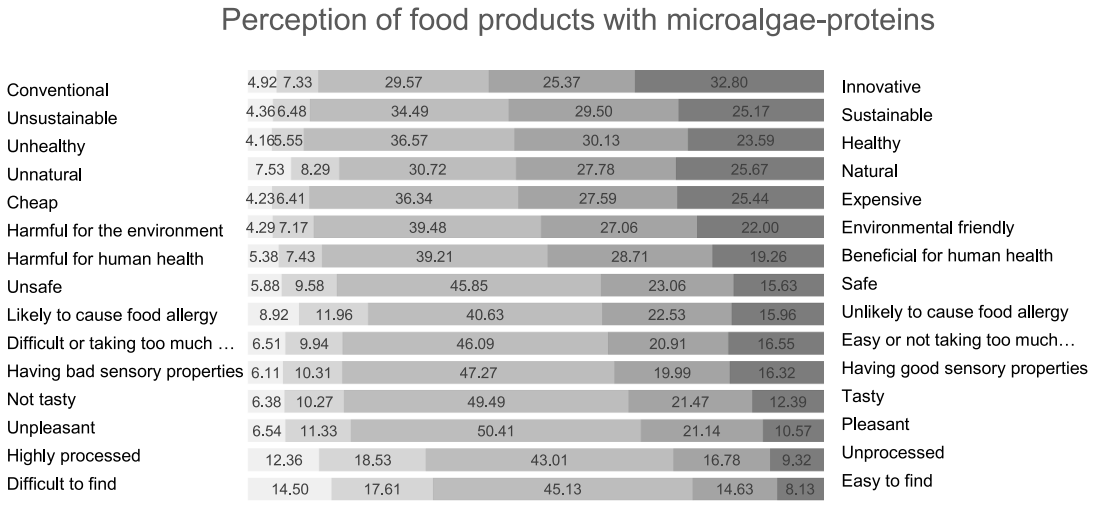

Fig. 1. Attribute perception of foods with microalgae proteins on five-point semantic differential scales, frequency distribution in percentages (N = 3027).

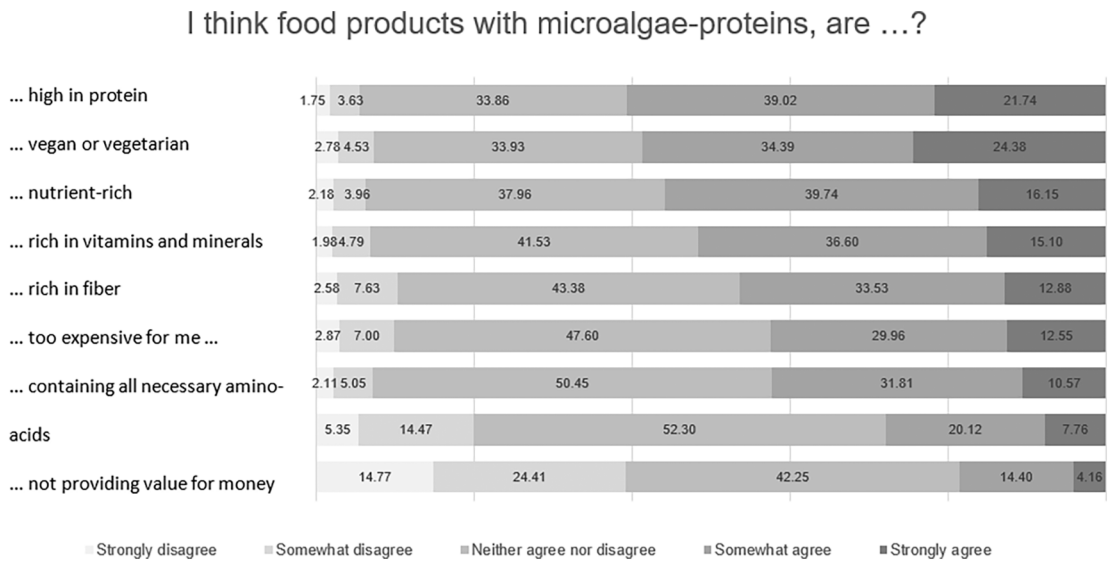

Fig. 2. Nutrient content and evaluative beliefs of foods with microalgae proteins on five-point interval scales, frequency distribution in percentages (N = 3027).

Table 2
Coefficient estimates and diagnostics from the binary and multinomial logistic regression explaining consumers' willingness to try foods with microalgae proteins (n = 2957).

	Willingness to try				Reference segment = Uninterested											
					Enthusiast				Cautiously curious				Undecided			
Variable	β	S.E.	Exp(β) (95 % CI)	Wald	β	S.E.	Exp(β) (95 % CI)	Wald	β	S.E.	Exp(β) (95 % CI)	Wald	β	S.E.	Exp(β) (95 % CI)	Wald
The Netherlands	−0.16	0.13	0.85 (0.66–1.10)	1.53	−0.27	0.23	0.76 (0.49–1.20)	1.40	0.19	0.21	1.20 (0.81–1.80)	0.82	0.28	0.20	1.33 (0.90–1.95)	2.10
Spain	0.08	0.13	1.08 (0.83–1.41)	0.36	−0.15	0.23	0.86 (0.55–1.35)	0.42	0.31	0.21	1.37 (0.91–2.06)	2.25	0.11	0.20	1.11 (0.75–1.66)	0.27
Hungary	−0.23	0.13	0.79 (0.61–1.02)	3.18	−0.45*	0.22	0.64 (0.41–0.98)	4.16	0.00	0.20	1.00 (0.68–1.47)	0.00	0.13	0.19	1.14 (0.79–1.64)	0.46
Italy	0.10	0.14	1.11 (0.85–1.44)	0.55	−0.02	0.24	0.98 (0.62–1.56)	0.00	0.38	0.22	1.46 (0.95–2.23)	3.05	0.20	0.21	1.22 (0.80–1.86)	0.87
Non-meat eaters	0.35	0.20	1.42 (0.96–2.09)	3.13	0.84*	0.39	2.34 (1.09–5.01)	4.76	0.85*	0.36	2.34 (1.15–4.75)	5.49	0.65	0.36	1.92 (0.96–3.87)	3.37
Flexitarian	0.45***	0.10	1.56 (1.29–1.89)	20.90	0.68***	0.18	1.98 (1.40–2.81)	14.92	0.59***	0.16	1.81 (1.31–2.50)	12.95	0.25	0.16	1.29 (0.93–1.78)	2.31
General health interest	0.41***	0.06	1.50 (1.32–1.70)	39.39	0.69***	0.11	1.99 (1.60–2.47)	38.46	0.48***	0.10	1.62 (1.33–1.96)	23.34	0.18	0.10	1.20 (1.00–1.45)	3.69
Food neophobia	−0.88***	0.07	0.42 (0.36–0.48)	160.72	−1.40***	0.12	0.25 (0.19–0.31)	136.90	−1.09***	0.11	0.34 (0.27–0.41)	102.56	−0.44***	0.10	0.65 (0.53–0.79)	18.01
Food technology neophobia	−0.11*	0.06	0.90 (0.80–1.00)	3.87	−0.33***	0.10	0.72 (0.59–0.87)	11.66	−0.15	0.09	0.86 (0.73–1.03)	2.69	−0.18*	0.09	0.84 (0.71–0.99)	4.08
Environmental concern	0.32***	0.06	1.38 (1.23–1.56)	28.65	0.33***	0.10	1.40 (1.14–1.72)	10.19	0.26	0.09	1.30 (1.08–1.57)	7.90	−0.03	0.09	0.97 (0.81–1.16)	0.10
Conventional: Innovative	0.33***	0.04	1.39 (1.28–1.51)	65.30	0.77***	0.07	2.17 (1.87–2.50)	108.38	0.23***	0.06	1.26 (1.12–1.42)	14.26	0.10	0.06	1.10 (0.98–1.24)	2.80
Highly processed: Unprocessed	0.14***	0.04	1.15 (1.07–1.24)	13.18	0.68***	0.07	1.98 (1.73–2.26)	97.40	0.33***	0.06	1.39 (1.23–1.57)	28.01	0.40***	0.06	1.49 (1.32–1.68)	42.59
Harmful for human health: Beneficial for human health	0.20***	0.04	1.22 (1.12–1.33)	22.45	0.87***	0.08	2.39 (2.05–2.78)	127.94	0.07	0.07	1.07 (0.94–1.22)	1.19	0.17**	0.06	1.19 (1.05–1.35)	7.15
Difficult to find: Easy to find	0.11**	0.04	1.11 (1.03–1.20)	7.82	0.42***	0.07	1.52 (1.34–1.74)	39.57	0.03	0.06	1.03 (0.91–1.16)	0.25	0.08	0.06	1.08 (0.96–1.22)	1.76
Intercept	−2.30***	0.46		24.56	−7.27***	0.83		77.19	−0.51	0.71		0.51	−0.18	0.69		0.07

β = estimated logistic regression coefficient; S.E. = Standard error; Exp(β) = odds ratio; baseline country = Germany; baseline dietary status = no specific diet; * significant differences at the 0.05-level; ** significant differences at the 0.01-level; *** significant differences at the 0.001-level.

increase in GHI increases the willingness to try foods with microalgae proteins with 50%. FNS was the largest influential factor in the model (Wald $\chi^2 = 160.72$): a one-point increase in FNS is associated with a 58% decrease in willingness to try while a one-point increase in FTNS is associated with a 10% decrease in willingness to try. Furthermore, one-unit increase of EC results in a 38% increase of the willingness to try foods with microalgae proteins. While accounting simultaneously for the effects of flexitarian diet, GHI, FNS, FTNS and EC, no significant influence of country and adherence to a non-meat diet (i.e. vegetarian, vegan or pescatarian) compared to no dietary restrictions were found. Willingness to try foods with microalgae proteins also increases as consumers are more convinced that these foods are innovative, beneficial for human health, unprocessed and easy to find.

3.4. Exploratory factor analysis

A factor analysis was conducted using principal components for the fifteen attributes on consumer perceptions of foods with microalgae proteins, resulting in a three-factor solution based on the scree plot. Varimax rotation was used. However, five items, i.e. 'unprocessed - processed', 'cheap - expensive', 'harmful to human health - beneficial to human health', 'difficult - easy to find' and 'conventional - innovative' were excluded due to factor loadings below 0.4 on each of the resulting factors, indicating a lack of fit with any of the three factors. A second factor analysis was then conducted, explaining 59.4% of the variance in the original data and yielding a two factor-solution based on the Kaiser criterion (Table 3). The first factor consisted of seven items related to credence attribute perceptions, while the second factor included three items related to experience attribute perceptions.[1] Both credence attribute perceptions (α = 0.88) and experience attribute perceptions (α = 0.67) showed sufficient internal reliability (Lavarkas, 2008).

3.5. Segmentation analysis

Segment 1 ("Enthusiast", 27.7%) showed the highest willingness to try and the most positive credence attribute perceptions (n = 2957) (Table 4). Experience attribute perceptions were not significantly different from the "Undecided" but higher than the other segments. Hence, this segment was named "Enthusiast" because of their positive attitude towards these foods. Segment 2 ("Cautiously curious", 29.5%) is characterised by consumers who have a slightly lower willingness to try than segment 1 and a rather average credence attribute perception, while they have a rather low experience attribute perception regarding foods with microalgae proteins. Segment 3 ("Undecided", 29.8%) is the largest segment and consists of respondents who have a lower-than average willingness to try but an average perception and therefore do not have a clear opinion of these products. Segment 4 ("Uninterested", 13.0%) is the smallest segment. This segment has the lowest scores on all three segmentation variables compared to the other segments and is therefore less appealing for promoting foods with microalgae proteins, as these respondents would be the most difficult to convince.

The differences between the "Uninterested" segment (baseline) and the other three segments are shown in Table 2 based on multinomial logistic regression analysis. Differences between segments in terms of country are rather minor. The only significant country effect concerns a 36% lower likelihood of Hungarian consumers (compared to German consumers, which serve as the baseline nationality in the analysis) to

[1] An additional factor analysis extracting two factors for each of the countries separately was conducted. The same items were assigned to the factors showing robustness, with the exception of the items "Bad sensory properties - Good sensory properties" and "Difficult or too much time to prepare - Easy or not too much time to prepare" in Spain which were assigned to Factor 1: Credence attribute perceptions. Nevertheless, given the satisfactory Cronbach alpha, we maintained a single factor structure across the countries.

Table 3
Factor loadings (varimax rotation) from principal component analysis for attribute perceptions of foods with microalgae proteins (N = 3027).

	Factor 1: Credence attribute perceptions	Factor 2: Experience attribute perceptions
Unnatural - Natural	0.75	
Unhealthy - Healthy	0.79	
Unpleasant - Pleasant	0.71	
Harmful to the env. - Env. friendly	0.75	
Unsafe - Safe	0.80	
Unsustainable - Sustainable	0.78	
Likely to cause food allergy - Unlikely to cause food allergy	0.70	
Bad sensory properties - Good sensory properties		0.73
Difficult to prepare - Easy to prepare		0.67
Not tasty - Tasty		0.74
% Variance explained	42.8	16.6
Cronbach's α	0.88	0.67

belong to the "Enthusiast" segments rather than to the "Uninterested" segment. The likelihood that non-meat eaters and flexitarians belong to the "Enthusiast" or "Cautiously curious" segments rather than to the "Uninterested" segment is about double as compared to consumers who do not follow a specific diet (i.e. consumers on an omnivorous diet). Country and dietary status do not distinguish between the "Undecided" and "Uninterested" segments.

All four tested attitudes showed significant effects in terms of distinguishing between segments. A one-point increase in GHI and EC led to a higher probability of 99% and 40%, respectively, of belonging to the "Enthusiast" segment rather than to the "Uninterested" segment. On the contrary, a one-point increase in FNS and FTNS led to a 75% and 28% decrease, respectively, in the likelihood of belonging to the "Enthusiast" segment rather than to the "Uninterested" segment. Similar effects – albeit somewhat weaker – are seen for GHI and FNS when distinguishing the "Cautious curious" from the "Uninterested" segment. The findings also suggest that neophobia (FNS and FTNS) is the main distinguishing factor between the "Undecided" and the "Uninterested" segment.

Respondents who had stronger beliefs that foods with microalgae proteins are beneficial for human health, innovative, unprocessed and easy to find were more likely to classify as "Enthusiast" than as "Uninterested". The significant effect of perceiving foods with microalgae proteins as being highly processed vs. unprocessed is persistent across segments. Especially for distinguishing the "Undecided" segment from the "Uninterested" segment, the belief that these foods are unprocessed emerges as a most decisive factor, next to a minor effect related to the belief that these foods are beneficial for human health.

The differences between the segments were also examined in terms of specific perceptions regarding the nutritional content and value for money of foods with microalgae proteins, as well as interest in different types of information about these foods (Table 5). A general tendency was observed in the perception of nutritional content: respondents who believed to a greater extent that foods with microalgae proteins were rich in vitamins and minerals, fiber and nutrients, and contain all necessary amino acids classified rather in a segment with a higher willingness to try and a more positive credence attributes and experience attributes. These respondents were also less likely to believe that foods with microalgae were contaminated or unhealthy because of toxins but had a higher believe that foods with microalgae proteins are vegetarian or vegan. Segments with a lower willingness to try and less positive credence attributes and experience attributes perception, thought that foods with microalgae proteins were lesson providing value for money and were too expensive compared to the conventional foods. Lastly, segments characterised by a higher willingness to try and more positive perceptions, showed a greater interest in receiving information about these products, regardless of the type of information.

These findings provide valuable insights for understanding consumer perceptions of foods with microalgae protein and can serve as the basis for strategies to promote their acceptance and adoption.

4. Discussion and conclusion

4.1. Familiarity and perception of foods with microalgae proteins

The findings of this study show that almost half of the surveyed consumers have never been exposed to foods with microalgae proteins. This result is in line with previous research that 47% of consumers were unaware of these products (Roßmann & Rösch, 2020). Other studies reported slightly higher levels of awareness of "algae"-based food. Palmieri and Forleo (2020) found that 57% of Italian consumers had already consumed seaweed, and Mattucci (2016) reported that 58% of German consumers had either tried or expressed interest in seaweed. These different results may be attributed to the greater familiarity and awareness of consumers for macroalgae compared to microalgae (the focus of our study). Anno 2023, no numbers regarding the familiarity with (foods with) microalgae proteins were found. However, previous studies have shown that familiarity has a positive influence on consumer acceptance and preference for foods containing spirulina (Onwezen et al., 2021) and that familiarity with "algae" has a significant positive effect on the likelihood of consumption (Birch et al., 2019). Although the current study did not examine such relationships, it highlights the potential for future research on the relationship between familiarity and consumer acceptance of foods with microalgae proteins.

Consumers who have a high willingness to try and a positive perception of foods with microalgae proteins view them as innovative, unprocessed, and expensive. These consumers also believe that these products are rich in vitamins, minerals, fiber, and nutrients. Foods with microalgae proteins are also considered natural, which is favorable because the perception of unnaturalness has been shown to negatively affect consumer acceptance (Roman et al., 2017). The current study thus provides insight into the potential of foods with microalgae proteins to meet consumer demand for nutritious, natural, healthy, and environmentally friendly options. The perceived benefits are supported by previous research by Nova et al. (2020). Despite the potential benefits of

Table 4
Segmentation variables for market segmentation regarding food products with microalgae proteins (n = 2957).

		Segments (% of respondents)				
	Means ± SD (Total sample)	**Enthusiast (27.7 %)**	**Cautiously curious (29.5 %)**	**Undecided (29.8 %)**	**Uninterested (13.0 %)**	**Test-value**
Willingness to try[1]	3.55 ± 1.13	4.50^{d} ± 0.54	4.23^{c} ± 0.42	2.90^{b} ± 0.31	1.47^{a} ± 0.53	2557.09
Credence[2]	3.51 ± 0.81	4.30^{d} ± 0.52	3.38^{c} ± 0.56	3.28^{b} ± 0.61	2.64^{a} ± 0.83	1362.08
Experience[3]	3.14 ± 0.78	3.74^{c} ± 0.67	2.83^{b} ± 0.61	3.07^{c} ± 0.69	2.78^{a} ± 0.79	761.12

The superscripts a-d indicate significant differences across the four segments (across rows) at a 0.001-level in ascending order. [1]Willingness to try food products with microalgae proteins on a scale from 1: 'Strongly agree' to 5: 'Strongly disagree'; [2]Credence combined by seven attributes (i.e. naturalness, healthiness, pleasantness, harmfulness for the environment, safety, sustainability, causing food allergy); [3]Experience combined by three attributes (i.e. sensory properties, difficulties or taking too much time to prepare and tastiness) on a 5-point bipolar scales. Significance was based on the 0.05 level.; n = number of respondents included; SD = Standard deviation.

Table 5
Segment characteristics based on perceptions and interest in information about foods with microalgae proteins (N = 2957). Sociodemographics given in percentage for each segment.

		Mean ± SD Enthusiast	Cautiously curious	Undecided	Uninterested	H
"I think food products with microalgae-proteins, are …"	… too expensive for me compared to the conventional products	$3.41^{b} \pm 0.95$	$3.49^{b} \pm 0.83$	$3.36^{a} \pm 0.83$	$3.47^{b} \pm 1.06$	14.15
	… rich in vitamins (e.g. vit B12) and minerals (e.g. iron, potassium, phosphorus and calcium)	$4.11^{d} \pm 0.75$	$3.63^{c} \pm 0.74$	$3.32^{b} \pm 0.78$	$2.99^{a} \pm 0.95$	559.82
	… rich in fiber	$3.96^{d} \pm 0.85$	$3.49^{c} \pm 0.81$	$3.25^{b} \pm 0.75$	$2.90^{a} \pm 1.00$	444.68
	… not providing value for money	$2.96^{a} \pm 1.07$	$3.12^{b} \pm 0.81$	$3.13^{b} \pm 0.78$	$3.33^{c} \pm 1.10$	36.23
	… high in protein	$4.29^{d} \pm 0.75$	$3.82^{c} \pm 0.79$	$3.50^{b} \pm 0.76$	$3.12^{a} \pm 0.98$	584.15
	… containing all necessary amino-acids	$3.90^{d} \pm 0.82$	$3.43^{c} \pm 0.70$	$3.24^{b} \pm 0.71$	$2.97^{a} \pm 0.88$	430.44
	… vegan or vegetarian	$4.14^{c} \pm 0.89$	$3.79^{b} \pm 0.92$	$3.48^{a} \pm 0.88$	$3.34^{a} \pm 1.08$	299.32
	… nutrient-rich	$4.20^{d} \pm 0.74$	$3.68^{c} \pm 0.76$	$3.35^{b} \pm 0.73$	$3.02^{a} \pm 0.95$	648.36
	… polluted or unhealthy due to toxins	$2.35^{a} \pm 1.20$	$2.72^{b} \pm 0.96$	$2.85^{c} \pm 0.81$	$2.95^{c} \pm 1.00$	157.20
Interest in information cues	Price	$4.11^{d} \pm 0.86$	$3.90^{c} \pm 0.91$	$3.39^{b} \pm 1.10$	$2.84^{a} \pm 1.53$	331.12
	European regulation and control	$3.89^{d} \pm 1.06$	$3.54^{c} \pm 1.04$	$3.10^{b} \pm 1.11$	$2.59^{a} \pm 1.45$	344.69
	Health risks	$4.19^{d} \pm 0.89$	$3.92^{c} \pm 0.96$	$3.46^{b} \pm 1.11$	$2.91^{a} \pm 1.56$	319.59
	Health benefits	$4.26^{d} \pm 0.86$	$3.91^{c} \pm 0.94$	$3.35^{b} \pm 1.10$	$2.73^{a} \pm 1.49$	499.87
	Nutritional information	$4.01^{d} \pm 0.99$	$3.70^{c} \pm 1.05$	$3.26^{b} \pm 1.11$	$2.82^{a} \pm 1.39$	325.59
	Environmental risks	$4.01^{d} \pm 0.94$	$3.62^{c} \pm 1.03$	$3.20^{b} \pm 1.11$	$2.57^{a} \pm 1.45$	403.00
	Environmental benefits	$4.08^{d} \pm 0.91$	$3.69^{c} \pm 1.01$	$3.17^{b} \pm 1.10$	$2.54^{a} \pm 1.41$	492.38
	Product characteristics (e.g. taste, colour, texture, etc.)	$4.07^{d} \pm 0.88$	$3.78^{c} \pm 0.94$	$3.24^{b} \pm 1.07$	$2.60^{a} \pm 1.44$	459.71
	Used production technology	$3.82^{d} \pm 0.99$	$3.52^{c} \pm 1.00$	$3.04^{b} \pm 1.09$	$2.51^{a} \pm 1.37$	376.41
	Product origin	$4.05^{d} \pm 0.93$	$3.69^{c} \pm 0.97$	$3.22^{b} \pm 1.10$	$2.58^{a} \pm 1.46$	427.45
	List of ingredients	$4.11^{d} \pm 0.89$	$3.78^{c} \pm 0.96$	$3.30^{b} \pm 1.09$	$2.69^{a} \pm 1.49$	401.92
	Company that produced it	$3.63^{d} \pm 1.06$	$3.31^{c} \pm 1.07$	$2.98^{b} \pm 1.06$	$2.35^{a} \pm 1.33$	320.15
	Brand name	$3.37^{d} \pm 1.17$	$3.08^{c} \pm 1.09$	$2.79^{b} \pm 1.08$	$2.25^{a} \pm 1.28$	244.39

The superscripts $^{a\text{-}d}$ indicate significant differences across the four segments (across rows) at a 0.001-level in ascending order; SD = Standard deviation; H = test statistic for the Kruskal-Wallis test.

these foods, there are still barriers such as price and taste expectations that may prevent consumers from adopting a plant-based diet (Fehér et al., 2020) which may also refer to foods with microalgae proteins as they are vegetarian and in the most cases even vegan.

It is worth noting that a large number of respondents believe that foods with microalgae proteins do not offer good value for money. There are several factors that may contribute to these results. One possible explanation is the higher price of novel foods in general compared to conventional foods. This may have limited the accessibility of foods with microalgae proteins to certain population groups that are more price sensitive. It is also possible that consumers who were unfamiliar with foods with microalgae proteins were less able to appreciate their value and benefits, which may have affected their willingness to try or pay. Nevertheless, it has already been shown that willingness to pay for foods with microalgae is independent of the product to which they are added and the amount of microalgae in the food (Weinrich & Gassler, 2021).

4.2. *Willingness to try foods with microalgae proteins*

Consumer willingness to try foods with microalgae proteins is in general moderate. A slight difference was found between southern European countries and central and northern European countries. Despite the relevance of the willingness to try foods with microalgae proteins, previous studies in this area seem to be lacking. Therefore, this study serves as the first investigation of consumer willingness to try foods with microalgae proteins and may provide useful insights for future research in this area.

The binary logistic regression has demonstrated the significant influence of a flexitarian diet, GHI, FNS, FTNS and GHI on the willingness to try foods with microalgae proteins. Diets of the target population have been shown already to influence the acceptability of foods with microalgae proteins (Chacón-Lee & González-Mariño, 2010). The dietary habits of the target population have already been observed to significantly influence the acceptability of foods containing microalgae proteins (Chacón-Lee & González-Mariño, 2010). Specifically, flexitarians emerge as a crucial group to target when promoting plant-based products (Schmid, 2022), owing to their receptiveness to novel food options. Research has indicated that consumers with a high meat consumption showed reduced interest in foods with macroalgae (de Boer et al., 2013). This was confirmed in the present study since flexitarians had a higher willingness to try foods with microalgae proteins compared to those without a specific (i.e., an omnivorous) diet. However, there was no significant difference in willingness to try between non-meat eaters and consumers without a specific diet in this study. This contrasts a previous study on alternative proteins, in which vegetarians and vegans have higher food neophobia compared to omnivores (Elorinne et al., 2019) possibly leading to a lower willingness to try new foods.

This study showed that consumers with a higher environmental concern were significantly more willing to try foods with microalgae proteins. Previous research has shown conflicting results regarding the influence of environmental concerns on consumer willingness to try foods with spirulina. Moons et al. (2018) found no significant influence of environmental awareness regarding the adoption intention of eco-friendly functional food. Meanwhile, Apostolidis and McLeay (2016) found that despite being informed of the environmental benefits of spirulina production, there was no influence on consumers' intention to try these foods. However, several studies have shown that higher levels of environmental awareness can have a positive effect on consumers' intention to switch to foods with a more favorable environmental footprint (Verbeke, 2015).

Consumers with higher levels of food neophobia were less likely to be willing to try foods with microalgae proteins. This is in line with previous research showing the negative influence of food neophobia on willingness to try "algae" (Al-Thawadi, 2018) and the driver of acceptance of "algae" proteins in foods (Onwezen et al., 2021). Additionally, food technology neophobia had a negative impact on willingness to try foods

with microalgae proteins. This is contradictory to previous research that showed that neophobia had no influence on the assessment of the potential of microalgae technology (Weickert et al., 2021). Consumers with a higher general health interest showed to have a higher willingness to try foods with microalgae proteins. Birch et al. (2019) showed already that health-conscious consumers are willing to consume macroalgae. Same results were shown for "algae" in general (Moons et al., 2018).

In this study, no significant differences between countries regarding willingness to try were found, which is consistent with previous findings (Grahl et al., 2018). Furthermore, age effects were not significant. However, this contrasts with some previous findings in the literature that suggested that younger individuals would show a higher willingness to consume alternative protein sources such as "algae" (Birch et al., 2019), while Moons et al. (2018) found no significant influence of age on the intention to adopt spirulina-enhanced foods. In the same study conducted by Birch et al. (2019), it was found that consumers with a higher level of education were more willing to consume macroalgae. However, this study did not establish a similar relationship between education and foods with microalgae proteins as no significant differences effects were found. In contrast, the findings of Weinrich and Elshiewy (2023) indicated that consumers with a higher educational level exhibited less positive attitudes towards microalgae in foods. These conflicting results highlight the complex and varied influence of education on the acceptance of "algae" in foods. The perceived household income did also not show any significant effects for willingness to try foods with microalgae proteins. However, according to the study by Weinrich and Elshiewy (2023), the impact of household income on attitudes towards microalgae varied depending on the country. In the Netherlands, a positive association was observed, while in France, it showed a negative correlation with positive attitudes towards microalgae. No significant differences in willingness to try were also found between countries, which contradicts the findings of previous studies (Grahl et al., 2018; Weinrich & Elshiewy, 2023). This study found that BMI had no significant influence on the willingness to try foods with microalgae proteins. This study is, to the best of our knowledge, the first to investigate the potential impact of BMI on the willingness to try foods with microalgae proteins. Finally, different genders did not appear to have differences in willingness to try foods with microalgae proteins, a finding that contrasts with the Weinrich and Elshiewy's (2023) study, which did reveal gender-based differences in attitudes towards microalgae. Nonetheless, it is important to consider that these variations might be attributed to other factors, such as dietary preferences such as meat consumption habits or interest in organic food.

4.3. Market segmentation

Segmentation analysis revealed four distinct segments, "Enthusiast," "Cautiously curious," "Undecided" and "Uninterested," as well as two distinct trends in the data. Two perceptual measures, namely credence attributes perception and experience attributes perception were used. The results revealed significant differences in the level of credence attribute perceptions across the four segments, with the most favourable perception found among the "Enthusiast" segment and the least favourable perception among the "Uninterested" segment. Similar results were obtained for the experience-attribute perceptions. However, the findings indicated that the "Cautiously curious" segment scored higher on the credence attribute perception than the "Undecided" segment, while the opposite was true for the experience attribute perception. These outcomes appear to diverge from the other descriptives.

Respondents with a higher food neophobia and food technology neophobia were more likely to be part of the segments with less favourable perceptions and lower willingness to try foods with microalgae proteins. Furthermore, when respondents had a higher health interest, environmental concern and interest in relevant information about foods with microalgae, the likelihood was higher that these respondents belong to segments with better perceptions and higher willingness to try.

Contrary to the willingness to try, cross-country differences were observed in the segmentation analysis which is consistent with previous research. However, this was only observed for the difference between Hungarian and Germany regarding the likelihood to belong to the "Uninterested" and the "Enthusiast" segments. This may indicate that the differences mainly link to perception of foods with microalgae proteins. A study by Grahl et al. (2018) found that spirulina was considered a more relevant food ingredient by French consumers than by German and Dutch consumers. Country-specific differences were also found by Weinrich and Elshiewy (2023) who researched attitudes towards microalgae consumption in France, Germany and the Netherlands. No significant differences were found between genders or ages in being part of a particular segment. These results are consistent with other studies that did not found a significant influence of gender or age on intention to consume spirulina-based foods (Moons et al., 2018). However, the results are in contrast to some previous findings in the literature that suggested that women and younger individuals would show a higher willingness to consume alternative protein sources such as "algae" (Birch et al., 2019). Gender differences in attitudes towards microalgae consumption have been reported by Weinrich and Elshiewy (2023). No significant influence of self-reported household income was found on belonging to a certain segment which is consistent with the results regarding the willingness to try. Similarly, when considering education, no notable influence on segment membership was found. These results are inconsistent with previous research showing a higher likelihood of "algae" consumption among individuals with higher levels of education (Birch et al., 2019). This study also demonstrated that individuals adhering to non-meat diets or identifying as flexitarians had a higher likelihood of belonging to the "Enthusiast" or "Cautiously curious" segments in comparison to the "Uninterested" segment, which is consistent with the findings of previous studies on consumer willingness to try insect-based foods (Elorinne et al., 2019) and the study of Weinrich and Elshiewy (2023) who showed that the target consumer group for microalgae consists out of vegetarians and flexitarians. Finally, no differences were found between the cluster membership of respondents with a different BMI. While previous research has reported about potential anti-obesity properties of microalgae (Gómez-Zorita et al., 2019), the results of this study do not allow drawing conclusions regarding this topic due to the lack of significant findings.

Only the results of the segmentation analysis for country is different to the results of the willingness to try analyses. Consequently, we can conclude that the noteworthy variation in cluster membership attributed to the country, primarily stems from different perceptions between Hungarian and German consumers rather than from their differences in willingness to try foods with microalgae proteins. This differentiation is observed solely in the case of these two countries in terms of "Enthusiast" membership as opposed to "Uninterested" membership.

Respondents with higher general health interest, showed a higher likelihood to belong to the segments with a greater willingness to try foods with microalgae proteins, which is consistent with previous studies that have found a positive correlation between health awareness and willingness to try new foods (Barrena & Sánchez, 2013). Specifically, it has been shown that the interest in foods with microalgae was higher when consumers are interested in healthy diets (Weichert et al., 2021; Weinrich & Elshiewy, 2023). The present study also showed significant influences of food neophobia and food technology neophobia on cluster membership. When respondents exhibited lower levels of food neophobia, their likelihood of belonging to the "Enthusiast" segment was the highest, followed by the "Cautiously curious" and "Undecided" segments, in comparison to the "Uninterested" segment. Similarly, with lower levels of food technology neophobia, the likelihood of being in the "Enthusiast" segment was the highest, followed by the "Undecided" segment, in comparison with the "Uninterested" segment. Thus, respondents who are more neophobic have a higher likelihood to belong to segments with a lower willingness to try foods with microalgae proteins.

These results are consistent with previous research showing a correlation between food neophobia and acceptance of novel foods with microalgae proteins (Barrena & Sánchez, 2013). The effects of food neophobia have also been documented in previous studies on the acceptance of meat alternatives with insects (Verbeke, 2015) and were found to directly affect the intention to try foods with "algae" (Al-Thawadi, 2018). Michel et al. (2021) found also a negative impact of food neophobia on the acceptance of burgers with "algae" which is in accordance of this study.

Respondents with higher environmental concern were more likely to be part of the "Enthusiast" segment, which had the highest willingness to try and the most favourable perceptions. Our results herewith suggest that consumers who are more concerned about the environment are more likely to be receptive to new, sustainable protein sources. This finding contradicts previous research that found no significant relationship between environmental awareness (Moons et al., 2018) and awareness of the environmental benefits of spirulina (Apostolidis and McLeay, 2016) and the intention to try foods with spirulina. However, it aligns with other studies which have demonstrated that consumers with a concern for environmental sustainability are more inclined to consume "algae" (Birch et al., 2019).

Perceptions of foods with microalgae proteins were more positive in the "Enthusiast" and "Cautiously curious" segments than in the "Undecided" and "Uninterested" segments. The significant differences between segments may provide valuable information for understanding and promoting adoption of these products. The nutritional benefits and risks of microalgae protein products were important factors influencing segment perceptions, consistent with previous research (Cardello et al., 2007). This study found also that segments with a higher willingness to try and more positive perceptions of foods with microalgae proteins showed a greater propensity to learn about such products, regardless of the type of information provided.

The differences in the types of information considered most interesting by each segment underscore the importance of accounting for the specific perspectives and needs of the various segments when developing and communicating information about foods with microalgae proteins (Vermeir & Verbeke, 2008). Previously was already shown that the target group for microalgae are interested in food production information (Weinrich & Elshiewy, 2023), which is also presented in this study. The "Uninterested" segment has an entrenched opinion that is unlikely to change. Based on the segmentation analysis of consumer attitudes and perceptions toward microalgae protein foods, the "Enthusiast," "Cautiously curious," and "Undecided" segments are clearly the most receptive to promotional activities. Therefore, specific promotional strategies might primarily target these segments.

4.4. Limitations

As with the acceptance of any food product, sensory expectations and experiences undoubtedly have a major impact on trial and adoption of foods with microalgae proteins. Considering the large sample size and survey method, the current study was not able to evaluate the impact of actual experienced taste on consumers' perception of foods with microalgae proteins, which is certainly an area for further research.

Prior information about foods can have a significant impact on consumer perception and acceptance. Studies have shown that providing information about insect-based foods prior to trial can increase acceptance (Verneau et al., 2016) or alter consumer perceptions (Barsics et al., 2017). Because microalgae products are still largely unknown to the general public, explanations were provided in the current study prior to the specific questions about microalgae protein foods. Although consumers on average reported being somewhat familiar with microalgae products, the information provided may have led to a more positive opinion/image of these products. Therefore, further confirmation is needed in future research based on situations that more closely mimic market introduction.

4.5. Recommendations

Based on the results of this study, recommendations can be made for each segment separately based on the characteristics of the consumers within the segments.

The "Enthusiast" consumer segment already has a positive perception of foods with microalgae proteins and is easily inclined to adopt them without much persuasion. However, there are significant differences between Hungary and Germany. Therefore, it is advisable to focus efforts on countries where microalgae are even less known, such as Hungary, where there are fewer consumers in this segment. This segment is open to learning more about microalgae and shows a strong interest in general health and environmental concerns. Consequently, highlighting the health benefits of microalgae proteins and their environmentally friendly production could be an effective approach to disseminate information to this consumer segment. Additionally, conducting food tastings of foods with microalgae proteins in supermarkets, focusing on products that effectively showcase microalgae proteins, could prove beneficial as this segment is open to trying unfamiliar foods.

The "Cautiously curious" segment and the 'Undecided" segment show promise in changing their perceptions and increasing their willingness to adopt foods with microalgae proteins. Nevertheless, the "Cautiously curious" segment has lower perception attributes perception compared to the "Undecided" segment. To improve this aspect of perception and facilitate the transition of these consumers into the "Enthusiast" segment, it is essential to invite them to tasting of foods with microalgae proteins at points of purchase such as supermarkets. This strategy fits well with the willingness of the "cautiously curious" segment to try unfamiliar foods. Both the "Enthusiast" and "Cautiously curious" segment contains a larger amount of non-meat eaters and flexitarians compared to the other segments. This can be addressed by offering meat analogues with microalgae proteins in the future.

The "Undecided" segment, in contrast to the "Cautiously curious" segment, shows lower experience attributes perception. To remedy this, effective communication of the positive aspects of foods with microalgae proteins through targeted campaigns is essential. However, the "Undecided" segment also exhibits high levels of food (technology) neophobia, although lower than the "Uninterested" segment, so clear communication about the nutritional benefits of foods with microalgae and the fact that current technology for producing (foods with) microalgae proteins is safe and environmentally friendly is also necessary to allay any health and environmental doubts. This was also shown by Weickert et al. (2021) who indicated that consumers who have a clearer idea of the production process do not have a strong rejection of novel foods and that consumer acceptance may be limited if not enough information about the production system has been provided. Lafarga et al. (2021) showed that residents of Almeria and Livorno responded positively to the construction of microalgae biorefineries after receiving information about the technologies and microalgae.

The last and most difficult segment to convince to adopt foods with microalgae proteins is the "Uninterested" segment. This segment shows very little interest in this type of foods. To persuade these consumers and thus move these consumers to a more positive segment, consumers could be explained where the price premium of foods with microalgae comes from compared to conventional foods without microalgae. On the other hand, food manufacturers could invest in technologies that make foods with microalgae proteins more affordable. Again, it is important to reduce the neophobia towards foods with microalgae proteins, as this is a barrier for this segment. Since they have the least environmental concerns compared to the other segments, it is more important here to focus on other positive aspects of these foods such as their nutritional value.

CRediT authorship contribution statement

Hélène Van der Stricht: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Yung**

Hung: Conceptualization, Data curation, Investigation, Methodology, Supervision, Writing – review & editing. **Arnout R.H. Fischer:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Wim Verbeke:** Conceptualization, Funding acquisition, Investigation, Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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