



Green color drives rejection of crackers added with algae in children but not in adults

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ABSTRACT

Recently, algae are receiving increasing attention as a nutritious and sustainable food source. Despite this, consumer acceptance of algae or food products added with algae remain an understudied topic, especially considering children. This study aims to assess the drivers of (dis)liking of crackers added with 5 % of different micro and macroalgae along with a control cracker without any addition, in a group of children ($n = 114$, 8–11 years, 47.4 % girls) and adults ($n = 108$, 18–67 years, 61.1 % females). Participants evaluated crackers' liking and perceived sensory attributes using the check-all-that-apply method. Children and adults showed similar crackers perception and liking. Crackers added with *Lithothamnium calcareum* and the fractionated Spirulina blue protein were comparable to the control sample and were preferred over the crackers added with green Spirulina (entire bacterium), *Palmaria palmata* and *Saccharina latissima*. Children differed from adults only for the lower acceptance provided to the sample added with green Spirulina. Correspondence Analysis and Principal Coordinate Analysis revealed that, for this sample, green color was the main driver of rejection for children, while it was a driver of liking for the adults. The present study suggests that algae are a promising ingredient for the development of healthy and sustainable products targeted to children, although color might be a consumption barrier among the pediatric population. Personalized strategies aimed at children must be implemented such the use of algae (*Lithothamnium calcareum*) or ingredients from algae (Spirulina blue protein) with familiar or engaging colors.

1. Introduction

The increasing world population is currently threatening food security, intensifying pressures on the finite planetary resources. One way to tackle this challenge is to seek for new and healthy food sources as one solution to overcome the ensuing food shortages taking in consideration consumer's needs and expectations (Hosseinkhani et al., 2022).

Recently, algae are receiving increasing attention as a nutritious and sustainable food source. Algae are aquatic, oxygen-evolving photosynthetic autotrophs that can be unicellular, colonial or composed of filaments or simple tissues. They encompass both microalgae and macroalgae, which are commonly known as seaweed (Guiry, 2012). Microalgae are microscopic prokaryotic or eukaryotic photosynthetic microorganisms, they are typically unicellular or simple multicellular

organisms, only visible with magnification, which grow and live in suspension in water. The only microalgae species approved by the European Food and Safety Authority for human consumption (Espinosa-Ramírez et al., 2023) and compliant with Novel Food Regulation EU (2015/2283) belong to the *Arthrospira*, *Chlorella*, *Dunaliella*, and *Haematococcus* genera.

Macroalgae are photosynthetic, complex, multicellular organisms visible to the naked eye. They can be broadly classified into three groups depending on their pigments, namely green (*Chlorophyta*), brown (*Phaeophyta*), and red (*Rhodophyta*) algae. Examples of edible macroalgae compliant with Novel Food Regulation EU (2015/2283) are *Ulva lactuca* (i.e. Sea lettuce, green alga), *Saccharina latissima* (i.e. kelp, brown alga), *Palmaria Palmata* (i.e. Dulce, red alga), and *Lithothamnium Calcareum* (i.e. Mäerl, red alga) (Wu et al., 2023).

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Algae are reported to be a more sustainable protein source compared to other terrestrial plants since they have a higher growth rate, productivity, and protein yield (Wu et al., 2023). Moreover, their cultivation has a low environmental footprint since it does not compete with traditional food sources for potable water and arable land (Caporgno & Mathys, 2018; Trentacoste et al., 2015; Wu et al., 2023). Algae also contain macronutrients, including carbohydrates (dietary fiber), proteins (essential aminoacids), and lipids (essential fatty acids, n-3 and n-6), as well as micronutrients, such as minerals and essential vitamins (Gullón et al., 2020). These components have anti-inflammatory, anti-obesity, anticancer, antioxidant, and antibacterial benefits (Hosseinkhani et al., 2022; Rogel-Castillo et al., 2023; Vaughan et al., 2022).

Despite the numerous benefits associated with algae consumption, several obstacles hinder their exploitation into food, especially in Western countries. First, unlike Asian populations, algae are not part of Western cuisine (van den Burg et al., 2021) and for this reason there may be resistance to their acceptance. Furthermore, algae are characterized by sensory attributes such as green/blue color and fishy flavor, which could affect consumer acceptance (Hosseinkhani et al., 2022), especially among children. Indeed, childhood is a very critical phase for the acceptance of new food since food neophobia (literally, the fear of new food) peaks in the age range 1–6 years (Hazley et al., 2022), and several studies have shown that higher levels of food neophobia are associated with aversion to fish and unexpected colors (Helland et al., 2017; Laureati et al., 2016; Rioux et al., 2016). Therefore, the use of algae as a food ingredient must include even more careful sensory optimization when considering children.

Recently, the use of algae or ingredients derived from algae to produce functional foods and beverages has grown exponentially. Their application extends to various foods and beverages, including meat analogs, pasta and noodles, bakery products (bread, cookies and snacks), milk and dairy products and beer (Wu et al., 2023). However, sensory properties and consumer acceptance are rarely explored (Koli et al., 2022; Laureati et al., 2024; Lucas et al., 2018; Özbal et al., 2022; Rabitti et al., 2024) and never involving specific target populations such as children.

To fill this important literature gap, the aim of the present study was to investigate the acceptance as well as factors affecting liking and rejection of crackers enriched with different micro- and macroalgae in Italian children aged 8–11 years. Since scientific evidence suggests the existence of differences between adults and children in taste (Liem et al., 2004; Liem & Mennella, 2003), texture perception (Chow et al., 2024; Laureati et al., 2020; Lukaszewicz & Mennella, 2012) and preference, as well as in incidental learning and memory of food stimuli (Laureati et al., 2008), the present study also intends to compare data collected with a population of adults to highlight possible age-related differences.

The results of this study may provide useful indications that can be exploited by the food industry to produce healthy and sustainable products targeting children. Considering the needs and expectations of vulnerable populations such as children is crucial as they are the consumers of the future. Moreover, since eating habits are shaped in childhood and often endure into adulthood, promoting the consumption of healthy and sustainable products among children could prove to be a strategic approach to foster the transition towards greener food systems.

2. Materials and methods

2.1. Participants

Two-hundred-twenty-two subjects (114 Italian children aged 8–11 years, mean age 9.4 ± 0.9 years, 47.4 % girls; 108 Italian adults aged 18–67 years, mean age 31.0 ± 13.1 years, 61.1 % women) participated in the study.

Children were recruited from a primary school in the metropolitan area of Milan (Italy). Parents were informed about the procedures of the

study and were asked to sign an informed consent when they agreed on their child's participation. The invited children were informed about the test and gave written consent. Adults were recruited among students and employees of the Faculty of Agriculture and Food Sciences of the University of Milan. Informed written consent was obtained from all adults on the test day. Only participants who did not suffer from food allergies, intolerances, taste and/or smell disorders, were not pregnant (adults), and liked crackers were involved in the study. Children without signed informed consent or declining participation were excluded from the study.

This study was approved by the Ethics Committee of the University of Milan (n. 94/22) and conducted in accordance with the Declaration of Helsinki.

2.2. Experimental samples

This study is part of a larger cross-national project aimed at exploring consumer perception and acceptance of food products added with algae.

Five cracker samples were prepared adding each of the following algae species, in powder form: *Arthrospira platensis* (green Spirulina), the isolated protein from *Arthrospira platensis*, which has a characteristic blue color (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. Therefore, we aimed to determine which species would be the most appropriate for use in foods targeted at a young consumer group compared to an adult consumer group.

The five crackers added with algae were compared with a control sample without algae addition. 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 (further detail about crackers production is available in Rabitti et al., 2024). 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 into food as seen in the literature (Lucas et al., 2019) and in the market, which was around 2 % w/w, for instance, in pasta and crackers sold in the Italian market. Furthermore, a pilot test involving 15 children and 6 adults 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 acceptability due to highly undesirable sensory characteristics.

All experimental cracker 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 Italy, batches of crackers were securely packaged in plastic boxes appropriate for the shipping. All in all, it took approximately between two and four weeks from production before respondents were able to taste and evaluate the products in Italy. As the products under study were crackers, they were not highly perishable and were stored in a dry place, away from light sources.

2.3. Experimental procedure

Sensory evaluations were carried out involving small groups of 6–8 children in a familiar and friendly setting (i.e. in a quiet room within their school) during a mid-morning or mid-afternoon break. Pairs of children were assigned to an experimenter (there were 3–4 female experimenters) who explained them the procedures and ensured a quiet atmosphere and high concentration during the evaluation preventing children from exchanging opinions on the test. All the experimenters visited the children a few days prior to the main experiment to provide

general information about the study and to get familiar to them. To avoid that children influenced each other, before starting each test and in the presence of the teacher, one experimenter explained to all the children that it was important to avoid discussing their opinions during the evaluation to prevent mutual influence. During the evaluation, the experimenters constantly monitored the children to ensure there were no instances of mutual influence. Pairs of children were seated in large tables allowing keeping a distance of approx 1 m from each other. In addition, the crackers were served in balanced order, thus children did not taste them in the same order.

For adults, sensory evaluation sessions were conducted in individual booths at the Laboratory of Sensory and Consumer Sciences at the University of Milan (Italy) approximately between 11 am and 1.30 pm. Both children and adults, received the six cracker samples using a balanced design to control for order and carryover effects (Lawless & Heymann, 2010). The crackers were evaluated under white light in plastic cups coded with a 3-digit number. The duration of each session was approximately 30 min for both adults and children. Children's data were collected using tablets running EyeQuestion software (version 5.9.4, Logic8 BV, The Netherlands), while adults' data were obtained through a computerized system using the Fizz software (version 2.31b, Biosystèmes, Couternon, France).

2.4. General questions on crackers and algae-based products consumption frequency

Adults answered questions on cracker consumption: "How often do you eat crackers?" by using a 7-point labelled frequency scale (1 = daily, 2 = a couple of times a week, 3 = weekly; 4 = a couple of times a month, 5 = monthly, 6 = less than once a month, 7 = never). Parents provided information about their children's cracker consumption. Both adults and children also answered the question: "Have you ever consumed algae or products made with algae in the past?" (choice among the options: in sushi, as snack, I have never consumed algae or products made with algae in the past).

2.5. Overall liking and check-all-that-apply (CATA) task

For each sample, children were asked to taste and express their overall liking using a 7-point facial scale (1 = Super bad, 2 = Really bad, 3 = Bad, 4 = Neither good nor bad, 5 = Good, 6 = Really good, 7 = Super good) (Laureati et al., 2015). Adults expressed their overall liking using a 7-point scale (1 = extremely disliked, 2 = very disliked, 3 = disliked, 4 = neither liked nor disliked, 5 = liked, 6 = very disliked, 7 = extremely liked). Participants were asked to rinse their mouth 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.

Concerning the generation of descriptive terms for the CATA task, 6 trained adults were involved in a pilot tasting session, wherein they used a free listing method through a word elicitation task like the approach used by Ares et al. (2010) to identify appropriate sensory attributes which can be used to describe the cracker samples. 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-savory, bland, spicy), and four for texture (dry, crunchy, brittle, hard).

Since the generation of CATA terms occurred involving only adults, for some terms a brief explanation was provided to children to facilitate their understanding (i.e. Thick = contrary of thin, e.g. thin like a paper sheet, Unnatural color = Strange color for a food, Umami = Savory, Brittle = that forms crumbles).

2.6. Food neophobia scale

Children completed a validated, child-friendly version of the Food Neophobia Scale (FNS) (Laureati, Bergamaschi et al., 2015). This questionnaire consists of eight items, 4 related to neophilic and 4 related to neophobic attitudes. Children scored them using a 5-point scale with facial expressions representing different degrees of agreement ("Very false for me" = a frown face with both thumbs down, "False for me" = a frown face with one thumb down, "So-so" = a neutral face with no thumbs shown, "True for me" = a smiley face with one thumb up and "Very true for me" = a smiley face with both thumbs up). The answers to the items of the FNS were summed up (after reversing the scores of the neophilic items) to have a food neophobia score ranging from 8 to 40. A higher score indicates a higher level of food neophobia.

Adults completed the validated Italian version (Laureati et al., 2018) of the Food Neophobia Scale (FNS) (Pliner & Hobden, 1992) which consists of ten statements, of which five are positively, and the other five negatively worded, each measured on a 7-point agreement scale ranging from 1 = "Strongly disagree" to 7 = "Strongly agree". As for the children, the answers to the items of the FNS were summed up (after reversing the scores of the neophilic items) to have a food neophobia score ranging from 10 to 70. Interpolation was performed to compare scores with those of the children (i.e., scores are expressed in the range 8–40 for both children and adults).

2.7. Data analysis

The frequency distribution of continuous variables (i.e., liking and food neophobia) was first checked for normality. According to Shapiro-Wilks test, the respondents' liking scores and food neophobia indices deviated from the normal distribution (liking, $p < 0.0001$; food neophobia, $p < 0.0001$). However, investigation of the Q-Q plots showed a normal pattern and thereby the data were handled as normally distributed (Naes et al., 2011).

The reliability of the FNS was investigated by calculating internal consistency (Cronbach's α and item-item correlation). Adults and children were categorized into three FN groups (low, medium and high FNS) according to FNS quartiles (low FNS $\leq$ Q1: Q1 adults = 9, Q1 children = 14; high FNS $\geq$ Q4: Q4 adults = 15, Q4 children = 22).

Data about algae-based products consumption were compared across age groups using Chi-square test. Liking was analyzed by means of the Generalized Linear Model (GLM) procedure considering the six cracker samples, age category (adults and children), gender (women/girls and men/boys), food neophobia level (low, medium, high) and their third-order interactions as factors. Food neophobia data were also analyzed by means of the Generalized Linear Model (GLM) procedure considering age category (adults and children), gender (women/girls and men/boys), and their interaction as factors. Least-squares means (LS-means), and relevant standard errors of the mean (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.

The CATA data were subjected to Cochran's Q test followed by Sheskin's multiple pairwise comparison tests to assess significant differences among the samples for each sensory attribute (Meyners & Castura, 2016). Correspondence Analysis (CA) and Principal Coordinate Analysis (PCoA) were run separately by age group and used to respectively examine the relationship between the cracker samples and sensory attributes and to study the association between crackers liking scores and their CATA descriptions.

The SAS/STAT statistical software package version 9.4 (SAS Institute Inc., Cary, NC, USA) and XLSTAT (version 2021.2.1, Addinsoft, Boston, MA, USA) were used for the data analysis.

3. Results

3.1. Algae consumption frequency: Comparison between children and adults

As expected, children had a significantly lower algae consumption frequency than adults (both as sushi $p < 0.001$ and snacks $p < 0.01$). Furthermore, 34.2 % of children reported having never consumed products containing algae in the past, compared to only 6.5 % of adults who had never tried these products ($p < 0.001$) (Table 1).

3.2. Participants' food neophobia

Total internal consistency calculated by age group was 0.89 for the adults ($n = 108$) and 0.76 for children ($n = 114$), higher than the suggested value of 0.70 given by Nunnally and Bernstein (1994). To verify the stability of the internal consistency of the scale, the Cronbach's alpha values were recalculated (for both adults and children) 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 age groups, suggesting that no improvement to the scale reliability was achievable 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.

GLM results showed a significant age effect ($F_{(1,218)} = 44.43$, $p < 0.0001$) on FN scores. As expected, children ($M = 18.3$, $SEM = 0.50$; range: 8–40) were significantly more neophobic than adults ($M = 13.4$, $SEM = 0.53$; range: 8–39). The main factor Gender and the interaction Gender*Age were not significant.

3.3. Crackers' overall liking

GLM results showed a significant effect of the main factors Crackers ($F_{5,1331} = 25.51$; $p < 0.0001$), Food neophobia ($F_{2,1331} = 15.68$; $p < 0.0001$) and Gender ($F_{1,1331} = 38.40$; $p < 0.0001$) on liking. Overall, crackers made with blue Spirulina ($M = 5.65$, $SEM = 0.12$) and *Lithothamnium calcareum* ($M = 5.61$, $SEM = 0.12$) were the most liked and comparable with the control sample ($M = 5.56$, $SEM = 0.12$). Crackers with green Spirulina ($M = 5.24$, $SEM = 0.12$) were significantly less liked than those with blue Spirulina and *Lithothamnium calcareum* but still comparable with the control sample. Crackers with *Saccharina latissima* ($M = 4.88$, $SEM = 0.12$) and *Palmaria palmata* ($M = 4.59$, $SEM = 0.12$) were liked significantly less than the other samples (including the control sample) although the average score was still higher than mean point of the scale. Concerning gender-related differences, men/boys ($M = 5.47$, $SEM = 0.1$) liked the crackers significantly more than women/girls ($M = 5.04$, $SEM = 0.01$). Subjects with a lower FNS score provided significantly higher liking ratings ($M = 5.59$, $SEM = 0.1$) than those with medium and high scores (FN_{medium} : $M = 5.23$, $SEM = 0.1$; FN_{high} : $M = 5.03$, $SEM = 0.1$) who were comparable. The interaction Age

group*Gender, which was also significant ($F_{1,1331} = 6.57$; $p < 0.05$), indicated that the main effect of gender was due to the girls who provided significantly lower ratings than boys while within the adults age group no significant differences were found (Fig. 1). Interestingly, boys scored significantly higher than women.

The interaction Crackers*Age group was also significant ($F_{5,1331} = 5.80$; $p < 0.0001$) and depended by the lower liking rating provided by children ($M = 4.84$, $SEM = 0.12$) compared to adults ($M = 5.65$, $SEM = 0.12$) to the crackers added with green Spirulina (Fig. 2). All other interactions were not significant.

3.4. Crackers description and drivers of liking and rejection: Comparison between children and adults

3.4.1. CATA description

Results from the Cochran's Q-test showed differences between children and adults in the ability to discriminate samples (Table 2). For children and adults, 13 out of 23 attributes and 21 out of 23 attributes discriminated the samples, respectively. Children had more difficulties with texture attributes since none of these descriptors discriminated the samples as well as with some taste/flavor descriptors (e.g. salty, bland, spicy and mushroom flavors). However, the frequency mention of terms was similar across age groups (Table 3).

3.4.2. Drivers of liking and rejection

The first and the second dimensions of the symmetric plot obtained from CA accounted for 85.83 % (children) and 76.79 % (adults) of the total variance of data (Fig. 3 a-b), indicating a good agreement in sample descriptions across subjects.

The description of cracker samples from children and adults was surprisingly similar. For both age groups, Factor 1 (children = 53.81 %, adults = 42.42 %) clearly separated the two cracker samples added with Spirulina (blue and green) from the rest of the samples, while Factor 2 (children = 32.02 %, adults = 34.38 %) distinguished Blue Spirulina from Green Spirulina added samples. On the right of Factor 1, both age groups described blue Spirulina as having a 'blue color' which was perceived as 'unnatural', while green Spirulina was associated with terms such as 'green color' as well as 'fishy', 'mushroom', 'spinach/grassy', 'umami', and 'bitter', which were considered as 'off-flavors'. On the other hand, positioned on the left side of Factor 1, the control cracker was evaluated as very similar to the one added with *Lithothamnium calcareum*. These samples were associated with the terms 'Golden/Yellowish color', 'Sweet', 'Oily flavor' and 'Toasted bread flavor', while crackers added with *Palmaria palmata* and *Saccharina latissima* were considered by the adults as being 'Speckled' and 'Hard', as having a 'Brownish color' and, partly, a 'fish flavor' and 'off-flavor'. Children associated *Palmaria palmata* and *Saccharina latissima* with almost no descriptors. In general, the most pronounced difference between children and adults was that for children most of the CATA terms had a lower loading than for adults and were positioned near to the origin of the axes (e.g., 'Brittle', 'Crunchy', 'Dry', 'Hard', 'Salty', 'Bland').

Principal Coordinate Analysis, linking liking to CATA descriptions by children and adults, displays the sensory descriptors that drive samples overall (dis)liking (Fig. 4 a-b).

The relatively low proportion of variance explained by the first two dimensions (children = 19.8 %, adults = 19.6 %) indicates large individual variations in crackers liking across both children and adults, which is common in consumer test studies (Sandvik et al., 2020). Again, children and adults showed a very similar pattern with liking positively associated with the CATA terms 'sweet' and 'salty' (taste), 'crunchy' and 'brittle' (texture) and 'toasted bread' and 'oily' (flavors). According to Fig. 3 a-b, most of these descriptors were related to the control sample and the samples added with *Lithothamnium calcareum*. On the other hand, liking was negatively associated with 'bitter' (taste), 'fish' and 'off-flavor' (flavors) and 'hard' (texture) for both age groups, which described mainly crackers add with green Spirulina, *Palmaria palmata*

Table 1

Participants' consumption of algae products (answers to questions are reported as % of "Yes"); p -values according to Chi-square test.

Questions	Age group		
	Adults	Children	p-value
Have you ever consumed algae in the past? (% Yes)			
In sushi	80.6	54.4	$p < 0.001$
As snack (e.g. crackers, crisps)	16.7	7.0	$p < 0.01$
I've never consumed algae or products made with algae	6.5	34.2	$p < 0.001$

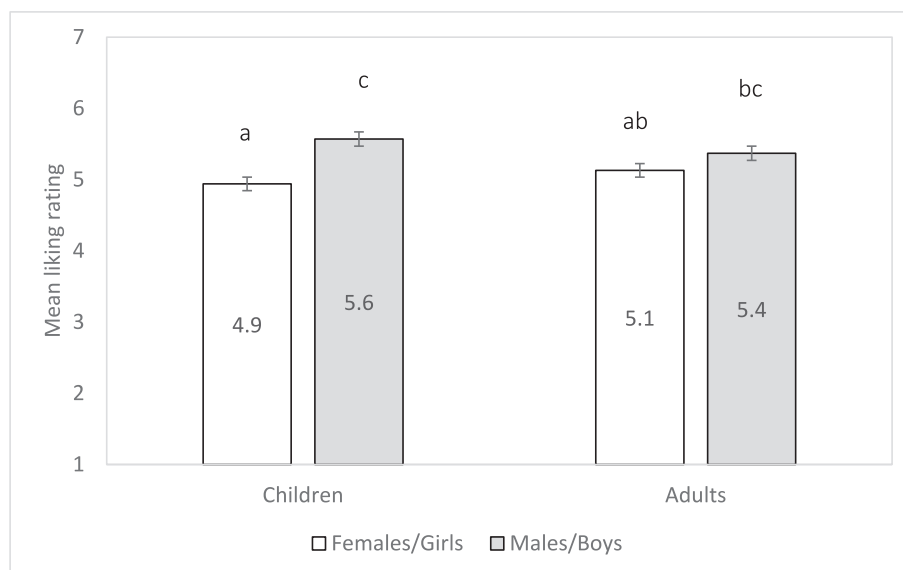


Fig. 1. Mean hedonic ratings ($\pm$ SEM) by age group and by sex. Different letters indicate significant differences according to Bonferroni post-hoc test.

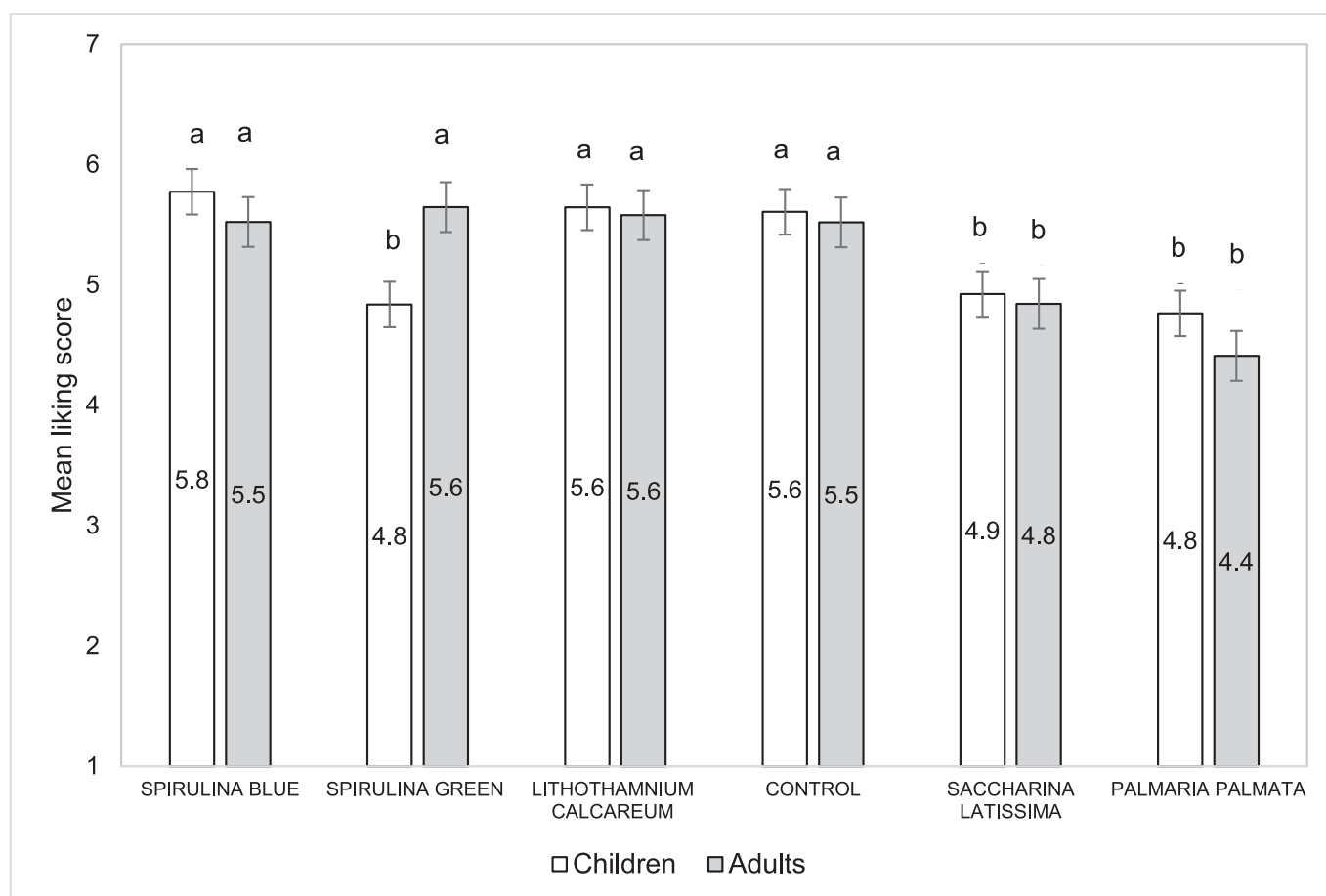


Fig. 2. Mean hedonic ratings ($\pm$ SEM) by age group for the six algae-added crackers. Different letters indicate significant differences according to Bonferroni post-hoc test ($p < 0.05$).

and *Saccharina latissima* (Fig. 3 a-b).

In order to have a clearer picture of the statistically significant drivers of liking and rejection by the two age groups, liking mean impact plots representing the influence of sensory descriptors from the CATA list on the overall liking of the six cracker samples for children and

adults are shown in Fig. 5 a-b. It is interesting to note that children and adults shared positive drivers of liking such as 'Crunchy', 'Salty' and 'Toasted bread flavor' as well as the driver of rejection 'Hard'. However, children considered 'green color' as a descriptor that contributed negatively to liking, while for adults this attribute contributed positively

Table 2
Cochran's Q test performed on each CATA attribute for children and adults. *P*-values in bold are significant (*p* < 0.05).

Sensory attributes	Children <i>p</i> -values	Adults <i>p</i> -values
Golden/yellowish color	<0,0001	<0,0001
Brownish color	<0,0001	<0,0001
Blue color	<0,0001	<0,0001
Green color	<0,0001	<0,0001
Thick (appearance)	0,093	0,025
Speckled	<0,0001	<0,0001
Unnatural color	<0,0001	<0,0001
Oily flavor	0,003	<0,0001
Off-flavor	<0,0001	<0,0001
Fish flavor	<0,0001	<0,0001
Spinach/grassy flavor	<0,0001	<0,0001
Mushroom flavor	0,113	0,000
Toasted bread flavor	<0,0001	<0,0001
Bitter	<0,0001	<0,0001
Sweet	0,001	0,036
Salty	0,402	0,032
Umami	<0,0001	<0,0001
Bland flavor	0,123	<0,0001
Spicy flavor	0,341	0,023
Dry	0,112	0,456
Crunchy	0,481	0,530
Brittle	0,519	0,002
Hard	0,066	<0,0001

to liking. This pattern is coherent with the significant lower liking attributed by children to the cracker added with green *Spirulina* compared to adults.

4. Discussion

The present study investigated the factors affecting overall acceptance of crackers with the addition of micro and macro-algae in a population of children aged between 8 and 11 years and compared them with a sample of adults to explore any cross-age difference.

One of the main findings of the present study is that children, in general, liked the crackers enriched with 5 % of various types of micro and macro-algae, as each sample received an overall liking score higher than middle point of the scale. This result suggests that it is possible to leverage algae as an innovative and sustainable food ingredient in the formulation of foods for children.

The comparison between children and adults in terms of liking revealed marginal age-related differences. Children were, in general, comparable to adults in terms of crackers overall acceptance, except for the sample added with green *Spirulina* (entire bacterium), which was liked significantly less by children. This difference may be attributed to several factors, such as different familiarity levels of algae-containing foods (e.g., sushi and snacks), which was significantly higher in adults than in children. This result is expected because children do not have yet a broad food repertoire, which could explain the higher degree of children food neophobia compared to adults found in the present study. However, despite age-related food neophobia differences are in line with previous research (Hazley et al., 2022), the differences in absolute terms were marginal.

Another factor that may have driven children's rejection of cracker added with green *Spirulina* could be the green color that characterized this sample. The presence of this attribute may have led children to think it might contain algae. However, one might expect that the blue color of the cracker added with the *Spirulina* blue protein could also have negatively influenced the children's liking, but this did not occur. Interestingly, the blue color was considered unnatural by children and adults but did not represent an obstacle to liking, while green color was a significant driver of rejection for children while for adults it represented a driver of liking. The green color associated with vegetables, which are notoriously disliked by children (Lynch et al., 2013), may have negatively influenced children's liking, while for adults the green color may

Table 3
Contingency table built from CATA data by children and adults.

Age group	Samples	Appearance				Taste/Flavor										Texture								
		Golden color	Brownish color	Blue color	Green color	Unnatural color	Thick	Speckled	Bitter	Sweet	Salty	Umami	Oily	Off-flavor	Fish	Spinach grassy	Mush room	Toasted bread	Bland	Spicy	Dry	Crunchy	Brittle	Hard
Children	Control	102	1	0	0	5	18	78	3	15	44	2	32	4	1	4	7	60	26	2	32	85	24	28
	<i>Lithothamnium</i>	96	6	0	0	6	25	75	4	23	44	1	48	4	2	5	1	64	20	3	40	86	24	22
	<i>C. palmaria</i>	63	21	0	20	15	13	97	12	7	48	13	26	16	28	27	10	35	28	2	43	78	18	37
	<i>palmaria</i>	62	20	0	18	23	22	96	18	9	50	10	33	16	10	24	5	38	20	7	48	76	18	32
Adults	<i>Saccharina l.</i>	6	6	71	29	46	16	50	4	16	47	6	33	6	6	22	5	40	15	5	37	83	25	22
	Blue <i>Spirulina</i>	1	8	4	106	26	15	21	18	13	38	7	29	13	15	47	7	26	27	5	45	84	19	28
	Green <i>Spirulina</i>	105	0	0	0	0	14	34	2	13	29	3	60	3	1	2	3	71	43	2	33	85	35	30
	Control	99	4	0	0	2	9	32	1	11	27	4	57	5	2	1	3	75	42	2	34	85	38	30
	<i>Lithothamnium</i>	59	23	0	13	3	5	77	7	5	35	27	15	29	73	35	9	20	10	1	30	89	31	33
	<i>C. palmaria</i>	60	13	1	24	5	10	59	13	4	39	22	28	21	31	35	17	38	25	3	28	79	24	45
	<i>Saccharina l.</i>	4	0	81	13	48	4	36	4	12	34	15	30	9	8	26	7	59	33	5	27	84	45	10
	Blue <i>Spirulina</i>	0	3	3	106	17	5	4	12	6	24	16	24	17	12	72	16	34	27	9	36	82	44	16
	Green <i>Spirulina</i>																							

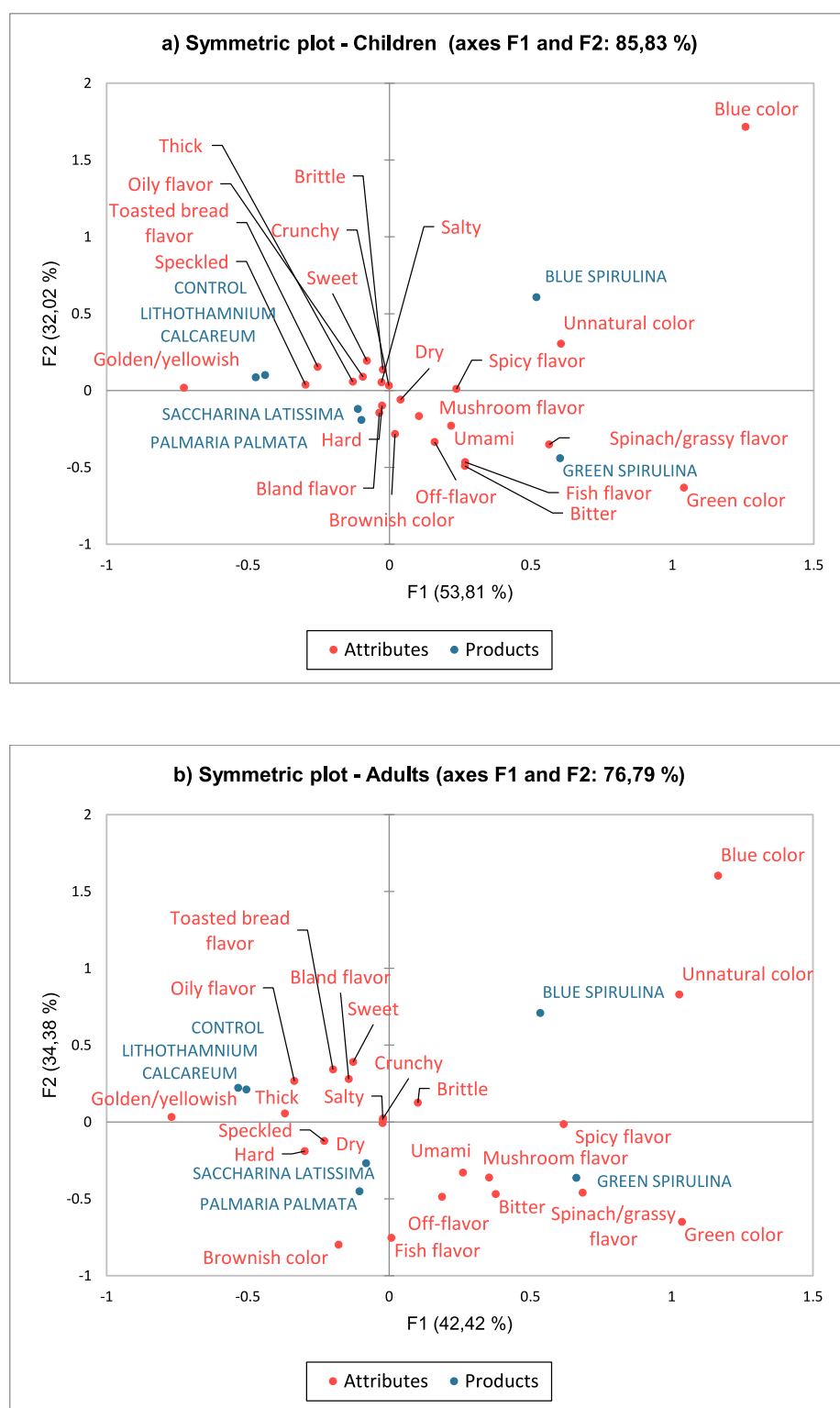


Fig. 3. a-b. Symmetric plot based on CATA descriptions of the six cracker samples by children ($n = 114$) and adults ($n = 108$).

have seemed odd for crackers but not in association with a product derived from algae.

Color is reported as one of the main barriers to the consumption of seaweeds and seaweed products (Hosseinkhani et al., 2022; Laureati et al., 2024). In this context, one of the objectives of the present study was to select a wide range of algae varying in terms of color as well as a series of other sensory properties such as taste and aroma. Previous research involving children has shown that appearance characteristics

(i.e., green color) are important for the appreciation of food products including vegetables (Raggio & Gambaro, 2018) but not for others. In this sense, the present study demonstrates that green color can be a concrete barrier to the consumption of bakery products enriched with algae in children and suggests as a possible mitigatory strategy the use of algae with more familiar colors (golden/yellow color) or Spirulina proteins whose color can increase curiosity in both children and adults.

Comparing the present results with previous studies is difficult

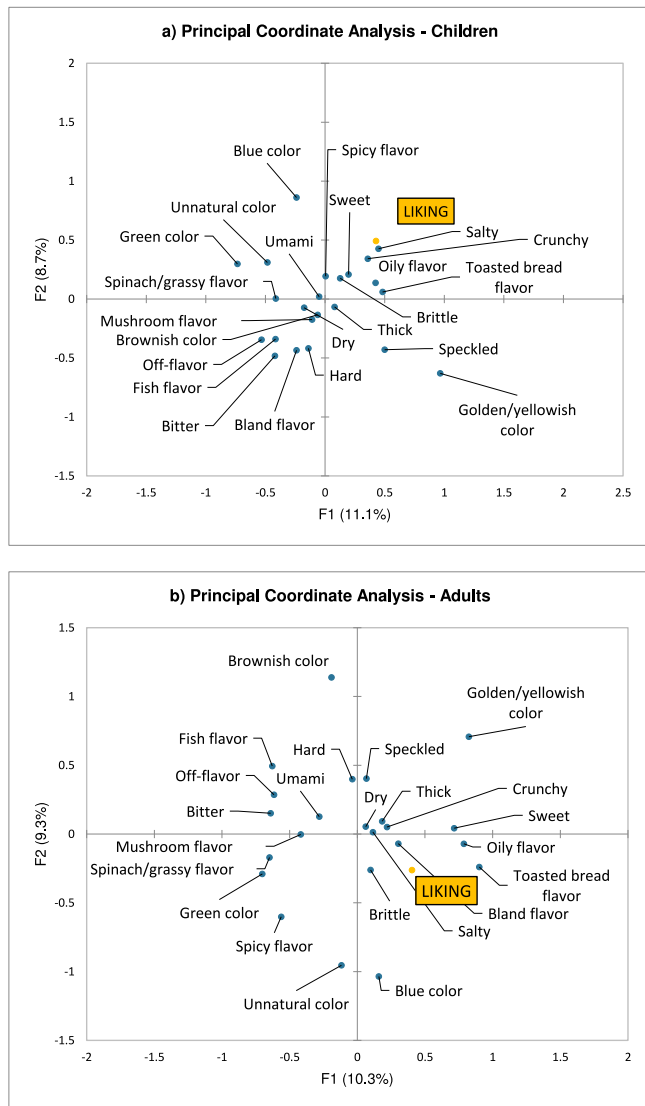


Fig. 4. a-b. Principal coordinate plot based on CATA descriptions and liking of six cracker samples evaluated by children ($n = 114$) and adults ($n = 108$) for the six samples.

because sensory and consumer research on seaweed products involving children is scanty. Lucas et al. (2019) did not find any difference in visual acceptance between snack bars enriched with 6 % Spirulina and a control sample among Brazilian children aged 8–13 years, despite the intense green color provided by the alga. The divergence between the present results and those by Lucas et al. (2019) may be due to the different products tested (crackers are a salty snack while snack bars are sweet), the nationality of the children (Italian vs Brazilian) and the fact that Lucas et al. (2019) involved a very small number of children ($n = 50$) who did not carry out a description of the sensory properties of the snack bars therefore it is difficult to make an analysis of the drivers of the rejection and liking of their products.

Unlike children, there are various studies that assess sensory acceptance of algae-enriched food in the adult population. For instance, Santos et al. (2016) developed a shake for the elderly incorporating Spirulina sp. LEB 18 and observed higher sensory acceptance scores compared to a commercial shake. Lucas et al. (2018) found that extruded snacks enriched with Spirulina sp. LEB 18 achieved a high acceptance rate, with average scores for flavor, texture, taste, and overall acceptance falling between “like moderately” and “like very much.” Batista et al. (2017) assessed the sensory characteristics of

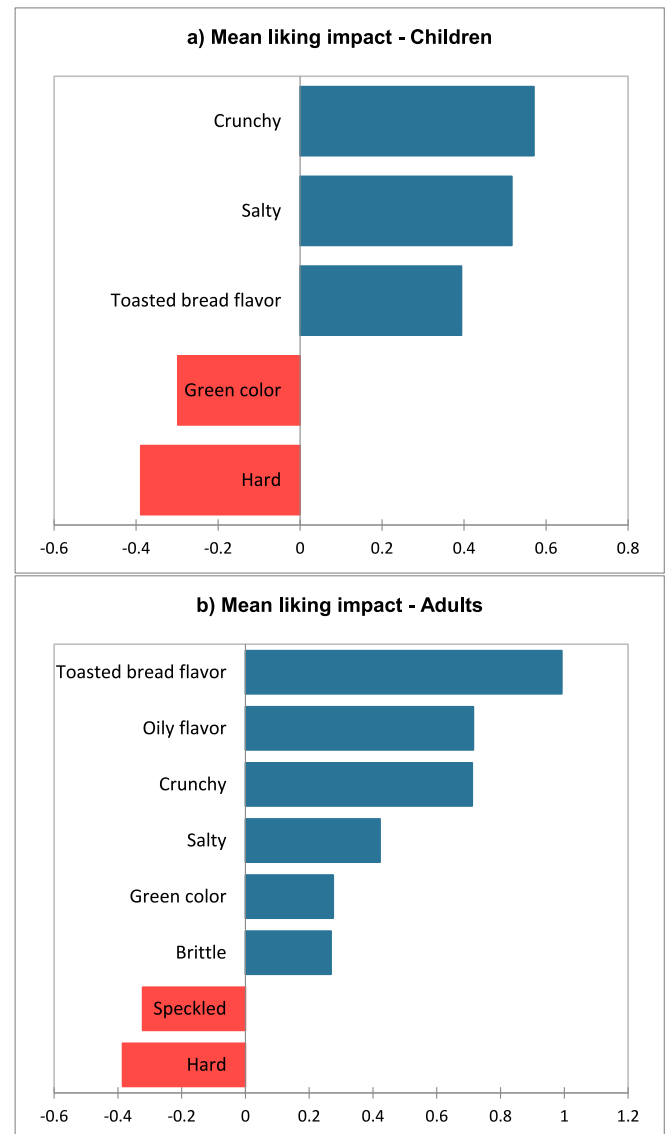


Fig. 5. a-b. Liking mean impact plot representing the impact of sensory descriptors from the CATA list on the overall liking of the six cracker samples for children ($n = 114$) and adults ($n = 108$) (b). The red bars to the left of 0 indicate that the attribute's presence was correlated to decreases in overall liking while the blue bars to the right of 0 indicate that the attribute's presence was correlated to increases in overall liking. Only attributes that resulted in significant increase or decrease in overall liking are present. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

cookies enriched with 2 % and 6 % of the microalgae Spirulina and Chlorella. The study revealed that cookies enriched with 2 % Spirulina were preferred by consumers in terms of sensory parameters such as taste and overall appreciation. The decrease in liking with an increase in Spirulina powder addition was also observed by Shahbazizadeh et al. (2015) for Iranian traditional cookies containing 8 % algae. The present study confirms the literature data related to the overall acceptability of spirulina-based products in adult consumers with addition up to 5 %. Furthermore, the added value of the present study is that of having extended the evaluation of acceptance to a series of other macroalgae for which in general little information exists, especially in children.

Concerning the characterization of the algae crackers, children were able to discriminate the product's properties based on almost all descriptors except for texture, confirming that CATA is a suitable task for

children to gain insights in children's sensory perceptions of foods (Laureati et al., 2017; Rocha et al., 2021; Sandvik et al., 2020). The reduced ability to discriminate products by children may be due to the fact that in this study, CATA attributes were elicited by a group of adults and children may have not fully understood some terms, especially those related to texture perception that might be trickier than other descriptors to be deciphered. To overcome this limit, terms with difficult meaning (i. e., thick, umami, unnatural) were provided with a definition to help children understanding, resulting in a comparable overall term elicitation across age (Table 3). However, it would be desirable for the attributes to be defined directly by children themselves in order to develop a lexicon that is appropriate for them (Laureati et al., 2017; Sandvik et al., 2020).

Interestingly, the less liked crackers were generally associated with sensory descriptors such as fishy, grassy and mushroom flavors, bitter taste, and hardness for both children and adults, confirming that off-flavors can be a sensory hurdle to the consumption of food enriched with algae (Hosseinkhani et al., 2022; Laureati et al., 2024). Specifically, crackers enriched with *Palmaria palmata*, and *Saccharina latissima*, were rated significantly lower compared to crackers enriched with *Lithothamnium calcareum*, blue Spirulina, and the control sample, indicating a nuanced variation in the potential incorporation of algae species in crackers.

The fact that the sample enriched with *Lithothamnium calcareum* was comparable to the control in terms of liking, even among children, is particularly promising because this alga is known for its substantial calcium content (32,000 mg/100 g). Guidelines indicate that children aged 7 to 10 years have a daily calcium requirement of 1000 mg per day, increasing to 1200 mg for the age group 11–17 years (LARN, 2014). The present results suggest that *Lithothamnium calcareum* might be a promising innovative ingredient to develop sustainable foods that are well accepted and may potentially ensure an adequate calcium intake among sensitive populations such as children and adolescents, although further studies are needed to verify the actual calcium content in the processed product and how much mineral is absorbed by the intestine.

Finally, gender-related differences in liking were highlighted, with girls providing the lowest ratings to algae-based products, while boys gave the highest scores comparable to men and even higher than women. The lower appreciation of girls compared to boys is difficult to explain. The most obvious explanation could lie in a higher neophobic attitude in girls, but the present results did not highlight gender-related differences in terms of food neophobia. Furthermore, the small number of children involved in the present study makes it difficult to formulate hypotheses and therefore further research is recommended to confirm and extend the present findings.

4.1. Strengths and limitations of the study

This is one of the first studies investigating the drivers of liking and rejection of algae-enriched products among children and adults. The present study contributes to the exploration of the perception and attitudes of the pediatric population towards seaweed-based products, which are reported as a promising ingredient for the development of environmentally sustainable products in Western countries. Another strength relies in the use of different species of algae varying in different sensory dimensions (i.e. appearance, odor and taste) to identify the best species to be exploited for future product development.

The limitations of the study concern the use of a convenience sample of the population which can reduce the generalization of findings and the use of only one concentration of algae in the same product. Future research should be addressed to deepen the understanding of the factors underpinning the perception and attitude of food product enriched with algae among sensitive populations such as children and adolescents by exploring the addition of different levels of algae to different food matrices other than crackers.

5. Conclusions

The present study demonstrated that children and adults have a similar perception and liking of crackers added with different micro and macroalgae at a concentration of 5 %, suggesting that algae can be an excellent ingredient to deliver beneficial nutrients to this sensitive population target.

Green color is one of the main barriers to children consumption of foods added with algae therefore the use of Spirulina (entire bacterium) is not recommended for the development of foods targeted at pediatric population, while the use of algae (*Lithothamnium calcareum*) or ingredients from algae (Spirulina blue protein) with familiar or engaging colors is encouraged.

Use of AI

During the preparation of this work the author(s) used ChatGpt in order to improve readability. After using this tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Ethical approval for the involvement of human subjects in the study “Green Color Drives Rejection of Crackers Added with Algae in Children but Not in Adults” was granted by the Ethical Committee of the University of Milan, Reference number 94/22, 28 October 2022.

CRediT authorship contribution statement

Noemi Sofia Rabitti: Writing – original draft, Visualization, Investigation, Formal analysis. **Pernilla Sandvik:** Writing – original draft, Supervision, Resources, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization. **Susanne Neugart:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization. **Joachim Jietse Schouteten:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization. **Monica Laureati:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

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

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Data availability

Data will be made available on request.

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