



Analysis of the knowledge and attitudes of Brazilian consumers regarding microalgae: A strategy to assess the development potential of new foods

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Abstract

Consumer profiles, expectations, and the factors that affect food purchases are essential information for evaluating the inclusion of new products on the market. This work assessed Brazilian consumers' knowledge about microalgae and its use in food. The survey had 1,499 participants: 68% women, 29% with higher education, and 53% from the southern region of Brazil. Most (70%) had already heard about microalgae, 51% knew what they were, 72% had never ingested microalgae biomass, and 84% would be willing to consume food with biomass or its byproducts. Participants indicated they would like to see microalgae as an ingredient in the following food groups: nutritional supplements (73%), seasonings (56%), bakery products (49%), sauces and mayonnaise (44%), beverages (32%), and dairy products (25%), and 40% would pay between 5 and 10% more for this. In conclusion, although most participants were unaware of the benefits of microalgae, they were willing to consume them in their byproducts, demonstrating the potential for developing and commercializing new food products, such as seasonings, sauces, mayonnaise, dairy, and bakery products.

Keywords: biomass; consumption habits; emerging methods; novel foods; questionnaire.

Practical Application: The study demonstrated that limited knowledge about microalgae is the main barrier to consumer preference for products containing biomass. The attitude of the Brazilian consumer highlights the potential value of products added with microalgae. This study reveals promising results that can help the food industry expand its market options, especially for vegans and vegetarians, encouraging the development of new products in both the national and international markets. Microalgae can be used in seasonings, sauces, and mayonnaise.

1 INTRODUCTION

The pattern of food consumption is evolving, with health promotion becoming a key factor influencing food choices (Savelli & Murrura, 2023). This shift impacts the food industry, increasing demand for foods with health benefits and appealing sensory characteristics (Rosenthal et al., 2021). The rise in vegetarianism and veganism, driven by concerns about animal welfare, environmental sustainability, and health issues, also plays a significant role (Heras-Delgado et al., 2023; Pimentel et al., 2021). Consequently, numerous products have been developed to provide sustainable protein alternatives to conventional animal sources. These alternatives include proteins derived from plants, cells, mycoproteins, and precision fermentation, which mimic animal meat and dairy products' taste, appearance, and smell (Thornton et al., 2023). According to the Good Food Institute (2023), around 1,300 companies work on alternative

proteins. In this context, microalgae are an excellent protein source for food production (Koyande et al., 2019; Tang et al., 2020; Terriente-Palacios & Castellari, 2021).

Spirulina platensis and *Chlorella* sp. are notable for their high protein content (~50%) (Casazza et al., 2020; Seghiri et al., 2019). The microalgae market produces an estimated 5,000 tons of biomass annually, generating revenues of USD1.25 billion per year, excluding byproducts (Nethravathy et al., 2019), with a projected compound annual growth rate of 6% by 2027 (Bonnell, 2021). Numerous studies have been focused on incorporating microalgal biomass into various food products, including dairy derivatives, vegan kefir, cereal bars, functional sauces, and hamburgers (Almeida et al., 2020; Atallah et al., 2020; Atik et al., 2021; Atitallah et al., 2019; Barkallah et al., 2019; Batista et al., 2019; Hlaing et al., 2019; Oliveira et al., 2021; Pan-Utai et al., 2020; Žugčić et al., 2018).

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Understanding consumer expectations, their profiles, and the factors impacting their purchasing decisions is crucial to successfully introducing new products to the market (Pacheco et al., 2018). Weinrich and Elshiewy (2023) examined consumer attitudes and lifestyle influences on microalgae consumption in Germany, France, and the Netherlands. Lafarga et al. (2021) studied Spanish consumers' knowledge, willingness to purchase, and motivations regarding microalgae. Al-Thawadi (2018) investigated the factors influencing the consumers' acceptance of seaweed (including *Spirulina*) as an alternative food in the Kingdom of Bahrain (United Kingdom (UK)).

Given the lack of studies on consumer knowledge and attitudes toward microalgae in South America and Brazil's status as the world's largest exporter of processed foods (ABIA, 2023), Brazil holds significant potential for processing and distributing microalgae-based foods. The country can creatively incorporate microalgae into new food products, expanding market options and offering valuable nutritional alternatives. Research in Brazil has explored the perspectives, scenarios, and technical-economic evaluations of microalgae production, including market discussions, policies, and the benefits of mapping regions suitable for eco-industrial plants dedicated to microalgae production (Andrade et al., 2020).

Therefore, this study aimed to evaluate Brazilian consumers' knowledge and attitudes about microalgae and its use in food. Through this study, consumers reported the desirable characteristics of microalgae-based products, what they expected to find in the available product, which aspects would draw their attention, and mainly, in which products they would like microalgae to be inserted.

2 MATERIALS AND METHODS

2.1 Participants

The study was approved by the Ethics Committee of Human Research of the Universidade Federal de Santa Catarina, Brazil (n° 5.096.722) in November 2021. The data collection occurred between January and May 2022 and was carried out through the Google Form survey management platform. Participants were recruited through emails and social networks (WhatsApp, Instagram, Facebook, and/or LinkedIn). The inclusion criteria consisted of individuals residing in all regions of Brazil (Northeast, North, Central-Western, South, and Southeast), aged 18 years or older, who voluntarily agreed to the Informed Consent Form.

2.2 Questionnaire design

Data collection was performed through a questionnaire structured in four sections, with response options that best reflected the opinion or behavior pattern of the participants. After agreeing with the informed consent form, the sections consisted of (1) socio-demographic data (gender, age group, place of residence, education, household income, and occupation), diet profile, and willingness to try foods with different characteristics; (2) general knowledge about microalgae, with some specific statements formulated based on the literature

regarding consumption, general knowledge, healthiness concerning microalgae, and sensory characteristics to assess the level of agreement of the participants. A 05-point hedonic scale was used (1—totally disagree to 5—totally agree). Section (3) presented questions concerning the composition, segments, and application and consumption frequency of microalgae; (4) regarded consumers' perception of foods using microalgae and mode of consumption (intention to purchase food products using microalgae).

In the last section (4), consumers were asked to read a short paragraph about microalgae, addressing its definition, production, environmental impact, and nutritional value. They were then asked again to express their intention to consume microalgae as food, to purchase products formulated with microalgae if they found them in the supermarket, and what extra price they would be willing to pay for a microalgae product.

2.3 Data analysis

A verification question was applied to confirm that participants answered all questions in the online questionnaire. Statistical differences in the frequency of mention in the correlation step of the responses between participants were assessed using simple correspondence analysis (CA) ($p < 0.05$). STATISTICA software version 13.0 (StatSoft Inc., Tulsa, USA) was used for this purpose. The chi-square test per cell was also employed to identify the variation of the overall chi-square test (Symoneaux et al., 2012).

3 RESULTS AND DISCUSSION

3.1 Participant profile

A total of 1,499 Brazilian participants completed the study questionnaire. Most participants identified themselves as female (68%), with a predominance of participants aged between 30 and 39 years (31%) and residents of the southern region of Brazil (53%) (Table 1).

The most significant number of participants from the South region can be explained by greater access to contacts in this region, considering that the research originates from a university in Southern Brazil. Other work on consumer knowledge and attitudes toward microalgae conducted in Switzerland (56%), Spain (61%), and Poland (76%) also showed higher participation of women (Franco Lucas et al., 2023; Lafarga et al., 2021; Rzymiski & Jaśkiewicz, 2017). Weinrich and Elshiewy (2023) propose that women are more interested in food issues, thus reflecting the higher number of responses by this gender.

The greater participation of individuals with a high level of education (36% complete higher education) is justified because the dissemination was carried out mainly in educational institutions. In addition, most of the research participants have full-time jobs and average household income above five minimum wages. The results indicated that the research reached many professors/employees of the research institutions that received the disclosure. Lafarga et al. (2021) and Rzymiski and Jaśkiewicz (2017) found that 69 and 33% of the women participating in their studies had completed higher education, respectively.

Table 1. Socio-demographic and diet profiles of the online survey participants.

Participants profile	Regions of Brazil											
	Total (n = 1.499)		North (n = 63)		Northeast (n = 315)		Central-Western (n = 66)		South (n = 786)		Southeast (n = 269)	
Age group	n	%	n	%	n	%	n	%	n	%	n	%
18–29	467	31	19	30	96	30	21	32	218	28	113	42
30–39	472	31	15	24	126	41	27	41	232	29	72	27
40–49	294	20	13	21	52	17	9	14	165	21	55	20
50–59	176	12	13	21	30	9	6	9	111	14	16	6
> 59 years old	90	6	3	4	11	3	3	4	60	8	13	5
Gender	n	%	n	%	n	%	n	%	n	%	n	%
Female	1.024	68	37	59	226	72	42	64	524	67	194	72
Male	467	31	26	41	89	28	24	36	252	32	74	28
Prefer not to say	8	1	0	0	0	0	0	0	10	1	1	0
Education	n	%	n	%	n	%	n	%	n	%	n	%
Primary school	8	1	0	0	3	1	0	0	5	1	0	0
High school	63	4	2	3	12	2	6	9	25	3	18	7
Graduate studies	537	36	15	23	125	41	19	29	264	33	116	43
Master's degree	266	17	16	26	65	21	11	17	133	17	41	15
Doctorate	625	42	30	48	110	35	30	45	359	46	94	35
Household income	n	%	n	%	n	%	n	%	n	%	n	%
< 01 minimum wage ^a	190	13	8	13	39	12	8	12	84	11	50	19
01–02 minimum wage ^a	341	23	19	30	101	32	16	24	156	20	54	20
03–04 minimum wage ^a	231	15	9	14	50	16	12	18	117	15	42	16
> 05 minimum wage ^a	624	41	24	38	107	34	25	38	366	47	99	36
Prefer not to say	113	8	3	5	18	6	5	8	63	7	24	9
Diet profile	n	%	n	%	n	%	n	%	n	%	n	%
Conventional diet	1.394	93	60	4	303	20	64	4	723	48	244	16
Vegan	19	1	0	0	5	0	1	0	8	1	5	0
Vegetarian	80	5	2	0	7	0	1	0	52	3	18	1
Prefer not to say	6	0	1	0	0	0	0	0	3	0	2	0

n: number of answers. Commercial dollar conversion: US\$ 5.27 (<https://www.bcb.gov.br>). Accessed on February 22nd, 2023); ^aBrazil's national minimum wage in 2022 was US\$ 230.28 (R\$ 1,212.00).

The results concerning diet profile demonstrate that most participants (93%) have a conventional diet, and 1 and 5% mentioned a vegan or vegetarian profile, respectively. Despite this, current studies evaluate the potential replacement of animal protein by proteins from other sources (Kaur et al., 2022). Weinrich and Elshiewy (2023) analyzed consumers' preferences in Germany, France, and the Netherlands on replacing meat with microalgae-based substitutes, observing that vegetarians/vegans represented 10% of consumers.

3.2 GENERAL KNOWLEDGE OF MICROALGAE

Most participants (70%) had prior knowledge of microalgae (Figure 1a) but ultimately agreed (72%) on the lack of information about them (Figure 1b). Al-Thawadi (2018) found that while about 90% of participants in the Kingdom of Bahrain knew the meaning of “algae,” 55% stated that they had not heard of seaweed as an alternative food. A similar result was obtained by Franco Lucas et al. (2023), who reported that around 50% of participants did not know *Spirulina*, demonstrating the need to offer more information to consumers concerning these microalgae.

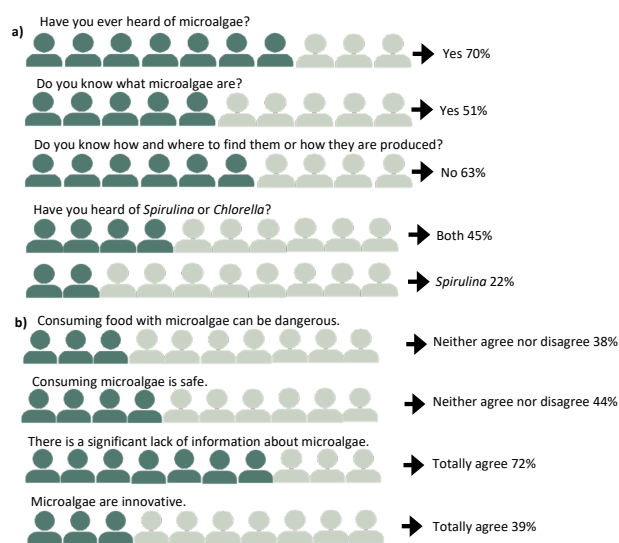


Figure 1. (a) General knowledge of participants concerning microalgae; (b) Levels of agreement on consumption and information on microalgae.

A similar result was obtained in the present study; the answers showed that 55% of the participants did not know that *Spirulina* and *Chlorella* are microalgae, and 42% knew that *Spirulina* and *Chlorella* are microalgae (Figure 1b). A small percentage (3%) mentioned other types of microalgae, including *Dunaliella salina*, *Scenedesmus obliquus*, *Nannochloropsis gaditana*, *Chaetoceros tretracelmus*, *Acutodesmus obliquus*, *Tetraselmis*, *Rhodomonas*, *Pavlova*, *Haematococcus pluvialis*, *Phaeodactylum tricornutum*, *Arthrospira stizenbergeri*, *Schizochytrium* sp., and *Haematococcus pluvialis*. These findings highlight that terms like “microalgae,” “*Spirulina*,” and “*Chlorella*” are familiar to 42% of Brazilians.

However, 67% of participants indicated they needed to know the nutritional benefits of consuming microalgae for human health. This lack of knowledge was most prevalent among participants aged 18–29 (23%). Studies with similar approaches reported that higher education levels and age influence positive responses regarding knowledge about microalgae (Al-Thawadi, 2018; Franco Lucas et al., 2023; Lafarga et al., 2021).

A high percentage of participants did not have an opinion about the safety of microalgae, and only 39% considered microalgae as innovative (Figure 1b). The lack of safety information can hinder boosting the conscious consumption of microalgae and added products (Ahmad & Ashraf, 2023).

Research related to microalgae has grown in recent years, as they are an innovative raw material and promote sustainable production (Ahmad & Ashraf, 2023; Attar et al., 2022; Franco Lucas & Brunner, 2024; Weinriche & Elshiewy, 2023). Figure 2 shows the participants’ level of agreement concerning the statements about microalgae. It was possible to notice an association between the gender of the participants and the statements presented. Female participants (38%) strongly agreed that microalgae are sustainable ($p < 0.05$) (Figure 2). The acceptance and development of products are heavily influenced

by sensory characteristics (Maehle & Skjeret, 2022). Female participants remained neutral (neither agree/disagree) (62 and 46%, respectively) regarding taste and aroma characteristics. However, they liked the green color of microalgae (40%). However, consumers often find the color changes that occur when incorporating microalgae into foods to be undesirable. To circumvent this problem, low inclusion rates, using other ingredients, and developing new products allow consumers to accept new products (Nunes et al., 2023).

For statements related to health (nutritious, rich in proteins, and a good supplement for vegetarians or vegans), the responses remained neutral (neither agree/nor disagree) for participants of both genders. This reinforces the need for greater dissemination of the health benefits of microalgae. Franco Lucas et al. (2023) observed that arguments related to health and sustainability had a more significant influence on *Spirulina* consumption.

3.3 Composition, segments, application, and consumption of microalgae

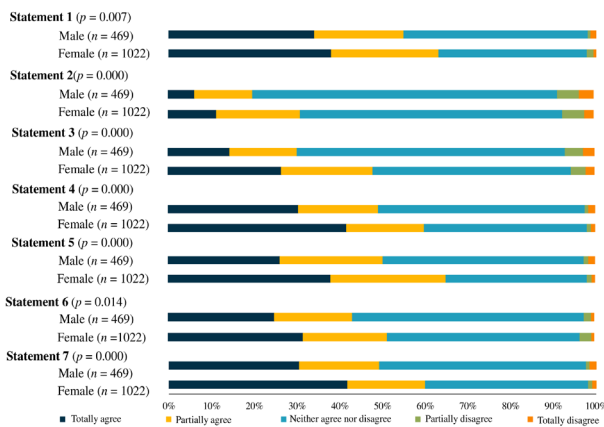
Brazilian consumers mentioned that the main compounds present in microalgae were antioxidants (20%), proteins (19%), vitamins (17%), pigments (17%), minerals (15%), and lipids (7%) (Figure 3a).

Microalgae can serve as alternatives or supplements to dietary intake of food products due to their rich content of lipids, vitamins, and antioxidants (Tan et al., 2023).

Figure 3b shows the main segments participants said they believe use microalgae biomass; most indicated nutritional supplements (19%), followed by food (18%). Although food is among the mentioned segments, the market presents few products added with microalgae biomass. Other segments, such as pharmaceuticals, biofertilizers, and aquaculture products, often stand out (Cao et al., 2023; Qian et al., 2022; Wei et al., 2023).

Lafarga et al. (2021) report how microalgae are gaining increasing importance in the European economy. Microalgae biomass is mainly marketed by Asian countries (Subramanian & Sayre, 2022). This study showed that most participants (73%) had never consumed microalgae biomass (capsule, tablet, and powder), regardless of the income range.

The relationship between income and the form of microalgae biomass consumption (Figure 4) revealed that participants with income greater than five minimum wages primarily consumed microalgae biomass in capsules (52%) and tablets (10%).



Statement 1: Microalgae are sustainable; Statement 2: Its taste/aroma is very intense; Statement 3: Its color is very intense; Statement 4: I like the green color of microalgae; Statement 5: Microalgae are nutritious and healthy; Statement 6: Microalgae are rich in proteins; Statement 7: Microalgae are a good supplement for vegetarian or vegan consumers.

Figure 2. Levels of agreement regarding characteristics and healthiness of microalgae according to the gender of Brazilian participants (n = 1,491).

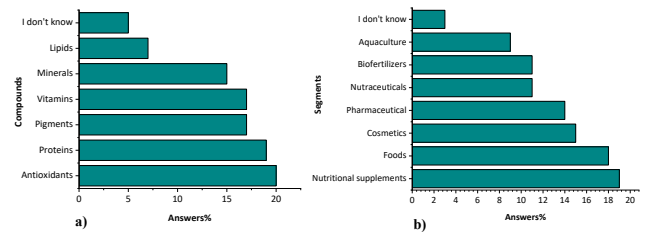


Figure 3. (a) Main compounds present in microalgae, according to participants. (b) Segments that participants believe microalgae can be applied.

On the contrary, participants with an income of less than one minimum wage showed a preference for powdered consumption (9%). The higher income provides greater access to different options for consuming microalgae biomass.

Most *Spirulina* biomass produced is consumed as a nutritional supplement promoted as a “superfood” and sold as a dry powder, flakes, or capsules (Lafarga et al., 2019). The use of microalgae in the food industry faces some challenges, including intense color and flavor, and strategies such as encapsulation have been studied to overcome these problems (Lafarga et al., 2019; Lafarga et al., 2020).

Several sociodemographic factors, including income, price, and the year's season, can generally influence the frequency of food consumption (Cameron et al., 2022). Participants who said they consumed microalgae biomass (28%) were asked about the frequency of consumption (Figure 4).

The CA ($p < 0.05$) revealed correspondence in the age groups between 18 and 29 years and 40 and 49 years in consuming microalgae biomass two to three times a week, and participants between 30 and 39 years and 50 and 59 years reported consuming microalgae biomass daily or rarely. Dimensions 1 and 2 of the CA revealed 87% variability in the data; that is, the age of the participants influenced the frequency of consumption of microalgae biomass.

3.4 Potential for product development with microalgae

A total of 91% of the individuals answered that they would be willing to consume foods with microalgae. Regarding pricing, 40% were willing to pay 5–10% extra for microalgae products. This result shows that Brazilian participants are interested in microalgae products. Similarly, Lafarga et al. (2021) found that Spanish consumers would be willing to pay 6–10% more for microalgae products. In addition, they said that knowing the health benefits of a specific product can influence purchase and consumption intention and the amount of extra money consumers would be willing to pay.

Participants preferred microalgae as an ingredient in nutritional supplements (26%), seasonings (20%), bakery products (17%), sauces and mayonnaise (16%), beverages (12%), and dairy products (9%). The studies include adding microalgae biomass to functional soy yogurt (Sengupta et al., 2018), soy

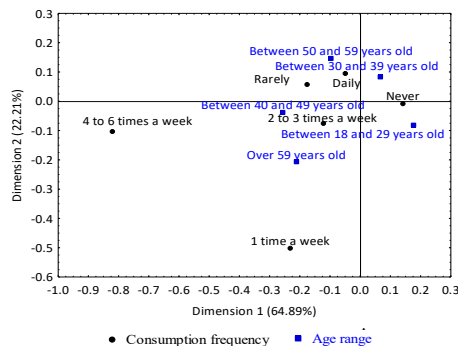


Figure 4. Correspondence analysis between the age group of the participants and the frequency of consumption of microalgae biomass.

beverages (Niccolai et al., 2020), and vegan biscuits (Silva et al., 2021). Participants reported that they mainly evaluated health benefits (16%), sensory characteristics (15%), price (13%), product quality certification and nutritional information (11% each), ingredient list, appearance, and minimal chemical additives (9% each), recommendations from friends (4%), and brand (3%) when choosing foods with microalgae.

Dimensions 1 and 2 of the CA revealed 100% variability in the data; that is, the gender of the participants directly influenced the food groups they would like to have microalgae as ingredients (Figure 5a). Gender significantly influenced preferred food groups ($p < 0.05$). Females favored nutritional supplements, bakery products, and beverages, whereas males preferred spices and dairy products. Nutritional supplements containing microalgae are widely available on the market, while dairy products, bakery items, beverages, sauces, mayonnaise, and seasonings with microalgae are less developed industrially. Dimensions 1 and 2 showed 95% variability in the data, that is, the income of the participants directly influenced the choice of the main aspects evaluated as a priority when choosing food with microalgae (Figure 5b).

Those who received less than one minimum wage and between one and two minimum wages evaluated primarily the product's price. On the contrary, participants who received between three and four minimum wages mainly evaluated the health benefits and the list of ingredients, and those who received more than five minimum wages evaluated the sensory characteristics, certification, and product brand. The results show that the participants' purchasing power influences food product choices, considering all the characteristics that make up the desirable quality aspects of a product. The Brazilian participants (48%) said they would “probably buy” a product formulated with microalgae. This result can serve as an incentive for elaborating products with microalgae biomass since consumers become more familiar with these products with various options, which can increase the percentage of purchases. A similar result was found by Al-Thawadi (2018), where about 47% of UK consumers demonstrated a willingness to consume products containing microalgae. The information presented in this study reveals that there are consumer expectations regarding products made with microalgae if they offer the desired aspects and are of high quality. The results are extremely important for food producers and traders who wish to expand their participation in the microalgae-based food market.

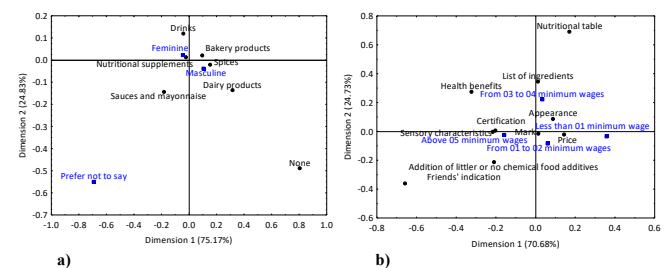


Figure 5. (a) Correspondence analysis between the participants' gender and the food groups they mentioned. (b) Correspondence analysis between the income of the participants and the aspects evaluated as a priority when choosing a food that had microalgae added.

4 CONCLUSIONS

This investigation showed that most participants had some prior knowledge about microalgae. However, it highlighted the scarcity of information about its use in food and its health benefits. Additionally, most participants were willing to consume foods with added microalgae and even pay more for the products. Participants primarily expected microalgae-based products to offer health benefits and sustainability, specifically looking for antioxidants and proteins in these products. This study shows results that can help the food industry to innovate and diversify market options, especially for vegans and vegetarians looking for new foods. The potential for using microalgae as a raw material can drive the advancement of further research and the development of a promising market niche, as seen in other countries.

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