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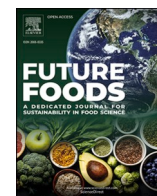
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A sense of seaweed: Consumer liking of bread and spreads with the addition of four different species of northern European seaweeds. A pilot study among Swedish consumers

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ABSTRACT

Current food systems pose one of the greatest health and environmental challenges of the 21st century. Expanded utilization of seaweed for food in Western societies seems like one promising measure in the transition toward sustainable food systems. However, introducing and expanding seaweed to new markets brings certain challenges, such as limited food acceptance and availability. In this pilot consumer study, four common northern European seaweed species (*Saccharina latissima*, *Alaria esculenta*, *Palmaria palmata*, and *Ulva* sp.) were introduced into two complementary plant-based products (bread and spread), which were presented to consumers ($n = 49$ (bread), $n = 52$ (spread)) in a Swedish setting. The consumers' liking of the products was evaluated based on a 9-point hedonic scale, and the product characteristics were determined by texture, pH, and color analysis. Whereas the different spreads' pH was similar, the texture and color overall varied more between the different samples. Overall, the consumers slightly liked the two seaweed-containing products, with taste/texture and texture being main contributing factors to the consumers' liking. For the bread, *S. latissima* was liked best as a supplement. *S. latissima* and *A. esculenta* were liked best for the spread, whereas *P. palmata* received the lowest scores. The preference for brown seaweeds may relate to their relatively more neutral taste/flavors and finer structure, whereas the lower scores for *P. palmata* may be explained by its marine-associated flavors and coarser structure. The studied consumer liking of seaweed-based products can become valuable for developing and improving future seaweed products and increasing their availability in Western food cultures.

1. Introduction

Current food systems pose one of the greatest health and environmental challenges of the 21st century (Béné et al., 2019; Willett et al., 2019). Hence, a transition towards more sustainable food systems is argued to be necessary for compliance with the global goals communicated in the United Nations' Agenda 2030 and the Paris Agreement. This proposed systematic shift in the food sector can be accelerated by technologies and innovations throughout the whole value chain, but must be accompanied by social and institutional factors enabling their deployment (Herrero et al., 2020).

One such innovation with transformation potential is the expansion of seaweed for food in Western societies (Doumeizel et al., 2020; Herrero et al., 2020). A major motivator for the consumption of seaweed is the health aspect, which is attributable to a variety of nutritional content, especially some compounds with potential functional properties. Edible seaweed could be a good source of dietary fiber (35–62 % dry weight (DW)), proteins (< 44 % DW), and minerals (7–55 % DW). In addition, these sea vegetables contain bioactive compounds, such as polyphenols, polysaccharides, and sterols, responsible for functional properties associated with seaweed (Holdt and Kraan, 2011; Jönsson et al., 2020; Marsham et al., 2007; Peñalver et al., 2020). Vitamins of

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interest in seaweed include vitamin A, thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), folic acid (B9), cobalamin (B12), ascorbic acid (C), vitamin D, and vitamin E. Since vitamin B12 is not synthesized by higher plants, seaweed could exert a valuable component in a plant-based diet. The high content of minerals predominantly comprises sodium, calcium, magnesium, potassium, chloride, sulfate, phosphorus, and micronutrients such as iodine, iron, zinc, copper, selenium, molybdenum, fluoride, manganese, boron, nickel, and cobalt (Jönsson et al., 2023; Peñalver et al., 2020). However, it is widely known that certain species harbor undesirable elements in varying concentrations, with notably elevated levels of iodine in sugar kelp (*S. latissima*), making iodine a limiting factor for seaweed consumption (FAO and WHO, 2022; Jönsson et al., 2023; Jönsson and Nordberg Karlsson, 2023). Overall, seaweeds' adaptation to marine environments has not only resulted in their unique nutritional content, but also in special textures, odors, and flavors.

These special textures, odors, and flavors of seaweed together create their unique sensory profiles. In a previous study by Jönsson et al. (2023), sensory descriptors for the four different species used in this study were formulated by a trained sensory panel. *P. palmata* (dulse) distinguished itself from the other species by its dark magenta color, chewy hard texture, odor resembling sea and shellfish, flavor of fish-liver-oil, and umami taste. *A. esculenta* (winged kelp) and *S. latissima* (sugar kelp) overall resembled each other, with crispy, semi-hard, and semi-chewy textures. *Ulva* sp. was described as light green, with a curly soft texture, grassy odor, lemon flavor, and salty taste. Overall, all species' taste profiles were described as high saltiness and taste intensity, medium umami, low bitterness and sourness, and no sweetness (Jönsson et al., 2023). Due to the variation in sensory profiles, different species are anticipated to suit various culinary purposes.

This differentiation between various seaweed varieties and their suitability for different food products are clearly distinguished in cultures with a rich tradition of eating seaweed, such as China, Korea, or Japan (Mouritsen et al., 2018). Seaweed is part of an everyday diet and is for example used in soups, salads, teas, snacks, and desserts (Mouritsen et al., 2018). Although seaweed is a common ingredient in various regional cuisines around the world, in Sweden it is a niche product today. However, studies have pointed to consumers being familiar with eating seaweed in "Asian" restaurants. It is expected especially in connection with sushi, which has become increasingly popular and can even be bought ready-made in major supermarkets. In contrast, consumers are surprised about finding seaweed as an ingredient in "Western" or "Scandinavian" cuisine, such as the New Nordic Cuisine (Merkel et al., 2021).

Although seaweed is not a new food resource from a global perspective, it has poor cultural and traditional values in the Swedish diet. Seaweed has historically been used as, among other things, animal feed, soil improver, or as material for insulation (Fredriksson and Säwe, 2023). In the pre-industrial society, seaweed functioned as a resource that also organized social life. Today, seaweed as a food has only reached a niche market towards creative and curious chefs and retailers at the forefront (Fredriksson et al., 2024; Merkel et al., 2021). Hence, unavailability, unfamiliarity, and food neophobia may constitute barriers to introducing seaweed into the Swedish food culture (Blikra et al., 2021; Chapman et al., 2015; Losada-Lopez et al., 2021; Moss and McSweeney, 2021; Young et al., 2022). Although these barriers may aggravate the introduction of seaweed to new markets, Swedish consumers seemingly exhibit an overall positive attitude towards eating seaweed, which is motivated by health, taste, and pro-environment arguments (Fredriksson et al., 2024; Wendin and Undeland, 2020).

The environmental sustainability associated with seaweed relates to its proposed beneficial cultivation practices, where neither fertilizers, pesticides, herbicides, land space, nor freshwater irrigation is required, while they also proliferate at growth rates exceeding terrestrial plants and utilize carbon dioxide for their photosynthesis (Jönsson et al., 2020).

As a step to evaluate the social factors associated with introducing seaweed to new food markets, this study investigates the consumer acceptability of two complementary locally sourced European seaweed-containing food products. Local food systems can be considered more sustainable than global ones due to for example reducing transportation distances (Gössling and Hall, 2021). Although the concept of sustainability remains poorly defined (Béné et al., 2019), the shift towards more healthy and environmentally sustainable diets is argued to constitute an expanded use of plant-based food sources (Clark et al., 2019; Willett et al., 2019). In line with this, previous studies (Moss and McSweeney, 2021; Wendin and Undeland, 2020) have shown that consumers seem to be more willing to combine seaweed with plant-based foods (e.g., bread, noodles, biscuits, and pasta), rather than animal-derived products (e.g., yogurts or sausages). Hence, in this consumer study, four organically grown types of common northern European seaweed species, *Saccharina latissima*, *Alaria esculenta*, *Palmaria palmata*, and *Ulva* sp., were included in two familiar plant-based products, wheat bread and spread. In the present study, the spread was based on locally grown yellow peas. A particular emphasis has been placed on locally sourced ingredients, as studies have shown that consumers connect local foods to sustainability, better taste, and freshness (Gössling and Hall, 2021). As a natural extension to the descriptive sensory study, where a trained sensory panel was used (Jönsson et al., 2023), the consumer acceptance of products containing the same seaweed species was evaluated in the current study. Given the intricacies and challenges inherent in modern food systems, an interdisciplinary approach to food production and consumption is essential, and a dialog between consumers and product developers plays a crucial role in the development of new food products and ingredients (Fredriksson et al., 2023). Hence, the social factors, in this case consumer acceptance in a Swedish context, are important for the transition towards a more sustainable food system in general, and for the introduction of seaweed to new markets in particular.

This study aimed to formulate two complementary food products containing seaweed. For that, four types of seaweed were included in the two products, bread and spreads, which were compared based on nutritional content (from Jönsson et al. (2023)), physicochemical properties, and consumer liking in a Swedish context. This study addresses the question: How does the inclusion of seaweed in two different food products influence the consumers' liking and the physicochemical properties of the products?

2. Materials and methods

2.1. Seaweed

Four common northern European species of seaweed were included in the products in this study. *Saccharina latissima* [(L.) C.E. Lane, C. Mayes, Druehl, and G.W. Saunders, 2006], *Alaria esculenta* [(L.) Greville, 1830], *Palmaria palmata* [(L.) Weber & Mohr, 1805], and *Ulva* sp. (tubular morphology) were purchased from Connemara Seaweed Company, Ireland. *S. latissima* (SL), *A. esculenta* (AE), and *Ulva* sp. (UL) were harvested in April 2021 and *P. palmata* (PP) was harvested in September 2021. The wild-grown seaweeds were hand-harvested within a 15-mile radius from Rossaveal, Galway, dried on drying racks for 20 h at 38 °C, and milled to 3 mm powder. The nutritional values (Table 1) of respective seaweed species were determined by Jönsson et al. (2023). Based on the amount of seaweed supplied to the products, the total fiber content was calculated to increase by around 40 % by adding 3.5 % seaweed to the bread, and by 20 % by adding 3.0 % seaweed to the spread.

2.2. Products

Previous studies have indicated that Swedish consumers are generally positive about eating seaweed, preferably as an ingredient in snacks, bread, or various dishes (Wendin and Undeland, 2020). Based on this,

Table 1

Summary of macronutrients and selected minerals in the four seaweed species presented as mean values with standard deviation. Significant differences (Tukey's HSD, $p < 0.05$) are indicated by letters (a–d). Data obtained from previous work by Jönsson et al. (2023).

	Unit	SL	AE	PP	UL
Carbohydrates	g/ 100 g DW	53.4 ± 1.4 a	36.3 ± 0.9 b	54.6 ± 2.6 a	29.6 ± 1.1 b
Protein	g/ 100 g DW	8.06 ± 0.11 c	11.4 ± 0.1 a	10.0 ± 0.3 b	6.67 ± 0.22 d
Lipids	g/ 100 g DW	2.36 ± 0.07 a	1.70 ± 0.06 b	1.66 ± 0.10 bc	1.31 ± 0.13 c
Minerals (total)	g/ 100 g DW	26.5 ± 0.2 c	32.9 ± 1.0 b	25.8 ± 1.0 c	36.8 ± 0.5 a
Arsenic	mg/ kg DW	70.3 ± 8.0 a	75.3 ± 8.5 a	14.6 ± 1.7 b	8.69 ± 1.0 b
Cadmium	mg/ kg DW	0.477 ± 0.058 b	1.210 ± 0.150 a	0.170 ± 0.021 c	0.100 ± 0.013 c
Mercury	mg/ kg DW	0.0295 ± 0.0034 b	0.0484 ± 0.0055 a	0.0299 ± 0.0035 b	0.0373 ± 0.0044 ab
Lead	mg/ kg DW	0.380 ± 0.048 bc	0.252 ± 0.031 c	0.737 ± 0.095 b	1.98 ± 0.26 a
Iodine	mg/ kg DW	3 530 a	1 250 b	426 c	276 d
Iron	mg/ kg DW	249 ± 34 b	279 ± 37 b	228 ± 32 b	1 840 ± 260 a
Sodium	mg/ kg DW	37 800 ± 4900 bc	47 900 ± 6200 b	22 100 ± 3000 c	65 800 ± 8900 a

S. latissima (SL), *A. esculenta* (AE), *P. palmata* (PP) and *Ulva* sp. (UL).

two complementary plant-based seaweed-containing products were developed in this study; a loaf of bread, and a savory yellow pea spread. Four varieties, with each seaweed species, were developed for both products. Hence, eight products were produced in total. The amount of seaweed added to the products was based on previously reported sensory appeal (Gorman et al., 2023; Hall et al., 2010; Lamont and McSweeney, 2021; Quitral et al., 2022), and its iodine content, which is the main limiting factor for seaweed consumption. The product development was based on creative design, an experimental design methodology formulated by Naes and Nyvold (2004). The production of the bread and spread was conducted in a pilot plant setting according to the recipes in Table 2 and the descriptions below.

2.2.1. Bread

Four varieties of bread were made (Table 2), with each one distinguished by the type of seaweed incorporated.

The breadmaking comprised three crucial steps: kneading, fermenting, and baking. First, in a stainless-steel bowl, water was mixed with fresh yeast before wheat flour, canola oil, salt, sugar, and hydrated seaweed were added. The dough was kneaded for 10 min in a food processor (Bear Varimixer Teddy AR005, Denmark) followed by resting (fermenting) for 90 min in an oven (Electrolux EOB53010X, Sweden) along with a container of water. Subsequently, the dough was worked by hand to eliminate air bubbles and formed into baguettes. Again, the baguettes were let to rest (ferment) for 30 min at room temperature. Finally, the baguettes were oven-baked at 240 °C in the presence of water steam for about 20 min until the internal temperature reached 98 °C.

Table 2

Ingredients list for production of 100 g bread and spread, respectively.

Product	Ingredient	Amount (per 100 g product)
Bread	Water	34 mL
	Fresh yeast ¹	2 g
	Wheat flour (high protein) ²	50 g
	Canola oil ³	10 mL
	Salt, fine-grained ⁴	A pinch
	Granulated sugar ⁵	A pinch
Spread	Seaweed ⁶	3.5 g
	Yellow peas, dry ⁷	33 g (66 g wet)
	Water	18 mL
	Vinegar essence, 12 % ⁸	2 mL
	Canola oil ³	10 mL
	Salt, fine-grained ⁴	A pinch
	Seaweed ⁶	3.0 g

¹ KronJäst, Sweden.

² Kungsörmen, Sweden.

³ Martin & Servera, Sweden.

⁴ Falsalt, Sweden.

⁵ DanSukker, Sweden.

⁶ Connemara Organic Seaweed Company, Ireland.

⁷ GoGreen, Sweden.

⁸ Winborgs, Sweden.

2.2.2. Spread

Similar to the breads, four types of spread were produced (Table 2), only differing by the seaweed type added.

Dried yellow peas were soaked in water overnight to swell to double size. The hydrated peas were drained and rinsed before being simmered in a saucepan for 45 min. The peas were thereafter drained again to remove as much cooking water as possible before being added to a blender (Hållde SB-4L-2, Sweden) with water, vinegar essence, canola oil, salt, and seaweed. The mixture was blended until smooth and stored cooled at 4 °C.

2.3. Product characterization

2.3.1. Color of the bread and spread

The color of both bread and spreads was assessed using a portable colorimeter CM-700d (Konica Minolta, Japan), presented as L^* , a^* , and b^* values in the CIELAB color space. L^* renders the lightness of a sample, a^* represents a value ranging from green (–) to red (+), and b^* similarly designates the color direction from blue (–) to yellow (+). The total color difference (ΔE^*) was calculated using the following equation:

$$\Delta E^* = \sqrt{(L_c^* - L_i^*)^2 + (a_c^* - a_i^*)^2 + (b_c^* - b_i^*)^2},$$

where c denotes the control (bread and spread without seaweed added) and i the respective formulation (with UL, PP, AE, or SL). Slices of bread (crumb and crust) were placed on a homogeneous white surface and the calibrated device was positioned above. The same method was repeated for the spreads. All measurements were performed in triplicates.

2.3.2. pH of the spread

pH measurements ($n = 3$) using a pH meter (Mettler Toledo FE20/EL20, USA) were carried out for the different spreads (with UL, PP, AE, SL, and control without any seaweed).

2.3.3. Texture of the bread

Texture profile analysis (TPA) of the bread was performed in triplicates by a CTX Texture Analyzer (Ametex Brookfield, USA) with the accompanying software Texture Pro 1.0.15. For the analysis, the baguettes were cut into slices of 3 cm, each slice representing one sample. Texture profile curves were generated by compressing the samples twice with a cylinder (TA-AACC36) to understand the breads' behavior during mastication. The texture of the crumbs was analyzed by placing the cross

section facing toward the probe, and for the texture of the whole bread, the crust was facing the probe. Bread without seaweed added was used as control.

2.4. Consumer study

The hedonic consumer study was designed to evaluate the degree of liking of four seaweed species added to two complementary products among Swedish consumers. One centimeter thick slices of the different breads and one teaspoon (5 mL) of each of the spreads were anonymized and randomly presented to the consumers in neutral product containers labelled with three-digit codes. Samples were served at ambient temperature, approximately 21 °C. Allergy information was provided in the questionnaire. 49 consumers (bread) and 52 consumers (spread) participated in the study held in Sweden at the H22 City Expo in Helsingborg and at Kristianstad University during the summer of 2022. The inclusion criterion was age above 18 years. The bread test group comprised 45 % women and 55 % men, and the corresponding gender distribution for the spread test group was 61 % women, 37 % men, and 2 % other. The age distribution for both bread and spread test groups were 10 % under 25 years, 37 % between 25 and 40 years, 42 % between 41 and 60, and 11 % above 60 years.

An online questionnaire, designed in the software Eye Question (version 3.9.7, Netherlands), was filled out by the participants either in English or Swedish for each sample (i.e., four breads, and four spreads). Bread slices and spreads were evaluated separately. The degree of liking of the included products was assessed using the 9-point hedonic scale, ranging between 1: dislike extremely, 2: dislike very much, 3: dislike moderately, 4: dislike slightly, 5: neither dislike nor like (center point), 6: like slightly, 7: like moderately, 8: like very much, and 9: like extremely. The 9-point hedonic scale, as described by Nicolas et al. (2010), was used in the present study since it is widely recognized as a simple method with ease of use for the participants and allowing sufficient discrimination between results. Each sample was evaluated based on the following questions:

- What do you think about the appearance?
- What do you think about the smell/odor?
- What do you think about the taste/flavor?
- What do you think about the texture?
- What is your overall level of appreciation of the product?
- Spread only: If any, what additional spice do you think can improve this spread? (Max 3)
- No spice · garlic · bell pepper/paprika · oregano · basil · chili pepper · pepper · cumin · ginger · turmeric · curry · or other (specify).
- Do you have any comments or suggestions that could help improve the products?

Research carried out in Sweden which includes any processing of sensitive personal data is covered by the Swedish Ethics Review Act. This study includes questions about food perception that are not classified as sensitive personal data, according to the Data Protection Ordinance. According to the General Data Protection Regulation (GDPR), no information from any of the questionnaires can be traced to or used to identify any individual participant. All participants received written and oral information about the analytical test and the contents of the tested products, including allergens, and gave their informed consent to participate.

2.5. Statistics

Descriptive statistics (means and standard deviation) were calculated for all data. Potential differences between the samples were analyzed by one-way ANOVA ($p < 0.05$) with Tukey's HSD *post hoc* test

and complemented with a pairwise comparison by Student's *t*-test for the consumer study. Letters (a-d) or asterisk (*) were used to indicate significant differences between samples. Correlation analysis of average values was carried out by Pearson correlation analysis, with coefficients larger than 0.7 ($r \geq |0.7|$) considered indicative of a strong relationship between two variables (Akoglu, 2018). The Eye Question software (version 3.9.7, Netherlands), Microsoft Excel (version 2310, USA), and the open-source statistical tool, jamovi (version 2.3.28, Australia), was used for all statistical computations.

3. Results

3.1. Product characterization

3.1.1. Color of the bread and spread

The color analysis demonstrated the lightness (L^*) and color directions (a^* , b^*) of the products, and how much the products differed from the control (ΔE^*) in terms of color (Fig. 1). For crumbs, the bread containing *S. latissima* distinguished itself most from the other products, with slightly darker tones (L^* , $p < 0.05$), and more red (a^* , significantly different ($p < 0.05$) from all but PP) and yellow (b^* , significantly different ($p < 0.05$) from all but UL) features. The color of the crust was overall similar (ΔE^* , $p < 0.05$) between all four breads, but with variances within each color direction, suggesting the Maillard reaction from baking of the bread blurs out differences observed in the crumb. For spreads, the product containing *P. palmata* differed most from the control, with significantly redder (a^* , $p < 0.05$) and less yellow (b^* , $p < 0.05$) color tones. The crumb and spread containing *Ulva* sp. were the significantly greenest (a^* , $p < 0.05$) of all four products. All seaweed-containing products were significantly darker (L^* , $p < 0.05$) than the controls. See Fig. 3 for images of the products.

The color analysis further demonstrated that the food matrix influenced the color of the products. Although the lightness (L^*) correlated well between the three analyses (crumb/crust (0.91), crust/spread (0.94), and crumb/spread (0.70)), fewer relationships were observed for red (a^* , crumb/spread (0.74), and crumb/crust (0.80)), and yellow (b^* , crumb/spread (0.82)) color directions. No correlations were at a significant ($p < 0.05$) level.

3.1.2. pH of the spread

In contrast to color analysis, the pH of the spread was not considerably affected by the inclusion of the different species. The pHs of the different spreads were similar, with the lowest pH in *A. esculenta* (5.0 ± 0.02) and the highest pH in *Ulva* sp. and *S. latissima* (5.2 ± 0.01 , respectively). All samples, except *P. palmata* (5.1 ± 0.02), deviated from the control (5.1 ± 0.01). The level of pH in the spreads did neither correlate with the taste of the products, nor with the sourness of each species (Jönsson et al., 2023), suggesting it had little impact on the liking and the small variance cannot be deduced from the seaweeds.

3.1.3. Texture of the bread

Texture profile analysis (TPA) was performed to determine the hardness, cohesiveness, and resilience of bread crumb and whole bread (Fig. 2). Hardness exerts the force required to compress a product between the teeth, cohesiveness indicates how well the structure of the product resists compression, and resilience refers to the ability of the product to recover after deformation. For the crumb, whereas all seaweed-containing products did not deviate from the control, *Ulva* sp. and *P. palmata* had significantly ($p < 0.05$) harder textures than *A. esculenta* and *S. latissima*. *Ulva* sp., the hardest of all breads, had similar hardness in both the test of the crumb and whole bread, just like *S. latissima*. *P. palmata* and the control, had harder crumbs compared to when measuring the whole bread (including the crust). *A. esculenta* showed an opposite pattern. Minor variances in cohesiveness and resilience between the crumbs of the four bread products were observed. The observed differences in bread texture may be attributed to variances

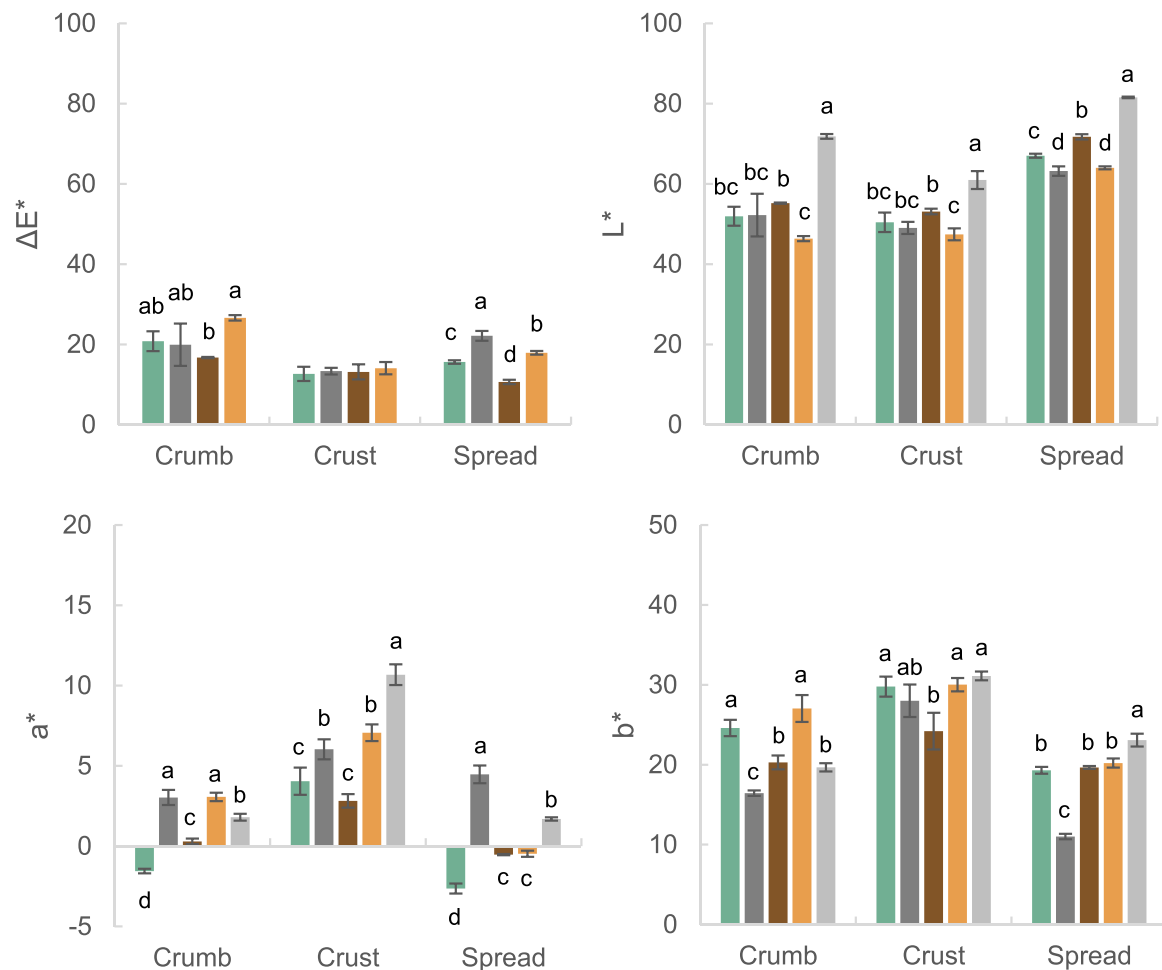


Fig. 1. Color characterization ($n = 3$) of the products: color difference (ΔE^*) from control, lightness (L^*), green-red color direction (a^*), and blue-yellow color direction (b^*). Significant differences (Tukey's HSD, $p < 0.05$) within each product group are indicated with letters (a–d). Samples comprise formulations with *S. latissima* (SL), *A. esculenta* (AE), *P. palmata* (PP), *Ulva* sp. (UL), and control (C) without seaweed.

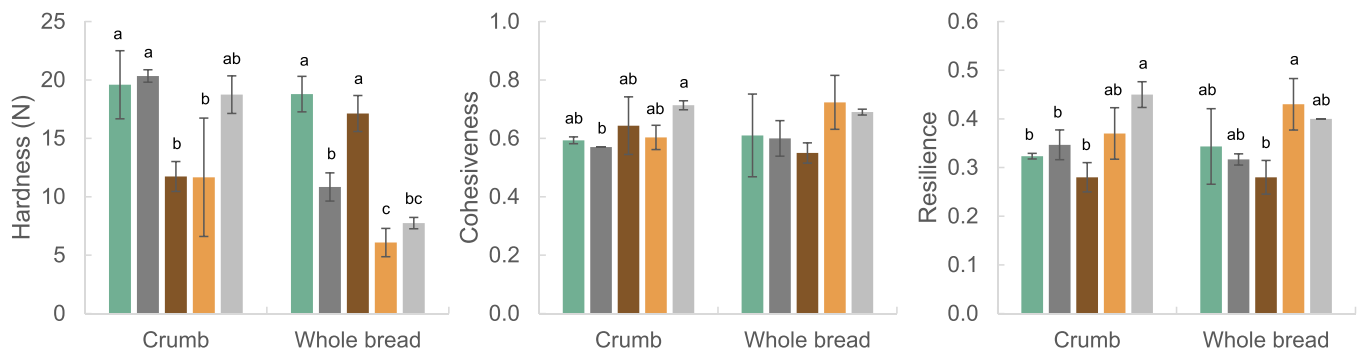


Fig. 2. Texture characterization ($n = 3$) of the products measured as hardness, cohesiveness, and resilience. Significant differences (Tukey's HSD, $p < 0.05$) within each product group are indicated with letters (a–c). Samples comprise formulations with *S. latissima* (SL), *A. esculenta* (AE), *P. palmata* (PP), *Ulva* sp. (UL), and control (C) without seaweed.

from the baking as well as the effect of the added seaweed.

3.2. Consumer study

The consumer study showed that respondents were overall slightly positive toward including seaweed in bread and spread products (Fig. 4). The percent of the participants who gave overall positive evaluations (scored >5) for bread were: 77.6 % for *S. latissima*, 59.2 % for *A. esculenta*, 57.1 % for *P. palmata*, and 53.1 % for *Ulva* sp.

Corresponding percentages for the spread was: 67.3 % for *S. latissima*, 59.6 % for *A. esculenta*, 50.0 % for *P. palmata*, and 63.5 % for *Ulva* sp. The scores ranged between 5.2 ± 2.1 (“neither dislike nor like”) and 5.9 ± 1.7 (“like slightly”) for the spreads and between 5.6 ± 1.8 and 6.3 ± 1.7 (“like slightly”, respectively) for bread. Although the scores appeared similar at the group level (Tukey's HSD, $p > 0.05$), some significant differences were observed between the four species using pairwise comparison by Student's *t*-test ($p < 0.05$). The bread containing the brown seaweed *S. latissima* was liked better by the consumer group.

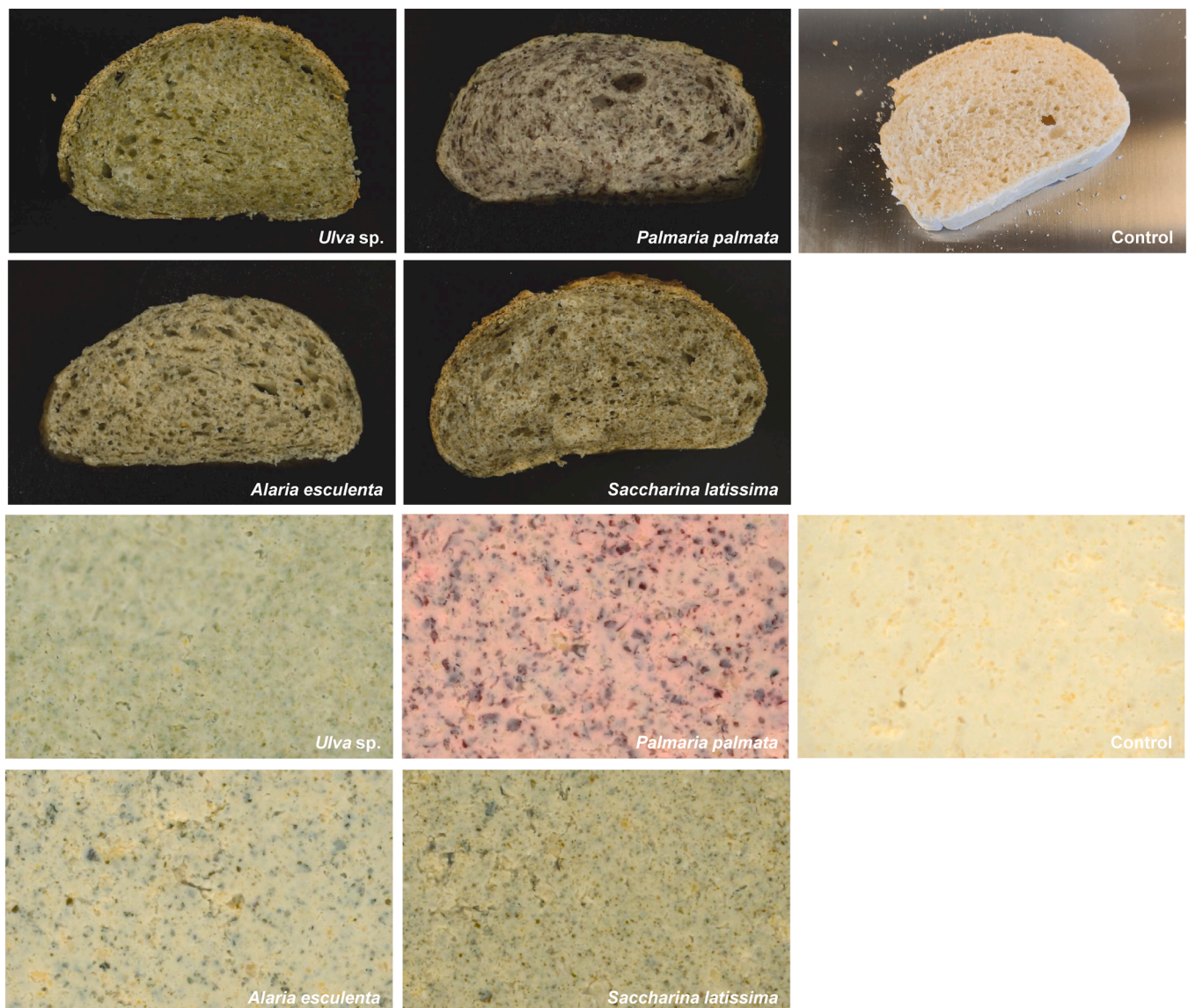


Fig. 3. Picture of bread slices (top) and spreads (bottom).

Similarly for spreads, *S. latissima* and *A. esculenta* (the two kelps) received the highest overall liking scores. *P. palmata* was overall least appreciated as an ingredient in the spread.

Similar to the overall perceptions, the degree of liking, within respective attribute categories (appearance, smell/odor, taste/flavor, and texture) for the two products, varied within the range from 4.9 ± 2.2 to 6.5 ± 1.7 . In general, analysis by Tukey's HSD test did not indicate significant differences between the samples for each attribute at the group level. Only the appearance between bread containing *Ulva* sp. and *P. palmata* differed. However, a pairwise comparison (Student's *t*-test) indicated differences between samples. Outstanding among the breads was the *S. latissima* sample which received the highest scores in all four categories appearance (6.5 ± 1.7), smell/odor (6.1 ± 1.7), taste/flavor (6.1 ± 1.7), and texture (6.5 ± 1.7). Also, the appearance and the texture appeared overall to be the best-approved attributes among both the breads and spreads. The most protruding sample among the spreads contained *P. palmata*, which received the lowest scores in the categories; smell/odor (5.0 ± 1.7), taste/flavor (4.9 ± 2.2), and texture (5.5 ± 1.9).

Correlation studies indicated that the overall liking was seemingly most influenced by the taste/flavor (0.94) and texture (0.86) of both the bread and the spread. On the contrary, the parameters of appearance

and smell/odor did not contribute to the overall liking to the same extent. In terms of texture, the hardness of the crumb correlated negatively with the bread texture liking (-0.83), which indicated that softer breads were better liked. The texture analysis, in Section 3.1, indicated that the two brown seaweeds gave softer breads. Although the appearance was not decisive for the overall liking, it was shown that a redder (less green) color was better appreciated. This was demonstrated through correlation analysis, where appearance correlated positively with the a^* value of bread crumb (0.96 , $p < 0.05$) and a^* value (0.84) of spread. However, correlations were not at a significant ($p < 0.05$) level.

In addition to the hedonic test, consumers were also asked to rate certain species or suggest other flavorings to include in the spread. Overall, consumers were most positive to flavor the spread with garlic or to not add any additional spice (Fig. 5). However, around 20 % of the consumers were also positive toward adding chili pepper to the spreads already containing *Ulva* sp. and *A. esculenta*. Around 10 % of the consumers gave suggestions for other flavorings (Fig. 5). From these suggestions, salt and lemon were generally most frequently proposed.

The final question in the questionnaire concerned whether the participants had any comments or suggestions for improvement of the products (Table 3). For breads, some of the positive remarks included

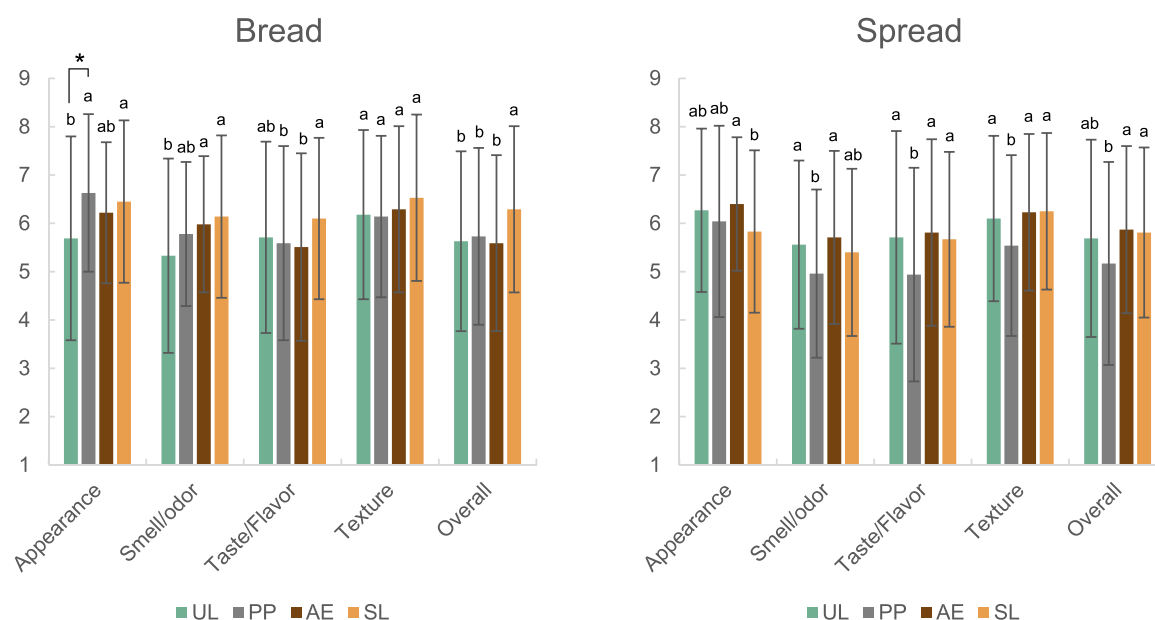


Fig. 4. Consumer liking of bread ($n = 49$) and spread ($n = 52$). Significant differences are indicated with asterisk (*) for Tukey's HSD test ($p < 0.05$) and different letters (a, b) indicate significant differences calculated by Student's t -test (pairwise comparison, $p < 0.05$). *S. latissima* (SL), *A. esculenta* (AE), *P. palmata* (PP) and *Ulva* sp. (UL).

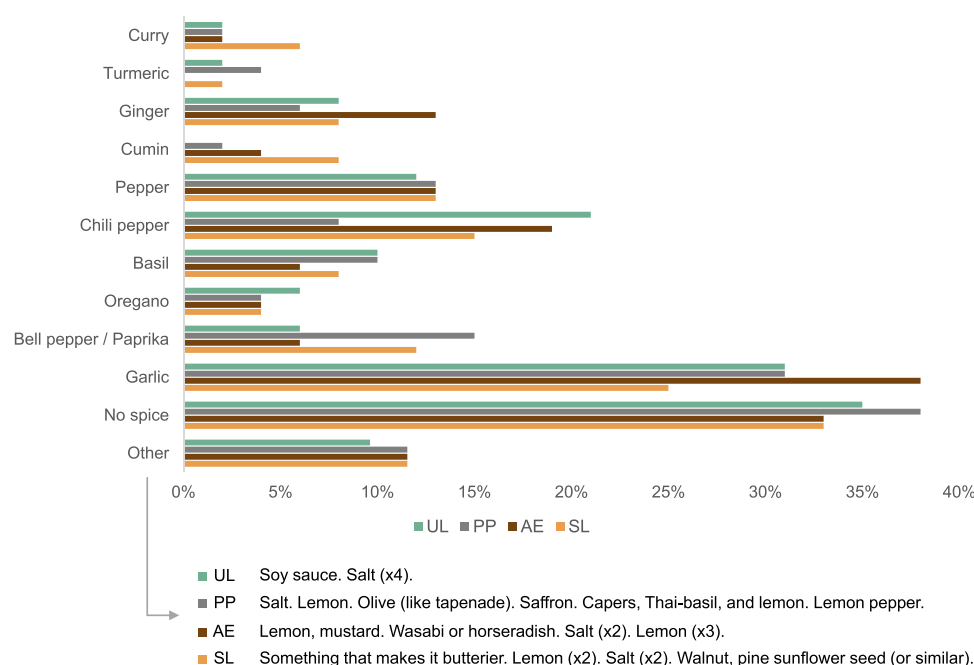


Fig. 5. Percent of consumers ($n_{(SL)}=6$, $n_{(AE)}=7$, $n_{(PP)}=6$, and $n_{(UL)}=5$) positive about adding the proposed flavorings to the spreads, and specification of consumers' suggestions of other flavorings. *S. latissima* (SL), *A. esculenta* (AE), *P. palmata* (PP) and *Ulva* sp. (UL).

encouragement to increase the seaweed content and suggestions of what to serve it with. On the contrary, the negative remarks included senses of off-flavor, too little salt, too high astringency, associations to mold (green color), and a negative taste of sea. For the spreads, several consumers expressed their appreciation. However, negative remarks indicated too little saltiness, too much sea taste, and, contrary to bread, that green color was perceived as more appetizing.

4. Discussion

This pilot study has provided insight into how the inclusion of

seaweed in two different food products, bread and spread, influences the consumers' liking and the physicochemical properties of the products. Four species of seaweed, *Saccharina latissima*, *Alaria esculenta*, *Palmaria palmata*, and *Ulva* sp., common in northern Europe, were studied in a Swedish context.

The consumers in this study overall slightly liked both products, with average scores ranging between 5.6 and 6.3 ("like slightly") for the bread, and 5.2–5.8 (between "neither dislike nor like" and "like slightly") for the spreads. This agrees with previous studies indicating a positive attitude toward eating seaweed among Swedish consumers (Fredriksson et al., 2024; Wendin and Undeland, 2020). Hence, the

Table 3

Consumers' answers to the free text question: Do you have any comments or suggestions that could help improve the products? Comments originally formulated in Swedish were freely translated to English by the authors.

Bread	Spread
Positive remarks "Overall good stuff!" "I am surprised how good it is, can imagine eating it with vegan salmon or something similar."	Positive remarks "I like fried and salty algae snacks, so I really liked the spreads!" "[...] But I like all of them in general!" "I like the spreads." "Surprisingly good." "Good texture."
Negative remarks Salt (x2): "Lack salt." "Maybe some more salt to remove the algae taste." Off-flavor/sea (x4): "Strange off-flavor in all samples.", "There is a taste of sea and clams which I do not like.", "Strange off-flavor in all samples. They are best when there is a crust.", and "Maybe some more salt to remove the algae taste." Texture (x4): "A softer structure maybe works better.", "The samples are dry. Possible to make them juicier?", "Maybe crispbread or crackers work better.", and "The astringency is too high, almost feels like small particles."	Negative remarks Salt (x2): "More salt." and "Maybe add some more salt?" Off-flavor/sea (x3): "Too much sea flavor.", "Remove the flavor of sea and clams (AE).", and "Decrease the flavor of sea (SL)." "The aftertaste is better than the initial taste (UL)." "Balance the bitterness (AE)."
Overall suggestions for improvement "The breads taste very similar to regular bread, maybe you could try to be bolder and add more seaweed." "[Add] sunflower seed, sesame seed." "Sample 835 [UL] is okay; however, the green color may be connected to mold."	Overall suggestions for improvement "Change the color – green is more appetizing." "They would taste very good as pickles, like tapenades." "Maybe add more spices to some of the samples!"

expectation conforms with the experience. Correlation analysis showed that the taste/flavor and texture of the products contributed most to the consumers' overall liking. Appearance and smell/odor were less important factors. Altogether, different species demonstrated distinct levels of consumer appreciation.

Of the species investigated, *S. latissima*, a brown seaweed, was liked best as a supplement in bread (6.3 ± 1.7 , "like slightly"). This finding relates to three observations. Firstly, as previously demonstrated by Jönsson et al. (2023), the particle sizes differed between the four different seaweed powders. In the current study, the milling degree (obtained from Jönsson et al. (2023)) correlated with bread texture (0.92). This means that smaller particles give a more appealing texture. Secondly, as also shown in a previous study by Jönsson et al. (2023), the two brown species generally have more neutral tastes and flavors compared to the green and red species, with neither substantial grassy nor sea-associated flavors. Thirdly, although appearance is not the most important factor for liking, it appears that redder colors of the bread are more appreciated than green colors. From the open comments, it is understandable that green particles can be associated with mold by some consumers. It can be further deduced from the open questions that although some consumers enjoyed the breads and could imagine increasing the seaweed content, others would prefer to formulate the product as crackers or hard bread to better mask the seaweed.

In the case of the spread, the two brown seaweeds, *S. latissima* and *A. esculenta*, were best liked by the consumers (5.8 ± 1.7 and 5.9 ± 1.8 , respectively, translating to "like slightly"), whereas the red seaweed, *P. palmata*, received the lowest scores (5.2 ± 2.1 , "neither dislike nor like"). The liking of the brown seaweed species may be explained by the same reasoning as for bread. However, the low scores for *P. palmata* may be attributed to bigger particles of the powder and associations with sea and shellfish (from Jönsson et al. (2023)). This was demonstrated by correlation analysis which indicated that the milling degree related positively (0.92) to the perceived spread texture. Additionally, a previous study by Jönsson et al. (2023) showed that *P. palmata* distinguished itself from the other species by its associations with sea, shellfish, and fish liver oil. The free comments from the current study indicate that

associations with "sea" are not appreciated in these types of products by some consumers.

To further elaborate the comparison with findings from the sensory study by Jönsson et al. (2023), the color of the products in the current study did not follow the same color pattern as for dried pieces of seaweed. Whether this discrepancy is due to an increase in moisture content or the impact of the formulation, this observation can be important for product developers to consider. The previous sensory study by Jönsson et al. (2023), showed that *Ulva* sp. was perceived as the saltiest species, however, in the current study, most suggestions of additions (Fig. 5) to the spread with green seaweed revolved around adding more salt.

To increase the saltiness of the two products, more seaweed could be added as the taste profiles (Jönsson et al., 2023) of studied seaweed species show a high degree of saltiness. However, adding more seaweed would also impact the texture and flavor of the products, which might decrease the sensory appeal. Another limiting factor for how much seaweed to add is the seaweed's levels of potentially toxic compounds (PTE), such as iodine, which is highest in *S. latissima* (Table 1). Regulatory frameworks for maximum levels of PTEs in seaweed are currently scattered in Europe. The main actors, including the European Food Safety Authority (EFSA), the European Commission, the French Agency for Food, Environmental and Occupational Health and Safety (ANSES), and the Algae Technology and Information centre (CEVA), provide tolerable daily/weekly intake (TDI/TWI) levels and maximum levels in seaweed products (ANSES, 2020; CEVA, 2019; EFSA, 2009, 2010, 2011, 2012, 2014; EFSA et al., 2023). Accordingly, considering iodine being the limiting factor for seaweed consumption (Jönsson and Nordberg Karlsson, 2023), the tolerable daily intake restrictions of 600 µg/day for adults (EFSA, 2014; EFSA et al., 2023) and the maximum levels of 2 000 mg/kg dry weight (ANSES, 2020; CEVA, 2019) must especially be considered when developing new food products containing seaweed. In the present study, the TDI level of iodine from EFSA limits the consumption of bread to between 5 and 62 g of bread pre-baking (5 g SL, 14 g AE, 40 g PP, and 62 g UL) and 6–73 g of spread (6 g SL, 16 g AE, 47 g PP, and 73 g UL). Hence, considering these small amounts of product recommended, pretreatment of seaweed, by for instance blanching, soaking, high-pressure, high-temperature, and fermentation, can become useful since it has been shown to successfully reduce the levels of several PTEs (Jönsson and Nordberg Karlsson, 2023; Krook et al., 2023; Nielsen et al., 2020; Stévant et al., 2018; Trigo et al., 2023). However, several methods applicable for PTE-removal also reduce the levels of salts such as sodium. Pretreatment steps of the seaweed can also be added to increase the sensory acceptance of the ingredient.

High-pressure processing (HPP) has proved efficient in reducing the hardness of seaweed textures, by up to 87.7 % in *S. latissima* (Jönsson et al., 2023), while also reducing the iodine levels by 73 % (Jönsson and Nordberg Karlsson, 2023). By introducing HPP as a pretreatment step before the product formulation, the hardness could be reduced and better integrated into the bread and spread. Additionally, an increased amount could be used since the iodine level, as the limiting factor, would be lower in the seaweed. Another well-studied method for reducing the iodine content in kelps is blanching (Blikra et al., 2022; Krook et al., 2023; Nielsen et al., 2020; Stévant et al., 2018; Trigo et al., 2023), however further understanding of processing's influence on the sensory profile is needed.

Beyond the suggestions of increasing saltiness, reducing astringency, and increasing softness, some consumers also suggested adding lemon to the spread, and removing the flavor of sea in both bread and spread. Adding lemon could be interpreted as a request to increase the freshness or sourness of the spread. Sourness is not pronounced in the studied seaweeds (Jönsson et al., 2023). The compounds in seaweed giving rise to the typical associations of "sea" include bromophenols, dimethyl sulfide (in red and green algae), and methyl mercaptan (in brown and some red algae) (Mouritsen, 2013). Hundreds of volatile compounds, hydrocarbons, ketones, aldehydes, alcohols, halogen, sulfur-containing

compounds, acids, esters, furans, and phenols, contribute to the sensory perception of seaweeds, but, to date, little is known about the influence of post-harvest treatment of seaweed on the sensory profile (Vilar et al., 2020).

Although knowledge about the impact of processing on sensory profiles of seaweeds is scarce, several strategies for the prevention of off-flavors are known (Colonia et al., 2023). These strategies include counteracting synthesis in the biomass, avoiding its liberation (through encapsulation), masking with other flavors, avoiding generation during processing, and removal by processing. Among these categories, fermentation exerts one promising strategy for the removal of off-flavors in seaweed. Seo et al. (2012) were able to decrease the expected odor intensity by four-fold after fermentation with the fungus *Aspergillus oryzae*. Similarly, alteration of the aroma profile was observed by Hung et al. (2023) after fermentation with *Bacillus subtilis* and *Saccharomyces cerevisiae*. Fermentation of seaweed prior to the addition to food products could be a strategic improvement to further increase the liking of seaweed. Pre-treatment of seaweed could hence be a necessity to further increase the proportion of seaweed in various products.

Whereas it seems more uncommon to include seaweed in various spreads, supplementing breads with seaweed has previously been investigated in several studies. According to Quitral et al. (2022), the maximum proportion of seaweed (not specifying species) in bread should not exceed 4 % to remain a sensory-appealing product. Lamont and McSweeney (2021) showed that the inclusion of a maximum of 4 % *Ascophyllum nodosum* and 2 % *Chondrus crispus* was accepted by consumers. Another study (Mamat et al., 2014) shows, contrary to the current study, that the hardness of the bread increases with the inclusion of seaweed (*Kappaphycus alvarezii*, 2–8 %) in the dough. Overall, these studies indicate that only a minor fraction of seaweed can be added to bread to retain its appealing sensory attributes.

Previous studies have shown that several factors drive the consumers' choice for seaweed food products. For example, Young et al. (2022) show that whereas flavor, nutritiousness, and healthiness are key motivators for an Australian population to consume seaweed, main barriers comprised limited accessibility, unaffordable pricing, and undesirable packaging. Moreover, younger, and health-conscious consumers with higher educational levels and higher income as well as females are more likely to become future seaweed consumers (Birch et al., 2019a). Researchers have also found differences between various groups of consumers among the Norwegian population, where progressive consumers are more likely to consume seaweed (Govaerts and Olsen, 2023). Contrarily, consumers with hesitancy toward unfamiliar products may have little sensory appeal for seaweed foods. The perceptions of seaweed as natural, unique, healthy, and sustainable create attitudes that promote seaweed consumption. Several traits, such as awareness of healthiness, environmental consideration, and consumer food innovativeness, can explain the consumers' willingness to eat seaweed. However, how this *intention* reasons with the future *behavior* of consuming seaweed remains unclear (intention-behavior gap) (Govaerts and Olsen, 2022). Understanding consumers' attitudes and choices for seaweed food products can give insights of practical relevance for several stakeholders.

Gaining insights into consumers' liking and attitudes regarding seaweed products holds practical significance when it comes to strategically positioning products in the market, creating product innovations, and developing effective communication strategies (Birch et al., 2019a, 2019b; Govaerts and Olsen, 2023; Palmieri and Forleo, 2020). For instance, progressive consumers could be motivated to eat seaweed if marketing communication emphasizes its uniqueness, healthiness, naturalness, and environmental sustainability. When targeting a reluctant consumer group, product developers could manage the sensory characteristics of seaweed, include seaweed in already familiar food products, or carefully choose various species for different purposes. As previous research has shown, consumers who live on vegan or vegetarian diets can be considered part of an early adopter group and could

be targeted more specifically (Merkel et al., 2021; Moss and McSweeney, 2021; Wendin and Undeland, 2020). Food producers should also consider developing packages appealing to the consumer (Lucas et al., 2019), and retailers should consider the positioning in the stores, so seaweed foods are placed around related products (Fredriksson et al., 2024). Finally, more research could focus on the social and cultural aspects of seaweed consumption in a European food context, to address the gap between consumers' intention and behavior for eating seaweed products.

While this current study offers valuable insights into the liking among Swedish consumers for two food products incorporating seaweed, it is important to acknowledge the limited number of participants as a considerable constraint. The study's reduced participant count diminishes its statistical power, explaining its categorization as a pilot study. To also account for the products without seaweed added, control samples could have been introduced to the consumer study. However, this would increase the number of samples the participants would need to evaluate. Another limiting factor relates to the amount of seaweed included in the products. As previously discussed, due to safety considerations and sensory-appealing constraints, only a minor proportion of seaweed was included in the two products. We believe that for seaweed to make a substantial contribution as a sustainable marine food source, it is imperative to increase the quantity we can consume to more than a few grams of dry weight per day.

5. Conclusions

This study investigated how the inclusion of seaweed in two different food products influenced the consumers' liking and the physicochemical properties of the products. For the bread, the color changed most when including *S. latissima*, whereas *P. palmata* had the greatest impact on the color of the spread. The texture changed differently with the inclusion of various seaweed types, but the baking of the bread may also exert an influencing factor. The consumers in this study overall slightly liked seaweed in both the formulations of bread and spread, where taste/flavor and texture proved to be the most important factors for the consumer's liking experience. *S. latissima* was liked best as a supplement in bread, and whereas *S. latissima* and *A. esculenta* were the preferred species in the spread, *P. palmata* received the lowest scores. Several suggestions for improvement were focused on improving the texture and removing the perceived marine off-flavors. This can be accomplished by introducing one or more pre-treatment steps, such as fermentation, deodorization, or high-pressure processing, before formulating the final product. Overall, this study provides a valuable understanding of consumer's liking of seaweed included in two food products in a Swedish context. This knowledge can become useful for product developers, retailers, marketers, researchers, and seaweed farmers in the transition toward a more sustainable food system.

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Ethical statement

Research carried out in Sweden which includes any processing of sensitive personal data is covered by the Swedish Ethics Review Act. This study includes questions about food perception that are not classified as sensitive personal data, according to the Data Protection Ordinance. According to the General Data Protection Regulation (GDPR), no information from any of the questionnaires can be traced to or used to identify any individual participant. All participants received

written and oral information about the analytical test and the contents, including allergens, of the tested products, and gave their informed consent to participate.

CRedit authorship contribution statement

Madeleine Jönsson: Conceptualization, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Ervan Maubert:** Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing. **Annabell Merkel:** Conceptualization, Writing – review & editing. **Cecilia Fredriksson:** Conceptualization, Funding acquisition, Resources, Writing – review & editing. **Eva Nordberg Karlsson:** Conceptualization, Funding acquisition, Resources, Writing – review & editing. **Karin Wendin:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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