European Food Research and Technology (2024) 250:2193–2209
https://doi.org/10.1007/s00217-024-04530-y

ORIGINAL PAPER

# Snacks from the sea: a cross-national comparison of consumer acceptance for crackers added with algae

**Noemi Sofia Rabitti[1] · Simoun Bayudan[2] · Monica Laureati[1] · Susanne Neugart[3] · Joachim Jietse Schouteten[2] · Linnea Apelman[4] · Sermin Dahlstedt[4] · Pernilla Sandvik[4]**

Received: 5 January 2024 / Accepted: 16 March 2024 / Published online: 27 April 2024
© The Author(s) 2024

## Abstract

One of the main priorities of current food systems is to develop new and healthy foods to overcome food shortages considering consumer's expectations. Algae are receiving increasing attention as nutritious and sustainable food, though studies are limited mainly to Arthrospira and Chlorella species and cross-national research is scant. This study aims to investigate European consumers' liking and perception of crackers added with powders from *Arthrospira platensis* (green Spirulina), isolated proteins from *Arthrospira platensis* (blue Spirulina), *Palmaria palmata*, *Saccharina latissima*, *Lithothamnium calcareum* and a control cracker. Belgian, German, Italian, and Swedish participants ($n = 413$, 18–69 years, 59.8% females) evaluated cracker liking and perceived sensory attributes using the check-all-that-apply (CATA) task. Food neophobia, familiarity towards, and consumption of algae were also collected. Partial Least Squares Regression (PLSR) analyses showed that across all countries, *Lithothamnium calcareum*, blue Spirulina and the control samples were perceived as similar and were liked more than the other crackers. "Sweet", "toasted bread", and "bland" attributes were significant contributors to liking, while "off-flavor", "fishy flavor", "umami" and "speckled" contributed negatively. PLSR performed by country provided similar results except for Italians who liked the green Spirulina sample equally as the samples added with *Lithothamnium calcareum,* blue Spirulina, and the control. These cross-national differences can be ascribed to Italians' lower food neophobia level. The present results suggest that *Lithothamnium calcareum* is the most promising algal species to be exploited in food formulations and that the use of isolated proteins from Spirulina (blue Spirulina) significantly reduces off-flavors, consequently improving consumers' acceptance.

**Keywords** Novel food · Liking · Food neophobia · Seaweed · Sensory evaluation · Check-all-that-apply (CATA)

## Introduction

We live in an era where global population growth, urbanization, and aging are accompanied by a massive increase in the demand for water, food and energy, all of which cause heavy burdens on environment [1]. One possible solution to counter these harmful effects is to encourage changes in people dietary habits, as current agri-food systems highly contribute to environment crisis [2]. A rising number of studies, especially in Western European countries, are showing interest in new dietary patterns and more sustainable food sources [2–4]. In this context, algae represent a promising food ingredient since they are rich in health-beneficial compounds and their production requires the exploitation of few natural resources [5–7].

The morphology and size of algae are highly variable. There are unicellular species measuring 3–10 μm

✉ Noemi Sofia Rabitti
noemi.rabitti@unimi.it

[1] Department of Food, Environmental and Nutritional Sciences, University of Milan, 20133 Milan, Italy

[2] Department of Agricultural Economics, Agri-Food Marketing and Chain Management, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

[3] Department of Crop Sciences, Division of Quality and Sensory of Plant Products, Georg-August-University Göttingen, Carl-Sprengel-Weg 1, 37075 Göttingen, Germany

[4] Department of Food Studies, Nutrition and Dietetics, Uppsala Universitet, Husargatan 3, 75237 Uppsala, Sweden

(microalgae), and huge water algae reaching as much as 70 m in length (macroalgae) [8]. Algae require carbon dioxide ($CO_2$), light, and some nutrients in the form of hydrogen, phosphorus, and potassium to produce sufficient biomass. They can grow in critical conditions such as in non-potable water (e.g., seawater) and on non-arable land, representing an interesting opportunity for development especially in arid regions [6, 9].

Algae possess potential health benefits such as antidiabetic, antihypertensive, antioxidant, anti-inflammatory properties [10, 11] and they are also suitable sources of dietary fibre, essential vitamins (pro-vitamin A, B vitamin family, C, E and K) [12], minerals, and other bioactive compounds [13]. Being rich in balanced amino acids, they are considered a high-quality protein source and a promising alternative to conventional livestock protein sources [14]. Algae are also an excellent source of omega-3 fatty acids which, for instance, cannot be provided by other sustainable food ingredients such as pulses [15].

Despite the environmental and nutritional benefits associated with algae, their use as food ingredients is still uncommon in Europe, and only a niche of the population, characterized by individuals having high levels of health and well-being awareness (e.g., athletes), consumes algae mainly as food supplement [16, 17]. On the contrary, the production and consumption of algae in Asian countries, particularly in East Asia, is more common especially in relation to the species belonging to the Laminariales order [18, 19].

The widespread exploitation of algae in food preparation among Western countries remains challenging due to several obstacles, one of the main being the presence of unpleasant sensory characteristics such as green/blue color, fishy flavor and off-odors [10]. Undesirable odors and flavors are mainly caused by volatile compounds such as geosmin and 2-methylisoborneol [20], that can be masked by the addition of other ingredients or specific food technologies in algae preparation. Bakery products have been reported as one of the most suitable food matrices to incorporate algae, due to the presence of masking ingredients (e.g., spices) and to the baking process, which can aid in hiding and moderating the perception of unpleasant smells and tastes among consumers [10].

Until now, studies have explored the sensory properties of food added with different concentrations of microalgae, mainly Spirulina (*Arthrospira platensis*) and Chlorella (*Chrolella vulgaris*), in bakery products [21, 22], and yogurt [23], while other species are underexplored [24]. Moreover, existing research exploited microalgae as ingredients using the entire cell, while no investigation has been done related to the sensory properties of fractionated microalgae (e.g., proteins and/or lipid components) added in food, which could be a possible solution to reduce undesired off-odors and flavors [10].

Furthermore, to the best of the authors' knowledge, there are no studies yet that have compared the impact of different microalgae and macroalgae species towards sensory profiles and consumer acceptance when incorporated in food matrices, especially in a European context. Exploring consumer perceptions and preferences of new food sources in different cultural frameworks is important because these may differ among each other, yet cross-national studies exploring sensory perception of food products made of algae are scanty [25, 26].

The present study aims to apply a pan-European approach to better understand cross-national differences in the acceptance and sensory description of crackers with the addition of different micro- and macroalgae powders. This study also considers the effect of isolated proteins from *Arthrospira platensis* in reducing off-odors and flavors from these products. Outcomes from the present study may provide useful insights which can be leveraged by the food industry in the manufacture of novel and sustainable food products based on algae.

## Materials and methods

### Participants

In the present study, 413 adults (247 women, 166 men) aged 18–69 years (mean age 28 ± 11.3 years), from four European countries (Belgium, Germany, Italy, and Sweden) were involved. The recruitment of participants was done among students and employees of the Faculty of Bioscience and Engineering of the University of Ghent, the Faculty of Agriculture of the University of Göttingen, the Faculty of Agriculture and Food Sciences of the University of Milan, and the Uppsala Biomedical Center at Uppsala University. Furthermore, only participants who did not suffer from food allergies, intolerances, taste and/or smell disorders, were not pregnant, and liked crackers were involved in the study. The study protocol was approved by the relevant research ethics committee of each country, and written consent was obtained from the individuals prior to participation, according to the declaration of Helsinki (Belgium: No. 2022-40, Germany: No. 63/11, Italy: No. 94/22, Sweden: 2022-06258-01) and in line with the General Data Protection regulation 2016/679.

### Experimental samples

Crackers were chosen as experimental products since they are familiar to almost all European countries [27]. Their sensory characteristics are stable for a reasonable time frame and they are also easy to distribute across the different countries involved in the study.

Five cracker samples were prepared by adding each of the following algae species, in powder form: *Arthrospira platensis* (green Spirulina), isolated protein from *Arthrospira platensis* (blue Spirulina), *Palmaria palmata*, *Saccharina latissima* and *Lithothamnium calcareum*. These micro- and macroalgae species were chosen as they are primarily approved for distribution on the EU market, and they possess varying levels of nutrients. These species also could elicit different sensory perceptions, for instance, through their different colors and flavors. In addition, the isolated protein from *Arthrospira platensis* was also included to verify whether its incorporation in a food matrix may limit the perception of unpleasant flavors delivered by the entire bacterium [10].

The five crackers added with algae were compared with a control sample without any addition of algae. The control cracker was produced according to the following formulation (w/w): 60.5% commercial all-purpose wheat flour (Type 00), 1.5% baking powder, 1% salt (NaCl), 1% sugar (sucrose), 7.5% vegetable oil, and 28.5% distilled water. For the other experimental samples, algal biomass powders were added at 5% (w/w) incorporation levels, replacing the corresponding amount of wheat flour. The decision to add 5% w/w micro- and macroalgae powders was driven by the goal of increasing the amount of algae incorporated in already existing products as seen in the literature [28] and in the market, which was around 2% w/w in pasta and crackers sold, for instance, in the Italian market. Furthermore, a pilot test involving six trained subjects was conducted prior to the main experiment to verify that the addition of 5% w/w micro- and macroalgae to cracker samples did not compromise consumers' acceptability due to highly undesirable sensory characteristics. All ingredients for each cracker formulation were placed directly and blended in a planetary mixer (Kenwood Chef, Bad Vilbel, Germany) with a dough hook attachment and subsequently mixed by hand, until a homogeneous and cohesive dough was formed. The dough mass was then pressed into thin sheets using a pasta roller machine in three different gauge positions, until a dough thickness of approximately 0.65 cm was obtained.

Afterwards, the rolled-out dough sheets were cut into round pieces of 6 cm diameter each. These rounds were then transferred to baking trays, adequately spaced, and were slightly perforated using wooden skewers to allow steam to escape and to prevent deformation during the baking process. The cracker rounds were then allowed to rest for 10 min at room temperature (22 °C). Once the rounds have rested for 10 min, the baking trays were then placed inside a forced-air convection oven pre-heated at 180 °C for 10 min. Upon completion of the baking time, the samples were further dried in the oven at a lower temperature (60 °C) for 30 min to maximize the loss of moisture in the crackers. They were then cooled at room temperature for 30 min and stored in plastic boxes. All experimental crackers samples were produced in a pilot plant at the Division of Quality and Sensory of Plant Products (Georg-August-University Göttingen, Germany). To facilitate transportation towards the different study countries, batches of crackers were securely packaged in plastic containers appropriate for the shipping to the different country destinations targeted in this study.

All in all, it took approximately two to four weeks from production before respondents were able to taste and evaluate the products in the respective laboratories of each study country. As the case products were crackers, they were not highly perishable and were stored in a dry place, away from light sources.

Table 1 provides the description of the algae powders used in the present study, as well as the graphical representation of the crackers used in the sensory evaluation experiments.

## Experimental procedure

The sensory evaluation sessions were carried out in sensory evaluation laboratories following a standardized procedure. All sessions were held in individual partitioned booths for each participant and under white lighting conditions. The questionnaire and procedures were initially developed in English and then translated by native speakers to adapt the text to the local languages of each study site. To maximize consistency across countries, experimenters were instructed not to deviate from the protocol instructions. The session lasted approximately 30 min. Data were acquired using the software EyeQuestion (v. 5.9.4, Logic8 BV, The Netherlands).

### General questions on crackers and algae-based products consumption

First, participants answered questions on cracker consumption choosing from the following possible options: "Daily"; "A couple of times a week"; "Weekly"; "A couple of times a month"; "Monthly"; "Less than once a month"; "Never", then they also answered questions concerning their knowledge of algae-based products before being enrolled in this study (1 = "Yes, I have heard of these products and already tried/tasted them"; 2 = "Yes, I have heard of such products and already tried/tasted them, but I did not know what they are"; 3 = "Yes, I have heard of such products and I know what they are, but never tried/tasted them"; 4 = "Yes, I have heard of such products, but I did not know what they are nor have I tried/tasted them"; 5 = "No, I have never heard of these products"). Subsequently, the participants were requested to provide their propensity to consume eight different food products enriched or fortified with algae (pasta, vegetable soup, vegetable alternative to meat, salty

**Table 1** Cracker samples and algae powder composition

| Experimental samples | | Algae powder composition and brand* (nutritional values for 100 g) |
|---|---|---|
|  | Control sample | No algae powder addition |
|  | Addition of 5% (w/w) *Arthrospira platensis* (green Spirulina, entire bacterium) | Caloric value: 1834 kJ/ 440 kcal<br>Fat: 13 g, of which saturated fatty acids: 2.72 g<br>Carbohydrates: 17.3 g, of which sugar: 0.5 g<br>Protein: 59.1 g<br>Salt: 0.14 g<br>Brand: Gewürzland, www.gewuerzland.com |
|  | Addition of 5% (w/w) isolated protein from *Arthrospira platensis* (blue Spirulina) | No declared nutritional information<br>Brand: Gewürzland, www.gewuerzland.com |
|  | Addition of 5% (w/w) *Palmaria palmata* | Caloric value: 930 kJ/ 223 kcal<br>Fat: 0.5 g, of which saturated fatty acids 0.1 g<br>Carbohydrates: 21.0 g, of which sugar 0.2 g<br>Protein: 18.0 g<br>Salt: 2.5 g<br>Brand: Algen Laden, www.algenladen.de |
|  | Addition of 5% (w/w) *Saccharina latissima* | Calorific value: 678 kJ/ 165 kcal<br>Fat: 0.6 g, of which saturated fatty acids 0.1 g<br>Carbohydrates: 3.0 g, of which sugar 0.2 g<br>Protein: 15.5 g<br>Salt: 0.7 g<br>Brand: Algen Laden, www.algenladen.de |
|  | Addition of 5% (w/w) *Lithothamnium calcareum* | Caloric value: 118 kJ/ 28 kcal<br>Fat < 0.5 g, of which saturated fatty acids 0 g<br>Carbohydrates 3.5 g, of which sugar 0 g<br>Protein 2.5 g<br>Salt 0.53 g<br>Calcium 32,000 mg<br>Magnesium 2900 mg<br>Iodine 600 µg<br>Brand: Algen Laden, www.algenladen.de |

*Nutritional values were obtained from available information from the food labels and suppliers database of the algae powders

bakery products, energy bars, salty snacks) by answering the question: “If algae were added to… I would be willing to try this food product” through a 5-point agreement scale (1 = strongly disagree, 2 = somewhat disagree, 3 = neither agree nor disagree, 4 = somewhat agree, 5 = strongly agree). The order of the food items was randomized across participants. Finally, participants answered the question: "Have you ever consumed algae or products made with algae in the past?". Participants were allowed to choose one or more options among seven items (as powder or pills, in sushi,

seaweed salad, as food ingredient e.g., in a soup, smoothie or other dish, as a snack e.g., crackers, crisps, other, I have never consumed algae or products made with algae in the past).

#### Overall liking and Check-All-That-Apply (CATA) task

Once the participants accomplished the initial section on general cracker and algae questions, they then received simultaneously the six cracker samples presented using a balanced design to control for order and carryover effects [29]. For each sample, participants were asked to taste and express their overall liking using a 7-point labelled scale (1 = dislike very much, 7 = like very much). Participants were asked to rinse their mouths with still water before and after each tasting. They were then requested to perform a CATA task by selecting all attributes which they found applicable for the given sample crackers.

Concerning the generation of descriptive terms for the CATA task, 6 trained subjects were priorly involved in a pilot tasting session wherein they used a free listing method through a word elicitation task similar to the approach used by Ares et al. [30] to identify appropriate sensory attributes which can be used to describe the cracker samples [31]. Aside from the free-listing activity, existing literature was also checked to ensure accuracy and completeness of terms used for the CATA task [32]. The resulting CATA questionnaire consisted of 23 sensory attributes: seven descriptors for appearance (golden/yellowish color, brownish color, blue color, green color, thick, speckled, unnatural color), twelve for odor/flavor and taste (oily flavor, off-flavor, fishy flavor, spinach/grassy flavor, mushroom flavor, toasted bread flavor, bitter, sweet, salty, umami, bland, spicy), and four for texture (dry, crunchy, brittle, hard).

#### Food neophobia scale

Participants completed the Food Neophobia Scale (FNS) [33] as it is reported to be one of the main barriers to the consumption of novel and unfamiliar food [34]. The FNS consists of ten statements, of which five are related to neophilic behaviors and the other five to neophobic behaviors. Each participant provided scores for the ten statements of the FNS through a 7-point agreement scale (1 = strongly disagree, 7 = strongly agree).

### Data analysis

The frequency distribution of continuous variables (i.e., liking and food neophobia) was first checked for normality. According to Shapiro–Wilk's test, the respondents' liking scores and food neophobia index deviated from the normal distribution (liking, $p \leq 0.0001$; food neophobia, $p \leq 0.0001$). However, investigation of the *Q*–*Q* plots showed a normal pattern and thereby the data were handled as normally distributed [35].

The answers to the ten items of the FNS were summed up (after reversing the scores of neophobic items) to have a score ranging from 10 to 70. Higher scores indicate higher levels of food neophobia, that is, aversion to novel food products and experiences [33]. The reliability of the FNS was investigated by calculating internal consistency (Cronbach's α and item-item correlation). The 25% and 75% quartiles of the FNS across all countries were used to segment participants into three food neophobia levels: low (scores ≤ 16, $n = 112$), medium (scores 17–29, $n = 185$), and high (scores ≥ 30, $n = 116$).

Data about algae and algae-based products consumption were compared across country using Chi-square test or the generalized linear model (GLM) procedure.

Liking was also analyzed by means of the GLM procedure considering the six cracker samples, country of origin (Belgium, Germany, Italy, Sweden), gender (women and men), age group (18–21 years $n = 147$; 22–27 years $n = 133$; 28–69 years $n = 133$), food neophobia level (low, medium, high) and their second-order interactions as factors. Least-squares means (LS-means), and relevant standard errors (SEM) were computed for each factor. When the GLM showed a significant effect ($p \leq 0.05$), the Bonferroni test adjusted for multiple comparison was used as post-hoc analysis.

CATA data were analyzed using Cochran's Q tests to determine significant differences across all descriptive attributes for each of the cracker samples. When significant differences were found, Sheskin's multiple comparison test was used.

CATA and liking data were then jointly analyzed using Partial Least Squares Regression (PLSR) analysis to predict drivers of liking and rejection of the cracker samples [36]. PLSR analysis was performed considering the CATA questions in the X matrix and the average liking scores by product in Y matrix. PLSR analysis was run across all countries and by country. Data were standardized (i.e., scaled to unit variance) prior to modeling and cross validation was chosen as the validation method.

The SAS/STAT statistical software package version 9.4 (SAS Institute Inc., Cary, NC, USA) was used to run univariate parametric and non-parametric analyses, while multivariate analyses (PLSR) was run using XLSTAT (version 2021.2.1, Addinsoft, Boston, MA, USA). Effects showing a *p*-value of 0.05 or lower were considered significant.

## Results

### Participants' characteristics

The participants' characteristics (socio-demographics and algae familiarity and consumption) are reported in Tables 2 and 3.

**Table 2** Participants' characteristics: socio-demographics (age is reported in years as mean ± standard deviation and range between brackets)

| Country | *N* (%) | Age (range) | Gender (% *F*) |
|---|---|---|---|
| Belgium | 113 (27.4) | 21.5 ± 5.0 (18–54) | 57.5 |
| Germany | 96 (23.2) | 31.0 ± 12.2 (20–62) | 53.1 |
| Italy | 108 (26.2) | 31.1 ± 13.2 (18–67) | 61.1 |
| Sweden | 96 (23.2) | 29.6 ± 10.7 (19–69) | 67.7 |
| Total | 413 (100) | 28.3 ± 11.4 (18–69) | 59.8 |

The number of subjects per country as well as the ratio of males to females were both comparable, while regarding age, the study sample in Belgium was significantly younger than in other countries ($F_{(3,409)} = 20.6$, $p < 0.001$).

In Italy, 60.2% of the respondents declared that they consume crackers at least on a weekly to a daily basis. The rest of the countries had significantly ($p < 0.001$) lower frequency distributions (Belgium: 15.9%, Sweden: 12.5%, Germany 5.2%).

Participants from Belgium had significantly lower knowledge levels and consumption frequencies of algae in sushi, in snacks and in general as food ingredient than the other countries (all $p < 0.001$). On the other hand, Swedish participants had the highest percentages of algae consumption frequencies in sushi, salad, and as food ingredient. Together with the Italian respondents, they were most willing to try algae in the series of food products presented, while individuals from Belgium showed in general lower willingness to try these food products added with algae.

### Participants' food neophobia scores

Total internal consistency calculated over all countries was 0.84 ($n = 413$), much higher than the suggested value of 0.70 given by Nunnally and Bernstein [37]. When calculated by country, internal consistency was also high and ranged between 0.76 (Germany) and 0.89 (Italy). To verify the stability of the internal consistency of the scale, the Cronbach's alpha values were recalculated (both overall and by country)

**Table 3** Participants' consumption frequency of crackers, familiarity towards and consumption of algae

| Questions | | Country | | | | |
|---|---|---|---|---|---|---|
| | | Belgium | Germany | Italy | Sweden | *p*-value |
| How often do you eat crackers? (consumption frequency, %) | | 15.9 | 5.2 | 60.2 | 12.5 | *** |
| Have you ever heard about algae in food? (% Yes) | | 72.6 | 92.7 | 86.1 | 88.5 | *** |
| Have you ever consumed algae in the past? (% Yes) | • As powder or pills | 10.6 | 19.8 | 13.9 | 20.8 | n.s |
| | • In sushi | 45.1 | 76.0 | 80.6 | 86.5 | *** |
| | • Seaweed salad | 40.7 | 38.5 | 44.4 | 72.9 | *** |
| | • As food ingredient (e.g., in a soup, smoothie, others) | 15.9 | 27.1 | 28.7 | 52.1 | *** |
| | • As snack (e.g., crackers, crisps) | 12.4 | 37.5 | 16.7 | 32.3 | *** |
| | • I've never consumed algae or products made with algae | 38.9 | 11.5 | 6.5 | 6.3 | *** |
| If algae were added to… I would be willing to try this food product *(mean)* | • Pasta | 4.3 | 4.1 | 4.0 | 4.3 | n.s |
| | • Vegetable soup | $4.0^{a}$ | $4.2^{ab}$ | $4.5^{bc}$ | $4.6^{c}$ | *** |
| | • Meat alternatives | $4.1^{ab}$ | $3.9^{a}$ | $4.1^{ab}$ | $4.4^{b}$ | * |
| | • Salty bakery products | $3.5^{a}$ | $4.1^{b}$ | $4.5^{c}$ | $4.6^{c}$ | *** |
| | • Snacks | $3.8^{a}$ | $4.3^{b}$ | $4.5^{b}$ | $4.5^{b}$ | *** |
| | • Energy bar | $3.9^{a}$ | $3.8^{a}$ | $4.1^{ab}$ | $4.4^{b}$ | ** |

Crackers consumption frequency is reported as % (the responses to the items "weekly", "couple of times a week" and "daily" were summed to represent high frequency of consumption). Answers to algae familiarity and consumption questions are reported as % of "Yes", while willingness to try algae in a specific food is reported as mean (5-point agreement scale)

n.s. not significant, *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$, according to Chi-square test or GLM. Different superscripts by row indicate significant differences

after removing one item at a time to show any changes to the expected standardized alpha coefficient. These calculations did not show a significant increase or decrease on the expected standardized alpha value for both overall and by country groups, suggesting that no improvement to the scale reliability was achievable even when some specific scale items were removed. Item-item correlations were always high and significant as a further indication of the reliability of the measurement. Hence, the full food neophobia scale was used for further analyses.

The overall FN mean for all the participants was 24.1 out of a maximum allowable score of 70. Furthermore, according to GLM results, cross-national differences were found in terms of FN ($F_{(3,409)} = 10.1$, $p < 0.001$). Italian subjects were significantly less food neophobic ($M = 20.1$) than all other countries which were, in turn, comparable (Belgium, $M = 26.4$; Germany, $M = 26.3$; Sweden, $M = 23.6$).

## Cross-national differences in crackers liking and sensory description

### Crackers liking

The main factors Cracker samples ($F_{(5,2401)} = 22.6$, $p < 0.001$), Country ($F_{(3,2401)} = 25.4$, $p < 0.001$), FN level ($F_{(2,2401)} = 5.2$, $p = 0.005$) and age group ($F_{(2,2401)} = 4.5$, $p = 0.01$) had significant effects on liking. Liking scores for crackers added with blue Spirulina ($M = 5.2$) and *Lithothamnium calcareum* ($M = 5.1$) were the highest and comparable to the control cracker ($M = 5.2$). On the other hand, the liking scores for crackers added with green Spirulina ($M = 4.8$) were significantly lower and comparable to the cracker added with *Saccharina latissima* ($M = 4.6$). Crackers added *Saccharina latissima* were also, in turn, comparable with the least liked cracker added with *Palmaria palmata* ($M = 4.5$). Moving to a country-level analysis, Italian participants ($M = 5.3$), scored higher than Belgian ($M = 4.9$) and Swedish respondents ($M = 4.9$), while German individuals ($M = 4.5$) provided the lowest scores. Individuals with low FN levels scored significantly higher ($M = 5.0$) than those with higher FN levels ($M = 4.8$), though differences were minimal.

Concerning age, older respondents had significantly lower liking scores for the crackers ($M = 4.8$) compared to younger participants ($M = 5.0$).

The interaction Country*Cracker samples ($F_{(15,2401)} = 3.8$, $p < 0.001$) had also a significant effect on liking. German participants provided significant lower scores than Italian and Swedish respondents for crackers added with blue Spirulina and *Lithothamnium calcareum*, while Italy was the country in which crackers added with green Spirulina received the highest scores compared to all other countries (Fig. 1).

The interaction Age group*Cracker sample ($F_{(10,2401)} = 2.1$, $p < 0.05$) showed that for the sample with the addition of *Palmaria palmata*, subjects aged 28–69 years gave significantly lower scores than those aged 22–27 years.

The interaction Country*Gender ($F_{(3,2401)} = 4.7$, $p = 0.003$) was also significant. This interaction revealed that male subjects in Italy liked the algae added crackers significantly more than males in all other countries. Moreover, German women had comparable liking scores to Swedish ones but significantly lower than Italian and Belgian women. Finally, the interactions Age group*Gender ($F_{(2,2401)} = 3.2$,

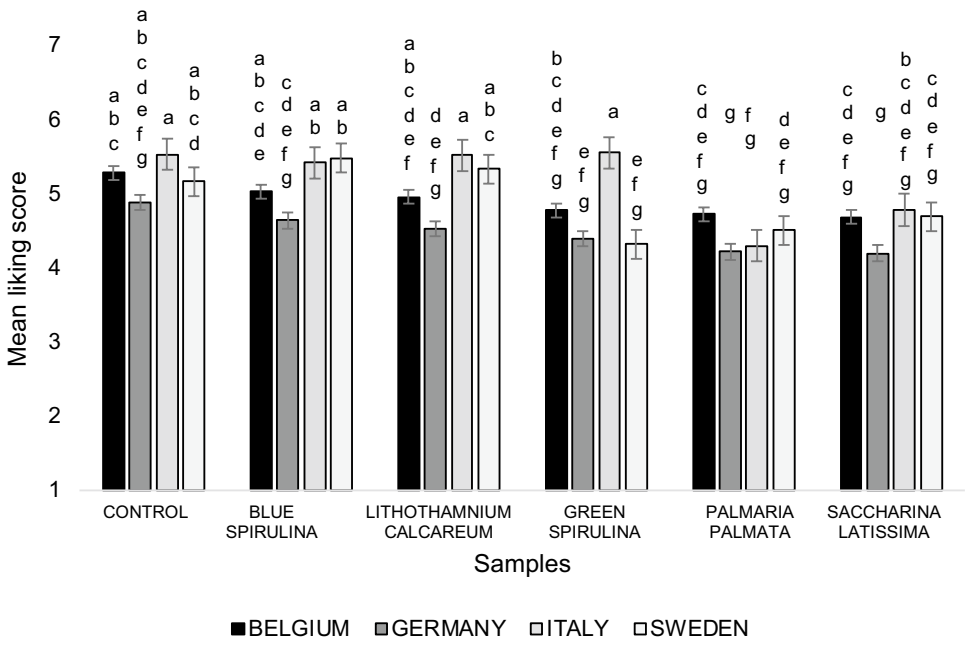


**Fig. 1** Liking scores ± standard error of mean (SEM) provided by Country for each cracker sample. Different letters on histograms indicate significant differences according to Bonferroni post-hoc test

$p < 0.05$) and Age group*FN ($F_{(4,2401)} = 3.3$, $p < 0.05$) were significant. Males aged 22–27 years liked the experimental samples significantly more than males aged 28–69 years. Neophilics aged 28–69 years liked the crackers significantly more than neutral subjects and neophobics of the same age group. All other interactions were not significant.

### Crackers sensory CATA description

The frequency table of terms checked by participants to describe the six different cracker samples over all countries is reported in Table 4. The descriptors selected by the participants as divided by country are reported in Supplementary Table S1. All the terms significantly differentiated the cracker samples ($p < 0.01$). Crackers added with *Lithothamnium calcareum* were perceived as comparable to the control samples in terms of golden color, while crackers added with *Palmaria palmata* and *Saccharina latissima* were characterized by brownish color and a speckled appearance. As expected, crackers with green and blue Spirulina were identified as having respectively green and blue colors, however only the blue Spirulina cracker was associated with unnatural color. The descriptor of thickness was almost never mentioned by the respondents except for crackers with blue Spirulina and *Lithothamnium. calcareum,* which showed higher frequencies of mentions for this term compared to the other samples. Concerning taste and flavor attributes, *Lithothamnium calcareum* added crackers were comparable to the control sample in terms of oily and toasted bread flavors. Off-flavors were reported for crackers added with *Palmaria palmata*, *Saccharina latissima* and green Spirulina. Crackers with *Palmaria palmata* were more frequently associated with fishy flavor, while those containing green Spirulina were more frequently described as having spinach/grass and mushroom flavors. *Saccharina latissima* added crackers were also described as bitter. For the texture descriptors, samples were mainly described as crunchy, with *Palmaria palmata* crackers and the control sample being the crunchiest in terms of descriptor mention

**Table 4** Frequency mention (reported as proportion) of sensory attributes associated with each product over all countries ($n = 413$)

| Sensory modality | Attributes | Control | Lithothamnium calcareum | Palmaria palmata | Saccharina latissima | Blue spirulina | Green spirulina |
|---|---|---|---|---|---|---|---|
| Appearance | Golden/yellowish color | **0.964** (c) | **0.903** (c) | 0.481 (b) | 0.498 (b) | 0.029 (a) | *0* (a) |
| | Brownish color | *0.051* (a) | *0.087* (a) | **0.454** (b) | **0.437** (b) | *0.017* (a) | *0.027* (a) |
| | Blue color | *0.005* (a) | *0* (a) | *0.007* (a) | *0.007* (a) | **0.906** (b) | *0.039* (a) |
| | Green color | *0* (a) | *0.027* (ab) | 0.116 (bc) | 0.193 (c) | 0.097 (b) | **0.976** (d) |
| | Thick | 0.082 (bc) | **0.101** (c) | *0.031* (a) | 0.048 (ab) | **0.123** (c) | 0.046 (ab) |
| | Speckled | 0.432 (b) | 0.481 (b) | **0.804** (d) | 0.710 (c) | 0.396 (b) | *0.048* (a) |
| | Unnatural color | *0.007* (a) | *0.024* (a) | *0.048* (a) | *0.058* (a) | **0.536** (c) | 0.275 (b) |
| Taste/flavor | Oily flavor | **0.280** (c) | **0.254** (bc) | *0.159* (a) | 0.208 (ab) | *0.164* (a) | *0.145* (a) |
| | Off-flavor | *0.065* (a) | *0.072* (a) | **0.244** (b) | **0.244** (b) | *0.123* (a) | **0.208** (b) |
| | Fishy flavor | *0.012* (a) | *0.012* (a) | **0.541** (d) | 0.196 (c) | *0.041* (ab) | 0.111 (b) |
| | Spinach/grassy flavor | *0.007* (a) | *0.022* (ab) | 0.244 (c) | 0.181 (c) | 0.092 (b) | **0.548** (d) |
| | Mushroom flavor | *0.019* (a) | *0.017* (a) | 0.080 (b) | 0.085 (b) | *0.043* (ab) | **0.147** (c) |
| | Toasted bread flavor | **0.626** (c) | **0.626** (c) | *0.278* (a) | *0.365* (a) | 0.512 (b) | *0.287* (a) |
| | Bitter | 0.027 (ab) | *0.010* (a) | 0.068 (bc) | **0.106** (c) | *0.029* (ab) | 0.065 (bc) |
| | Sweet | 0.099 (bc) | 0.097 (bc) | *0.036* (a) | *0.041* (a) | **0.118** (c) | *0.053* (ab) |
| | Salty | 0.338 (bc) | 0.295 (ab) | **0.396** (c) | **0.372** (bc) | **0.341** (bc) | *0.256* (a) |
| | Umami (e.g., savory, soy sauce) | *0.060* (a) | *0.063* (a) | **0.222** (c) | **0.174** (bc) | 0.140 (b) | **0.174** (bc) |
| | Bland | 0.524 (cd) | **0.556** (d) | *0.208* (a) | 0.338 (b) | 0.447 (c) | 0.297 (b) |
| | Spicy | 0.046 (ab) | *0.027* (a) | 0.068 (ab) | **0.085** (b) | 0.060 (ab) | **0.082** (b) |
| Texture | Dry | 0.428 (ab) | **0.481** (b) | *0.362* (a) | *0.399* (a) | *0.377* (a) | *0.396* (a) |
| | Crunchy | **0.768** (b) | *0.684* (a) | **0.771** (b) | 0.744 (ab) | 0.749 (ab) | 0.720 (ab) |
| | Brittle | 0.229 (ab) | 0.273 (bc) | *0.193* (a) | *0.174* (a) | 0.285 (bc) | **0.304** (c) |
| | Hard | 0.341 (ab) | 0.355 (b) | 0.360 (b) | **0.464** (c) | *0.271* (a) | *0.268* (a) |

All $p$-values were $p < 0.01$ according to Cochran's $Q$ test. Letters between brackets indicate significant differences by row according to Sheskin's multiple comparison test. Highest and lowest proportions are reported in bold and italic font, respectively

frequencies. A fewer proportion of individuals mentioned dryness, brittleness, and hardness for the general appraisal of the cracker samples.

Country-related differences were also observed in the description of the crackers. These differences are reported and described in the supplementary materials (Table S1).

### Cross-national differences in drivers of liking and rejection of cracker samples

The relation between CATA terms and overall liking of the six samples over all countries is depicted in Fig. 2a. The first factor explains, respectively, 49 and 93% of the variation in X and Y, while the second factor accounts for 27 and 3%. As

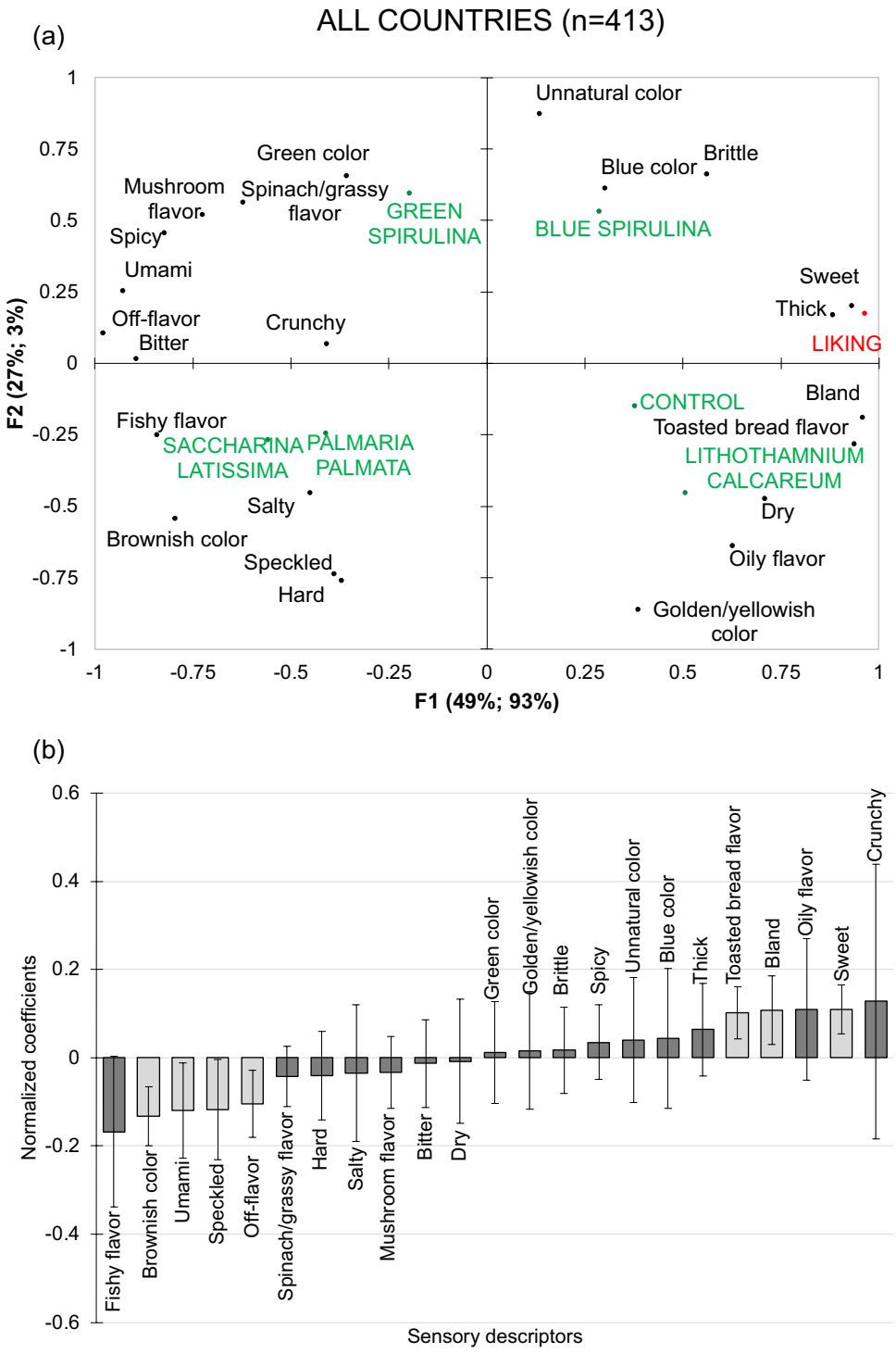


**Fig. 2** **a** Biplot and **b** normalized regression coefficients obtained by the PLSR model relating overall liking and CATA data ($n = 413$) for the six samples over all countries. Histograms in light grey indicate the significant sensory descriptors.

inferred from Fig. 2a, factor 1 distinguishes samples according to taste and flavor characteristics by positioning the Control, blue Spirulina and *Lithothamnium calcareum* samples, which were considered as being bland, well away from the samples with the addition of *Saccharina latissima*, *Palmaria palmata* and green Spirulina, which were characterized by off-flavors (fish, mushroom) and were also perceived as more bitter and umami. The second factor distinguished the samples according to appearance characteristics, separating samples added with green and blue Spirulina, described by the terms green and blue colors, from the rest of the samples characterized by golden/yellowish color. It is also worth mentioning that PLSR confirmed that only blue color was perceived as unnatural.

Consumers' liking was oriented towards crackers on the right side of the map (control, blue Spirulina and *Lithothamnium calcareum*), and these were mainly associated with the sensory descriptors bland, toasted bread, thick, sweet, oily flavor. Liking was opposed to the sensory terms off-flavors, fishy and spinach/grassy flavors, umami and bitter, and these terms were more associated with green Spirulina, *Palmaria palmata* and *Saccharina latissima*.

However, according to PLSR normalized coefficients (Fig. 2b), across all the countries, the descriptors that contributed significantly and positively to liking were toasted bread flavor, sweet, and bland, while significant contributors to disliking were brownish color, speckled appearance, off-flavor, umami, and, marginally, fishy flavor. Unexpectedly, the descriptors blue color and unnatural color did not have a negative impact on liking.

The PLSR results obtained on the overall sample of consumers ($n = 413$) were similar to those acquired on each country (Figs. 3, 4, 5, 6ab) with the exception of Italy, where the green Spirulina added sample was positioned close to the Control cracker and the samples added with *Lithothamnium calcareum* and blue Spirulina, suggesting that the Italian population liked the green Spirulina more than the other countries.

## Discussion

The main objective of the present study was to investigate consumer reactions towards an array of micro- and macroalgae species added to crackers, following a cross-cultural comparative approach in European countries.

Firstly, the present study revealed that respondents across all countries provided generally favorable liking scores for all the crackers added with algae, further providing support to the notion that algae incorporation in food products seems to be a promising venture aligned with more sustainable food consumption [38]. However, cross-national differences in terms of liking have been highlighted with Italian respondents providing higher scores than all other countries and German subjects providing the lowest. These differences may be attributable to the different prevailing gastronomical contexts characterizing the different countries involved in the present study. For instance, Swedish diets are more characterized by food groups such as fish and seafood, and this scenario may have led to their overall higher inclinations towards food including algae [39]. Conversely, conventional diets in Belgium and Germany are not predominantly based on seafood, thus potentially influencing the Belgian subjects' preferences for these types of commodities [40, 41]. On the other hand, fish and related products were observed to have an increasing trend among the Italian dietary patterns [42]. Hence, it was assumed that the different customary food consumed in these countries could drive consumer preferences and liking for algae powders (as a marine-sourced product) incorporated in crackers.

Although in the present study cross-national differences were found in algae familiarity and consumption, these variables seem to play a minor role in liking of crackers added with algae. Despite Swedish subjects having had a high algae familiarity level and a significantly higher frequency of prior algae consumption (as food ingredients and snacks) compared to the other countries, the Italian respondents rated the experimental samples significantly higher than the other countries. On the other hand, although Belgian subjects were those with the lowest algae knowledge, familiarity and consumption, German respondents where those showing the lowest liking ratings for algae added crackers.

In addition to the greater consumption of crackers by Italian users, another variable that can contribute to explain the existence of these cross-national differences could be food neophobia. In the present study, Italian subjects were significantly less neophobic than the other respondents. This result is in agreement with the general high willingness declared by Italian respondents to try a series of food products added with algae (e.g., bakery salty snacks). Cross-national differences in food neophobia are common both in children [43] and adults [44] and may be among the best predictors of consumer's acceptance of food products added with algae.

Regarding the descriptors the respondents selected for the algae crackers, it was seen that consumers were able to differentiate product properties on the basis of texture, appearance, and flavor. Interestingly, crackers tagged with off-flavor were also generally associated with sensory descriptors such as fishy, grassy, mushroom flavors, and bitter taste. The identification of disliking drivers can allow for sensory optimization and consequently a more suitable formulation of crackers, minimizing ingredients that can generate off-flavors, especially since these negative experiences can trigger product rejection [34]. These crackers, namely those added with *Palmaria palmata*, *Saccharina latissima* and green Spirulina, were rated significantly lower than crackers

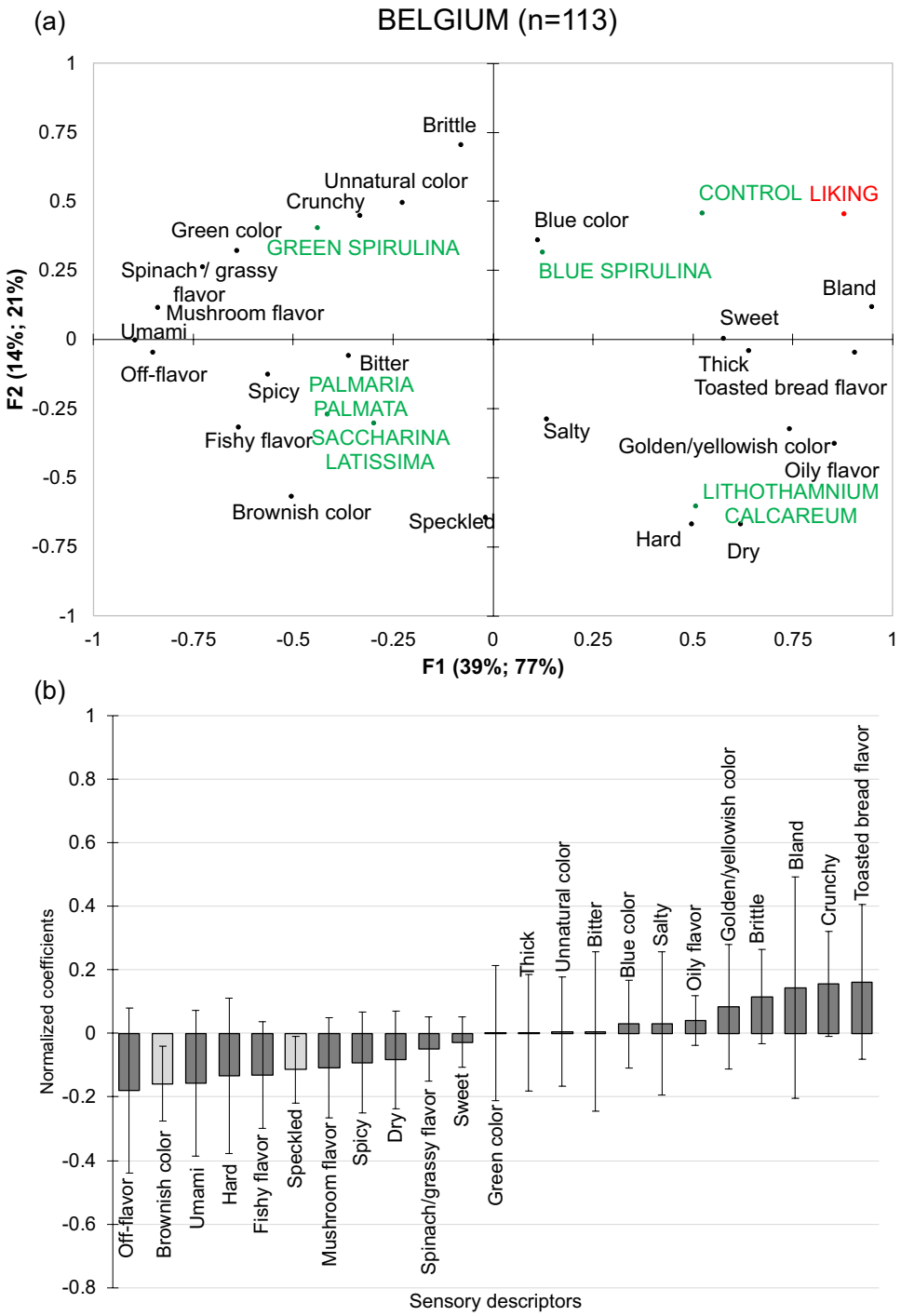


**Fig. 3** **a** Biplot and **b** regression coefficients obtained by the PLSR model relating overall liking and CATA data ($n = 113$) for the six samples on Belgian population. Histograms in light grey indicate the significant sensory descriptors

added with *Lithothamnium calcareum* and the control sample, indicating further nuanced variation in the potential incorporation of algae types in cracker. Likewise, an association between unnatural color and blue color was observed for samples added with blue Spirulina without, however, negatively influencing their liking. Indeed, blue Spirulina samples were rated substantially high. While these crackers were identified as unnatural, it may be likely that curiosity played a role in facilitating the liking of these crackers, as already seen in other novel food like insects [45]. Similarly, Durmaz et al. [46] also found that the addition of the red microalgae *Porphyridium cruentum* at low concentrations (< 0.3%) in ice cream imparted a pink color that was appreciated by consumers, thus overcoming one of the sensory problems related to appearance. Interestingly, crackers with green Spirulina were frequently identified as having a green color yet were not strongly associated with unnaturalness or disliking. Similar to prior research, green colors are often

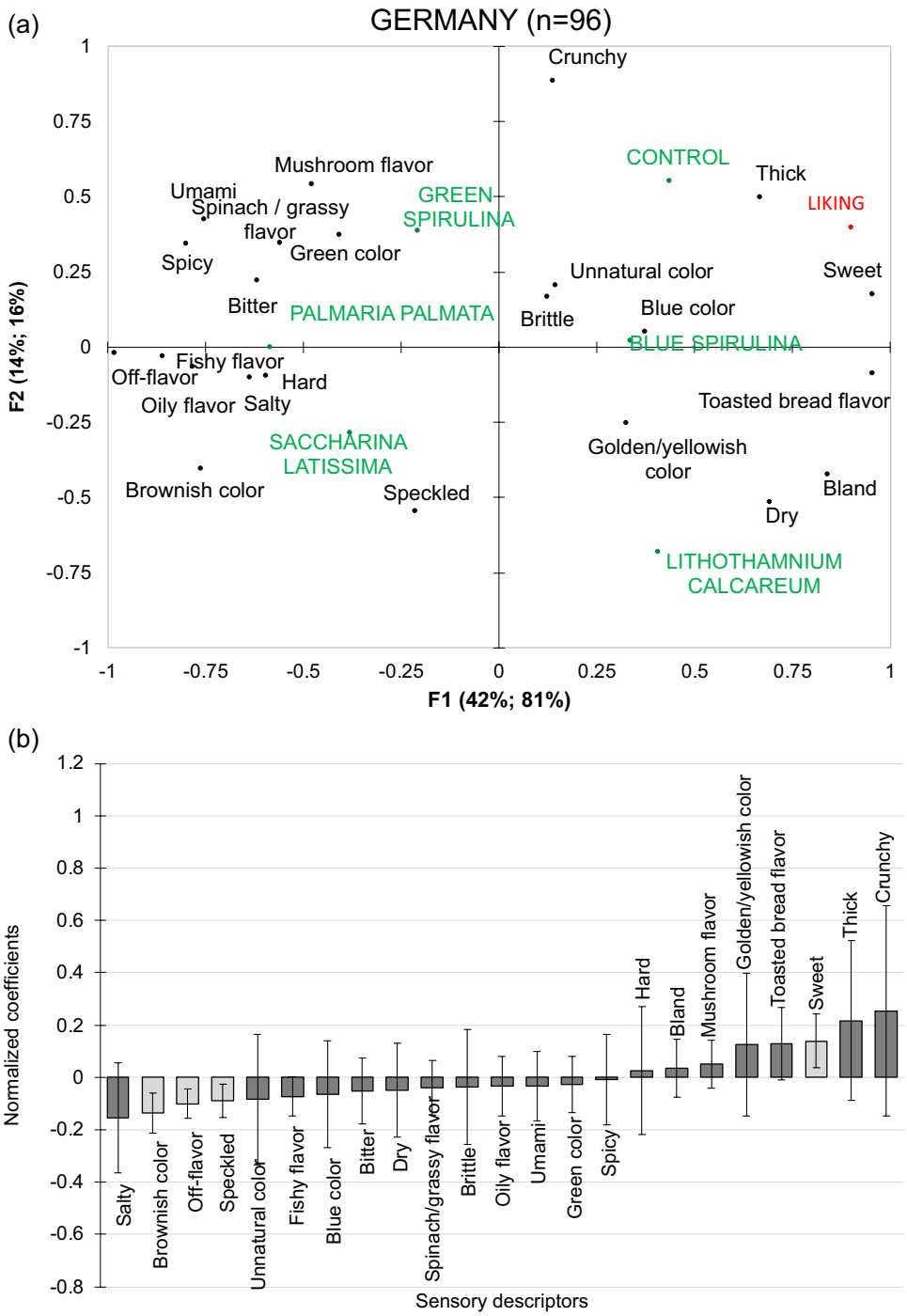


**Fig. 4** **a** Biplot and **b** regression coefficients obtained by the PLSR model relating overall liking and CATA data ($n = 96$) for the six samples on German population. Histograms in light grey indicate the significant sensory descriptors

associated with the naturalness of food products [47] but in this case, a congruence effect may have transpired as green algae species are also the most abundant, compared to brown and red algae species [48]. In addition, a study performed on snacks enriched with 2.6% of *Arthrospira platensis* supports the results of the present study; while the samples with the addition of green Spirulina were correctly identified as different from the control sample in terms of color, this did not negatively impact the liking of the experimental samples [28]. On the other hand, green colors for algae food products have been viewed elsewhere as negative qualities [49].

Another key finding that this study highlighted was that liking scores were more closely associated with the control sample, blue Spirulina, and *Lithothamnium calcareum* samples. These crackers were positioned on the opposite side of the descriptors that drove rejection such as off-flavor, fishy, mushroom flavors and umami taste. This finding regarding blue Spirulina is important because it confirms the

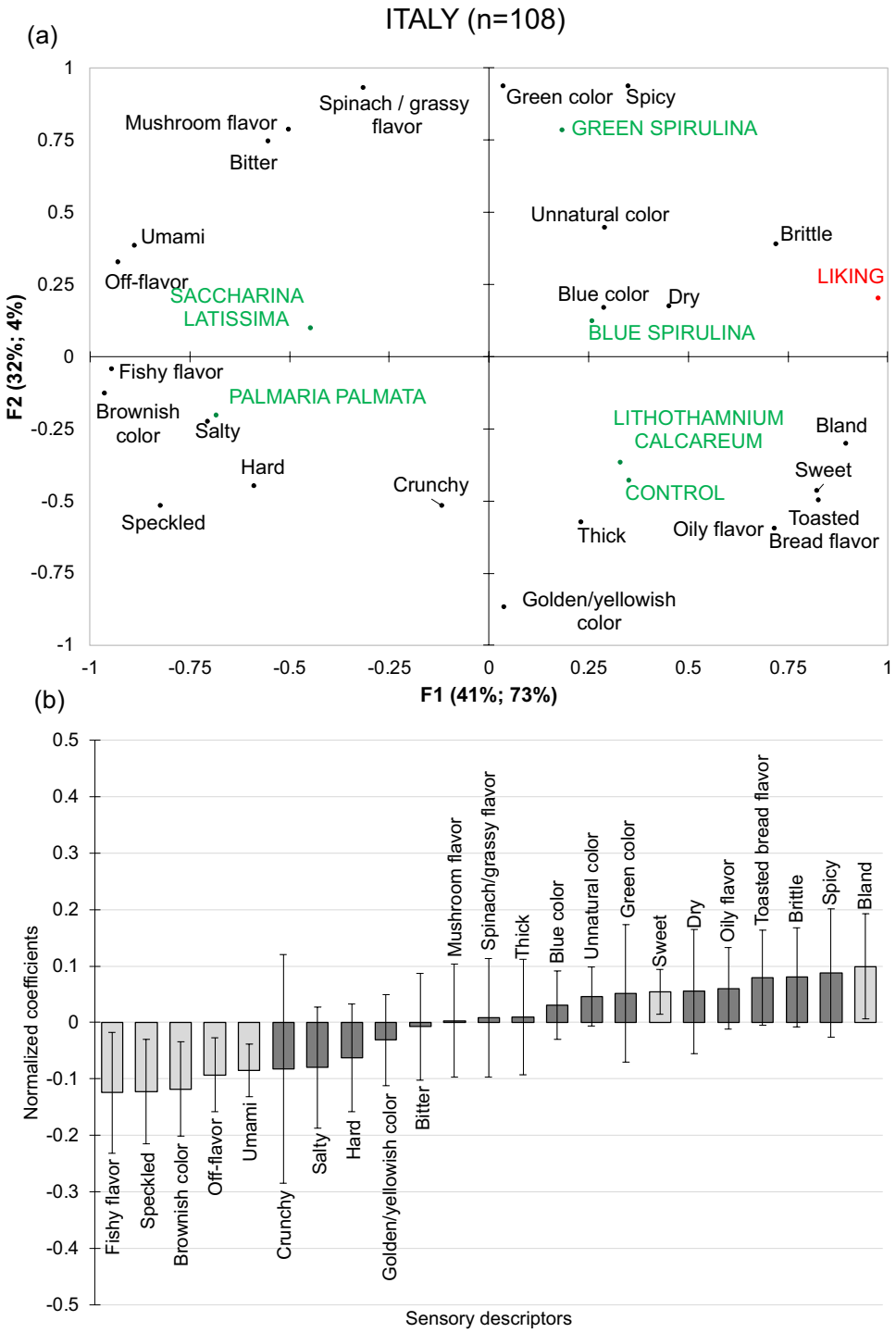


**Fig. 5** **a** Biplot and **b** regression coefficients obtained by the PLSR model relating overall liking and CATA data ($n = 108$) for the six samples on Italian population. Histograms in light grey indicate the significant sensory descriptors

authors' initial hypothesis that the use of isolated proteins from microalgae may be a strategy to reduce the perception of off-flavors, contributing positively to the acceptability of food formulations added whit algae [10]. In general, the use of proteins derived from *Arthrospira platensis* (blue Spirulina samples) resulted in a significant increase in liking compared to the sample simply added with *Arthrospira platensis* powder (green Spirulina samples). Conversely, the sample supplemented with *Lithothamnium calcareum* was considered comparable to the control in terms of liking. This is a result of considerable importance from a nutritional point of view. *Lithothamnium calcareum* differs from the other algae used in the present study for its exceptionally high calcium concentration (32,000 mg/100 g of product), which is higher than the daily requirement indicated by the guidelines (range 800–1200 mg) [50]. Therefore, the use

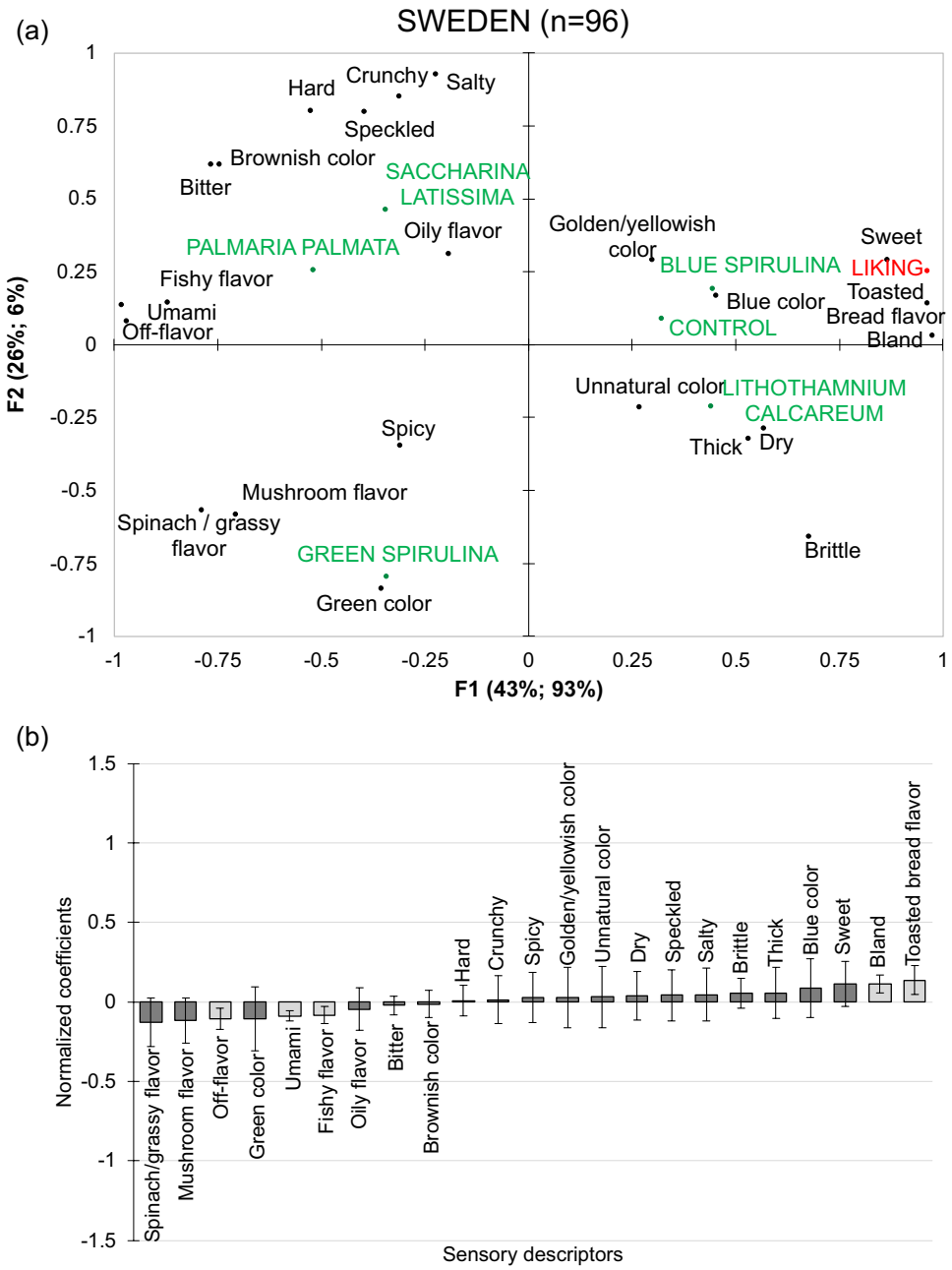


**Fig. 6** **a** Biplot and **b** regression coefficients obtained by the PLSR model relating overall liking and CATA data ($n = 96$) for the six samples on Swedish population. Histograms in light grey indicate the significant sensory descriptors

of this algae could help in the development of products for people who need higher calcium concentrations such as adolescents, vegans, pregnant women, and people with osteoporosis. To this end, in vivo studies are needed to investigate whether the high amount of calcium present in *Lithothamnium calcareum* is actually absorbed by the human body.

Overall, this study was able to capture perceptions and drivers of (dis)liking for algae-based crackers across four different European countries. Furthermore, part of the study's strengths lies in its use of both micro- and macroalgae species for comparative insights. This study also incorporated the use of psychological measurements, particularly food neophobia through validated scales for a better understanding of the factors that can affect liking towards algae-based crackers. Through this study, the use of crackers in introducing algae to a broader population has been elaborated. However, some limitations of the study should be acknowledged. Sampling was a main limitation of the study. Participants were recruited primarily within a university setting and biases may have affected the overall evaluation. Despite this, the final consumer samples were evenly distributed for all of the countries, based on certain parameters such as the amount of subjects and gender. Future research is encouraged regarding the investigation of consumer perceptions

and reactions towards algae-based products across different life stages such as children and the elderly. As this study focused on adult perceptions, identifying drivers of liking in other age groups may prove necessary in strategically positioning algae-based food in the market.

Furthermore, upcoming studies can also utilize different food matrices aside from crackers to enlarge the range of knowledge on consumers' attitude towards algae and algae products. It may likewise be interesting as well to observe how algae-based foods will be perceived when consumed with other food components, or if blending algae products with other flavor enhancing or masking compounds may lead to synergies in terms of building liking and appreciation for these products, as is the case for other novel food sources studied [51]. Thirdly, as this study used a constant ratio of algae powders added into food products, future research can focus on identifying an increased, optimal amount of algae ingredients to be added to consumer goods without necessarily compromising liking and, at the same time, tangibly delivering the nutritional benefits associated with algae. Response surface methodologies can be applied to identify an optimal mix of factors incorporating production and sensory evaluation of algae-based food [52]. Finally, it is suggested to conduct in vivo studies to complement present results with actual absorption of algae micro- and macronutrients by the human body.

## Conclusion

The results of this study, especially the overall high liking scores, show the potential of fortifying crackers with algae across different countries. However, the data indicated varying levels of consumer acceptance, with the majority of respondents from all countries favoring the crackers added with isolated proteins derived from *Arthrospira platensis* (blue Spirulina) and *Lithothamnium calcareum* the most, apart from the control sample. At a country-level, varying liking patterns were also revealed, with each study country having its own cracker acceptance results. Different descriptors were identified for each cracker added with algae type, and these can be leveraged in defining ideal cracker properties.

In addition, the liking scores seem to be driven by different properties, most notably sweet taste, toasted bread and bland flavors, as expected for cracker products. On the other hand, properties such as off-flavors, speckled appearance, and umami taste were more associated with rejection or lower liking scores for the algae cracker samples. Finally, the cross-national investigation based on liking scores for the algae crackers revealed differences in food neophobia, thereby indicating varying degrees of readiness and willingness to consume algae crackers.

While algae ingredients possess high potential as an ingredient in food matrices compared to being a stand-alone commodity, this study recognizes as well that there remain multiple avenues to explore in terms of identifying which consumer goods can benefit the most from algae addition. Collectively, leveraging on different preferred traits for algae food products as well as precise consumer segmentation can encourage more algae consumption.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s00217-024-04530-y.

**Acknowledgements** The authors are grateful to Gunda Jansen (University of Göttingen) for baking the experimental samples.

**Funding** Open access funding provided by Università degli Studi di Milano within the CRUI-CARE Agreement.

**Data availability** Data available on request.

## Declarations

**Conflict of interest** The authors declare no conflict of interest for this research.

**Compliance with ethics requirements** The authors declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work reported in this paper.

**Ethical Statement** The study protocol was approved by relevant research ethics committee of each country, and written consent was obtained from the individuals prior to participation, according to the declaration of Helsinki (Belgium: No. 2022-40, Germany: No. 63/11, Italy: No. 94/22, Sweden: 2022-06258-01) and in line with the General Data Protection regulation 2016/679.

**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

## References

1. UNEP (2020, January 12) Emissions Gap Report 2020. UNEP—UN Environment Programme. http://www.unep.org/emissions-gap-report-2020
2. Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, Garnett T, Tilman D, DeClerck F, Wood A, Jonell M, Clark M, Gordon LJ, Fanzo J, Hawkes C, Zurayk R, Rivera JA, De Vries W, Majele Sibanda L et al (2019) Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable

food systems. Lancet 393(10170):447–492. https://doi.org/10.1016/S0140-6736(18)31788-4
3. Macdiarmid JI (2013) Is a healthy diet an environmentally sustainable diet? Proc Nutr Soc 72(1):13–20. https://doi.org/10.1017/S0029665112002893
4. Verain MCD, Bartels J, Dagevos H, Sijtsema SJ, Onwezen MC, Antonides G (2012) Segments of sustainable food consumers: a literature review. Int J Consum Stud 36(2):123–132. https://doi.org/10.1111/j.1470-6431.2011.01082.x
5. Embling R, Neilson L, Randall T, Mellor C, Lee MD, Wilkinson LL (2022) 'Edible seaweeds' as an alternative to animal-based proteins in the UK: Identifying product beliefs and consumer traits as drivers of consumer acceptability for macroalgae. Food Qual Prefer 100:104613. https://doi.org/10.1016/j.foodqual.2022.104613
6. Caporgno MP, Mathys A (2018) Trends in microalgae incorporation into innovative food products with potential health benefits. Fronti Nutr. https://doi.org/10.3389/fnut.2018.00058
7. Anyanwu RC, Rodriguez C, Durrant A, Olabi AGi (2018) Micro-macroalgae properties and applications. Reference module in materials science and materials engineering. Elsevier, Amsterdam. https://doi.org/10.1016/B978-0-12-803581-8.09259-6
8. Ścieszka S, Klewicka E (2019) Algae in food: a general review. Crit Rev Food Sci Nutr 59(21):3538–3547. https://doi.org/10.1080/10408398.2018.1496319
9. Trentacoste EM, Martinez AM, Zenk T (2015) The place of algae in agriculture: policies for algal biomass production. Photosynth Res 123(3):305–315. https://doi.org/10.1007/s11120-014-9985-8
10. Hosseinkhani N, McCauley JI, Ralph PJ (2022) Key challenges for the commercial expansion of ingredients from algae into human food products. Algal Res 64:102696. https://doi.org/10.1016/j.algal.2022.102696
11. Vaughan K, Ranawana V, Cooper D, Aceves-Martins M (2022) Effect of brown seaweed on plasma glucose in healthy, at-risk, and type 2 diabetic individuals: systematic review and meta-analysis. Nutr Rev 80(5):1194–1205. https://doi.org/10.1093/nutrit/nuab069
12. Khan MI, Shin JH, Kim JD (2018) The promising future of microalgae: current status, challenges, and optimization of a sustainable and renewable industry for biofuels, feed, and other products. Microb Cell Fact 17(1):36. https://doi.org/10.1186/s12934-018-0879-x
13. Wells ML, Potin P, Craigie JS, Raven JA, Merchant SS, Helliwell KE, Smith AG, Camire ME, Brawley SH (2017) Algae as nutritional and functional food sources: revisiting our understanding. J Appl Phycol 29(2):949–982. https://doi.org/10.1007/s10811-016-0974-5
14. Sidari R, Tofalo R (2019) A comprehensive overview on microalgal-fortified/based food and beverages. Food Rev Intl 35(8):778–805. https://doi.org/10.1080/87559129.2019.1608557
15. Becker EW (2007) Micro-algae as a source of protein. Biotechnol Adv 25(2):207–210. https://doi.org/10.1016/j.biotechadv.2006.11.002
16. Lafarga T (2019) Effect of microalgal biomass incorporation into foods: nutritional and sensorial attributes of the end products. Algal Res 41:101566. https://doi.org/10.1016/j.algal.2019.101566
17. Mendes MC, Navalho S, Ferreira A, Paulino C, Figueiredo D, Silva D, Gao F, Gama F, Bombo G, Jacinto R, Aveiro SS, Schulze PSC, Gonçalves AT, Pereira H, Gouveia L, Patarra RF, Abreu MH, Silva JL, Navalho J et al (2022) Algae as food in Europe: an overview of species diversity and their application. Foods 11(13):Article 13. https://doi.org/10.3390/foods11131871
18. Nayar S, Bott K (2014) Current status of global cultivated seaweed production and markets. World Aquacult 45(2):32–37
19. van den Burg SWK, Dagevos H, Helmes RJK (2021) Towards sustainable European seaweed value chains: a triple P perspective. ICES J Mar Sci 78(1):443–450. https://doi.org/10.1093/icesjms/fsz183
20. Agustini TW, Dewi EN, Amalia U, Kurniasih RA (2019) Application of basil leaf extracts to decrease Spirulina platensis off-odour in increasing food consumption. http://agris.upm.edu.my:8080/dspace/handle/0/18910
21. Batista AP, Niccolai A, Bursic I, Sousa I, Raymundo A, Rodolfi L, Biondi N, Tredici MR (2019) Microalgae as functional ingredients in savory food products: application to wheat crackers. Foods 8(12):Article 12. https://doi.org/10.3390/foods8120611
22. Tańska M, Konopka I, Ruszkowska M (2017) Sensory, physico-chemical and water sorption properties of corn extrudates enriched with spirulina. Plant Foods Hum Nutr 72(3):250–257. https://doi.org/10.1007/s11130-017-0628-z
23. Robertson RC, Gracia Mateo MR, O'Grady MN, Guihéneuf F, Stengel DB, Ross RP, Fitzgerald GF, Kerry JP, Stanton C (2016) An assessment of the techno-functional and sensory properties of yoghurt fortified with a lipid extract from the microalga Pavlova lutheri. Innov Food Sci Emerg Technol 37:237–246. https://doi.org/10.1016/j.ifset.2016.03.017
24. García-Segovia P, Pagán-Moreno MJ, Lara IF, Martínez-Monzó J (2017) Effect of microalgae incorporation on physicochemical and textural properties in wheat bread formulation. Food Sci Technol Int 23(5):437–447. https://doi.org/10.1177/1082013217700259
25. Grahl S, Strack M, Mensching A, Mörlein D (2020) Alternative protein sources in Western diets: food product development and consumer acceptance of Spirulina-filled pasta. Food Qual Prefer 84:103933. https://doi.org/10.1016/j.foodqual.2020.103933
26. Michel F, Knaapila A, Hartmann C, Siegrist M (2021) A multinational comparison of meat eaters' attitudes and expectations for burgers containing beef, pea or algae protein. Food Qual Prefer 91:104195. https://doi.org/10.1016/j.foodqual.2021.104195
27. Sedej I, Sakač M, Mandić A, Mišan A, Pestorić M, Šimurina O, Čanadanović-Brunet J (2011) Quality assessment of gluten-free crackers based on buckwheat flour. LWT Food Sci Technol 44(3):694–699. https://doi.org/10.1016/j.lwt.2010.11.010
28. Lucas BF, da Rosa APC, de Carvalho LF, de Morais MG, Santos TD, Costa JAV (2019) Snack bars enriched with *Spirulina* for schoolchildren nutrition. Food Sci Technol 40:146–152. https://doi.org/10.1590/fst.06719
29. Lawless HT, Heymann H (2010) Sensory evaluation of food: principles and practices. Springer Science & Business Media, Berlin
30. Ares G, Deliza R, Barreiro C, Giménez A, Gámbaro A (2010) Comparison of two sensory profiling techniques based on consumer perception. Food Qual Prefer 21(4):417–426. https://doi.org/10.1016/j.foodqual.2009.10.006
31. Tzompa-Sosa DA, Dewettinck K, Gellynck X, Schouteten JJ (2021) Replacing vegetable oil by insect oil in food products: effect of deodorization on the sensory evaluation. Food Res Int 141:110140. https://doi.org/10.1016/j.foodres.2021.110140
32. Thomas C, Symoneaux R, Pantin-Sohier G, Picouet P, Maître I (2020) Perceptions of Spirulina from French consumers of organic products. *HAL*. https://hal.science/hal-02615769
33. Pliner P, Hobden K (1992) Development of a scale to measure the trait of food neophobia in humans. Appetite 19(2):105–120. https://doi.org/10.1016/0195-6663(92)90014-W
34. Tuorila H, Hartmann C (2020) Consumer responses to novel and unfamiliar foods. Curr Opin Food Sci 33:1–8. https://doi.org/10.1016/j.cofs.2019.09.004
35. Naes T, Brockhoff PB, Tomic O (2011) Statistics for sensory and consumer science. Wiley, New Jersey

36. Meyners M, Castura JC, Carr BT (2013) Existing and new approaches for the analysis of CATA data. Food Qual Prefer 30(2):309–319. https://doi.org/10.1016/j.foodqual.2013.06.010
37. Nunnally J, Bernstein DIH (1994) Psychometric theory. McGraw-Hill Companies, Incorporated.
38. Chen C, Tang T, Shi Q, Zhou Z, Fan J (2022) The potential and challenge of microalgae as promising future food sources. Trends Food Sci Technol 126:99–112. https://doi.org/10.1016/j.tifs.2022.06.016
39. Ax E, Lemming EW, Becker W, Andersson A, Lindroos AK, Cederholm T, Sjögren P, Fung TT (2016) Dietary patterns in Swedish adults; results from a national dietary survey. Br J Nutr 115(1):95–104. https://doi.org/10.1017/S0007114515004110
40. De Ridder K, Bel S, Brocatus L, Cuypers K, Lebacq T, Moyersoen I, Ost C, Teppers E (2014) Enquête de Consommation Alimentaire 2014–2015. Rapport 4. WIV-ISP, Brussel, 2016. Institut Scientifique de Sante Publique. https://fcs.wiv-isp.be/fr/SitePages/R%C3%A9sultats.aspx
41. Heuer T, Krems C, Moon K, Brombach C, Hoffmann I (2015) Food consumption of adults in Germany: results of the German National Nutrition Survey II based on diet history interviews. Br J Nutr 113(10):1603–1614. https://doi.org/10.1017/S0007114515000744
42. Vitale M, Giosuè A, Vaccaro O, Riccardi G (2021) Recent trends in dietary habits of the Italian population: potential impact on health and the environment. Nutrients 13(2):476. https://doi.org/10.3390/nu13020476
43. Proserpio C, Almli VL, Sandvik P, Sandell M, Methven L, Wallner M, Jilani H, Laureati M (2020) Cross-national differences in child food neophobia: a comparison of five European countries. Food Qual Prefer 81:103861. https://doi.org/10.1016/j.foodqual.2019.103861
44. Ritchey PN, Frank RA, Hursti UK, Tuorila H (2003) Validation and cross-national comparison of the food neophobia scale (FNS) using confirmatory factor analysis. Appetite 40(2):163–173. https://doi.org/10.1016/S0195-6663(02)00134-4
45. Stone H, FitzGibbon L, Millan E, Murayama K (2022) Curious to eat insects? Curiosity as a key predictor of willingness to try novel food. Appetite 168:105790. https://doi.org/10.1016/j.appet.2021.105790
46. Durmaz Y, Kilicli M, Toker OS, Konar N, Palabiyik I, Tamtürk F (2020) Using spray-dried microalgae in ice cream formulation as a natural colorant: effect on physicochemical and functional properties. Algal Res 47:101811. https://doi.org/10.1016/j.algal.2020.101811
47. Dantec M, Allain H, Yvert N, Sigrist J, Bensafi M, Lafraire J (2022) Olfactory attributes and colors associated with naturalness. Food Qual Prefer 98:104495. https://doi.org/10.1016/j.foodqual.2021.104495
48. Chapman RL (2013) Algae: the world's most important "plants"—an introduction. Mitig Adapt Strat Glob Change 18(1):5–12. https://doi.org/10.1007/s11027-010-9255-9
49. Matos ÂP, Novelli E, Tribuzi G (2022) Use of algae as food ingredient: sensory acceptance and commercial products. Front Food Sci Technol. https://doi.org/10.3389/frfst.2022.989801
50. Società Italiana di Nutrizione Umana (SINU) LARN: Livelli di Assunzione di Riferimento di Nutrienti ed Energia,4th ed.; SICS: Milano, Italy, 2014.
51. Lang M (2020) Consumer acceptance of blending plant-based ingredients into traditional meat-based foods: evidence from the meat-mushroom blend. Food Qual Prefer 79:103758. https://doi.org/10.1016/j.foodqual.2019.103758
52. Rheem S (2023) Optimizing food processing through a new approach to response surface methodology. Food Sci Anim Resour 43(2):374–381. https://doi.org/10.5851/kosfa.2023.e7

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.