Future Foods 12 (2025) 100765

Contents lists available at ScienceDirect

Future Foods

journal homepage: www.elsevier.com/locate/fufo

Sensory and physical characterization of cream cheese and baobab spreads containing seaweed (*Alaria esculenta*) and effect of LAB fermentation on consumer acceptance

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ARTICLE INFO

Keywords:
Alaria esculenta
Seaweed fermentation
Sensory properties
Physical properties
Consumer acceptance

ABSTRACT

In Western countries, brown seaweeds as a component in a meal are not well-accepted, mainly due to their 'fishy' and 'ocean-like' flavors. Therefore, ameliorating these notes might be essential for achieving wider acceptance of minimally processed seaweeds as ingredients in foods. In this study, brown seaweed *Alaria esculenta* (Badderlocks) was fermented with *Lactiplantibacillus plantarum* (formerly *Lactobacillus plantarum)* and included in two products (cream cheese and creamy baobab spread). Their sensory and physical properties were compared with those enriched with untreated (fresh frozen) and lactic acidified *A. esculenta* at 10 or 15 % (w/w) in these foods. Consumer testing ($n = 160$) was conducted on cream cheese, comparing the overall liking of those with 10 % untreated to those with 10 % fermented *A. esculenta* flakes. In the sensory test, the spreads containing untreated seaweed had a stronger 'seafood-like' flavor and 'harbor-like' odor than those with fermented seaweed. The spreads' texture and color varied, but pH, water activity, and moisture remained relatively constant during storage. The participants liked the cream cheese with the fermented seaweed more than the one with untreated seaweed. These findings support that seaweed fermentation is a promising processing route for developing new, functional seaweed-based foods with broader consumer acceptance.

1. Introduction

The use of seaweeds as a food ingredient is growing in popularity worldwide (Jayakody and Vanniarachchy, 2023). Seaweed is an attractive material for new product development in the food industry due to its unique nutritional profile and sustainability benefits (Jayakody et al., 2021). Seaweed farming has the potential to alleviate the negative environmental impact of traditional terrestrial agriculture due to the lower demand for land use and the decrease in agricultural greenhouse gas emissions. Recently, it was estimated that substituting human diets with 10 % seaweed worldwide would save up to 110 million hectares of land (Spillias et al., 2023). However, while seaweed is traditionally consumed as part of their diet, with the highest per capita consumption in Japan, the Republic of Korea, and China, there are still many countries where seaweeds are not well-accepted mainly due to the less-attractive 'fishy' and 'ocean-like' odor and flavor (Ranga Rao and Ravishankar, 2022; Jayakody and Vanniarachchy, 2023). Therefore, identifying solutions that effectively remove the fishy notes in seaweed are essential for achieving wider acceptance of seaweed as an ingredient for foods.

Microbial fermentation has shown the potential to improve the sensory properties of various foods, by reducing off-flavors and/or creating new flavor compounds (Canoy et al., 2024). In addition, due to its high energy efficiency compared to other biomass processing technologies like freezing or drying, fermentation has gained increasing interest since sustainability is an important priority today (Reboleira et al., 2021). Fermentation with lactic acid bacteria (LAB) has traditionally been used as a preservation technique in a wide range of food

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https://doi.org/10.1016/j.fufo.2025.100765
Received 14 July 2025; Received in revised form 15 September 2025; Accepted 18 September 2025
Available online 19 September 2025
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applications to increase their shelf-life and enhance their nutritional properties by improving nutrients' bioavailability (Zapaśnik et al., 2022). Lactic acid fermentation might also offer probiotic health benefits, possibly increasing consumer interest in fermented foods (Nithya et al., 2023).

Recently, the application of seaweed fermentation has gained increased interest, and there is evidence supporting its potential to improve its sensory properties (Reboleira et al., 2021). Bao et al. (2018) demonstrated that fermentation of *Spirulina* by *Lactobacillus plantarum* and *Bacillus subtilis* reduced off-flavors and generated high relative contents of acetoin, and other volatiles, resulting in a creamy odor. In addition, lactic acid fermentation of heat-treated brown seaweed species *Saccharina latissima*, resulted in less sea smell, milder taste, and a more attractive appearance (Bruhn et al., 2019). Despite the potential for developing fermented seaweed with improved sensory properties, only a few seaweed-containing fermented food products have been reported in the literature (Maiorano et al., 2022). Therefore, further research is needed to investigate whether incorporating fermented seaweed in food products can offer enhanced sensory properties in various food applications.

In preliminary investigations in our research group during the development of fermented seaweed, several LAB strains were tested, and volatile analyses were performed. These analyses revealed a reduction of organic halides in fermented seaweed, corresponding to a weaker ocean-like flavor as confirmed by descriptive sensory profiling with a trained panel. Based on these results, the strain with the most promising sensory properties was selected for use in the present study, motivated by the expectation that fermented seaweed would outperform both unfermented and acidified seaweed in food formulations.

The aim of this study was to assess the sensory profile, physical properties, and consumer acceptance of LAB fermented brown seaweed *Alaria esculenta* (Badderlocks) incorporated in two different products (cream cheese and baobab spread) at 10 or 15 % (w/w). The sensory and physico-chemical results were compared with untreated (fresh frozen) and lactic acidified *A. esculenta* (AE). The consumer study was conducted on the cream cheese containing the amount of fermented seaweed that showed the most promising sensory properties and was compared to untreated AE. The stability of the products' physical properties was evaluated.

2. Materials and methods

2.1. Seaweed raw materials

Fresh frozen (−20 °C) brown seaweed, AE was received from Seaweed Solutions (SES) Norway. The seaweed was harvested at the production site at Frøya. The frozen AE was segmented into approximately 0.5 × 0.5 cm flakes using an industrial meat cutter (Scharfen Germany, with a 5 mm diameter grinding plate). The seaweed was immediately vacuum-packed and refrozen at −20 °C in smaller portions until sample preparation.

2.2. Lactic acid fermentation of AE

2.2.1. Lactic acid bacteria and pre-culture preparation

The starter culture used for fermentation was *Lactiplantibacillus plantarum* (Lyoflora V-3, Sacco S.r.l., Cadorago, Italy). The stock culture of *Lactiplantibacillus plantarum* (L. *plantarum)* was stored at –80 °C in MRS medium supplemented with 20 % glycerol. The MRS medium used for pre-culture preparation comprised (in g/L): 10.0 sugar (glucose), 10.0 peptone, 10.0 beef extract, 5.0 yeast extract, 2.0 K_2HPO_4, 5.0 sodium acetate, 2.0 triammonium citrate, 0.2 $MgSO_4·7H_2O$, and 0.2 $MnSO_4·4H_2O$, with the addition of 1.0 mL Tween 80 per liter of distilled water. The inoculum was prepared by inoculating the stock culture (0.1 % (v/v)) into 100 mL MRS broth. The inoculated MRS broth was then incubated at 30 °C for 48 h. The bacteria were sub-cultured twice prior to their use in the fermentation experiments, ensuring sufficient biomass for the inoculation.

2.2.2. Solid-state fermentation process

Frozen ground AE (500 g) was thawed in vacuum-sealed bag with no additional water. The inoculum 0.5 % (v/w) was thereafter inoculated to reach the initial concentration of 1.0×10^6 CFU/g seaweed. After inoculation, the mixture was thoroughly homogenized to ensure an even distribution of the bacterial culture. The bag containing inoculated AE was vacuum-sealed (Henkelman, Germany) to achieve anaerobic conditions. Solid-state fermentation of AE was conducted under anaerobic conditions at 37 °C for 96 h, the pH was monitored, and microbial analyses were conducted to assess the microbial safety of fermented AE. The initial and final pH values of fermented AE were measured in triplicate by pH meter (Metter Toledo, S220). The fermented AE was vacuum packed, stored at 5 °C and used within a week for the sample preparation.

2.3. Lactic acidification

L-lactic acid (5 % w/v Merck) was used to lower the pH of AE from an initial value of 6.25 to a target of 4.25. A maximum of 2 % (w/w) of the lactic acid solution was added incrementally to the seaweed. The pH was measured after each addition until the desired pH was achieved.

2.4. Safety of fermented and acidified AE

Microbiological analyses of AE *w*ere conducted using accredited ISO and NMKL methods to assess its microbiological profile, focusing on the detection of indicator organisms, pathogenic bacteria, and spoilage microorganisms. These analyses were performed immediately upon receipt of fresh frozen AE, after treatment with lactic acid, and after fermentation with L. *plantarum* to evaluate the hygienic quality and safety of the seaweed following each treatment step.

2.5. Sample preparation

Commercially available cream cheese 25 % (Arla® Pro) and the original creamy baobab (ARWA®) were mixed with the untreated AE, fermented AE, and acidified AE in two different levels of 10 %, and 15 %, respectively. The seaweed (AE) was prepared according to Sections 2.1, 2.2 and 2.3. The frozen untreated AE was refrigerated the day before it was mixed with the products.

Seaweed inclusion levels of 10 % and 15 % were selected to provide sufficient sensory space to discriminate between experimental samples. The higher level (15 %) was included to allow comparison and to investigate more pronounced sensory differences between unfermented, fermented, and acidified seaweed samples. Furthermore, at higher doses, the health benefits of seaweed in food may be attainable; however, sensory quality should be maintained.

Cream cheese was chosen as a familiar, widely consumed dairy product that is commonly enriched with different ingredients, while baobab spread was included as a plant-based alternative for comparison within the same product category.

2.5.1. Cream cheese samples

Cream cheese and AE were mixed in 1 kg batches using a Thermomix TM6 (Vorwerk) at 80 °C, 500 rpm for 1 min. The mixture was then combined into one batch per sample in a 5-liter container and refrigerated until sensory analysis. Each sample was transferred into 29 mL plastic cups for physical measurements and stored in the fridge. Six cream cheese samples were included in the experimental design: three samples with 10 % untreated AE, fermented AE or acidified AE (sample names: CUN10, CF10 and CLA10, respectively), and three samples with 15 % untreated AE, fermented AE or acidified AE (CUN15, CF15 and CLA15, respectively). Samples were stored at 5 °C for up to 14 days.

2.5.2. Baobab spread samples

The mixing of seaweed and baobab spread was done by ARWA FoodTech AB using Bamix Gastro 350 Pro with 18,000 rpm for 1 min for each 1 kg batch. Each sample was then combined in a 5-liter container and refrigerated. Six baobab samples were included in the experimental design: 3 samples with 10 % untreated AE, fermented AE or acidified AE (BUN10, BF10 and BLA10), and three samples with 15 % untreated AE, fermented AE or acidified AE (BUN15, BF15 and BLA15, respectively). Samples were stored at 5 °C for up to 7 days.

2.6. Physico-chemical characterization of the spreads

Cream cheese samples containing seaweed were measured on days 1, 7, and 14 post-production, while baobab samples containing seaweed were measured 1 and 7 days post-production due to a maximum of 7 days shelf-life of the baobab spread. Measurements were also taken on day 1 for the original cream cheese and baobab spread (without seaweed) for comparison purposes.

2.6.1. pH

The pH values of the cream cheese and baobab spread samples were measured in triplicate using a pH meter (Mettler Toledo FiveEasy benchtop).

2.6.2. Water activity (aw) and moisture content

The a_w values were obtained by transferring approximately 2 g of cream cheese or baobab spread into disposable sample containers and measured using a PreWater Activity Analyzer (Aqua Lab) at 24 °C. All samples were measured in triplicate.

Moisture content was determined by mixing 2 ± 0.1 g of cream cheese or baobab spread with approximately 20 g. of dried white quartz (Sigma Aldrich, Buchs, Switzerland). Samples were placed in a drying oven (Memmert) for water evaporation at 105 $^{\circ}C$ ± 2 °C for 17 h until the weight was constant. Triplicates were made for each sample. Moisture content was calculated using the Eq. (1) below:

$$Moisture(\%) = ((mbefore - mafter) / msample) \ x \ 100 \tag{1}$$

Where *msample* is the mass in grams of added sample, *mbefore* is the mass in grams of the beaker with quartz, spatula, and sample and *mafter* is the mass in grams after drying/evaporation.

2.6.3. Color

The color of cream cheese or baobab spread samples was measured using a color analyzer device (BYK Additives and Instruments) that compares test specimen to certified standards and expresses values according to the CIE coordinates of L*, a*, and b* using an illuminant D65. L* indicates the degree of lightness from 0 (black) to 100 (white). The a* values range from −60–60 and determine positive values for red, and negative values for green, while b* values determine negative values for blue and positive values for yellow (Wadhwani and McMahon, 2012). All samples were measured in triplicate. Pictures were taken on day 1 and throughout the storage period for all samples to support interpreting color differences. The total color difference (ΔE*) was computed using the Eq. (2) below:

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

Where c represents the control (cream cheese or baobab spread without seaweed) and i for the respective seaweed treatment (untreated, fermented, or acidified).

2.6.4. Texture analysis

The textural characteristics of cream cheese or baobab spread samples were measured using a compression test on a TA.XTplusC texture analyzer (Stable Micro Systems) with a set of matched male and female 90° conical probes. Directly from cold storage, approximately 7 g cream cheese or baobab spread was placed into the female cone and compressed to eliminate air pockets. All excessive material was further removed to ensure a flat testing surface. The samples were then placed in the refrigerator for 15 min to minimize temperature fluctuations and ensure a final testing temperature of 5 $^{\circ}C$ ± 1 °C for all samples. The cone was introduced 10 mm into the sample at a 3.00 mm/*sec* speed using a 30 kg compression load. The samples' firmness, spreadability and stickiness were determined utilizing force-time plots. Firmness was measured by the force, reached at a maximum penetration depth of 10 mm. The force required to perform a shearing process was used to measure spreadability, and the force used to withdraw the cone from the sample represented the samples' stickiness (Bayarri et al., 2012). All samples were measured in triplicate.

2.7. Sensory analysis

The sensory analysis was conducted in a laboratory built after ISO and ASTM standards. The sensory analysis was performed in two test settings, as the cream cheese and baobab spread samples had distinctive sensory properties. A quantitative descriptive sensory analysis was performed for each spread type using a similar training and evaluation process. The scope of the sensory study, test protocol, and adherence to General Data Protection Regulation (GDPR) were reviewed and approved by the Research Ethics Committee for the Faculty of Health and Science at the university (date: 16–05–2024, case number: 504–0501/24–5000).

2.7.1. Panel and training

Ten panelists were recruited from the external sensory panel at the Department of Food Science, University of Copenhagen. They participated in the sensory evaluation by informed consent. A total of 10 h of training (4 sessions) was performed for each spread type. During training, the panel familiarized themselves with the samples and developed sensory vocabularies with appropriate definitions and reference materials (Tables 1 and 2) to describe the appearance, odor, flavor, texture, and aftertaste of the samples. A total of 18 attributes for cream cheese and 6 attributes for baobab samples were used to describe their sensory profiles. The panel was trained to evaluate the attribute intensities in the samples using 150 mm line scales, which were marked with relevant anchor terms.

2.7.2. Evaluation

The evaluation was performed in the sensory booths at 22 ± 1 °C. The samples were taken from the refrigerator at 5 °C to a temperature-controlled cabinet and tempered to room temperature at 20 °C for half an hour before serving. Approximately 20 g of each sample was placed in 29 ml transparent plastic cups with lids, identified by a random 3-digit numeric code. For each spread type (cream cheese or baobab spread samples), the panel evaluated all 6 samples in one session using a complete randomized block design. Within each replicate block, the samples were presented successively in a randomized order to minimize systematic block effects. The sensory evaluation was performed in three replicates, with 10-minute breaks between each replicate. Each panelist evaluated the intensity of each sample's attribute on a scale, with higher numbers indicating greater intensities. The assessors were asked to cleanse their palates with ambient-temperature water or sparkling water or plain crackers between samples. Data were collected using the Fizz software (Biosyst'emes, France).

2.8. Consumer test

Consumer testing on the two cream cheese samples, the one with 10 % untreated AE and the one with 10 % fermented AE, was performed in Denmark (at a food festival). New batches of samples were prepared using the process described in Section 2.5.1. A teaspoon (5 g) of each sample was served on sausage tray cardboard (16×10 cm) coded with a

Table 1
Sensory attributes, definitions and reference materials used in the sensory descriptive analysis for the cream cheese samples containing different treatments of *Alaria esculenta.*

Cream cheese samples				
Modality	Attributes	Definition	Reference materials	Anchor points
Appearance (A):	Green	Light green, like the color of fresh avocado	No reference material was used	A little - A lot
Odour (O):	Seaweed	Link to the smell of harbor, presence of marine life notes/ crustacean like, e.g. mussels	Toasted Nori seaweed (~ 0.5 g)	None – A lot
	Sour cream	Creamy, buttery with mild acid notes	Crème fraiche (38 %), Karolines Køkken, Arla Foods	None – A lot
	Fresh green	Hints of herbs like chives and dill	Mix of chopped dill and chives	None - A lot
	Metallic	The smell of hands after touching coins	No reference material was used	None - A lot
Basic taste (BT):	Sour	Basic taste reminiscent of citric acid	0.6 g/L Citric acid in water	A little – A lot
	Sweet	Basic taste reminiscent of table sugar	12 g/L Sucrose in water	None - A lot
	Salty	Basic taste reminiscent of salt	4 g/L NaCl in water	A little – A lot
Flavor (F):	Seaweed	Salty with shellfish notes/ fishy notes/ seafood-like taste	Fresh frozen seaweed	None - A lot
	Sour cream	Buttery and slight acidic	A tablespoon of Crème fraiche 38 %, Arla Karolines Køkken	None - A lot
	Metallic	Fish mineral oil	No reference material was used	None - A lot
	Fresh green	Reminiscent of herbs like dill and chives	Mix of chopped dill and chives	None - A lot
	Balance	Harmony in the flavor, without any dominating taste notes	No reference material was used	None - A lot
	Novelty	Unusual and not a familiar flavor	No reference material was used	None - A lot
	Freshness	It feels like it has been freshly made. Lack of off flavor, pleasant in the mouth	No reference material was used	None - A lot
Texture (Tx):	Chewy	The amount of time needed to chew before swallowing	No reference material was used	None - A lot
	Melting	The ease with which cream cheese melts in the mouth	No reference material was used	A little – A lot
Aftertaste (AT):	Salty	Salty taste remaining in the mouth after 5 s of swallowing	No reference material was used	None - A lot

3-digit random number and presented in a balanced, randomized order. Mini toast crackers were provided as a carrier for tasting the cream cheese samples.

Participants tasted each cream cheese sample and indicated their overall liking on a 9-point hedonic scale (Jones et al., 1955). They also had the option to write their input for each sample. After tasting both

Table 2
Sensory attributes, definitions and reference materials used in the sensory descriptive analysis for the baobab spread samples containing different treatments of *Alaria esculenta.*

Baobab samples				
Modality	Attributes	Definition	References	Anchor points
Odor (O):	Ocean-like	Association with the smell of coastal shores	Toasted Nori seaweed	None - A lot
Flavor (F):	Sourness	Clear sour taste better described by fresh lemon juice - not citric acid	Freshly squeezed lemon juice	A little – A lot
	Acidity	Sharp acidity perceived in vinegar	Vinegar diluted in water (1:3)	A little – A lot
	Pungent	Sharp, tickling sensation similar to that of mustard	Colman mustard	A little – A lot
	Seaweed-like	Seafood notes like boiled mussels	Unfermented, raw seaweed	None - A lot
Mouthfeel (MF):	Astringent	Dry tongue, mouth and teeth after swallowing	Black tea (Medova original). A 500 ml boiling water with 2 teabags and 15 min soaking time	None - A lot

samples, participants were asked to express the level of agreement using a 5-point Likert scale on the statements: “I am aware that fermenting seaweed can improve its nutritional value”, “If I knew the seaweed in one of the products was fermented, I would prefer to buy it over the one with untreated seaweed” and “I would buy the product I liked the most, regardless of whether the seaweed in it was fermented”. Participants signed informed consent prior to participation and completed basic demographic questions.

2.8.1. Consumer population

A total of 160 adults participated in the test, of whom 62 % were women. The majority were above 45 years, with 21 % in the 45–55 age category and 62 % over 55 years. Income levels were equally distributed, with most having a higher educational level (35 % completed vocational studies and 50 % holding a bachelor’s or master’s degree). Regarding seaweed consumption, a significant proportion reported not consuming it frequently, with 45 % consuming it less than once a month and 38 % reporting they had never consumed it.

2.9. Data analysis

For the data from physical analysis, the significance of differences between the sample means was determined by one-way analysis of variance (ANOVA) with post-hoc test using the statistical package (RCMDR) in the R software (version 4.4.0). The sensory data were analyzed by three-way analysis of variance (ANOVA) using the Lmer test in R software to investigate sample differences. In this mixed model analysis of variance, the sample was a fixed factor, and assessor and replicate were random factors. Tukey post hoc pairwise comparisons were used in case of significant sample effect was found for a sensory attribute. Principal Component Analysis (PCA) was performed using the FactoMineR package in Jamovi (version 2.7.6) to study attribute sample relationships, including both sensory and physicochemical data. All variables were scaled and standardized prior to PCA. Only the sensory and physicochemical attributes that showed statistically significant differences between experimental samples were included, as these were considered as the most relevant variables for interpreting the structure of the samples. The resulting plots are provided in supplementary figures

S3 and S4. For the consumer test, a paired-t-test was used to see whether the two samples had a significant difference in the overall liking score.

3. Results

3.1. pH and microbiological quality of Alaria esculenta

In this study, the pH value of untreated (fresh frozen) seaweed was 6.25. After 96 h of lactic acid fermentation with L. *plantarum*, the pH dropped to 4.29, indicating the successful fermentation of *Alaria esculenta* (AE). Additionally, the lactic acid acidification of AE was controlled at a pH level of 4.25 by adding 5 % w/v l-lactic acid to the ground seaweed slurry.

Microbial safety analysis of untreated, fermented, and lactic acidified AE showed no bacterial pathogens or spoilage microorganisms in all tested samples, ensuring that the samples were safe for further study and the lactic acid fermentation process was conducted under optimal conditions. These results can be seen in supplementary tables S1 and S2.

3.2. Physico-chemical characteristics of the spreads

3.2.1. pH of the spreads

Adding seaweed increased the pH of cream cheese, independent of the AE treatment (untreated, fermented, or acidified) or dosage (10 or 15 %) (Table 3). The pH of all samples remained relatively constant during one week of storage at 5 °C, but it slightly decreased ($p < 0.05$) from day 7 to day 14 in most of the samples. After two weeks of storage, the pH ranged from 4.70–4.94, with the lowest for cream cheese with 15 % fermented AE (CF15) and the highest for cream cheese with 15 % untreated AE (CUN15).

Similarly, adding 10 or 15 % untreated, fermented or acidified *AE* to baobab spread significantly increased the pH compared to the baobab without seaweed, but all samples remained strongly acidic (pH < 3.0) (Table 4). There were no consistent pH differences between the baobab spreads with different doses and treatments of AE. After a week, the pH significantly increased, mainly in the samples with 15 % seaweed, and after 2 weeks, no measurements were performed due to a maximum of 7 days shelf-life of the baobab spread.

3.2.2. Water activity and moisture content of the spreads

In both cream cheese and baobab spread samples, the water activity was not influenced by the amount nor treatment of AE (Tables 3 and 4).

The moisture content of cream cheese was 66.7 ± 0.09 %, and, after adding AE, varied between 66.2 ± 0.4 - 68.6 ± 0.4 (Table 3). On day 1, the moisture content of the samples with fermented seaweed was slightly ($p < 0.05$) lower than that of untreated seaweed, at 10 % and 15 %, which was not observed after 1 or 2 weeks of storage. There was no clear effect of the amount or treatment of AE added on the storage time.

For the baobab spread, the moisture content significantly increased after adding AE from 43.1 ± 0.1 to 49.0 ± 0.1 - 52.0 ± 0.1 % (w/w) (Table 4). On day 1, the baobab spread with 10 % untreated AE had a higher moisture content than those with fermented or acidified AE. However, this difference was not observed for the samples containing 15 % AE. After 7 days, the moisture content slightly decreased for all spreads from 49.0 ± 0.1 - 52.0 ± 0.2 % (w/w) to 48.5 ± 01.- 51.5 ± 0.1 % (w/w).

Table 4
pH, water activity and moisture of baobab spread samples on day 1 and day 7 post production.

	Day 1			Day 7		
Samples	pH	aw	Moisture (%)	pH	aw	Moisture (%)
BB	2.78 (0.00)e	0.976 (0.002)a	43.1 (0.1) e	–	–	–
BUN10	2.99 (0.02)c	0.979 (0.002)a	50.3 (0.3) b	3.00 (0.01)a	0.975 (0.001)a	49.7(0.3) b
BF10	2.97 (0.02) ac	0.978 (0.003)a	49.0 (0.1) a	3.05 (0.04) ab	0.977 (0.002)a	48.5 (0.1) a
BLA10	2.94 (0.02) ab	0.978 (0.001)a	49.5 (0.1) a	3.03 (0.03) ab	0.973 (0.001)a	48.9 (0.4) ab
BUN15	2.87 (0.02) d	0.977 (0.002)a	51.7 (0.4) d	3.06 (0.07) ab*	0.974 (0.002)a	50.9 (0.1) c
BF15	2.94 (0.01) ab	0.980 (0.001)a	52.0 (0.2) d	3.12 (0.05) b*	0.977 (0.002)a	51.5 (0.1) c
BLA15	2.92 (0.03) bd	0.979 (0.002)a	51.0 (0.1) c	3.03 (0.04) ab*	0.977 (0.004)a	51.2 (0.5) c

Values are mean (SD), ($n = 3$). BB: baobab without seaweed; BUN10, BF10, BLA10: baobab with 10 % untreated, fermented and acidified AE; BUN15, BF15, BLA15: baobab with 15 % untreated, fermented and acidified AE. Letters indicate significant differences among samples ($p < 0.05$). The * indicates significant differences ($p < 0.05$) from day 7.

3.2.3. Color of the spreads

The incorporation of seaweed in the cream cheese significantly decreased the lightness (L* values) and yellowness (b* values) of the samples ($p < 0.05$) compared to the cream cheese without AE (Fig. 1). The sample with the fermented seaweed (CF15) showed the most pronounced ΔE* ($p < 0.05$, supplementary figure S1), with slightly darker and less yellow notes. The cream cheese samples containing the untreated AE showed greater negative a* values . During storage between day 1 and day 7, the color did not change; however, after two weeks, the a*values of the sample with 15 % untreated seaweed decreased, indicating a less green value. The b* values significantly increased in the samples with 10 % and 15 % untreated and fermented seaweed.

Similarly, adding AE in baobab spread significantly reduced the degree of lightness (L*), redness (a* values), and yellowness (b* values) in the samples ($p < 0.05$, Fig. 1). Neither the treatment of seaweed nor the seaweed concentration affected the samples' a* and b* values. The

Table 3
pH, water activity and moisture content of the cream cheese samples on day 1, day 7 and day 14 post production.

	Day 1			Day 7			Day 14		
Samples	pH	aw	Moisture (%)	pH	aw	Moisture (%)	pH	aw	Moisture (%)
CC	4.01 (0.00)c	0.992 (0.000)a	66.7 (0.09)a	–	–	–	–	–	-
CUF10	4.92 (0.19)ab	0.987 (0.003)a	68.0 (0.03)bc	5.04 (0.02)a	0.988 (0.001)a	67.9 (0.4)a	4.90 (0.01)cd	0.988 (0.002)a	67.8 (1.2)a
CF10	4.88 (0.05)ab	0.989 (0.001)a	66.4 (0.5)a	4.86 (0.01)b	0.987 (0.000)a	67.06 (0.7)a	4.75 (0.01)ab*#	0.991 (0.002)a#	67.7 (0.5)a
CLA10	4.87 (0.06)a	0.991 (0.002)a	66.2 (0.4)a	4.94 (0.01)ab	0.987 (0.001)a*	67.67 (1.0)a	4.79 (0.03)a#	0.991 (0.000)a#	67.2 (0.6)a
CUF15	5.13 (0.07)b	0.990 (0.002)a	68.6 (0.4)c	5.05 (0.03)a	0.987 (0.000)a*	68.1 (0.5)a	4.94 (0.04)d*	0.992 (0.001)a#	67.1 (1.2)a
CF15	4.94 (0.05)ab	0.990 (0.000)a	66.8 (0.9)ab	4.90 (0.09)b	0.993 (0.107)a	68.55 (0.7)ab*	4.70 (0.02)b*#	0.992 (0.001)a	67.3 (0.4)a
CLA15	5.01 (0.02)ab	0.991 (0.001)a	68.5 (0.5)c	4.92 (0.03)b	0.981 (0.001)a*	70.1 (0.5)b	4.82 (0.06)ac*	0.988 (0.006)a	68.1 (1.0)a#

Values are mean (SD), ($n = 3$). CC: cream cheese without seaweed; CUN10, CF10, CLA10: cream cheese with 10 % untreated, fermented and acidified AE; CUN15, CF15, CLA15: cream cheese with 15 % untreated, fermented and acidified AE. Letters indicate significant differences among samples ($p < 0.05$). The * indicates significant differences ($p < 0.05$) from day 1 and # indicates significant differences from day 7.

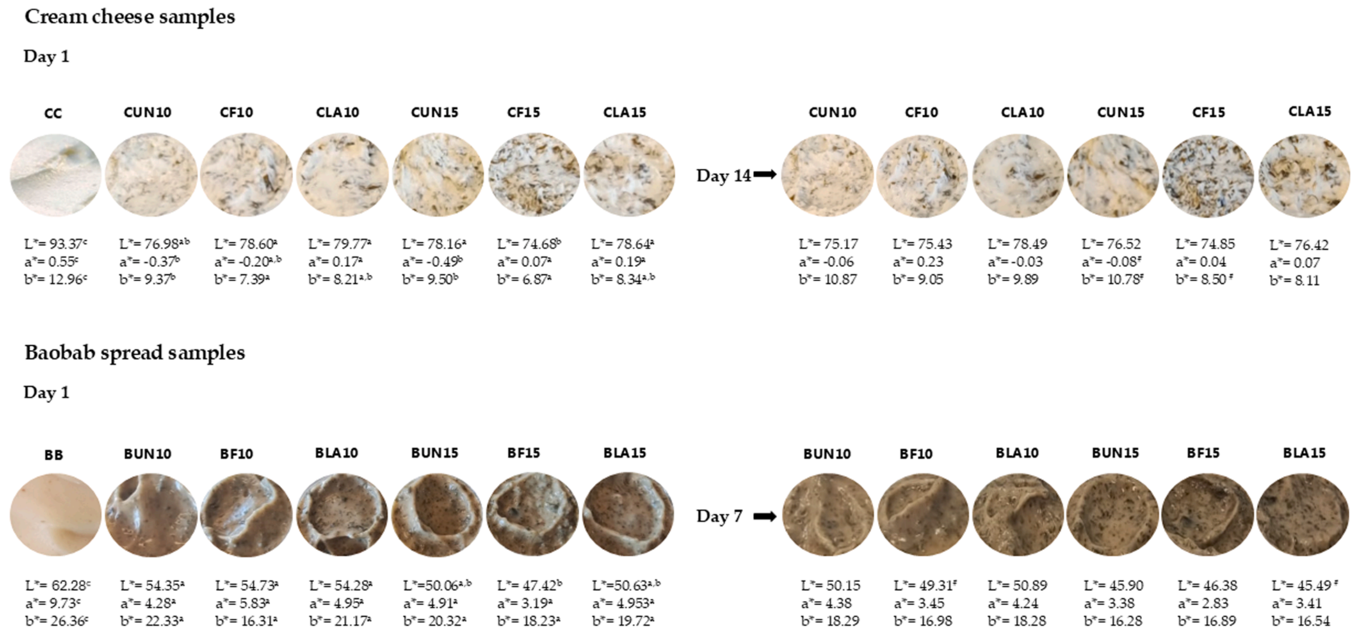

Fig. 1. Color characterization ($n = 3$). Cream cheese sammples. CC: cream cheese without seaweed; CUN10, CF10, CLA10: cream cheese with 10 % untreated, fermented and acidified AE; CUN15, CF15, CLA15: cream cheese with 15 % untreated, fermented and acidified AE. Baobab samples. BB: baobab spread without seaweed; BUN10, BF10, BLA10: baobab with 10 % untreated, fermented and acidified AE; BUN15, BF15, BLA15: baobab with 15 % untreated, fermented and acidified AE. Letters indicate significant differences among samples ($p < 0.05$) and # indicates significant differences ($p < 0.05$) from day 1.

fermented sample (CF15) showed the most pronounced ΔE* ($p < 0.05$, supplementary figure S2), with slightly darker notes (Fig. 1). After a week, the L* values decreased, most pronounced in the samples with 10 % fermented and 15 % acidified AE (darkness increased).

3.2.4. *Texture of the spreads*

The texture of cream cheese was affected by the treatment of AE. Even though all samples differed from the cream cheese without AE (solid black horizontal line in Fig. 2), the sample with untreated AE showed the most pronounced difference, whereas the samples with

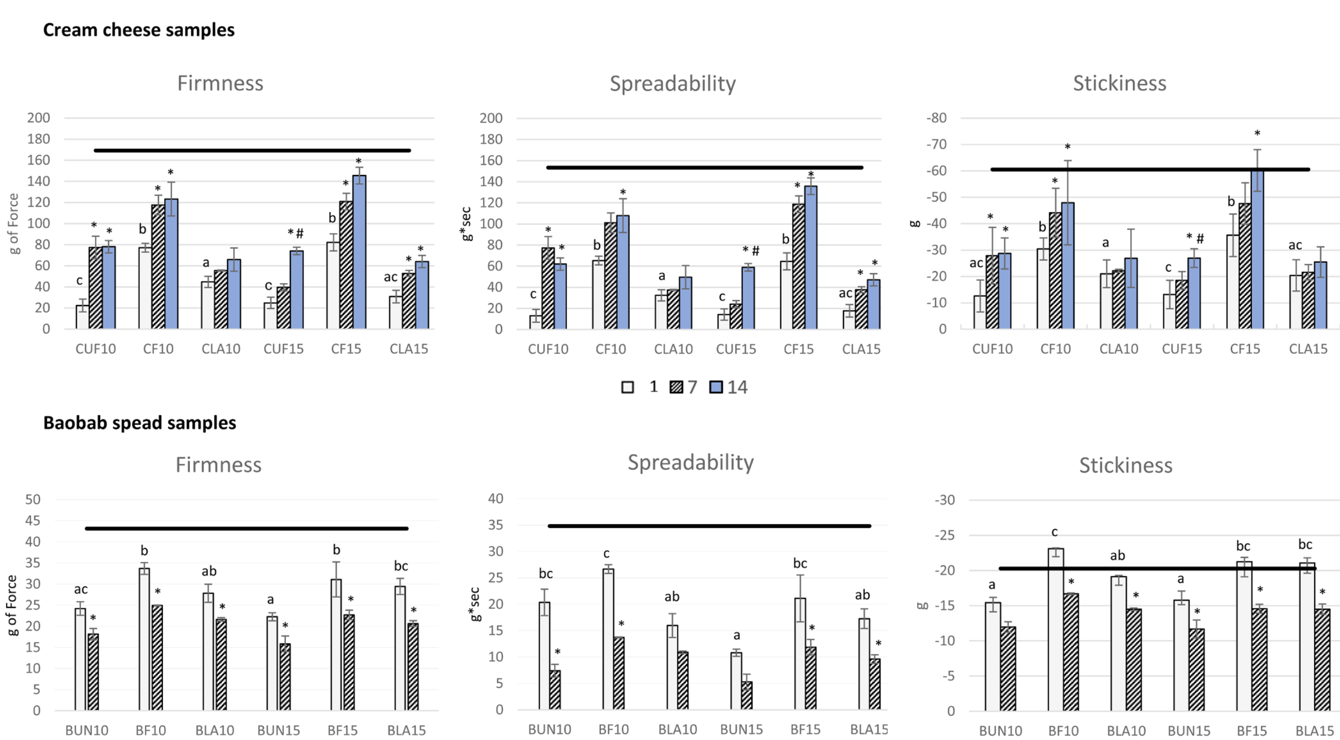

Fig. 2. Texture characterization ($n = 3$). The error bars indicate (SD). **The solid black horizontal lines represent the sample without seaweed.** CUN10, CF10, CLA10: cream cheese with 10 % untreated, fermented and acidified AE; CUN15, CF15, CLA15: cream cheese with 15 % untreated, fermented and acidified AE. BUN10, BF10, BLA10: baobab with 10 % untreated, fermented and acidified AE; BUN15, BF15, BLA15: baobab with 15 % untreated, fermented and acidified AE. Letters indicate significant differences among samples ($p < 0.05$). The * indicates significant differences ($p < 0.05$) from day 1 and # indicates significant differences from day 7.

fermented AE showed the least (Fig. 2). The samples with the untreated AE were slightly more liquid than those with the fermented and acidified AE. At both 10 % and 15 % concentrations, the samples with the fermented AE showed significantly higher firmness, spreadability, and stickiness values, indicating a firmer, less spreadable, and stickier texture than those with the untreated and acidified AE. After two weeks of storage, firmness, spreadability, and stickiness values increased significantly in most samples, indicating firmer, less spreadable, and stickier samples. The most significant changes in the texture parameters measured were observed for cream cheese with untreated and fermented AE, while cream cheese with acidified AE remained relatively stable.

For the baobab spread, the texture was also affected by the addition and treatment of AE

(Fig. 2). However, the impact of adding AE was less pronounced on the baobab spread's texture compared to the cream cheese. Higher firmness and stickiness were observed in the baobab spread with 10 and 15 % fermented AE compared to the samples with 10 and 15 % untreated AE. After a week, in contrast to the cream cheese samples, the firmness, spreadability, and stickiness values were reduced in all of the samples, indicating less firm, more spreadable, and less sticky samples. The spreadability values of baobab spread with 10 % untreated AE were reduced more than two times, and those with the fermented 10 and 15 % and acidified 15 % were reduced to half.

3.3. Descriptive sensory analysis of the spreads

3.3.1. Cream cheese samples

The samples with the untreated AE had significantly stronger seaweed odor/flavor, metallic odor/flavor, and greener color than those with fermented and acidified AE. The samples with fermented and acidified AE were characterized by higher sour cream odor/flavor notes, fresh green flavor, and higher freshness and balanced flavor. The perceived freshness of the samples increased when the perceived seaweed and metallic notes decreased in the cream cheese samples (Fig. 3).

The sensory properties of the samples with the 10 % fermented and acidified AE were similar. However, at the higher AE concentration (15 %), the seaweed flavor significantly increased, and the perceived sour cream flavor was significantly reduced in the sample with the acidified AE. In contrast, the sample with fermented AE maintained its freshness and balanced flavor with no increase in perceived seaweed flavor. The 15 % fermented AE sample showed some texture variation and was perceived as most chewy.

3.3.2. Baobab spread samples

The seaweed flavor was significantly more pronounced in the samples with untreated AE and significantly higher in the sample with 10 % untreated AE than with 10 % fermented AE. When the dose of AE increased, the seaweed flavor was significantly increased in both samples with untreated and fermented AE. It was strongly perceived in the sample with 15 % untreated AE, scoring at the top of the scale, with a statistically significant difference only from the sample with 15 % acidified AE. The perceived seaweed flavor was similar between the fermented and acidified AE samples in both doses. However, the perceived seaweed flavor significantly increased only in the sample with fermented AE when the dose increased, likely due to its low intensity at the 10 % concentration. The samples with untreated AE had a higher perceived ocean smell than those with fermented and acidified AE, with a statistically significant difference between the BUN15, BLA10, and BF10 samples (Fig. 4). The perceived sourness was significantly reduced when the seaweed concentration was increased in the fermented AE sample, although it remained similar to the other baobab spread samples.

3.4. Consumer test

The hedonic test showed that participants liked the cream cheese with the fermented rather than the untreated AE ($p < 0.05$), with an overall liking score of 7.2 (indicating liking moderately) and 6.1 (liking slightly), respectively. The proportion of participants scoring above 5 on the 9-point hedonic scale was 91 % for the sample containing fermented AE and 68 % for the untreated AE. Only 4 % of participants disliked the cream cheese with fermented AE (scoring below 4 on the 9-point

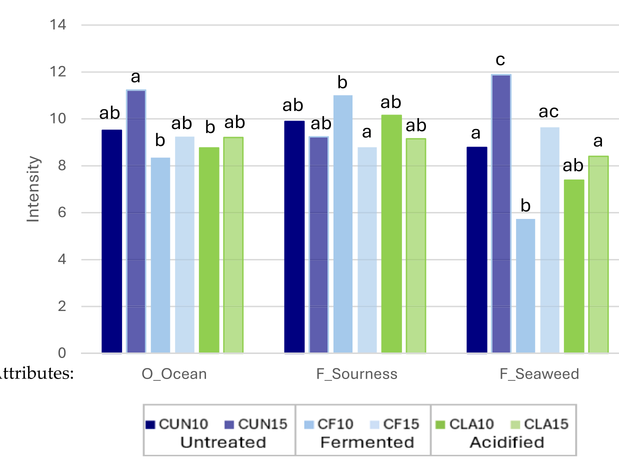

Fig. 4. Baobab spread samples' perceived sensory attributes with statistically significant differences ($p < 0.05$). BUN10, BF10, BLA10: baobab spread with 10 % untreated, fermented and acidified AE; BUN15, BF15, BLA15: baobab spread with 15 % untreated, fermented and acidified AE. Different letters indicate significant differences.

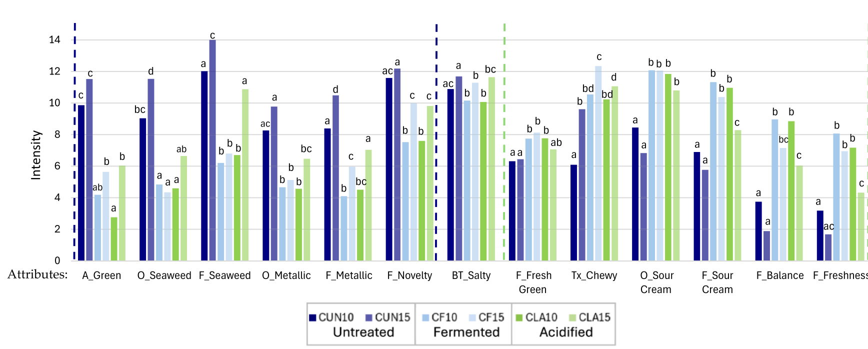

Fig. 3. Cream cheese samples' perceived sensory attributes with statistically significant differences ($p < 0.05$). Different letters indicate the differences. CUN10, CF10, CLA10: cream cheese with 10 % untreated, fermented and acidified AE; CUN15, CF15, CLA15: cream cheese with 15 % untreated, fermented and acidified AE. On the left side are the attributes with higher perceived intensity in the samples with untreated AE, while on the right are those perceived higher in the samples with fermented and acidified AE.

hedonic scale) whereas 22 % disliked the cream cheese with untreated AE.

A total of 103 participants provided feedback on the two cream cheese samples. The cream cheese with fermented seaweed received mostly positive reactions, with 54 comments highlighting its milder, creamier taste, less fishy flavor, and more balanced and fresher taste.

Negative feedback (6 comments) mentioned a less-than-expected taste. On the other hand, the cream cheese with untreated seaweed received more negative feedback (28 comments), with strong fishy and seaweed flavors, some mentioning it tasted like old fish or was too acidic. Positive comments (15 comments) praised its stronger, saltier taste and more pronounced seaweed flavor.

Half of the participants were unsure about the nutritional benefits of fermenting seaweed. When asked if they would buy the one they liked, regardless of whether it was fermented, 74 % agreed with this statement. If they knew which of the samples they tasted contained fermented seaweed, 38 % reported that they would prefer it, and 50 % were unsure.

4. Discussion

This study underlines the potential of LAB fermentation of seaweed (*Alaria esculenta*) to create spreads with improved sensory properties and higher consumer acceptance. Both spreads (cream cheese and baobab) containing untreated *Alaria esculenta (AE)* had stronger seaweed flavor (reminiscent of seafood) and odor (reminiscent of the harbor), which were less pronounced with fermented and acidified AE. The effects on the physical properties of the spreads varied, highlighting the importance of the food matrix. The baobab spread, an oil-in-water emulsion, and the cream cheese, an acid-induced gel, reacted differently to the seaweed addition. However, the pH, water activity, and moisture content of both spreads remained relatively constant after addition of seaweed.

4.1. Physico-chemical characteristics of cream cheese and baobab spread containing seaweed

The addition of AE significantly influenced the texture of both cream cheese and baobab spread. All samples were less firm and sticky but more spreadable than the spreads without seaweed. Their higher pH and moisture content might explain these texture differences (Brighenti et al., 2008). The moisture content of both spreads slightly increased with the addition of seaweed, which could be related to differences between the cream cheese/baobab and the seaweed that has higher water holding capacity (WHC) as it is fiber-rich (Roohinejad et al., 2017).

In cream cheese, when comparing the different seaweed treatments, fermented AE caused increased firmness, lower spreadability, and greater stickiness than the untreated and acidified AE. In addition to this, the sample with fermented AE was described as the chewiest in the descriptive sensory test. A previous study has reported that participants prefer firmer cream cheese (Foguel et al., 2021) and in our study, it was found that the samples with fermented AE showed a firmer texture closer to the texture of spreads without seaweed, as compared to the samples with untreated and acidified AE, where firmness and spreadability were reduced dramatically. In baobab, the samples with fermented AE appeared more similar to the samples with acidified AE but also had higher firmness, lower spreadability, and greater stickiness than the untreated AE.

There were no significant variations in pH for both spreads, and the moisture differences between the different seaweed treatments could not completely translate the perceived differences in texture. Moisture was lower in both spreads with fermented AE except for the 15 % concentration in baobab samples. Studies have shown that fermentation of seaweed results in a notable decrease in fiber content; therefore, the WHC would be expected to be reduced and moisture to be lower (Michalak and Chojnacka, 2016). Research also supports that fermentation is expected to change the texture of seaweed due to alterations in chemical composition and nutrient content, but to what extent this can change the functionality of seaweed as an ingredient is difficult to speculate (Figueroa et al., 2023). In addition, the textural properties of food are influenced by several factors, including composition, processing, rheological properties and environmental conditions (Vithanage et al., 2009). Therefore, other factors not detected in this study might explain the significantly higher firmness of the samples with fermented seaweed, compared to those with untreated seaweed.

Many studies have shown that seaweed can change the color of the final products by integrating its natural pigments (Ranga Rao and Ravishankar, 2022). The addition of seaweed slightly changed the cream cheese's and baobab's color, increasing the darkness and reducing the redness and yellowness. This finding correlates well with other studies where seaweed was incorporated into spreads and other food matrixes and significantly changed the color by reducing lightness and increasing the green color (Roohinejad et al., 2017; Jönsson et al., 2024). The untreated AE slightly enhanced the greener color of cream cheese, as confirmed by both analytical measures and sensory results, and the samples with 15 % fermented AE were slightly darker. The importance of color in a product is correlated with the importance of appearance, which can significantly influence the overall acceptability of the products (Lakshminarayana et al., 2022). However, the differences in color in our samples between the different AE treatments were not easily visible to the naked eye. Lastly, in our consumer test, color did not influence acceptance, where taste was the primary determinant.

4.2. Storage stability

This study observed a decrease in pH during storage of up to 14 days in all cream cheese samples containing AE, which typically occurs in cream cheese during storage, as reported in earlier studies (Perveen et al., 2011). The reduction in pH may be attributed to the continuous production of lactic acid by the starter cultures. It is, therefore, difficult to determine if this change is affected by the addition of seaweed, but it was observed that the change was more pronounced with the addition of fermented AE. For baobab, it was observed that the pH of the samples slightly increased only in the 15 % samples during 7 days of storage. Information about baobab spread is very limited, and it is therefore difficult to address how the changes during storage are related to the baobab itself, or if the changes are related to the addition of seaweed. A study on the production of baobab-based mayonnaise by Lam and Zhu (2021) showed a much higher pH of 3.23 and a decrease of pH during two weeks of storage.

Cream cheese is susceptible to syneresis due to poor WHC; therefore, moisture and water activity loss are expected during storage (Fox et al., 2017). In addition, the reduction of pH causes the protein matrix of an acid curd to contract and expel water (Perveen et al., 2011). However, no significant changes in water activity and moisture content were observed, and there were no clear tendencies between the three different AE treatments. This may be attributed to seaweed, which contains dietary fibers that exhibit water-holding capacity and have been shown to improve the overall WHC of several products, including meat and dairy products (Roohinejad et al., 2017). There were also no changes in the water activity and moisture during the storage of the baobab samples.

Regarding color changes during storage, the color of both spreads and all samples appeared slightly darker. While this change may be undesirable, this study did not investigate whether or to what degree it can affect consumer acceptance.

During storage, all cream cheese samples containing seaweed exhibited increased firmness and stickiness and decreased spreadability. Earlier studies have shown that cream cheese undergoes textural and structural changes during prolonged cold storage and that this is likely related to the slow crystallization of fat or other structural rearrangements in the gel network (Brighenti et al., 2018). These studies also observed increased hardness, which is highly correlated with a decrease in spreadability and an increase in stickiness, as observed in the present study. On the other hand, the firmness of the baobab samples decreased during storage. This could be explained by the baobab fruit's pectin content, a common hydrocolloid used to enhance the emulsion stability of various foods (Patova et al., 2021; Büyük et al., 2024). Pectin is very efficient in quickly stabilizing an emulsion, but less efficient in maintaining stability during prolonged storage, which explains the loss of firmness during storage.

4.3. Sensory and consumer test results

The descriptive sensory analysis showed an inverse association between seaweed flavor and perceived freshness and balance in flavor in the cream cheese samples. A previous study found a similar result: adding 0.50 % of different dehydrated seaweed species in dairy products resulted in lower perceived flavor quality as seaweed flavor increased (del Olmo et al., 2018). Our sensory test also showed that the cream cheese with fermented AE exhibited reduced seaweed and metallic flavor notes. Previous studies on cream cheese highlight that consumers expect it to be mild with slight acidic notes, and therefore, intense flavors from seaweed might negatively affect its acceptance (Foguel et al., 2021). Indeed, the findings from our consumer test showed that more people disliked the cream cheese with the untreated seaweed because it had a strong fishy flavor, and as a result, some participants reported that seaweed could not pair well with cream cheese. Conversely, when the seaweed was fermented, cream cheese maintained its mild and creamy notes, which resulted in a statistically significant increase in consumer liking on average.

The sensory analysis indicated that the inclusion level appeared significant in the baobab spread, as in the lower levels, the baobab could easily mask other flavors due to its high sourness. When the dose was higher, the untreated seaweed imparted a stronger seaweed flavor. However, the sourness from the baobab could still mask this flavor, particularly in the fermented and acidified AE samples, up to a certain point. Given the increasing focus on sustainability and growing interest in new plant-based foods, baobab spread might be a promising option for incorporating seaweed (Fredriksson et al., 2023). In addition, previous research has demonstrated that consumers prefer the incorporation of seaweed in foods that could effectively hide its strong flavor, and a plethora of studies have highlighted the nutritional benefits of seaweed and the need for possibilities to mask or minimize its flavor (Rioux et al., 2017; Moss and McSweeney, 2021; Jönsson et al., 2024).

The literature has demonstrated the potential of LAB fermentation to improve seaweed's sensory properties (Hung et al., 2023), and our findings support this in real food applications. AE was the seaweed species applied, and previous studies have shown that it is among the species with a milder flavor (Jönsson et al., 2023). An earlier study compared the liking of spreads incorporated with different dehydrated seaweed species; *Palmaria Palmata* was the least liked due to its strong marine notes, whereas AE was the most liked (Jönsson et al., 2024). Therefore, the observed effect of fermentation may be more pronounced in seaweed species with a stronger marine flavor. Additionally, research supports the incorporation of seaweed in food products to improve their health benefits, ensuring that its addition does not negatively impact the taste (Du et al., 2021). Even at the relatively high dose of seaweed utilized in this study (10 and 15 %), fermentation proved efficient in maintaining sensory quality. In the cream cheeses fermentation assisted in maintaining its perceived freshness, which proved even advantageous to regular acidification.

During the consumer test, it was also found that half of the participants were uncertain about the nutritional benefits of seaweed fermentation, indicating a need to increase their knowledge. According to the findings from a systematic review and meta-analysis of consumer knowledge and acceptance of functional foods, increased awareness can enhance consumer perception and preference (Baker et al., 2022). Most of the participants mentioned that taste could be the most critical factor in choosing the product, whether it is fermented or not. However, almost half of them mentioned that they would prefer to buy the cream cheese with fermented seaweed rather than untreated seaweed if it was labeled. Therefore, if a fermented seaweed product is tasty and marketed with educational efforts, it might outperform products containing untreated seaweed regarding consumer preference.

4.4. Strengths and limitations

To our knowledge, this is the first study to directly compare all three treatments—fermented, unfermented, and acidified (pH- adjusted) —in a product context, using two different food applications. Acidification is a widely used industrial preservation method (much easier to perform than fermentation), so including it as a reference was essential to evaluate whether fermentation provides additional benefits. Demonstrating whether fermentation offers advantages over acidification in real food applications is, therefore, an important step toward assessing its relevance for both industry practice and product development. Additionally, considering two different food formulations offers a more comprehensive insight into how the food matrix itself impacts the effect of fermentation. One limitation of this study is that consumer testing was not conducted with the acidified samples. We encourage future studies to investigate whether there are differences in consumer preferences between acidified and fermented seaweed. Furthermore, the consumer test results have limited generalizability to the whole population as the convenient sample was overrepresented with older individuals who do not frequently consume seaweed. Lastly, in this study, physicochemical analyses were limited to parameters most relevant to sensory properties and storage stability (pH, water activity, moisture, color, and texture). A broader physicochemical characterization would be important for future studies.

4.5. Conclusion

This study highlights the potential of LAB seaweed fermentation to improve sensory properties and consumer acceptance of seaweed-enriched spreads. Fermentation can significantly reduce seaweed flavors and odors in the untreated seaweed, making the spreads more appealing. Both spreads with fermented AE showed higher firmness compared to those with untreated AE. This study indicates that fermentation also provides advantages over acidification in terms of sensory quality in two different food products, suggesting that fermentation might offer added value beyond the acidification process. A comparable storage stability of the spreads with or without seaweed was obtained as measured by pH and water activity values. These findings support that LAB seaweed fermentation is a promising strategy for developing new, functional seaweed-based foods with wider consumer acceptance.

Funding

This study was funded by the Eurostars program (grant number: E115346).

Ethical statement

The scope of the sensory study, test protocol, and adherence to the General Data Protection Regulation (GDPR) were reviewed and approved by the Research Ethics Committee for the Faculty of Health and Science at the University of Copenhagen (date: 16–05–2024, case number: 504–0501/24–5000).

CRediT authorship contribution statement

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Mølgaard Jensen: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Supansa Y. Westman:** Writing – review & editing, Methodology. **Dragana Stanojevic:** Writing – review & editing, Methodology. **Eva Nordberg Karlsson:** Writing – review & editing, Funding acquisition. **Maren Sæther:** Writing – review & editing, Project administration, Methodology, Funding acquisition. **Lilia Ahrné:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Wender LP Bredie:** Writing – review & editing, Supervision, Methodology, Funding acquisition, 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.

Acknowledgements

We thank Arwa Mustafa and Benita Geppert for producing and providing the baobab spread samples. We also appreciate the assistance of Belinda Lange, panel leader of the descriptive sensory analysis, and Charlotte Dandanell in sample preparation.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.fufo.2025.100765.

Data availability

Data will be made available on request.

References

Baker, M.T., Lu, P., Parrella, J.A., Leggette, H.R., 2022. Investigating the effect of consumers' knowledge on their acceptance of functional foods: a systematic review and meta-analysis. Foods 11 (8), 1135. https://doi.org/10.3390/foods11081135.

Bao, J., Zhang, X., Zheng, J.H., Ren, D.F., Lu, J., 2018. Mixed fermentation of Spirulina platensis with Lactobacillus plantarum and Bacillus subtilis by random-centroid optimization. Food Chem 264, 64–72. https://doi.org/10.1016/j.foodchem.2018.05.027.

Bayarri, S., Carbonell, I., Costell, E., 2012. Viscoelasticity and texture of spreadable cheeses with different fat contents at refrigeration and room temperatures. J. Dairy Sci. 95 (12), 6926–6936. https://doi.org/10.3168/jds.2012-5711.

Brighenti, M., Govindasamy-Lucey, S., Jaeggi, J.J., Johnson, M.E., Lucey, J.A., 2018. Effects of processing conditions on the texture and rheological properties of model acid gels and cream cheese. J. Dairy Sci. 101 (8), 6762–6775. https://doi.org/10.3168/jds.2018-14391.

Brighenti, M., Govindasamy-Lucey, S., Lim, K., Nelson, K., Lucey, J.A., 2008. Characterization of the rheological, textural, and sensory properties of samples of commercial US cream cheese with different fat contents. J. Dairy Sci. 91 (12), 4501–4517. https://doi.org/10.3168/jds.2008-1322.

Bruhn, A., Brynning, G., Johansen, A., Lindegaard, M.S., Sveigaard, H.H., Aarup, B., Fonager, L., Andersen, L.L., Rasmussen, M.B., Larsen, M.M., Elsser-Gravesen, D., Børsting, M.E., 2019. Fermentation of sugar kelp (Saccharina latissima)—Effects on sensory properties, and content of minerals and metals. J. Appl. Phycol. 31 (5), 3175–3187. https://doi.org/10.1007/s10811-019-01827-4.

Büyük, M., Ata, A., Yemenicioğlu, A., 2024. Application of pectin-grape seed polyphenol combination restores consistency and emulsion stability and enhances antioxidant capacity of reduced oil aquafaba vegan mayonnaise. Food Bioprod. Process. 144, 123–131. https://doi.org/10.1016/j.fbp.2024.01.010.

Canoy, T.S., Wiedenbein, E.S., Bredie, W.L.P., Meyer, A.S., Wösten, H.A.B., Nielsen, D.S., 2024. Solid-state fermented plant foods as new protein sources. Annu. Rev. Food Sci. Technol. 15. https://doi.org/10.1146/annurev-food-060721.

del Olmo, A., Picon, A., Nuñez, M., 2018. Cheese supplementation with five species of edible seaweeds: effect on microbiota, antioxidant activity, colour, texture and sensory characteristics. Int. Dairy J. 84, 36–45. https://doi.org/10.1016/j.idairyj.2018.04.004.

Du, X., Xu, Y., Jiang, Z., Zhu, Y., Li, Z., Ni, H., Chen, F., 2021. Removal of the fishy malodor from Bangia fusco-purpurea via fermentation of Saccharomyces cerevisiae, Acetobacter pasteurianus, and Lactobacillus plantarum. J. Food Biochem. 45 (5), e13728. https://doi.org/10.1111/jfbc.13728.

Figueroa, V., Farfán, M., Aguilera, J.M., 2023. Seaweeds as novel foods and source of culinary flavors. Food Rev. Int. 39 (1), 1–26. https://doi.org/10.1080/87559129.2021.1892749.

Foguel, A., Neves Rodrigues Ract, J., Claro da Silva, R., 2021. Sensory characterization of commercial cream cheese by the consumer using check-all-that-apply questions. J. Sens. Stud. 36 (4), e12658. https://doi.org/10.1111/joss.12658.

Fox, P.F., Guineee, T.P., Cogann, T.M., Mcsweeney, P.L.H., 2017. Fundamentals of Cheese Science. Springer, New York second ed.

Fredriksson, C., Merkel, A., Säwe, F., 2023. Trending Seaweed: future Opportunities in Retail? Eds. In: Bäckström, K., Egan-Wyer, C., Samsioe, E. (Eds.), The Future of Consumption: How Technology, Sustainability and Wellbeing will Transform Retail and Customer Experience. Springer Int. Publishing, Cham, pp. 145–158.

Hung, Y.H.R., Peng, C.Y., Huang, M.Y., Lu, W.J., Lin, H.J., Hsu, C.L., Fang, M.C., Lin, H.T.V., 2023. Monitoring the aroma compound profiles in the microbial fermentation of seaweeds and their effects on sensory perception. Ferment 9 (2). https://doi.org/10.3390/fermentation9020135.

Jayakody, M.M., Vanniarachchy, M.P.G., 2023. Seaweed-derived snack foods: products and processing. Eds.. In: Hefft, D.I., Adetunji, C.O. (Eds.), Applications of Seaweeds in Food and Nutrition. Elsevier, pp. 215–224.

Jayakody, M.M., Vanniarachchy, M.P.G., Wijesekara, W.L.I., 2021. Development and characterization of a seaweed snack using Ulva fasciata. J. Food Sci. Technol. 58 (4), 1617–1622. https://doi.org/10.1007/s13197-020-04880-x.

Jones, L.V., Peryam, D.R., Thurstone, L.L., 1955. Development of a scale for measuring soldiers' food preferences. J. Food Sci. 20 (5), 512–520. https://doi.org/10.1111/j.1365-2621.1955.tb16862.x.

Jönsson, M., Maubert, E., Merkel, A., Fredriksson, C., Karlsson, E.N., Wendin, K., 2024. 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. Future Foods 9, 100292. https://doi.org/10.1016/j.fufo.2023.100292.

Jönsson, M., Merkel, A., Fredriksson, C., Karlsson, E.N., Wendin, K., 2023. Nutritional, physicochemical, and sensory characterization of four common Northern European seaweed species intended for food. Algal Res. 75, 103258. https://doi.org/10.1016/j.algal.2023.103258.

Lakshminarayana, R., Vijay, K., Ambedkar, R., Ranga Rao, A., Ravishankar, G.A., 2022. Biological activities and health benefits of seaweed carotenoids with special reference to fucoxanthin. Eds.. In: Ranga Rao, A., Ravishankar, G.A. (Eds.), Sustainable Global Resources of Seaweeds Volume 2: Food, Pharmaceutical and Health Applications. Springer Int. Publishing, Cham, pp. 539–558.

Lam, N.T.L., Zhu, S., 2021. Investigation of Physical Stability of Baobab Pulp Emulsion-For Food Application. Lund University. Master's thesis. https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=9047721&fileOId=9047753.

Maiorano, G., Ramires, F.A., Durante, M., Palamà, I.E., Blando, F., De Rinaldis, G., Perbellini, E., Patruno, V., Gadaleta Caldarola, C., Vitucci, S., Mita, G., Bleve, G., 2022. The controlled semi-solid fermentation of seaweeds as a strategy for their stabilization and new food applications. Foods 11 (18), 2811. https://doi.org/10.3390/foods11182811.

Michalak, I., Chojnacka, K., 2016. Functional fermented food and feed from seaweed. Eds.. In: Montet, D., Ray, R.C. (Eds.), Fermented Foods, Part I: Biochemistry and Biotechnology. CRC Press (Taylor & Francis Group), Boca Raton, pp. 231–248.

Moss, R., McSweeney, M.B., 2021. Do consumers want seaweed in their food? A study evaluating emotional responses to foods containing seaweed. Foods 10 (11), 2737. https://doi.org/10.3390/foods10112737.

Nithya, A., Misra, S., Panigrahi, C., Dalbhagat, C.G., Mishra, H.N., 2023. Probiotic potential of fermented foods and their role in non-communicable diseases management: an understanding through recent clinical evidences. Food Chem. Adv. 3, 100381. https://doi.org/10.1016/j.focha.2023.100381.

Patova, O.A., Luanda, A., Paderin, N.M., Popov, S.V., Makangara, J.J., Kuznetsov, S.P., Kalmykova, E.N., 2021. Xylogalacturonan-enriched pectin from the fruit pulp of Adansonia digitata: structural characterization and antidepressant-like effect. Carbohydr. Polym. 262, 117946. https://doi.org/10.1016/j.carbpol.2021.117946.

Perveen, K., Alabdulkarim, B., Arzoo, S., 2011. Effect of temperature on shelf life, chemical and microbial properties of cream cheese. Afr. J. Biotechnol. 10 (74), 16929–16936. https://doi.org/10.5897/AJB11.1695.

Ranga Rao, A., Ravishankar, G.A., 2022. Sustainable Global Resources of Seaweeds Volume 2: Food, Pharmaceutical and Health Applications. Springer Int. Publishing, Cham.

Reboleira, J., Silva, S., Chatzifragkou, A., Niranjan, K., Lemos, M.F.L., 2021. Seaweed fermentation within the fields of food and natural products. Trends Food Sci. Technol. 116, 1056–1073. https://doi.org/10.1016/j.tifs.2021.08.018.

Rioux, L.E., Beaulieu, L., Turgeon, S.L., 2017. Seaweeds: a traditional ingredients for new gastronomic sensation. Food Hydrocoll 68, 255–265. https://doi.org/10.1016/j.foodhyd.2017.02.005.

Roohinejad, S., Koubaa, M., Barba, F.J., Saljoughian, S., Amid, M., Greiner, R., 2017. Application of seaweeds to develop new food products with enhanced shelf-life, quality and health-related beneficial properties. Food Res. Int. 99, 1066–1083. https://doi.org/10.1016/j.foodres.2016.08.016.

Spillias, S., Valin, H., Batka, M., Sperling, F., Havlík, P., Leclère, D., Cottrell, R.S., O'Brien, K.R., McDonald-Madden, E., 2023. Reducing global land-use pressures with seaweed farming. Nat. Sustain. 6 (4), 380–390. https://doi.org/10.1038/s41893-022-01043-y.

Vithanage, C.R., Grimson, M.J., Smith, B.G., 2009. The effect of temperature on the rheology of butter, a spreadable blend and spreads. J. Texture Stud. 40 (3), 346–369. https://doi.org/10.1111/j.1745-4603.2009.00186.x.
Wadhwani, R., McMahon, D.J., 2012. Color of low-fat cheese influences flavor perception and consumer liking. J. Dairy Sci. 95 (5), 2336–2346. https://doi.org/10.3168/jds.2011-5142.
Zapaśnik, A., Sokołowska, B., Bryła, M., 2022. Role of lactic acid bacteria in food preservation and safety. Foods 11 (9), 1283. https://doi.org/10.3390/foods11091283.