

Article

Sustainable but Sensory Challenged: The Case of Spirulina in Brazilian Diets

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Abstract

Spirulina, a cyanobacterium recognized for its nutritional and environmental advantages, has emerged as a potential ingredient for sustainable diets. Consumer acceptance remains limited despite its benefits, particularly due to sensory challenges and limited prior awareness. This study aimed to investigate knowledge, consumption patterns, and attitudes toward Spirulina among a Brazilian sample. A cross-sectional online questionnaire distributed via social media and public spaces yielded 933 valid responses, categorized into three groups based on prior awareness and consumption history. Results indicated limited prior awareness and low consumption, with more than half of consumers having tried Spirulina only once. Education, income, generation, and health-related behaviors were associated with knowledge and consumption, although most effect sizes were small. Knowledge of Spirulina was concentrated on nutritional attributes, whereas environmental and technological attributes were less widely recognized. Health and environmental benefits were most often rated as increasing willingness to consume Spirulina, while self-reported barriers included taste, smell, and issues related to powdered and capsule forms. Preferred applications were in familiar food categories such as baked goods and powdered mixes. These findings indicate that Spirulina occupies a niche position among respondents and suggest the relevance of sensorially acceptable formulations, tailored communication strategies, and inclusive educational efforts.

Keywords: microalgae; consumer behavior; consumption drivers; consumption challenges; survey; alternative proteins

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1. Introduction

Spirulina (*Limnospira*), a protein-rich cyanobacterium with polysaccharides and bioactive compounds, has emerged as a promising raw material for biorefineries that convert renewable biomass into value-added products, contributing to the United Nations (UN) Sustainable Development Goals (SDGs) [1,2]. Its cultivation offers environmental advantages, including CO₂ capture and effluent bioremediation, while its biomass can be processed into food, biofuels, and bioplastics [3].

In addition to providing essential amino acids, vitamins, and antioxidants, Spirulina exhibits functional properties such as emulsification and coloring potential [4–6].

However, unfavorable sensory attributes, including earthy flavors, bitterness, and marine-like aromas, often limit its application in food systems [7,8]. To mitigate these barriers, strategies such as microencapsulation, fermentation, enzymatic or acid hydrolysis, and flavor pairing have been proposed [9,10].

Consumer acceptance of Spirulina-based products is also shaped by non-technical factors, including familiarity and benefit communication, while broader food-acceptance research indicates that consumption context and cultural background can influence product evaluations [11,12]. Studies conducted in Europe and Asia have shown that health- and sustainability-oriented consumers tend to be more receptive, and that labels, familiar product formats, and benefit-oriented communication may support consumer acceptance [13–15]. Other relevant factors include generation, income, and educational level [16,17].

Recent bibliometric evidence highlights the growing research interest in Spirulina and its use in the food sector. An analysis of the literature published between 2014 and 2024 identified Brazil as a major contributor to research on Spirulina in food-related applications, reflecting the country's active role in studies of its nutritional, technological, and industrial uses [18]. Similarly, another scientometric assessment has ranked Brazil among the leading contributors to Spirulina-related research worldwide, reinforcing the country's prominent role in advancing knowledge of this microalga and its potential uses [19].

Despite growing interest in Spirulina, there is little research on consumer characteristics in developing countries, particularly regarding microalgae consumption [20]. Developing countries such as Brazil have favorable climatic conditions for growing Spirulina [21], and expanding its production for applications such as food could support circular-economy and sustainable food-system strategies aligned with climate action, resource efficiency, food security, and socioeconomic development [2].

Given this context, a deeper understanding of the motivators and barriers associated with Spirulina acceptance is essential, particularly from sociocultural, economic, and sensory perspectives. The following sections synthesize current literature on sustainable food consumption, consumer segmentation, and factors influencing the acceptance of novel foods, providing the basis for the research questions addressed in this study.

1.1. Perceived Benefits as Drivers of Sustainable Food Consumption

In a systematic review, Nichifor et al. [22] identified health concerns, environmental awareness, taste and quality, and social norms as recurrent drivers of sustainable food consumption. Consistent with the role of health-related motives, Huang et al. [23] found that health consciousness was associated with purchase intention for healthy food among Chinese consumers, partly through perceived psychological benefits and perceived naturalness. For alternative proteins, including microalgae, consumer acceptance has been associated with health-related motives, familiarity, attitudes, food neophobia, disgust, and social norms, with the relative importance of these factors varying by product category and consumer segment [24].

Although interest in sustainable food consumption has increased, its adoption remains constrained by recurring economic, availability-related, and informational barriers, particularly high prices, limited product availability, and insufficient awareness [22]. Beyond these barriers, studies on sustainable food and beverage options suggest that consumer decisions are shaped not only by positive evaluations but also by specific reasons for and against consumption, social contexts, implicit food evaluations, and mindfulness-related traits [25,26]. Consistent with this multifactorial perspective, Flores and Jansson [27] grouped the determinants of green innovation adoption into social,

personal, innovation-related, and contextual domains, supporting the need to examine how perceived benefits are associated with responses across consumer profiles.

Within this context, Spirulina can be framed as a promising sustainable food option, as Spirulina-based biorefineries may support resource-efficient production, waste minimization, and biomass generation through the biological fixation of atmospheric carbon dioxide [3]. Consumer research on microalgae-based foods has identified receptive consumer segments [28], while a discrete-choice study on pasta with microalgae proteins found higher willingness to pay when organic, Nutri-Score, or vegan labels were present [15]. However, limited prior knowledge of Spirulina was reported in a Swiss sample, and health and sustainability information appeared more influential than sensory information, suggesting that awareness-oriented strategies may support future consumption [29].

In the present study, these potential benefits were operationalized as three predefined categories presented in the survey: human health, environmental impact, and food production. Because these dimensions may be evaluated differently depending on previous exposure to Spirulina and sociodemographic or lifestyle characteristics, the study examines how they are rated in relation to willingness to consume the product. This led to Research Question 1 (RQ1): How are the predefined health, environmental, and food-production benefits of Spirulina rated in relation to willingness to consume it across consumer profiles within the surveyed Brazilian sample?

1.2. Sociodemographic Profiles, Knowledge, and Barriers in Novel Sustainable Foods

Demographic factors such as age and income may shape sustainable consumption patterns. Ágoston et al. [30] showed that environmental concern and behavior differed by age, with younger adults tending to report stronger eco-anxiety and older groups reporting more frequent engagement in some practices, including reduced meat consumption, recycling, and conservation. These differences suggest that sustainable food-related behaviors should be examined in relation to broader sociodemographic patterns.

In a study on Spanish consumers' knowledge of microalgae as food, Lafarga et al. [17] found greater awareness and basic knowledge among adults aged 25 to 44 and participants with higher levels of education, especially those with a doctoral degree. Similarly, in a Singaporean sample, Wassmann et al. [16] reported greater willingness to buy microalgae-based foods among younger men, consumers with higher income, meat reducers, and participants characterized by stronger health and sustainability concerns and lower food neophobia. These findings indicate that sociodemographic profiles can play an important role in the acceptance of microalgae-based foods.

Barriers to sustainable and microalgae-based food consumption can also vary across consumer profiles. Nichifor et al. [22] identified high prices, financial constraints, limited availability, and insufficient information as recurrent barriers to sustainable food adoption, while Lucas and Brunner [28] suggested that strategies to promote microalgae-based products should consider competitive pricing, information about microalgae benefits, and familiar product formats to reach consumer segments differing in knowledge, neophobia, and openness to innovation. Age-related differences in sensory acceptance have also been observed in algae-enriched foods: in an Italian study evaluating crackers enriched with different micro- and macroalgae, Rabitti et al. [31] found that green color was associated with lower liking among children but contributed positively to liking among adults.

Taken together, these findings indicate that knowledge of, consumption of, and perceived barriers to Spirulina and microalgae-based foods should be examined in relation to sociodemographic differences. Accordingly, Research Question 2 (RQ2) is

posed as follows: Are Spirulina-related prior awareness, knowledge, consumption patterns, and selected perceived barriers associated with selected sociodemographic variables, such as education, generation, gender, and income, within the surveyed Brazilian sample?

1.3. Psychographic and Lifestyle Factors in Prior Awareness, Consumption, and Reported Barriers

Consumer responses to novel sustainable foods are not explained by sociodemographic characteristics alone. Mosikyan et al. [32] showed that research on novel food and beverage acceptance frequently examines psychological factors such as food neophobia, perceptions, emotions, and perceived risks and benefits. Information processing may also differ across consumers: in experiments on food-product health claims, Lin and Lee [33] found that health knowledge and need for cognition moderated product evaluations. For this reason, health-related information-seeking, prior awareness, and previous consumption experience were considered relevant for examining Spirulina-related knowledge, consumption, and reported barriers.

Among Swiss consumers, Lucas and Brunner [28] used cluster analysis to show that receptiveness to microalgae-based foods varied across consumer profiles, with more receptive profiles characterized by favorable attitudes toward microalgae, lower food and food technology neophobia, and a lower preference for familiar or traditional foods. In a Norwegian consumer panel, Maehle and Skjeret [34] used structural equation modeling and found that environmental concern and subjective norms were positively related to attitudes toward microalgae-based bread and beer, while subjective norms also showed a strong direct association with purchase intention.

In a Swiss survey on Spirulina and açai, Lucas et al. [29] reported low previous knowledge of Spirulina and found that health and sustainability arguments elicited stronger agreement than sensory arguments as reasons that could encourage Spirulina consumption; among the Spirulina-enriched products evaluated, pasta and cereal bars were the most likely to be included in participants' diets. The low prior knowledge reported in that survey is consistent with broader evidence that unfamiliarity, food neophobia, and perceived risks can constrain consumer acceptance of novel foods and beverages [32]. In a broader European context, Van der Stricht et al. [35] found that willingness to try foods with microalgae proteins and membership in more favorable consumer segments were positively related to general health interest, environmental concern, and interest in information, and negatively related to food neophobia and food technology neophobia.

In the present study, these factors included health-related information-seeking behaviors, dietary supplement use, and food- and health-related learning experiences. Accordingly, Research Question 3 (RQ3) is formulated as follows: Are selected psychographic and lifestyle factors associated with Spirulina-related prior awareness of Spirulina, consumption patterns, and reported barriers among the surveyed Brazilian sample?

Collectively, the literature reviewed supports a multidimensional approach to the potential adoption of Spirulina that goes beyond willingness to consume alone by considering broader consumer profiles. Therefore, this exploratory study aimed to characterize Spirulina-related knowledge, prior awareness and consumption history, consumption patterns, willingness to consume, and reported barriers among respondents in the surveyed Brazilian sample. The study also examined whether these variables were associated with participants' self-reported sociodemographic, psychographic, and lifestyle characteristics.

2. Materials and Methods

2.1. Participants

To investigate consumers' knowledge, perceptions, and preferences regarding Spirulina, an online questionnaire was designed in Google Forms and administered from 30 September to 31 December 2024. The survey was widely disseminated through social media platforms (Instagram, Facebook, LinkedIn, and WhatsApp), as well as through flyers and posters placed in high-traffic public areas, such as bus and subway stops, convention center entrances (on event days), university cafeterias, and shopping mall exits, in the cities of São Paulo and Santos (São Paulo State, Brazil).

The complete questionnaire is available in Supplementary Material S1. Notes indicating which participants each section targeted were included for structural purposes and were not visible to respondents. Similarly, conditional logic and redirects (e.g., "were taken to Section X") were shown only in the backend structure and not to participants. The questions were also presented without numbering.

This study was approved by the Research Ethics Committee of the Federal University of São Paulo (UNIFESP), under CAAE number 79637724.5.0000.5505. Eligibility criteria were residence in Brazil, aged 18 years or older, and agreement with the Informed Consent Form (ICF).

2.2. Questionnaire Design

The questionnaire was developed drawing on previous studies examining consumer perceptions, knowledge, and attitudes toward microalgae-based foods and alternative proteins [13–17,28,29,34–36]. Some questions were adapted from these sources, while others were developed specifically for this study, informed by concepts and findings in the literature (Table S1).

To ensure contextual relevance, the questionnaire was tailored to the Brazilian context, incorporating self-declared race/skin color categories, income brackets based on Brazil's 2024 minimum wage, educational levels, commercial forms of Spirulina available in the Brazilian market, and brands available in the national market [37,38]. Insights from a recent literature review on foods enriched with Spirulina [10] also contributed to the development of the questionnaire.

The survey instrument was reviewed by the research team to ensure alignment with the study objectives and the suitability of response formats for the planned statistical analyses. Subsequently, the questionnaire underwent internal pretesting with members of the research team and lay individuals to assess question clarity, comprehensibility, survey flow, and completion time. Minor adjustments in wording and format were made when necessary. Because the questionnaire was designed to collect descriptive information rather than to measure a latent construct through a scale, scale validation procedures were not performed.

2.2.1. All Participants

After agreeing to the ICF, participants completed the first section, which collected sociodemographic data (age, gender, state and city of residence, education level, household income, and number of household members). They also provided information on dietary classification, recent health-related behaviors during the previous three months, and prior exposure to content related to "food and human health" (psychographic data). All questions were mandatory, except for income. At the end of this section, participants indicated whether they had heard of Spirulina, had not heard of it, or could not recall whether they had heard of it. Based on this response, they were categorized into three groups, described below.

2.2.2. Group 1—No Familiarity with Spirulina

This group included participants who had not heard of Spirulina or could not recall whether they had heard of it. These individuals were presented with brief texts and a Canva-developed subtitled video explaining three predefined benefits of Spirulina: human health, environmental impact, and food production. Afterward, they rated, on a five-point Likert scale (1 = very low willingness; 5 = very high willingness), the extent to which each benefit would affect their willingness to try Spirulina for the first time.

2.2.3. Group 2—Familiar with Spirulina but Never Consumed It

Participants in this group had heard of Spirulina but had never consumed it (or could not recall consuming it). They first completed a knowledge test consisting of six statements about Spirulina, each rated as “True,” “False,” or “I don’t know.” They also selected Spirulina brands they had seen in the Brazilian market, either in physical stores or online. These participants were then exposed to the same video and text as Group 1 and rated, on the same Likert scale, the extent to which each presented benefit would affect their willingness to start consuming Spirulina. Participants who confirmed they had never consumed Spirulina remained in Group 2 and were evaluated on predefined reasons for non-consumption using a five-point Likert scale (1 = strongly disagree; 5 = totally agree), selecting from barriers related to awareness and perception (not sensory, as they had no prior experience). For barriers involving sensory-related attributes, such as color and smell, responses reflected participants’ perceptions or expectations rather than direct sensory experiences with Spirulina. An open-text field was available to report other possible reasons.

2.2.4. Group 3—Previous Spirulina Consumers

This group included participants who had consumed Spirulina at least once. In addition to the knowledge test and benefit evaluation (as in Group 2), they answered questions about consumption frequency, preferred formats and applications, and the food categories in which they would like to see Spirulina added. They also evaluated, on a five-point Likert scale, predefined potential barriers to more frequent consumption. The list of barriers differed from that used for Group 2, reflecting participants’ distinct experiential basis. Sensory-related barriers, such as taste, smell, and color, were assessed based on participants’ self-reported perceptions and previous consumption experiences rather than through direct sensory evaluation of Spirulina-containing products. An open-ended item allowed them to report additional challenges not covered in the list.

2.3. Data Analysis

Sample size was calculated assuming an infinite population, a 95% confidence level, and a 3% margin of error, resulting in a minimum target of 1072 respondents. A quota-based stratified recruitment plan with uniform allocation was defined using 16 strata formed by sex (female/male), social class (AB: income $\geq$ 10 minimum wages; CDE: income $<$ 10 minimum wages), and generation (Baby Boomers: 1945–1964; Generation X: 1965–1980; Generation Y: 1981–1996; Generation Z: 1997–2006) [37–42], with a target of at least 67 respondents per stratum. Because recruitment relied on voluntary responses to an online questionnaire disseminated through digital and in-person channels, the final sample should not be interpreted as a probabilistic or nationally representative sample.

Income values were converted to USD using an exchange rate of 1 USD = R\$5.83, the average between 30 September and 31 December 2024 [43] (Central Bank of Brazil, 2025). Exclusions included participants under 18 or over 79 years of age ($n = 20$), non-residents of Brazil ($n = 1$), duplicate entries ($n = 1$), and those who selected a non-binary gender option ($n = 2$). These cases were excluded because the stratified sampling design and

planned analyses were based on female and male categories, and the number of non-binary respondents was insufficient to support a separate analytical stratum. With the exception of minors, some excluded cases may be considered in future analyses when compatible with the specific analytical design. After exclusions, the final analytical sample comprised 933 respondents. Although the final sample was smaller than the initially estimated target sample size and some strata did not reach the planned quota, all predefined strata remained represented. Statistical analyses were conducted using R software (R version 4.2.2; 2022 October 31).

2.4. Statistical Analysis

Descriptive statistics were used to characterize the sample: means, medians, standard deviations, quartiles, and ranges for continuous variables, and absolute and relative frequencies for categorical variables. Proportions were compared using 95% confidence intervals [44].

Comparisons between groups were conducted using the Kruskal–Wallis test for continuous or ordinal variables appropriate for nonparametric analysis, followed by Dunn’s post hoc test with Bonferroni correction, where appropriate. The effect size was calculated using eta-squared (η^2). Associations between nominal variables were tested using Chi-square or Fisher’s exact tests, with Cramer’s V used as the effect-size measure.

Within-group analyses were also performed. In all groups, ratings of the extent to which each of the three predefined benefits presented in the survey would affect willingness to consume Spirulina were compared across generations (Kruskal–Wallis with Dunn’s post hoc test and η^2), gender (Mann–Whitney test and r statistic), and income (Spearman’s rank correlation). In Group 2, associations between the type of “food and health” knowledge and two specific barriers were tested using Chi-square and Cramer’s V.

In Groups 2 and 3, associations between income and a specific consumption barrier were tested using Chi-square and Cramer’s V. In Group 3 only, the frequency of Spirulina consumption was analyzed in relation to dietary type (Kruskal–Wallis test) and lifestyle habits (Spearman’s rank correlation). Preferred food categories for Spirulina inclusion were also compared across generation, gender, and income (using Chi-square or Fisher’s exact tests, and Cramer’s V where applicable).

3. Results

3.1. Sociodemographic and Psychographic Profile

A total of 933 valid responses were analyzed. Respondents were from 20 Brazilian states and the Federal District. The sample was highly concentrated in São Paulo state, which accounted for 75.5% of respondents ($n = 704$), followed by Minas Gerais (8.6%) and Rio de Janeiro (4.0%). Participants had a mean age of 38 years, were predominantly from Generation Y, and were mostly female (67.8%), self-declared White (62.4%), and highly educated (41.7% had completed postgraduate studies). About 28.7% reported a family income of up to USD 726.58/month, and 95.4% participated in grocery shopping decisions. Most followed an omnivorous diet (82.2%), and the median household size was three individuals. Based on prior awareness of and consumption history with Spirulina, participants were categorized into Group 1 (never heard of it; 44.6%), Group 2 (had heard of it but never consumed it; 34.3%), and Group 3 (had consumed it; 21.1%) (Table 1 and Supplementary Figures S1–S4).

Table 1. Comparisons and associations between groups (sociodemographic and psychographic data).

Characteristic	Overall	Group 1	Group 2	Group 3	p-Value (Effect)
Age (n = 933)					
Min-Max	18–77	18–77	19–76	19–77	0.285 f ($\eta^2 = 0$)
Q1–Q3	28–45	26–46	28–45.25	29–44	
Median	36	34.5	36	37	
Mean	38.05	37.98	38.08	38.16	
SD	13.3	14.84	12.2	11.5	
Education level (n = 933)					
Incomplete elementary school	12 (1.29%)	10 (2.4%)	0 (0%)	2 (1.02%)	<0.001 *** f ($\eta^2 = 0.08$)
Completed elementary school	9 (0.96%)	8 (1.92%)	1 (0.31%)	0 (0%)	
Completed high school	186 (19.94%)	128 (30.77%)	41 (12.81%)	17 (8.63%)	
Completed undergraduate education	337 (36.12%)	146 (35.1%)	122 (38.12%)	69 (35.03%)	
Completed postgraduate education	389 (41.69%)	124 (29.81%)	156 (48.75%)	109 (55.33%)	
Family income (n = 850)					
Up to US\$726.58	244 (28.71%)	120 (32.17%)	84 (28.38%)	40 (22.1%)	<0.001 *** f ($\eta^2 = 0.01$)
Between US\$726.59 and US\$1453.16	238 (28%)	113 (30.29%)	83 (28.04%)	42 (23.2%)	
Between US\$1453.17 and US\$2421.95	193 (22.71%)	81 (21.72%)	63 (21.28%)	49 (27.07%)	
From US\$2421.96	175 (20.59%)	59 (15.82%)	66 (22.3%)	50 (27.62%)	
People living in the household (n = 933)					
Min-Max	1–14	1–11	1–14	1–6	0.016 * f ($\eta^2 = 0.01$)
Q1–Q3	2–3	2–4	2–3	2–3	
Median	3	3	3	2	
Mean	2.71	2.83	2.66	2.55	
SD	1.24	1.25	1.32	1.05	
Diet classification (n = 933)					
Flexitariana	83 (8.9%)	43 (10.34%)	24 (7.5%)	16 (8.12%)	0.064 b
Omnivorous	767 (82.21%)	338 (81.25%)	272 (85%)	157 (79.7%)	
Other	21 (2.25%)	14 (3.37%)	3 (0.94%)	4 (2.03%)	
Pescetarian	23 (2.47%)	6 (1.44%)	10 (3.12%)	7 (3.55%)	
Vegan (or strict vegetarian)	8 (0.86%)	1 (0.24%)	3 (0.94%)	4 (2.03%)	
Vegetarian	31 (3.32%)	14 (3.37%)	8 (2.5%)	9 (4.57%)	
Racial self-declaration (n = 933)					
Yellow	31 (3.32%)	13 (3.12%)	9 (2.81%)	9 (4.57%)	0.333 a (v = 0.06)
White	582 (62.38%)	245 (58.89%)	209 (65.31%)	128 (64.97%)	
Brown	236 (25.29%)	115 (27.64%)	79 (24.69%)	42 (21.32%)	
Black	84 (9%)	43 (10.34%)	23 (7.19%)	18 (9.14%)	
Generation (n = 933)					
Baby boomer	88 (9.43%)	52 (12.5%)	22 (6.88%)	14 (7.11%)	<0.001 *** a (v = 0.12)
X	192 (20.58%)	78 (18.75%)	72 (22.5%)	42 (21.32%)	
Y	425 (45.55%)	162 (38.94%)	156 (48.75%)	107 (54.31%)	
Z	228 (24.44%)	124 (29.81%)	70 (21.88%)	34 (17.26%)	

Gender (n = 933)					
Female	633 (67.85%)	243 (58.41%)	235 (73.44%)	155 (78.68%)	<0.001 *** a
Male	300 (32.15%)	173 (41.59%)	85 (26.56%)	42 (21.32%)	(v = 0.19)
Decision-maker for household groceries (n = 933)					
Just me	225 (24.12%)	80 (19.23%)	90 (28.12%)	55 (27.92%)	<0.001 *** a (v = 0.12)
Other people and me	665 (71.28%)	303 (72.84%)	222 (69.38%)	140 (71.07%)	
Only other people	43 (4.61%)	33 (7.93%)	8 (2.5%)	2 (1.02%)	
Seeking information on healthy eating (n = 933)					
1—Never	22 (2.36%)	15 (3.61%)	5 (1.56%)	2 (1.02%)	<0.001 *** f (η^2 = 0.08)
2—Rarely	114 (12.22%)	69 (16.59%)	37 (11.56%)	8 (4.06%)	
3—Occasionally	251 (26.9%)	143 (34.38%)	68 (21.25%)	40 (20.3%)	
4—Frequently	298 (31.94%)	125 (30.05%)	108 (33.75%)	65 (32.99%)	
5—Very frequently	248 (26.58%)	64 (15.38%)	102 (31.87%)	82 (41.62%)	
Seeking information on physical exercise practices (n = 933)					
1—Never	27 (2.89%)	17 (4.09%)	5 (1.56%)	5 (2.54%)	<0.001 *** f (η^2 = 0.02)
2—Rarely	83 (8.9%)	47 (11.3%)	26 (8.12%)	10 (5.08%)	
3—Occasionally	248 (26.58%)	122 (29.33%)	82 (25.62%)	44 (22.34%)	
4—Frequently	304 (32.58%)	137 (32.93%)	103 (32.19%)	64 (32.49%)	
5—Very frequently	271 (29.05%)	93 (22.36%)	104 (32.5%)	74 (37.56%)	
Seeking information on mental health (n = 933)					
1—Never	38 (4.07%)	25 (6.01%)	6 (1.88%)	7 (3.55%)	<0.001 *** f (η^2 = 0.03)
2—Rarely	125 (13.4%)	76 (18.27%)	32 (10%)	17 (8.63%)	
3—Occasionally	230 (24.65%)	105 (25.24%)	86 (26.88%)	39 (19.8%)	
4—Frequently	280 (30.01%)	116 (27.88%)	107 (33.44%)	57 (28.93%)	
5—Very frequently	260 (27.87%)	94 (22.6%)	89 (27.81%)	77 (39.09%)	
Consumption of dietary supplements (n = 933)					
1—Never	255 (27.33%)	144 (34.62%)	87 (27.19%)	24 (12.18%)	<0.001 *** f (η^2 = 0.07)
2—Rarely	150 (16.08%)	84 (20.19%)	43 (13.44%)	23 (11.68%)	
3—Occasionally	155 (16.61%)	63 (15.14%)	60 (18.75%)	32 (16.24%)	
4—Frequently	152 (16.29%)	59 (14.18%)	52 (16.25%)	41 (20.81%)	
5—Very frequently	221 (23.69%)	66 (15.87%)	78 (24.38%)	77 (39.09%)	
I have a technical degree, undergraduate or postgraduate degree in this or related areas (n = 933)					
No/I don't remember	576 (60.77%)	329 (79.09%)	148 (46.25%)	90 (45.69%)	<0.001 *** a
Yes	366 (39.23%)	87 (20.91%)	172 (53.75%)	107 (54.31%)	(v = 0.34)
I work or have worked in this or related areas (n = 933)					
No/I don't remember	576 (60.77%)	329 (79.09%)	148 (46.25%)	90 (45.69%)	<0.001 *** a
Yes	366 (39.23%)	87 (20.91%)	172 (53.75%)	107 (54.31%)	(v = 0.34)
I do or have done one or more short courses in this or related areas (n = 933)					
No/I don't remember	605 (64.84%)	346 (83.17%)	159 (49.69%)	100 (50.76%)	<0.001 *** a
Yes	328 (35.16%)	70 (16.83%)	161 (50.31%)	97 (49.24%)	(v = 0.34)
Through networks and social media (n = 933)					
No/I don't remember	605 (64.84%)	346 (83.17%)	159 (49.69%)	100 (50.76%)	<0.001 *** a
Yes	328 (35.16%)	70 (16.83%)	161 (50.31%)	97 (49.24%)	(v = 0.34)
Through networks and social media (n = 933)					
No/I don't remember	310 (33.23%)	155 (37.26%)	101 (31.56%)	54 (27.41%)	0.040 * a (v =
Yes	623 (66.77%)	261 (62.74%)	219 (68.44%)	143 (72.59%)	0.08)

Note: p -values marked with the letter $\mathcal{K}$ indicate the Kruskal–Wallis test and eta-squared effect size; p -values marked with the letter $\mathcal{F}$ indicate Fisher's exact test; p -values marked with the letter $\mathcal{C}$ indicate the Chi-square test followed by Cramer's V effect size; * significant at 5%; *** significant at 0.1%.

Regarding lifestyle and psychographic characteristics, participants most frequently sought information on exercise, healthy eating, and mental health (58–62%). In contrast, only 40% reported frequent or very frequent use of dietary supplements during the previous three months. Most participants had learned about “food and human health” through social media (66.8%) (Table 1 and Supplementary Table S2).

3.2. Comparisons and Associations Between Groups

No significant differences were observed among Groups 1, 2, and 3 for age ($p = 0.285$). In contrast, significant differences were found for education level ($p < 0.001$), family income ($p < 0.001$), and household size ($p = 0.016$) (Table 1). Participants in Group 1 had lower educational attainment than those in Groups 2 and 3, whereas Groups 1 and 2 reported lower income levels than Group 3. Effect sizes were small to moderate ($\eta^2 = 0.01$ – 0.08).

Group membership was not associated with diet classification ($p = 0.064$) or self-declared race ($p = 0.333$). However, significant associations were observed for generation, gender, and decision-maker for household groceries (all $p < 0.001$). Effect sizes were small ($V = 0.12$ – 0.19). Group 1 included more Baby Boomers and Gen Z participants, fewer women, and fewer participants involved in household grocery shopping than expected under the independence hypothesis.

Significant group differences were observed for all habit and lifestyle variables analyzed (all $p < 0.001$). Effect sizes were small to moderate ($\eta^2 = 0.02$ – 0.08). Participants in Group 1 reported lower frequencies of seeking information on physical exercise and mental health than those in Groups 2 and 3, while Groups 2 and 3 did not differ significantly from each other. For seeking information on healthy eating and dietary supplement consumption, significant differences were observed among all three groups.

Regarding food- and health-related learning sources, significant associations were found between group membership and having a technical, undergraduate, or postgraduate degree in related areas, work experience in related areas, and participation in short courses (all $p < 0.001$, $V = 0.34$). Groups 2 and 3 included more participants with these backgrounds than expected under the independence hypothesis, whereas Group 1 included fewer. Although learning through social media was also associated with group membership ($p = 0.040$), the effect size was negligible ($V = 0.08$), and no significant pairwise differences were identified. The results of this section are also shown in Table 1.

3.3. Knowledge About Spirulina

Among participants who had heard of or consumed Spirulina (Groups 2 and 3), knowledge was highest for statements related to its antioxidant and nutritional properties, whereas environmental benefits and its use as a natural colorant were less frequently recognized, as represented in Figure 1. Overall, only 17.2% of respondents answered all six knowledge items correctly (Figure 1A). Group 3 consistently showed higher proportions of correct responses than Group 2 across all knowledge items (Figure 1B), although effect sizes were small ($V = 0.12$ – 0.20) (Supplementary Figure S5 and Supplementary Table S3).

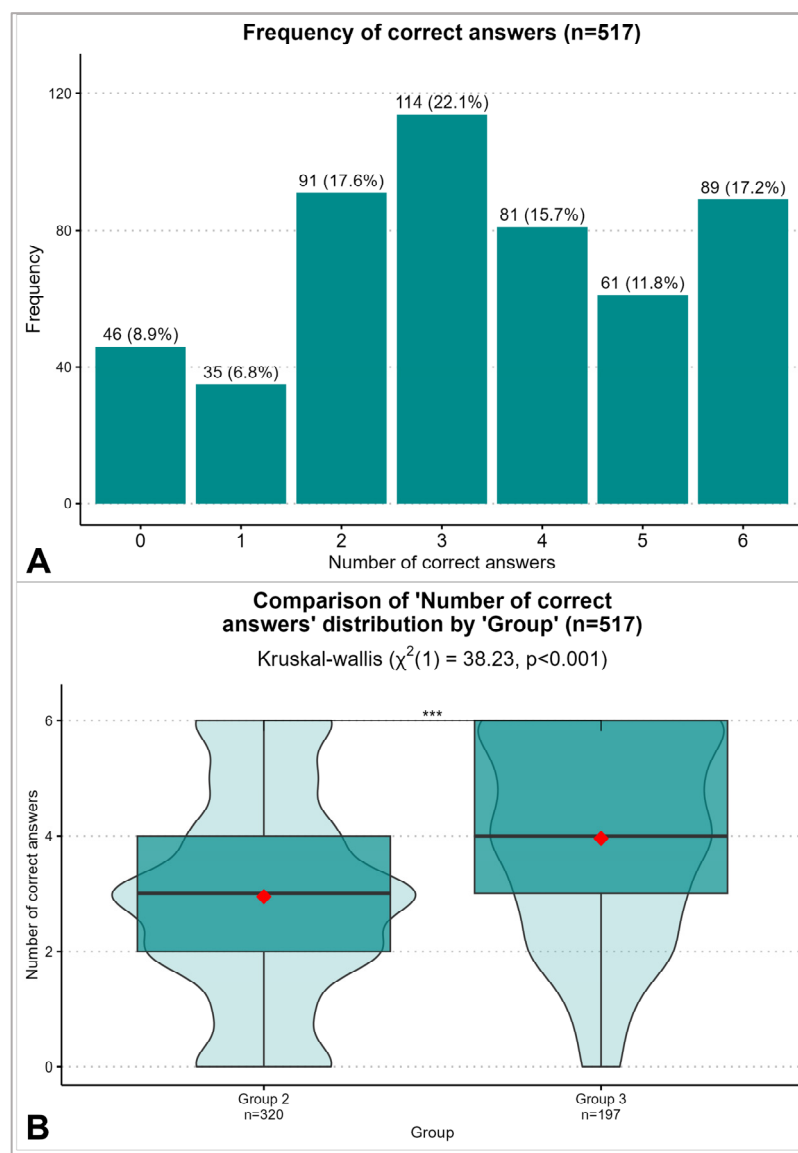


Figure 1. Representation of answers from groups 2 and 3 regarding knowledge about Spirulina (A) Frequency of correct answers in the Spirulina knowledge test, and (B) comparison between Groups 2 and 3. *** significant at 0.1%.

Regarding Spirulina brand recognition, Brand 5, Brand 4, and the response “I don’t remember” were the most frequently selected options. Significant associations were observed between group membership and recognition of several Spirulina brands (all $p \leq 0.012$). In general, Group 3 had a higher proportion of participants who reported having seen these brands than Group 2, whereas the opposite pattern was observed for the response “I don’t remember”. However, effect sizes were small ($V = 0.12$ – 0.26) (Supplementary Figure S6 and Supplementary Table S4).

3.4. Willingness to Consume Spirulina

Among participants unfamiliar with Spirulina (Group 1), environmental benefits were most frequently rated as increasing willingness to try the product (57%) (Figure 2A). Among participants who had heard of or consumed Spirulina (Groups 2 and 3), human health benefits (66%) were most frequently rated as increasing willingness to consume it, followed by environmental and food production benefits (Figure 2B). Participants in Group 3 reported greater willingness to consume Spirulina than those in Group 2 across

all benefit categories (all $p < 0.001$), although effect sizes were small ($\eta^2 = 0.02$) (Supplementary Table S5).

Within Group 1, willingness to consume Spirulina varied by generation and gender. For human health benefits, Baby Boomers reported lower willingness than Generations Y and Z. For environmental and food production benefits, Baby Boomers reported lower willingness than Generation Z (Supplementary Table S6). Women reported greater willingness than men regarding human health and environmental benefits, whereas no gender differences were observed for food production benefits (Supplementary Table S7). Family income was not associated with willingness to consume Spirulina (Supplementary Table S8). Effect sizes for the associations observed in Group 1 were small.

In Group 2, willingness to consume Spirulina was not associated with generation, gender, or family income. In Group 3, women again reported greater willingness than men regarding human health and environmental benefits, although effect sizes were small ($r = 0.18$ – 0.23). No significant associations were observed for generation or family income, and no gender differences were found for food production benefits.

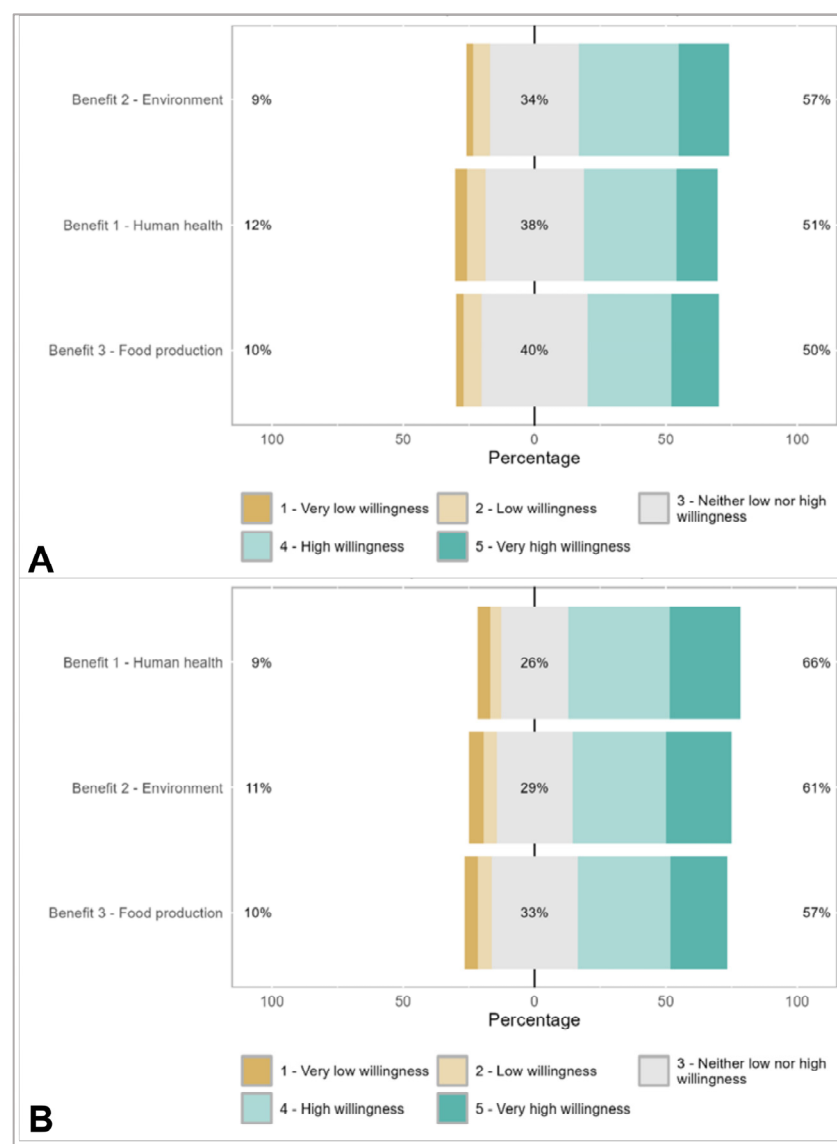


Figure 2. Willingness to consume Spirulina according to perceived benefits. (A) Ratings among participants unfamiliar with Spirulina (Group 1). (B) Ratings among participants who had heard of or consumed Spirulina (Groups 2 and 3).

3.5. Barriers to Consuming Spirulina

Among Group 2 participants, agreement with the proposed barriers was generally low, ranging from 6% to 25%. Barriers related to Spirulina consumption forms, such as powdered products, capsules, and tablets, were among the most frequently endorsed. Food neophobia, unpleasant color, and lack of knowledge about Spirulina's benefits or uses were among the least frequently endorsed barriers, whereas unpleasant smell, price, and limited market availability received more neutral responses (Figure 3A).

In Group 2, the barrier "I don't know what Spirulina is used for" was weakly associated with having attended short courses in food- and health-related areas ($p = 0.044$, $V = 0.12$), whereas no associations were observed for other learning sources. No learning source was associated with the barrier "I don't know Spirulina's benefits" (Supplementary Table S9). Price incompatibility was associated with family income ($p = 0.032$, $V = 0.17$), with participants in the lowest income category reporting this barrier more frequently. Both associations had small effect sizes. No such association was observed in Group 3 ($p = 0.730$) (Supplementary Table S10).

Among Group 3 participants, all proposed barriers received more disagreement than agreement. However, unpleasant smell (32%), unpleasant taste (29%), and difficulty finding pleasant ways to consume Spirulina (28%) were the most frequently reported barriers to more frequent consumption, whereas unpleasant color, dislike of capsules/tablets, and the perception of already consuming an adequate amount were the least frequently endorsed barriers (11% each) (Figure 3B).

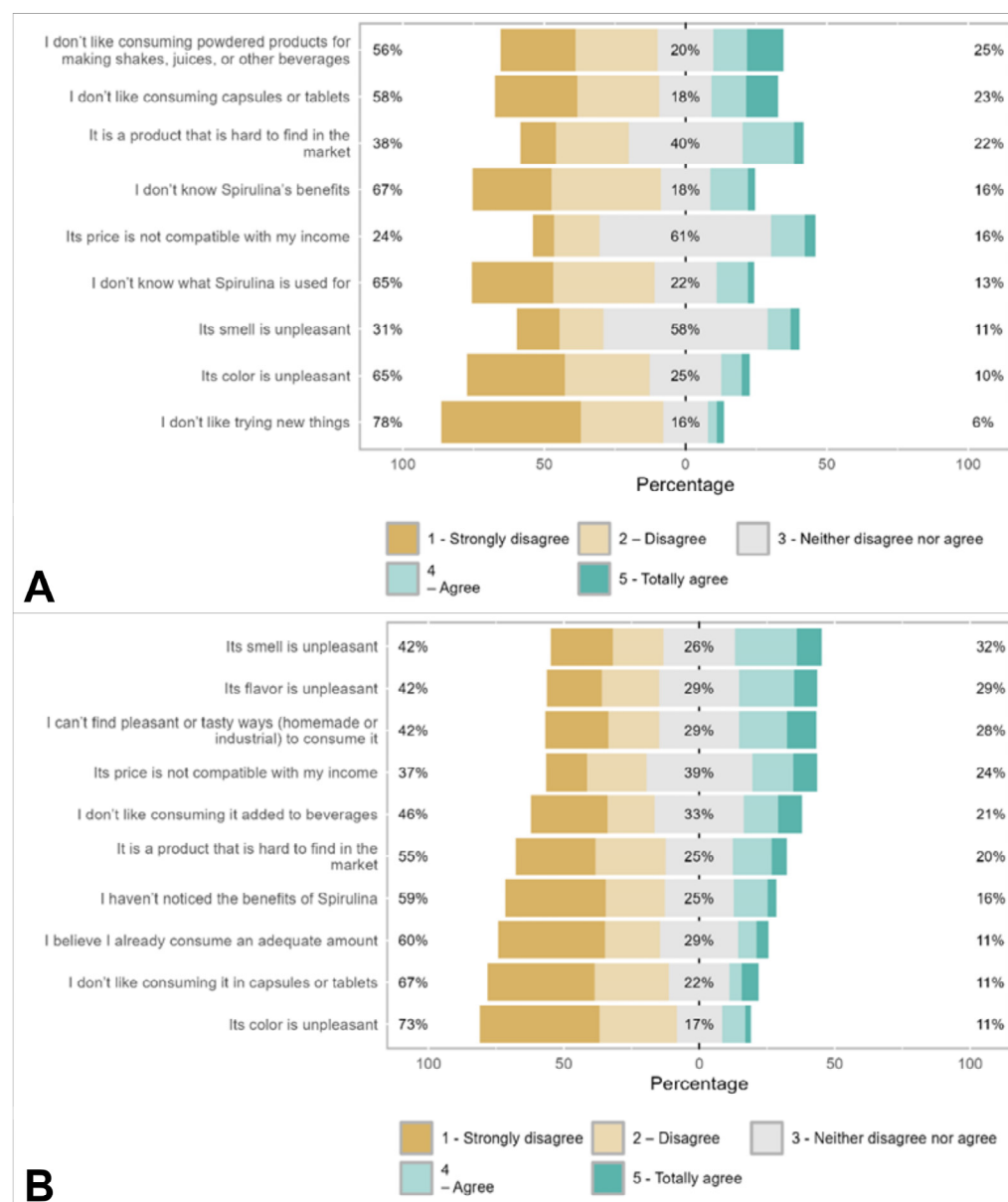


Figure 3. Reported barriers to Spirulina consumption according to previous consumption history. (A) Barriers reported by participants who had heard of but never consumed Spirulina (Group 2). (B) Barriers reported by participants who had consumed Spirulina (Group 3).

3.6. Spirulina Consumption Habits and Preferences

Capsules or tablets were the most frequently reported Spirulina consumption format, followed by intake with water or other beverages, whereas incorporation into homemade recipes, homemade dishes, or ready-to-eat products was less common (Figure 4). Regardless of the format, more than half of the participants (55%) reported having consumed Spirulina only once (Table 2).

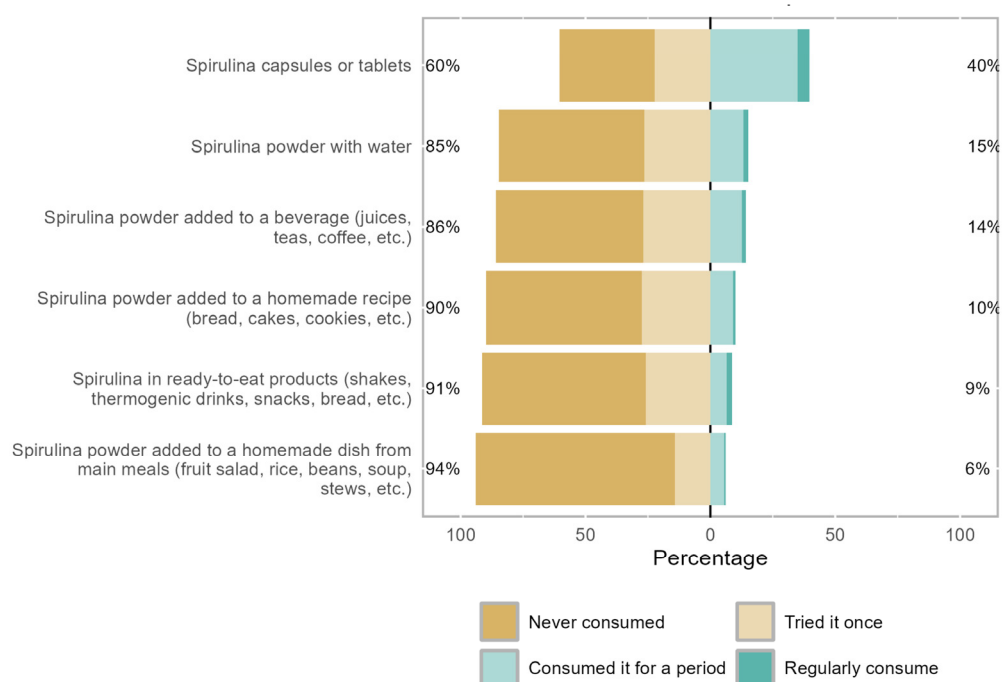


Figure 4. Forms of Spirulina consumption among participants who had previously consumed Spirulina.

Table 2. Frequency of Spirulina consumption in Group 3.

Variable	Statistic
How often do you usually consume Spirulina? Added or not to food and beverages (n = 197)	
Tried it only once	107 (54.31%)
Less than once every 6 months	31 (15.74%)
Once every 3 to 6 months	9 (4.57%)
Once every two months	8 (4.06%)
Once per month	6 (3.05%)
Twice per month	4 (2.03%)
At least once per week	32 (16.24%)

Consumption frequency did not differ by diet classification ($p = 0.481$, $\eta^2 = 0.00$) (Supplementary Table S11). However, weak positive correlations were observed with seeking information on healthy eating ($\rho = 0.21$, $p = 0.003$) and dietary supplement use ($\rho = 0.29$, $p < 0.001$), suggesting that participants with greater interest in nutrition and supplement consumption tended to report more frequent Spirulina use (Table 3).

Table 3. Frequency of Spirulina consumption and interests and habits in Group 3.

Variable	<i>p</i> -Value	Statistic	Shared Variance	CI (95%)
Seeking information on healthy eating	0.003 ** g	0.21	0.05	(0.08, 0.35)
Seeking information on physical exercise practices	0.087 g	0.12	0.01	(−0.02, 0.26)
Seeking information on mental health	0.121 g	0.11	0.01	(−0.03, 0.25)
Consumption of dietary supplements	<0.001 *** g	0.29	0.08	(0.16, 0.42)

Note: p -values marked with the letter α indicate Spearman's rank correlation; ** significant at 1%; *** significant at 0.1%.

Bulk Spirulina was the most frequently consumed product among the options presented, whereas the remaining brands were rarely consumed (Supplementary Figure S7).

Preferred food categories for Spirulina incorporation were baked goods, ready-made powdered food mixes, food bars, savory snacks, and pasta products, whereas meat products and the option “no food category” were the least preferred (Figure 5 and Supplementary Table S12). A single significant association was identified: women were more likely than men to prefer Spirulina in savory snacks ($p = 0.035$, $V = 0.16$), although the effect size was small (Supplementary Tables S13–S15).

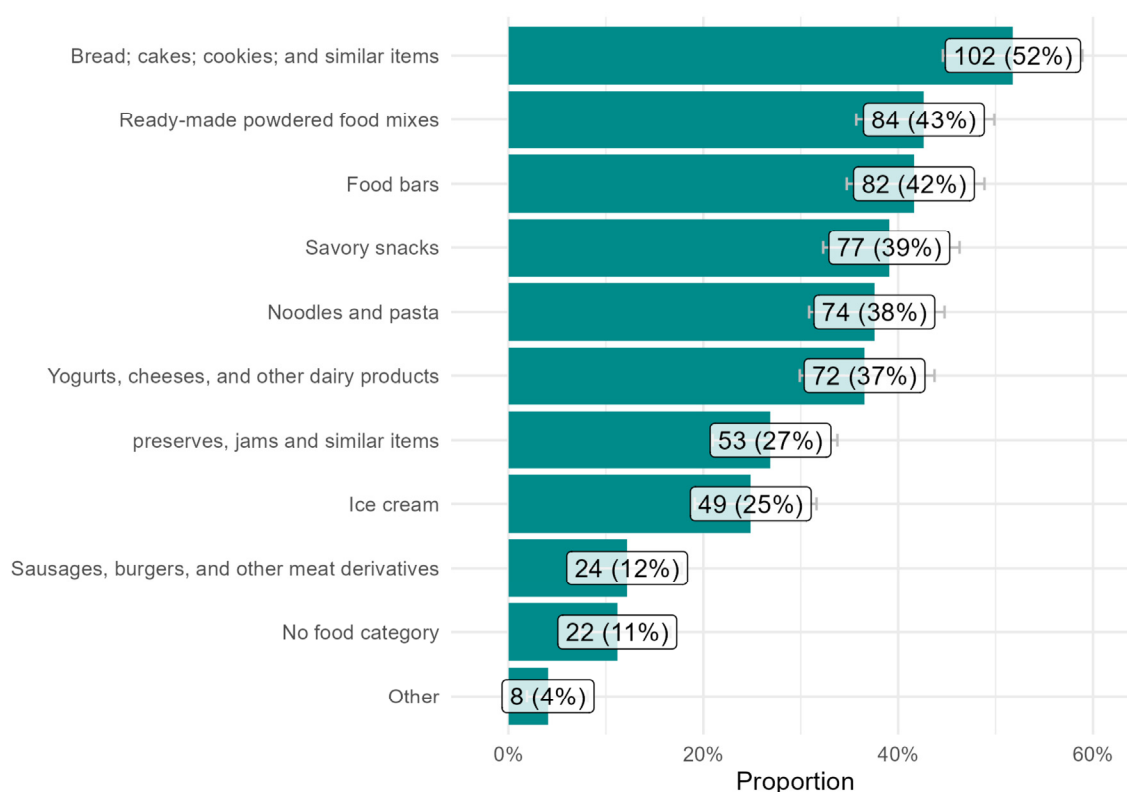


Figure 5. Food categories preferred by participants for Spirulina addition.

4. Discussion

This exploratory study characterized Spirulina-related knowledge, prior awareness and consumption history, willingness to consume, and perceived barriers among respondents with different levels of previous exposure to Spirulina. The findings showed limited prior awareness and consumption, uneven knowledge of Spirulina's attributes, and differences in motivations and perceived barriers according to previous experience with the product.

Several sociodemographic, psychographic, and lifestyle variables were associated with prior awareness, knowledge, or consumption patterns, but these associations were generally small. This suggests that Spirulina-related knowledge and consumption are unlikely to be explained by isolated demographic or lifestyle characteristics alone. This pattern is consistent with research on novel foods, which shows that acceptance is shaped by several consumer-related factors, particularly psychological factors such as perceptions, emotions, food neophobia, and perceived risks and benefits [32].

Participants unfamiliar with Spirulina generally reported lower educational attainment, lower income, and lower engagement in health-related practices. In contrast, Spirulina consumers tended to report higher educational attainment, higher income, and greater involvement in health-related behaviors. Participants who had heard of Spirulina but had never consumed it showed intermediate characteristics. The most consistent group difference involved food- and health-related educational or professional backgrounds, which were more frequently reported among participants with previous exposure to Spirulina.

Similar patterns have been reported in previous studies. In Switzerland, Lucas and Brunner [28] identified more receptive consumer segments with stronger health interest and more favorable attitudes toward microalgae-based foods. In Spain, Lafarga et al. [17] found that knowledge about microalgae varied by age and educational level, with higher knowledge generally reported among more educated respondents. In a study involving consumers from five European countries, Van der Stricht et al. [35] found that higher general health interest, stronger environmental concern, and greater interest in information were associated with segments that showed higher willingness to try foods containing microalgal proteins.

Weinrich and Elshiewy [14] also found that attitudes toward microalgae as food were related to food-related lifestyle characteristics, including a healthier lifestyle orientation, openness to new foods, lower meat consumption, and interest in food-product information. In the present study, respondents with characteristics similar to those observed in Group 3 may therefore be more receptive to Spirulina-based products and may represent a relevant group for future communication and product-positioning efforts involving Spirulina-containing foods.

However, this profile is not representative of the broader Brazilian population. National demographic data indicate that 55.5% of Brazilians self-identify as Black (10.2%) or Brown (45.3%), 13.7% lack home internet access, and only 16.8% have completed higher education [38]. Therefore, the respondent profile identified in this study should be interpreted as a niche within the surveyed sample rather than as representative of Brazilian consumers as a whole. Considering the potential nutritional and environmental benefits of Spirulina, future efforts may benefit from socially inclusive strategies to increase awareness of its consumption and culinary applications among underrepresented population groups.

The knowledge test also points to information gaps. Participants showed greater awareness of Spirulina's nutritional attributes than of its environmental and technological characteristics, and only a minority answered all knowledge items correctly. Communication efforts could therefore address not only nutritional aspects but also Spirulina's sustainability-related and technological attributes. Lafarga et al. [17] identified a lack of information as one of the main reasons for not consuming microalgae. In a Japanese survey comparing five alternative proteins, Takeda et al. [13] showed that scientific interest was an important factor related to attitudes toward these foods, supporting communication strategies tailored to different alternative protein categories.

Recognition of specific Spirulina brands was limited, with "I don't remember" among the most frequent responses. In addition, bulk Spirulina was the most frequently consumed product among the options presented. This pattern may indicate low brand salience among respondents and is consistent with the perception of Spirulina as a product more commonly recognized in generic or supplement-like forms than as a familiar branded food ingredient.

Regarding willingness to consume Spirulina, motivations varied according to participants' prior awareness and consumption history. Environmental benefits were more frequently rated as increasing willingness to try Spirulina among participants

unfamiliar with it, whereas health-related benefits were most frequently rated as increasing willingness to consume the product among participants who had heard of or consumed Spirulina. This pattern is consistent with a systematic review identifying health concerns and environmental awareness as primary drivers of sustainable food consumption [22].

Some differences in willingness to consume Spirulina were observed by gender and generation, but these associations were generally small and inconsistent across all groups. Women tended to report greater willingness when health and environmental benefits were considered, whereas younger participants showed higher willingness than Baby Boomers only in Group 1. Family income was not associated with willingness to consume Spirulina. The higher willingness observed among younger participants in Group 1 is consistent with Wassmann et al. [16], who found that willingness to buy microalgae-based foods in a Singaporean sample was positively associated with younger age, sustainability and health concerns, lower food neophobia, and meat reduction, among other factors.

Barriers to consumption also varied between groups. In Group 2, barriers related to common forms of Spirulina consumption, such as powders, capsules, and tablets, were more prominent. In Group 3, sensory aspects such as smell and taste were reported more frequently. These findings align with previous studies highlighting the role of product form and expected sensory quality in microalgae-based foods. Wassmann et al. [16] concluded that expected taste should be prioritized when developing and positioning such products. In the present study, sensory characteristics were among the most frequently reported barriers to more frequent consumption among Spirulina consumers, although disagreement remained higher than agreement for all proposed barriers. Price concerns were observed mainly among lower-income participants in Group 2, although the magnitude of this association was small.

Participants' consumption habits followed a similar pattern. Capsules and tablets were the most frequently reported forms of Spirulina consumption, whereas homemade preparations and ready-to-eat products were less common. Participants also expressed greater interest in incorporating Spirulina into familiar food categories, such as baked goods, powdered mixes, food bars, and pasta products. Consumption frequency did not differ by diet classification, suggesting that more frequent Spirulina use was not restricted to a specific dietary group within the surveyed sample. In this sample, Spirulina therefore appeared closer to a supplement-like product than to a familiar food ingredient.

This finding aligns with evidence from alternative protein research showing that familiarity is one of several drivers of acceptance, alongside taste, health motives, attitudes, food neophobia, disgust, and social norms [24]. Comparable findings were reported in Switzerland by Lucas et al. [29], who found that pasta and cereal bars were among the Spirulina-containing products most likely to be included in participants' diets. Grahl et al. [36] similarly found that Spirulina-filled pasta was preferred over less familiar product concepts, with familiarity with the product category partly explaining product liking. In addition, Braga-Souto et al. [10] reported that bakery products and pasta were among the Spirulina-enriched food categories with comparatively favorable acceptability in certain formulations, although sensory outcomes varied with Spirulina concentration, product matrix, and study design.

Overall, the findings addressed the three research questions proposed in this study. Regarding RQ1, the predefined health, environmental, and food-production benefits of Spirulina were rated differently in relation to willingness to consume it, particularly across groups defined by prior awareness and consumption history, generation, and gender. For RQ2, Spirulina-related prior awareness, knowledge, consumption patterns, and selected perceived barriers were associated with sociodemographic variables, including education, income, generation, and gender. For RQ3, selected psychographic

and lifestyle factors, including health-related information-seeking behaviors, dietary supplement use, and food- and health-related learning experiences, were associated with prior awareness of Spirulina, consumption patterns, and reported barriers.

Although several associations were identified across the analyses, most effect sizes were small. The results should therefore be interpreted primarily as evidence of descriptive patterns within the surveyed population. Prior awareness of Spirulina was limited; knowledge focused on health-related benefits; consumption occurred mainly through capsules, tablets, and powdered products; and sensory characteristics remained relevant barriers even among Spirulina consumers. These findings should be interpreted in light of the limitations discussed below.

This study had some limitations. First, the final sample size ($n = 933$) was smaller than the initially estimated sample size ($n = 1072$). In addition, although a stratified sampling approach with uniform allocation was planned, some strata did not reach the target number of respondents. Nevertheless, all strata remained represented in the final sample, and the primary consequence of the smaller-than-planned sample size was likely a reduction in statistical power, increasing the possibility of Type II error for associations that did not reach statistical significance.

Although some differences between groups were statistically significant, most effect sizes were small, suggesting that additional factors not addressed in this study may influence knowledge about and consumption of Spirulina. The exclusion of non-binary respondents from gender-based analyses, due to the very small number of cases, should also be considered a limitation because it restricts the inclusiveness of gender-related interpretations. Another limitation relates to the classification adopted for Group 3. This group included participants with varying levels of experience with Spirulina consumption, ranging from one-time users to regular consumers, which may have masked potentially relevant differences within the group. A more refined segmentation based on consumption frequency could provide additional insights into Spirulina acceptance and use.

Another limitation is the geographical concentration of respondents, predominantly from the Southeast region of Brazil, which limits the generalizability of the findings to regions with distinct cultural, racial, socioeconomic, and dietary characteristics. Although the online format was useful for large-scale data collection, it may have excluded individuals with limited internet access or digital literacy. The predominance of respondents from São Paulo state also limited the feasibility of meaningful regional comparisons.

The recruitment strategy, which relied on social media, universities, and public spaces, may have contributed to the overrepresentation of participants with higher educational attainment and greater interest in health-related topics. All information, including perceptions regarding sensory barriers, was self-reported and may therefore be subject to recall bias, reporting inaccuracies, or social desirability bias. Importantly, no sensory testing was conducted; therefore, findings related to taste, smell, color, and product formats should be interpreted as self-reported perceptions or previous consumption experiences rather than direct sensory responses to Spirulina-containing products.

An additional limitation concerns the assessment of participants' willingness to consume Spirulina when they are unfamiliar with the product. These participants were exposed to information describing Spirulina's potential benefits before reporting their willingness to consume it. Therefore, the study evaluated willingness after information exposure rather than initial attitudes, which may have influenced participants' responses.

Future research should include more representative samples of the Brazilian population, incorporating participants from diverse regions, income levels, educational

backgrounds, and age groups. Qualitative studies could further clarify motivations, resistance, and symbolic perceptions surrounding Spirulina. Multivariate analyses may also help identify which factors independently contribute to Spirulina-related knowledge, perceptions, and consumption. Experimental studies incorporating sensory evaluations, consumer choice experiments, and educational interventions are warranted to assess how product formats, labeling, and communication strategies affect consumer acceptance.

5. Conclusions

The present study showed limited prior awareness and consumption of Spirulina among the surveyed participants. Prior awareness and consumption history were associated with sociodemographic, psychographic, and lifestyle characteristics, although most observed effect sizes were small. Knowledge about Spirulina was largely concentrated on its nutritional and health-related attributes, whereas its environmental and technological characteristics were less widely recognized. The predefined health, environmental, and food-production benefits were rated differently in relation to willingness to consume Spirulina across consumer profiles. Sensory characteristics and consumption formats also emerged as relevant aspects of consumer perception, with more than half of consumers reporting having tried Spirulina only once and consumption occurring predominantly through capsules, tablets, and powdered products. Taken together, these findings provide baseline information on Spirulina awareness, perceptions, and consumption among the surveyed Brazilian sample and may inform future research and communication strategies to increase familiarity with this microalga.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/phycology6030070/s1>, Supplementary Material S1—Questionnaire: “Spirulina in Food”; Supplementary Material S2—Table S1. References to papers on consumer research related to microalgae for developing questions in the “Spirulina in Food” questionnaire; Supplementary Material S3—Table S2. Learning sources; Table S3. Answers in the knowledge test per group; Table S4. Spirulina brands seen in the market per group; Table S5. Consumption motivators per group; Table S6. Consumption motivators per generation per Group; Table S7. Consumption motivators per gender per Group; Table S8. Consumption motivators per family income per Group; Table S9. Association between the learning source and the barriers to consumption in Group 2; Table S10. Association between the family income and the barrier “Its price is not compatible with my income” in Groups 2 and 3; Table S11. Frequency of Spirulina consumption and diet classification in Group 3; Table S12 Food categories for Spirulina addition; Table S13. Association between the selected food category for Spirulina addition and generation in Group 3; Table S14. Association between selected food category for Spirulina addition and gender in Group 3; Table S15. Association between selected food category for Spirulina addition and family income in Group 3. Supplementary Material S4—Figure S1. Age, gender, and racial self-declaration profile of respondents; Figure S2. Educational level, monthly family income, and household size of respondents; Figure S3. Household grocery decision-making and dietary profile of respondents; Figure S4. Spirulina awareness, previous consumption, and group classification of respondents; Figure S5. Item-level results of the Spirulina knowledge test, overall and by group; Figure S6. Spirulina brands seen in the market overall and by group; Figure S7. Spirulina brands consumed by participants who had previously consumed Spirulina.

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