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Food or fad? Challenges and opportunities for including seaweeds in a Nordic diet

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Abstract: Seaweeds represent highly nutritious seafood products with the potential for becoming more central elements in Western human diets than currently realized. Using locally available seaweed species (*Palmaria palmata, Saccharina latissima, Laminaria digitata* and *Alaria esculenta*), we tested preparation methods, flavour and taste perception in the context of a culinary experience. In collaboration with a local cooking school and a group of chefs, a cooking workshop explored the possibilities for seaweeds to be included in a variety of region-specific menus, testing their individual qualities and characteristics as sea vegetables, flavour enhancers and in condiments. Through developing quality descriptors for both steamed and dried products of the target species, the study laid the foundation for future systematic sensory analyses. Preliminary tests revealed a strong impact of species on sensory perception, with *P. palmata* having a sensory profile distinct from the kelp species. A consumer test of *S. latissima* in fish cakes confirmed our hypothesis that seaweeds as food ingredients do not negatively affect the taste experience for seafood dishes.

Keywords: consumer perception; flavour descriptors; Nordic cuisine; sensory analyses.

Introduction

Throughout past decades, the use of marine macroalgae in food production has undergone a renaissance in the Western world. Particularly in coastal countries such as Norway, seaweeds offer potential solutions for problems concerning food production (e.g. area conflicts), global climate change and environmental challenges. In contrast to terrestrial biomass, seaweeds are produced without demand on fresh water or land area. Moreover, macroalgal production rates exceed agricultural plant production (Brinkhuis et al. 1987) and, by integrating production in multitrophic aquaculture systems (IMTA), excess nutrients from fish farming activities become valuable resources for biomass production at lower trophic levels (Chopin et al. 2001, Abreu et al. 2009, Sanderson et al. 2012). Hence, the interest for sustainable cultivation of macroalgal biomass to be used as food and animal feed, as well as raw material for the provision of valuable compounds is growing rapidly in Norway, and opportunities for industrial development have been identified (Olafsen et al. 2012, Skjermo et al. 2014). In a culinary context seaweeds can be used both as a vegetable, salt and spices in one (McHugh 2003).

Traditionally, seaweeds have been a major element of the human diets in Asian countries and are extensively used as food in China, Japan, Korea and the Philippines. Although seaweeds occur with high diversity and abundance along the coasts of Europe and North America, they have not been a significant food resource in Western societies throughout the past centuries, and traditions for eating seaweeds have been limited to coastal Atlantic communities in Ireland, Brittany, Galicia, Maine and Nova Scotia (Guiry and Blunden 1991). In Nordic countries, historical records for consuming seaweeds document the importance of the red alga dulse (*Palmaria palmata)* as an important source of minerals and vitamins (especially vitamin C) in ancient, i.e. Viking times (Hallsson 1964, Mouritsen et al. 2013a).

In general, eating habits and what is considered suitable as food are culturally determined, and, despite limited uses historically, macroalgae are not a significant part of the current Nordic cuisine. However, with a recent trend and increasing popularity of Asian dishes (e.g. sushi) across Europe, seaweeds are being re-introduced also to Nordic palates. In Scandinavia, the renewal of the Nordic cuisine fronted by avant-garde restaurants and based on locally available natural ingredients has re-kindled interest for including seaweeds in cooking (Mortensen et al. 2004, Mouritsen et al. 2012).

The recent use of seaweeds as food in Europe is supported by well-known nutritional and health benefits of seaweeds in human diets, especially regarding the high content of minerals, vitamins and trace elements in the most relevant species (Mabeau and Fleurence 1993,

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Rupérez 2002, MacArtain et al. 2007, Holdt and Kraan 2011, Pereira 2011). Furthermore, seaweed biomass also has potential as a functional food ingredient: excessive sodium salts in processed foods, which often are associated with common health risks such as high blood pressure and cardiovascular diseases (Gibbs et al. 2000), may be replaced by macroalgae rich in potassium salts (Hotchkiss 2009), resulting in healthier mineral profiles (Cofrades et al. 2008, López-López et al. 2009). In addition, nutritional properties such as high content in dietary fibres (Dawczynski et al. 2007), protein and amino-acid profile (Fleurence 2004, Mæhre et al. 2014) and lipid profile (Sánchez-Machado et al. 2004) are highly relevant for food applications.

In Asia, seaweeds are also recognized for their rich and unique flavours. The brown seaweed *kombu* (*Saccharina japonica*) is known to be an excellent source of umami flavour which is directly linked to its high content in free amino acid monosodium glutamate (Ikeda 2002, Mouritsen et al. 2014), with industrial application as a flavour enhancer. Seafood-like flavour was successfully obtained from the enzymatic hydrolysis of protein by-products of the red seaweed *Gracilaria fisheri* after agar extraction (Laohakunjit et al. 2014). Mouritsen et al. (2012) investigated several seaweed species abundant along the coast of Northern Europe for their free amino acid content and revealed the potential of *P. palmata* and the brown seaweed sugar kelp (*Saccharina latissima*) as promising ingredients in the New Nordic Cuisine, to be included in a wide range of foodstuff such as ice cream, fresh cheese and bread. However, systematic knowledge concerning all aspects of utilising edible seaweeds available in Northern Europe in a modern Nordic cuisine are missing, including (i) sensory profiling of relevant species, (ii) preparation methods and suitable dishes and (iii) consumer perception of seaweeds as a food ingredient.

The aim of the present work was to lay the foundation for a systematic sensory description of edible seaweeds, focusing on four target species common to the Norwegian coast and with high potential for future aquaculture production, i.e. dulse (*P. palmata*), sugar kelp (*S. latissima*), winged kelp (*Alaria esculenta*) and oarweed (*Laminaria digitata*).

Materials and methods

Tests and activities were carried out in Ålesund, western Norway in 2014. The Association test, sensory analysis and cooking workshop took place in June. The consumer testing was conducted at the Ålesund aquarium (Atlanterhavsparken) on November 22, 2014. Testing was carried out using Norwegian language, with all terminology, quality descriptors and sensory attributes translated subsequently to English for the purpose of this publication.

Flavour descriptive analysis – Association test

The sensory panel consisted of 15 judges aged 28 to 58 who were recruited among project partners, i.e. Møreforsking and Klippfiskakademiet (cooking school) employees. Prior to testing, all judges were somewhat familiar with macroalgae as a raw material, but had limited experience with sensory profiling of seaweed.

Test design: Four species of seaweed were presented to the judges, i.e. (i) sugar kelp *Saccharina latissima* (Linnaeus) C. E. Lane, C. Mayes, Druehl *et* G. W. Saunders, (ii) winged kelp *Alaria esculenta* (Linnaeus) Greville, (iii) oarweed *Laminaria digitata* (Hudson) J. V. Lamouroux, as well as the red alga dulse [*Palmaria palmata* (Linnaeus) F. Weber *et* D. Mohr]. Algal material was acquired from a commercial supplier (The Northern Company™, Oslo, Norway) using dried seaweeds from Iceland. The study used material from a single batch for each species to ensure standardized material. Seaweeds were presented as fragments of 2–5 cm^2, of approximately 1–2 g dry weight, and identified by 3-digit numbers.

The test included two parts separated by a break of approximately 10 min: (i) first, seaweeds were presented in the dried condition (as supplied), and (ii) prior to presentation, seaweeds were rinsed in cold water, covered with a plastic film and then heated in a microwave oven (30 s at 600 W).

Panel members were asked to list key words which they associated with the texture, flavour, and mouthfeel attributes of the different seaweed species (Lyon and Watson 1994, Monteleone and Langstaff 2014). Subsequently, associated terms were collected and grouped by species and treatment method, and the most consistent terms were selected to design a quality control test (Lyon and Watson 1994, Mojet and de Jong 1994, Gawel et al. 2000, Koch et al. 2012).

Quality control test

The panel of judges consisted of seven chefs aged 17 to 65, gathered for a seaweed cooking workshop. All of the subjects worked regionally, i.e. with a focus on Nordic food traditions, and four of them had some prior experience with using seaweeds in their cooking.

Sample presentation: The same four species of seaweeds as in the Association test, i.e. *Saccharina latissima*, *Alaria esculenta*, *Laminaria digitata* and *Palmaria palmata*, acquired from the same supplier (The Northern Company™) dried and vacuum packaged, were presented to the panel. *Laminaria digitata* was used as a reference, as it appeared relatively mid-scale in relation to its attributes after the Association test. Samples were presented as for the Association test, i.e. first in dried form and subsequently pre-treated with heat. Heat treatment in this case consisted of (i) rinsing in cold water and (ii) steaming at 100°C for 15 min.

Test performance: Panel subjects were asked to compare 11 taste, flavour and mouth-feel qualities (Glossary, Table 2) of three species of seaweeds to a reference sample (*L. digitata*) by using a quality control test relative ranking method (ISO:6564, 1985). Hence, for each sample and quality, panellists related its placement to a reference sample of *L. digitata* on a numerical scale from -3 to +3, with *L. digitata* representing 0.

Panel judges underwent a training session in order to get familiarized with the material, after which different perceptions of tasks and use of test-forms were discussed and calibrated for consistent test performance across the panel.

The main testing was carried out in two parts with a 15-min break in between. Part one was carried out with dried seaweed samples and part two was carried out with steamed material.

Cooking workshop

The same chefs who constituted the panel for the quality control tests participated in a cooking workshop following the sensory analysis of the four seaweed species. This was carried out at Klippfiskakademiet, the partner cooking school, with suitable medium-scale facilities. Over the course of a day, the chefs first discussed the integration and use of the selected seaweed species in Nordic cuisine and then prepared a selection of 17 dishes where these ideas were implemented. In a creative process, chefs specifically explored how the final food products were affected by (i) preparation method of seaweed raw material, (ii) amounts of raw material used, (iii) application of seaweeds as sea vegetables, relish or flavour enhancers in broth or condiments, and (iv) physical properties and colour of the material.

However, the procedure was both flexible and unregimented, and the above variables were not systematically controlled for.

Resulting dishes were presented to a tasting panel of 17 volunteers who each selected favourite dishes, awarding 3, 2 and 1 points, respectively for the three highest ranking dishes. In addition, the chefs summarised their experiences and conclusions qualitatively.

Consumer test of fish cakes with and without *Saccharina latissima*

In November 2014, a consumer test was conducted at Ålesund aquarium, comparing a seafood product (fish cakes) which contained dried flakes of *Saccharina latissima*, to a control fish cake without seaweed ingredient. The tasting panel consisted of visitors to the aquarium volunteering to participate in this research on seaweed as food ingredients.

Fish cakes were prepared in two versions, distinguished only by the content of about 1 g dried sugar kelp per 20 g fish cake in version A, and about 1 g of parsley per 20 g fish cake in version B. The primary purpose of replacing seaweed with steamed (i.e. neutral-flavour) parsley was to remove any visual clues to the content of seaweed ingredients which might bias the evaluation.

Questionnaires consisted of the following elements: (i) age and gender information (5 age groups: <20, 20–35, 36–50, 51–65, >65 years), (ii) choice of preference for product A or B, and (iii) separate assessments of taste and appearance of product A and B using a 7-category scale (dislike strongly, dislike moderately, dislike slightly, neither like nor dislike, like slightly, like moderately, like strongly).

Statistical analysis

For sensory testing, data were collected and pre-processed using common spreadsheet software for descriptive statistics (Association test). In the case of quality control testing, we used multivariate principal component analysis (PCA) using Unscrambler™ software (Version × 10.2, CAMO Software, Oslo, Norway) to visualise primary correlations between the selected seaweed species and their sensory attributes.

Factorial two-way ANOVA (seaweed species and preparation type as independent factors) was applied for comparing rankings of individual qualities (STATISTICA™ software, StatSoft, Boston, USA).

Homogeneity of variances was tested by using Cochran's test, and Tukey's honest significant difference (HSD) test was performed for post-hoc comparisons of significant ANOVA results. In case of the consumer test, we used Wilcoxon signed-rank tests to compare assessments for the two product types regarding (i) taste and (ii) appearance.

Results

Flavour descriptive analysis – Association test

From the total of attributes generated during the seaweed Association test (22 attributes for dried and 15 for steamed seaweeds, Table 1), a set of 11 quality descriptors was extracted (Table 2) by grouping the attributes used most frequently. In addition to the primary flavour qualities, others such as “odour intensity”, “grassiness” and “liquorice” flavour, as well as several mouth-feel attributes (“crispiness” and “chewiness”) were prominent. To a large extent, variation in mouth-feel attributes reflected the different preparation methods (dried vs. steamed presentation).

With regard to flavour differences and characterisation of the different seaweed species, *Laminaria digitata* appeared to be placed most neutrally for the majority of

Table 1: Attributes generated during association test, grouped by frequency mentioned by the panellists.

Attribute	PP-D	PP-S	SL-D	SL-S	LD-D	LD-S	AE-D	AE-S	Total
Salty	8	4	15	12	11	10	5	5	70
Sea	5	3	3	4	2	3	4	3	27
Sweet	6	2		2	2	2	2	6	22
Grass		1	4	4	1		3	3	16
Neutral			3			2	3	7	15
Sour	3	1	4	2	1	2	2		15
Bouillon	4	3	1		1	1			10
Liquorice	3		1	1	3	1			9
Bitter	2	3		2		1			8
Mild	1		1			1	3	1	7
Paper			3		1	1	2		7
Seaweed	2				1		3	1	7
Iodine			1	2	1	1			5
Umami	1	2			1	1			5
Nutty		2				1	1		4
Pungent	2		1	1					4
Repulsive		3					1		4
Beet root	2	1							3
Dried fish			2				1		3
Fresh			2					1	3
Fruity	1							2	3
Lemon			2		1				3
Hard			4	1	9	8	6	2	30
Tough	5	1	3	2	3	7	3	5	29
Soluble	5	8							13
Soft	7	2		1		1			11
Chewy			1	2	2			2	7
Slimy		1		6					7
Crackling			1		1		1	2	5
Melting	2	2							4
Smooth							1	3	4
Dry			2				1		3
Sharp	1	2							3
Slippery				3					3
Sticky	2				1				3
Strong		1	2						3
Rancid		2							2

All types of flavour, taste, texture and mouth-feel attributes that the panellists associated with the seaweeds tested were collected. Upper panel, flavour and taste; lower panel, mouth-feel attributes. Four seaweed species (PP – *Palmaria palmata*, SL – *Saccharina latissima*, LD – L*aminaria digitata*, AE – *Alaria esculenta*), presented either dried (D) or steamed (S).

Table 2: Glossary of qualities derived from association test and assessed in the quality control test.

Quality	Definition	Keywords
Odour intensity	Totality of odour impressions	
Sourness	Fresh flavour from organic acids	Citrus, green apple
Sweetness	Related to sweet flavour from glucose or fruity sweetness	Sugar, prune, melon
Saltiness	Salty flavours	Sea salt
Bitterness	Bitter flavours (e.g. caffeine or quinine)	Coffee, grapefruit, tannins
Umami	Strong flavour of broth associated with meat	Meat, broth, glutamate, fish sauce, smoked meat
Grassiness	Strong flavour of green related to plants	Grass, hay, green vegetables
Liquorice flavour	Flavour of liquorice	Anise, liquorice, fennel
"Sea" association	Related to smell and flavour of the sea	Sea, seaweed, coast, boat house, pier
Chewiness	Resistance when chewing	
Crispiness	Quality along a continuum from crispy to soggy	

quality descriptors. Hence this species was chosen as the 0-level reference for the quality control test, with which the other three species were compared.

Quality control test

Flavour and mouth-feel qualities of four seaweed species were compared using a set of 11 quality descriptors. In each case, three seaweed species were ranked against *Laminaria digitata* as a neutrally placed reference, and seaweeds were presented both dried and steamed.

Palmaria palmata was most distinct overall with regard to flavour and mouth-feel qualities compared to the other two species tested against *L. digitata* as a reference (Figure 1A, where *P. palmata* is placed furthest from the other species). Standardised PCA plots are commonly used in sensory analysis to visualise the relationship among sensory attributes, as well as among individual product samples. The PCA-loadings plot (Figure 1A) displays the positioning of, and association among, the seaweed attributes. In this case, "odour intensity" and "crispiness" were the attributes primarily distinguishing the seaweeds along axis PC-1, explaining 58% of the variation among samples. Although the distribution of attributes in Figure 1A is much more clustered around zero than the distribution of seaweeds in Figure 1A, comparing results from the PCA-scores and PCA-loadings plots (Figure 1A/B) indicates that *Saccharina latissima* was positively correlated with the attribute "crispiness", while *P. palmata* was positively correlated with "odour intensity". The vertical axis PC-2 explained 29% of the variation of among the seaweeds' sensory attributes, separating the attributes "sour", "salty" and "bitter" on the one hand from "sweet" on the other hand.

Saccharina latissima had the best correlation with flavour attributes "salty", "sour" and "bitter" (Figure 1B),

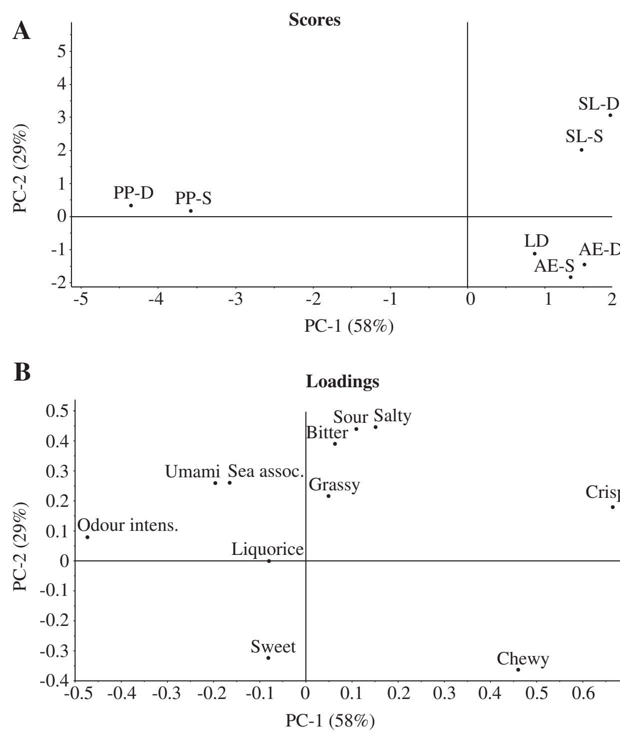

Figure 1: Results of quality control test: Principal component analysis (PCA) plots of seaweeds ranked for 11 sensory attributes relative to *Laminaria digitata* as the 0-level control. Top panel (A), PCA scores; bottom panel (B), PCA loadings. Samples are identified by species (LD – *Laminaria digitata*, AE – *Alaria esculenta*, SL – *Saccharina latissima*, PP – *Palmaria palmata*), as well as preparation method (S – steamed, vs. D – dried), with n=7 per group.

whilst *Alaria esculenta* appeared most similar to the reference species *L. digitata* with the attribute "chewiness" having the best correlation for the species.

Whereas PCA plots are useful in visualising overall variation in the samples with regard to sensory attributes, we used ANOVAs to test for differences in sensory profiles among the species assessed. The pre-treatment of seaweeds had no significant overall effect on the flavour qualities and, among mouth-feel qualities, only chewiness was affected by pre-treatment (ANOVA-results, Table 3). Both flavour and mouth-feel qualities varied significantly among species (Table 3). This result, confirmed by and visualised in the PCA-scores plot (Figure 1A) allowed us to carry out further analyses among seaweeds across treatments (steamed/dried), i.e. by pooling the respective treatment groups.

Significant differences among seaweed species for the individual quality attributes are summarised in Figure 2A–D. *Palmaria palmata* is clearly distinct from the two kelp species regarding mouth-feel and texture attributes in that it is softer, less crispy and more easily dissolved (Figure 2A). Its strong odour corresponds to a large degree with its ranking highest on "umami" flavour (panellists' feedback, Figure 2A, D). In spite of its name, sugar kelp *S. latissima* did not appear to be sweeter than the other seaweeds. On the contrary, *S. latissima* appeared

Table 3: Results (p-values only) from 2-way fixed factor ANOVA for individual quality parameters of the quality control test.

Independent variable	Seaweed	Treatment	Seaweed× treatment
Dependent variable			
Intensity of smell	**<0.01**	0.70	0.29
Chewiness	**<0.01**	**0.04**	0.10
Crispiness	**<0.01**	0.12	0.13
Sourness	**<0.01**	0.77	0.91
Sweetness	**0.03**	0.05	0.28
Saltiness	**0.01**	0.38	0.92
Bitterness	**0.01**	0.85	0.63
Umami flavour	**0.03**	0.56	0.92
Grassiness	0.27	0.49	0.62
Liquorice flavour	0.71	0.72	0.90
"Sea" association	0.15	0.22	0.30

Independent variables are (i) seaweed species (3 levels: *Alaria esculenta*, *Saccharina latissima* and *Palmaria palmata*, but NOT 0-level *Laminaria digitata*) and (ii) treatment (2 levels: dried and steamed). Within-group replication of n=7.
Significant differences ($p \leq 0.05$) are indicated in bold.

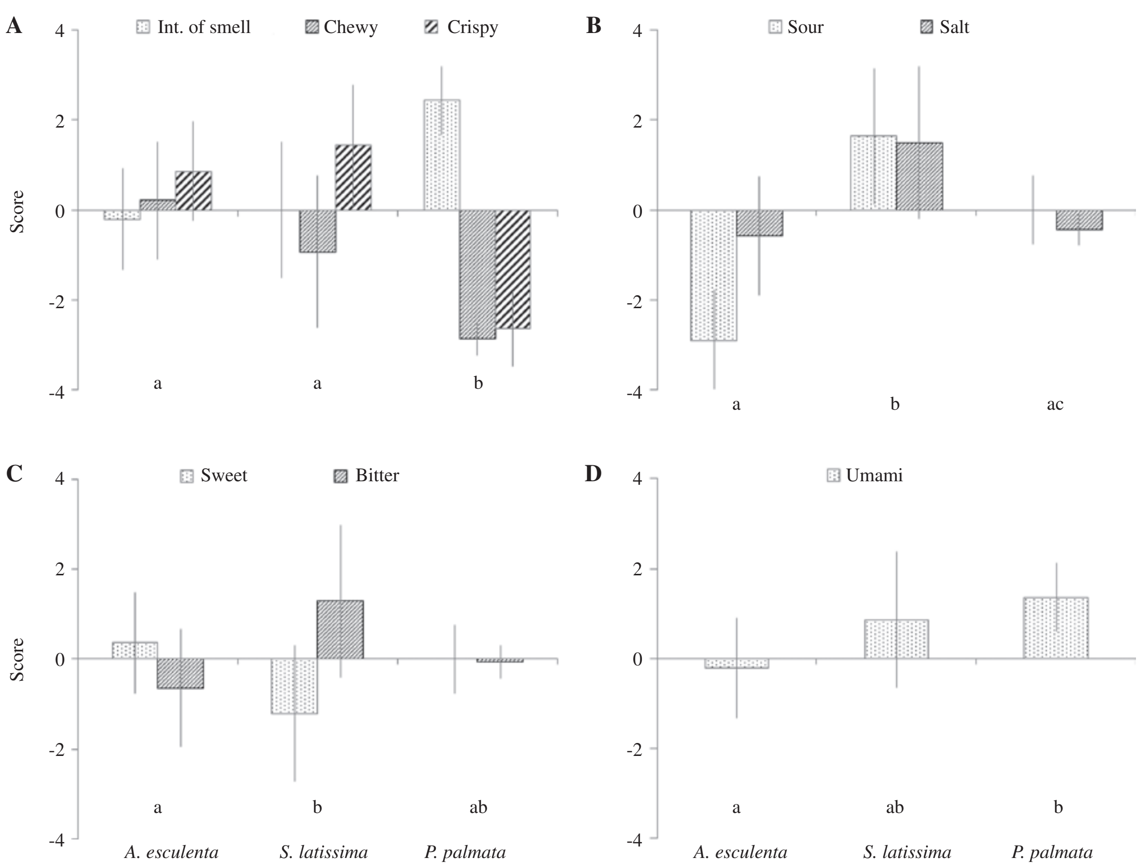

Figure 2: Results of quality control test: Comparative ranking of *Alaria esculenta, Saccharina latissima* and *Palmaria palmata* for 11 quality descriptors. For each sample and quality, panellists related its placement to a reference sample of *Laminaria digitata* on a numerical scale from -3 to +3, with *L. digitata* representing 0. Average scores of both steamed and dried products (n=14)±SD. Posthoc tests (Tukey HSD) reveal significant differences ($p<0.05$) among species for the descriptors in each panel as indicated by the letters below the histograms (identical letters indicate *no* significant differences). For the remaining attributes ("grassiness", "liquorice" and "sea-assoc."), no significant differences among species were found.

least sweet (Figure 2C) and instead most salty, sour and bitter compared to the other species tested (Figure 2B, C). The two kelps were best distinguished by the attributes “sour”, “salty”, “sweet” and “bitter”, in that *A. esculenta* appeared more sweet, and less salty, sour and bitter than *S. latissima* (Figure 2B, C). The flavour qualities, “grassy”, “liquorice” and “sea-association” did not contribute to distinguishing the species tested here (no significant difference among species, ANOVA, Tukey’s HSD-test with $p>0.05$, Table 3).

Cooking workshop

The cooking workshop revealed unexpected possibilities regarding the use of seaweeds in a Nordic cuisine. Seaweeds were included in all types of dishes, including seafood, meat and vegetarian dishes, as well as desserts and even drinks (Table 4). Aside from the wide usability of seaweeds in cooking, one of the primary results from the workshop was that flavour attributes were easily lost when only small amounts of seaweeds were included, i.e. all species used appeared less dominant than previously expected. This led to a gradual increase in the amount of seaweed added to the various dishes throughout the cooking workshop.

Table 4: List of food dishes produced during the cooking workshop, including the four test species of seaweed.

Dish	Type	No. of points
Clipfish (dried and salted cod) broth with winged kelp	Fish	**14**
Cod with sugar kelp and dulse	Fish	**13**
Fish cakes with oarweed	Fish	8
Cod cheeks with oarweed broth	Fish	5
Brandade with dulse	Fish	5
Saithe with winged kelp	Fish	3
Haddock with sugar kelp	Fish	3
Marinated halibut with oarweed	Fish	
Skate wings with dulse and sugar kelp	Fish	
Ling with sugar kelp crust	Fish	
Cassoulet with oarweed	Meat	
Seaweed pizza with sugar kelp	Veg.	12
Tagliatelle pasta with dulse	Veg.	5
Camembert with oarweed	Veg.	3
Chocolate icecream with sugar kelp	Dessert	**23**
Pancake with sugar kelp	Dessert	8
Vodka shot with dulse	Drink	

Panel evaluations (total no. of points from 17 panel lists) for each dish, with 3, 2 and 1 points, respectively given to first, second and third choice for “best dish”. The three top ranking dishes are indicated by bold print for the number of points. “Winged kelp” – *Alaria esculenta*, “Sugar kelp” – *Saccharina latissima*, “Dulse” – *Palmaria palmata*, “Oarweed” – *Laminaria digitata*.

Another important aspect was the visual changes of the seaweeds during the course of heat-treatment. Kelps went from olive-brown to bright green at first and then to a less distinct greenish colour. The brown colour of kelps is due to the presence of carotenoid pigments, mainly fucoxanthin, bound to chlorophyll a and c to form light-harvesting complexes (Douady et al. 1994). Whereas heat treatment of brown seaweeds, especially boiling, generally tends to increase phenol content, including fucoxanthin (Rajauria et al. 2010, Amorim-Carrilho et al. 2014), high temperature during cooking may dissociate the fucoxanthin from the light-harvesting complexes and consequently reveal the green colour of chlorophylls.

In contrast, the texture of the kelps used in this test remained comparatively stable, whereas the red seaweed *P. palmata* easily disintegrated, and lost its colour to the accompanying food ingredients – an effect that was explored further by using *P. palmata* to colour pasta as well as a vodka drink. The alginate content of brown seaweeds was utilised for altering viscosity, i.e. *Saccharina*-flakes were added to both desserts (a pancake dough, as well as chocolate ice-cream) so as to increase the dishes’ body. Semi-quantitative evaluation of dishes by a tasting panel revealed that both seafood-dishes, as well as vegetarian food combinations, were perceived to be tasty by the panellists (Table 4). The highest rated dish by far was the chocolate ice-cream with sugar kelp (*S. latissima*), followed by clipfish (dried and salted cod) broth with *A. esculenta*, and cod with *S. latissima* and *P. palmata* in third place.

In conclusion, seaweeds were easily combined with Nordic dishes and food items, and did not appear dominant in the flavour spectrum. Beyond the actual flavour, they have a large potential to affect texture, appearance and colour, as well as consistency of a variety of dishes.

Consumer test of fish cakes with and without *Saccharina latissima*

This test revealed clearly that fish cakes in which herbs were substituted by sugar kelp (*Saccharina latissima*) were equally attractive to consumers with regard to both flavour and appearance [Wilcoxon signed rank test (R): $V=646$, $p=0.73$, Figure 3]. Consumer responses to the direct question of preference for one of the two types of fish cake showed that both products were equally popular and that 22% of respondents could detect no difference (Figure 4). Neither age, nor gender affected the responses significantly.

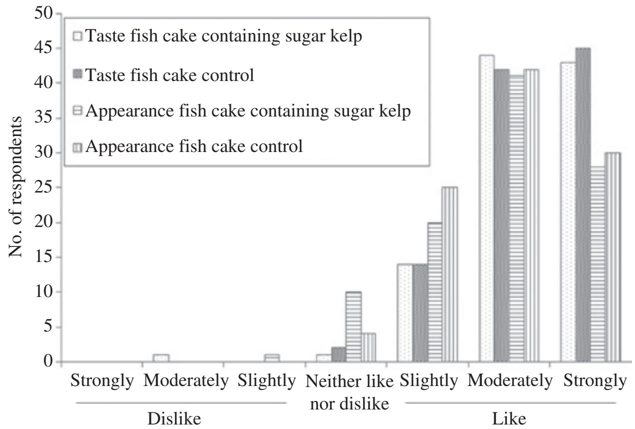

Figure 3: Frequency distribution of responses from consumers for taste and appearance of fish cakes containing sugar kelp (*Saccharina latissima*) or no seaweed (control with parsley). n=103 respondents (43 females, 60 males).

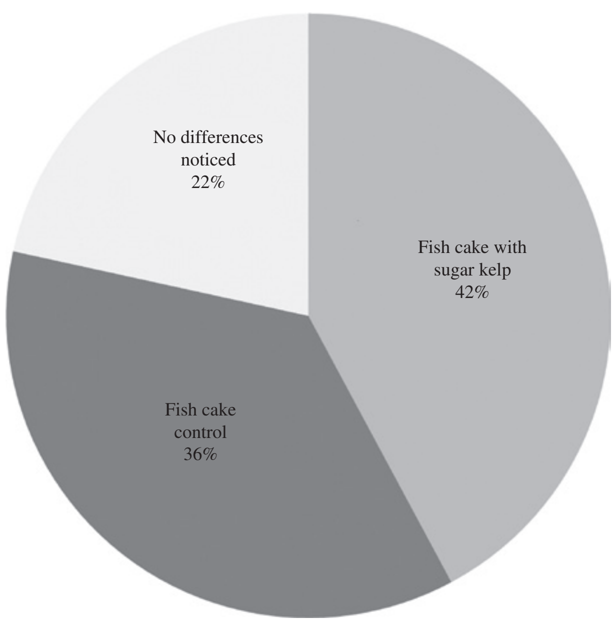

Figure 4: Pie chart showing responses from consumers to question "Which type of fish cake do you prefer?" with fish cakes containing sugar kelp (*Saccharina latissima*) or no seaweed (control with parsley). n=103 respondents (43 females, 60 males).

Discussion

In north-western Europe, using seaweeds as food currently represents a novel development, despite traditions of macroalgal diets reaching back to the Viking period. A renewed interest for using seaweeds in cooking bears witness to the fact that seaweeds are not only regarded as healthy ingredients but also as tasty food items (Rhatigan 2009, Mouritsen 2013, Tinellis, 2014). However, also the sensory science concerning macroalgae as food in Western cultures is still in its infancy. In this preliminary study, we demonstrate that the four species of seaweeds tested (all of them prime candidates for being integrated into Nordic diets in the future) had specific and diverse sensory characteristics. However, although 37 different attributes were generated during the first descriptive Association test, the sensory exploration of seaweeds remains a wide open field with a need to address other species, various preparation methods and numerous characteristics which are bound to change with geography, harvest season and processing methods, to name just a few relevant factors.

Descriptive sensory encyclopaedias or aroma wheels are commonly used in the sensory characterisation of tea, wine, beer and olive oil (Langstaff et al. 1991, Mojet and de Jong 1994, Gawel et al. 2000, Koch et al. 2012), and similar methods lend themselves to be applied also to seaweeds.

Within the clear limitations of this study [regarding the scope of (i) the species and properties tested and (ii) the expertise of the testing panel], certain conclusions may be drawn which indicate the potential for using the seaweeds tested in the context of a Nordic diet: The red seaweed dulse (*Palmaria palmata)* clearly had a sensory profile that was distinct from the three kelp species, notably characterised by a stronger umami flavour. A higher level of monosodium glutamate (MSG) in *P. palmata* compared to *Saccharina latissima* (Mouritsen et al. 2012) corroborates this result, as umami flavour is generally attributed to MSG content. Yamaguchi and Takahashi (1984) successfully maintained the palatability of a Japanese soup when reducing sodium chloride (NaCl) and substituting it with MSG, demonstrating the potential for replacing sodium salts with MSG, naturally contained in seaweeds. Using seaweeds' high MSG content as a substitute for sodium salt in human food preparation is beneficial with regard to reducing the risks of high blood pressure and cardiovascular disease associated with sodium salt consumption (Gibbs et al. 2000).

In addition to very large amounts of free MSG, Mouritsen et al. (2013a) also documented other flavourful free amino acids in dulse (*P. palmata*), including (i) aspartic acid (umami sensation), (ii) alanine, proline, glycine and serine (all sweet), and (iii) measurable amounts of isoleucine, leucine, and valine (all bitter).

Palmaria palmata was further distinguished from the three kelp species by texture and mouth-feel attributes, i.e. it appeared less chewy and less crispy. This result appears somewhat different from sensory analyses results by Le Pape et al. (2002), who describe dulse preserved in artificial seawater at 4°C for 15 days with the terms "seaside", "seaweed", "iodized" and "fresh", and associate frozen dulse with green aromas. A study by Michel et al. (1997)

showed *P. palmata* dried at 60°C to be correlated to the sensory descriptor “fishmeal”. This highlights the impact of processing and storage conditions on the organoleptic properties of edible seaweeds. The red pigment phycoerythrin of *P. palmata* inspired the chefs to use it in tagliatelle-pasta, brandade and vodka shot, all of which adopted the red colouration to a certain degree.

Sugar kelp (*S. latissima*) was the preferred species for using dried in desserts in this study, making use of its gelling properties associated with a high alginate content (Holdt and Kraan 2011). Sugar kelp turned out to be the least sweet of the species tested and instead was characterised as the most salty, sour and bitter of the kelps. Although sugar kelp may contain high amounts of the sweet tasting sugar alcohol mannitol (2 to 18% dry weight, Handå et al. 2013), the exact content is subject to wide seasonal and geographic variations. Biomass processing such as washing and drying may have adverse effects on the water-soluble carbohydrate content and may have impacted our specific results. Adams et al. (2014) did not observe a significant reduction in mannitol content with biomass processing of *L. digitata*. The exact cause of *S. latissima* being perceived as least sweet in our study remains unknown. Here, future sensory tests should investigate other factors which might alter the perception of these flavours, e.g. chemical composition of harvested material varying with harvesting season, geographical origin, as well as preservation and processing methods.

Our study showed no effect of preparation (steamed vs. dried material) on the sensory perception of the seaweeds tested. This is surprising given that processing treatments such as washing (Kuda et al. 2002) and drying (Gupta et al. 2011, Tello-Ireland et al. 2011) have been documented to alter the physico-chemical properties of seaweed biomass. Little is known about how processing of seaweed raw material will affect the product’s sensory characteristics. Mouritsen et al. (2013b) argue for applying physical sciences to the study of cooking and gastronomy, coining the term “gastrophysics” and applying it also to algal cuisine. In this approach, theoretical models and experimental methods are integrated to study small scale physical and macromolecular properties of raw and processed foodstuffs and how they relate to flavour and texture. Developing this new field of research will help establish best practices for harvesting, processing and storage of seaweeds for high-quality, i.e. defined and standardised, products.

In our study, the inclusion of 5% dried *S. latissima* in fish cakes did not negatively affect the sensory acceptability of the product. This agrees with a comparable test by Prabhasankar et al. (2009) who demonstrated that inclusion of 10% wakame (*Undaria pinnatifida*) in pasta or 3% kombu (*Laminaria japonica*) in pork patties did not negatively affect product acceptability. However, addition of 5% *Himanthalia elongata* in formulated low-fat frankfurter sausages reduced the product’s acceptability (López-López et al. 2009, Jiménez-Colmenero et al. 2010). To what degree acceptability of seaweed ingredients in food products depends on (i) the type of dish (seafood vs. meat or vegetarian), (ii) species of seaweed or (iii) percentage added remains to be established. Consumers’ growing interest in healthy foods, as well as guidelines recommending seaweeds as part of a “New Nordic Diet” (Mithril et al. 2012) should stimulate further research in this field.

In conclusion, seaweeds display a large variety of sensory qualities with potential applications in many Nordic food contexts. Whereas they were obviously acceptable to add flavour, texture and colour, their use as sea vegetables appears to be less likely in the immediate future according to the chefs participating in our study. Traditional cultural frameworks and prejudices towards rapid changes in Nordic cuisines were indicated as the primary reasons against adopting seaweeds faster and more comprehensively in Nordic cooking.

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