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Sensory descriptors for three edible Chilean seaweeds and their relations to umami components and instrumental texture

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Abstract
Although seaweeds exhibit many benefits as a food source, few studies have characterized their sensory attributes. An expert nine-member panel developed a vocabulary with 25 descriptors to describe the appearance, aroma, flavor, texture, and aftertaste of raw and cooked seaweeds consumed in Chile: *Durvillaea antarctica*, *Pyropia* spp., and *Ulva lactuca*. Subsequently, the vocabulary was used in a ranking descriptive analysis (RDA) to evaluate the sensory properties and relate them with physicochemical and physical data. Sensory attributes of the three seaweeds were very different from each other but similar between treatments (raw and cooked). *Pyropia* spp., both cooked and hydrated, had the highest glutamate content (310 and 324 mg (100 g) $^{-1}$ d.w., respectively), and was perceived by the sensory panel as having the most umami taste. Cooked *D. antarctica* was perceived as sweeter, had more caramel notes than the hydrated seaweed and was sensed as cartilaginous and hard in accordance with its mechanical properties. Generalized Procrustes analysis revealed that *D. antarctica* exhibited most of the desirable descriptors, such as caramel, umami and marine aromas while *U. lactuca* was described as bitter and moldy. This primary vocabulary can assist food scientists and chefs in the development of seaweed products and dishes for the consumer market.

Keywords Seaweeds · Sensory analysis · Texture profile analysis · Umami components · Generalized procrustes analysis

Introduction

Most seaweeds are novel foods in the Western world and have a great potential given their abundance, claimed nutritional and functional properties as healthy foods, and a tradition of uses in Oriental and Polynesian gastronomy. However, these positive attributes are not sufficient to attract consumers' preferences (Prager 2020). In fact, the unique textures and flavors of seaweeds are unfamiliar to most people in the Western world, except for a few seaweed species and their local use in some traditional dishes.

Seaweeds are called "the vegetables of the sea" They are subject to environmental conditions different from plants, therefore, their chemical composition, morphology and structural properties are quite different from leafy terrestrial products. Botanists describe seaweeds as having a cartilaginous thallus and elastic fronds. Unfamiliar consumers perceive flavors of seaweeds as marine, iodized, slightly bitter and fishy (Figueroa et al. 2021). Research articles, magazine reviews and books as well as famous chefs, have promoted the consumption of seaweeds in Western countries (Mouritsen 2013; O'Connor 2017; Figueroa et al. 2021). One major hindrance to increase their gastronomic applications is the limited knowledge of the specific sensory properties deemed undesirable by consumers. In Chile, *Durvillaea antarctica* ("cochayuyo") is by far the most consumed seaweed species. Other seaweeds used in traditional dishes are *Pyropia* spp. (ex *Porphyra* spp. "luche"), *Ulva lactuca*, *Chondracanthus chamissoi* and *Callophyllis variegata* (Aguilera 2021).

Key sensory descriptors (texture, aroma, flavor, aftertaste, etc.) of food products or dishes are expressed as words, terms or sentences associated with the human perception (Giboreau et al. 2007; Lawless and Civille 2013). They are widely used to identify, characterize, and compare sensory characteristics of foods, relate them to instrumental data, and inform and educate consumers on the gastronomic traits of novel foods

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(Suwonsichon 2019). A well-developed sensory vocabulary helps to conduct precise sensory analysis and the resulting descriptors become the universe of terms for untrained panelists and consumers alike (Hayakawa et al. 2010). Developing a sensory terminology is particularly relevant for novel and unfamiliar foods to better comprehend the sensory traits that may preclude or limit their consumption and how to overcome them (Yang and Lee 2019). Sensory quality is a major factor behind neophobia or the reluctance to eat new foods (Tan et al. 2017; Tuorila and Hartmann 2019; Yang et al. 2020).

The development of sensory lexicons requires trained panelists while sensory vocabularies pretend to describe in words the sensory characteristics of a food. For example, Talavera-Bianchi et al. (2010), Baker et al. (2014) and Chun et al. (2020) used six panelists to derive their lexicons for fresh leafy vegetables, caviar, and mushrooms, respectively. The degree of training of panelists also varies. Sharma et al. (2020) developed a lexicon for potato varieties with five expert panelists, while Sato et al. (2017) relied on untrained students to define sensory properties of the same tuber. Yang et al. (2020) used only four expert panelists to conceive a bilingual flavor lexicon for Sichuan pepper, but Galán-Soldevilla et al. (2005) trained eight subjects to develop a sensory vocabulary for the odor and flavor characteristics of floral honeys from Spain. Wu et al. (2017) in their panel for quinoa, used four habitual consumers and five others that had rarely consumed the food. Regarding seaweeds, Chapman et al. (2015), developed flavor sensory descriptors using fifteen assessors, none of which had a great experience with sensory profiling of seaweeds. Kato et al. (2015) utilized six skilled panelists to evaluate the appearance, taste, firmness, and stickiness of kombu softened by enzymatic treatments.

Well-defined and referenced descriptors provide valuable information on the sensory qualities of food products. Currently, scientific studies on edible macroalgae use several terms to describe their appearance, flavor and texture that are mostly adopted from other foods (Table 1).

A traditionally used method to obtain detailed information on the sensory profile and quantitative data of attributes is the Quantitative Descriptive Analysis (QDA). To provide reliable and consistent results, QDA uses a sensory panel trained with benchmarks of the product and ingredient (Meilgaard et al. 2016). This method has some limitations, namely, it requires plenty of time to train the panelists and it may generate some inconsistencies typical of the intensity evaluation method (Richter et al. 2010). Alternatively, the Ranking Descriptive Analysis method (RDA) compares multiple samples with different intensities of a given attribute. It is a relatively simple method, where the evaluators can be consumers or panelists with different levels of training (Richter et al. 2010; Chizoti et al. 2018). In RDA the evaluators classify samples using an ordinal scale, for example from 1 to 10, that facilitates achieving a final consensus in the panel (Mamede and Benassi 2016). RDA generally produces good results with respect to sample discrimination and it is cheaper and requires fewer samples than QDA. However, a shortcoming of RDA is that it does not provide the magnitude of the differences between samples. To compare the results of panels based on individual ranking data and a measure of variance, the RDA uses Generalized Procrustes Analysis (GPA), a statistical method of analysis (Guerrero et al. 2001).

Texture is a major factor in the acceptability of fresh and processed seaweeds as foods (Birch et al. 2018). The texture of most seaweeds is often described as "leathery, fibrous, and sticky" by Western consumers, traits that are positively appreciated by the Japanese (Tanaka 1986). Flavor is another important factor in the acceptability of seaweeds. The taste of seaweeds is mainly due to sugars, polyols, free amino acids and nucleotides, and organic acids. Umami, due to the presence of L-glutamate, L-aspartate, and 5'-ribonucleotides such as inosinate and guanylate, is the taste most often associated with seaweeds (Mouritsen 2013; Figueroa et al. 2021). Volatile compounds are fundamental contributors to the aroma of seaweeds with halogenated compounds providing notes like marine, crustacean, and herbaceous (López-Pérez et al. 2017; Santos and Narendra 2018).

The aims of this research are: (i) to develop a vocabulary with adequate descriptors for Chilean seaweeds; (ii) to determine the sensory properties of these seaweeds; (iii) to characterize the seaweeds in terms of chemical and physical properties; and (iv) to relate the outcomes of the sensory panel evaluation with desirable characteristics of the three seaweeds.

Materials and methods

Materials

Dried samples of *Durvillea antarctica*, *Pyropia* spp., and *Ulva lactuca* were purchased from the commercial purveyor Kaiso Spa (Chile). Seaweeds were harvested in April 2021, sun-dried near Puerto Montt (approximately 41°N, 72°W) and are representative of products used for culinary uses in local dishes. After purchase, they were kept in sealed plastic bags at room temperature (approximately 20 °C) until used in rehydrated and cooked forms.

Proximate analysis

The proximate composition of seaweeds was determined in duplicate samples, according to methods described in AOAC (2012). Moisture was determined by the oven method at 105 °C (AOAC 934.01). Total protein was determined following the Kjeldahl procedure (N × 6.25) (AOAC 2000.11). Lipids were extracted with petroleum ether in a Soxhlet and determined gravimetrically (AOAC

Table 1 Terms commonly used to describe sensory properties of seaweeds

Seaweed	Appearance	Texture	Flavor	Reference
Ulva spp.	Bright green Thin and transparent sheet	Thin, cartilaginous, slightly plastic Roasted: crispy	Fresh, slightly bitter, reminiscent of green and wild herbs	Pérez-Lloréns et al. 2017; Porto-Muiños 2021
Durvillaea antarctica	Fresh: green Dried: reddish brown	Fleshy, elastic, and firm consistency. Crunchy, damp, and spongy	Intense taste of the sea; flavor of wild mushrooms	Mansilla et al. 2012; Pérez-Lloréns et al. 2017
Macrocystis pyrifera	Olive green, with rough fronds along their length	Fresh: slightly slimy Dried: crunchy	Smooth taste of the sea	Mansilla et al. 2012
Pyropia spp.	Thin and transparent sheet Fresh: violet Toasted, cooked: green	Fine and cartilaginous	Dried: mushrooms Toasted, cooked: roasted sardines	Pérez-Lloréns et al. 2017; Porto-Muiños 2021; Kreischer and Schuttelaar 2016
Pyropia columbina	Greenish or pinkish brown	Fresh: elastic and slightly cartilaginous	Taste of the sea	Mansilla et al. 2012
Callophyllis variegata	Intense red	Fresh; cartilaginous Dried: crunchy	Intense, with hints of crustacean	Mansilla et al. 2012
Laminaria digitata	Dark olive green	Meaty and slightly cartilaginous	Iodised, lightly smoked, mild honey flavor, salty and seafood-like taste	Peinado et al. 2014; Pérez-Lloréns et al. 2017; Porto-Muiños 2021
Chondrus crispus	Small and ramified Fresh: red Cooked: green	Cartilaginous	Crustacean flavor	Peinado et al. 2014; Pérez-Lloréns et al. 2017
Undaria pinnatifida	Elongated and wavy sheets Fresh: yellow to brown Cooked: green	Fine, crispy, and somewhat meaty	Fishy, marine; reminds oysters, sweet	Kreischer and Schuttelaar 2016; Mouritsen et al. 2019; Porto-Muiños 2021
Palmaria palmata	Palm shape Deep red, brown or purple	Cartilaginous, soft, and dissolves easily	Sweet and slightly iodised flavour; strong marine aroma	Kreischer and Schuttelaar 2016; Mouritsen et al. 2012; Pérez-Lloréns et al. 2017
Saccharina japonica/ Saccharina lattisima	Slimy Yellow green	Fleshy and slightly cartilaginous	Mild taste of sea, sweet; intense umami, mushroom aroma	Mouritsen et al. 2019; Pérez-Lloréns et al. 2017
Himanthalia elongata	Narrow strips Fresh: brown Cooked: green	Crunchy and fleshy	Soft, reminds a land vegetable	Porto-Muiños 2021

991.36). The ash content was gravimetrically obtained after heating at 550 °C in a muffle furnace (AOAC 930.05). The total carbohydrate content in the samples was estimated by the anthrone method (Osborne and Voogt 1986). All results were expressed on a dry weight basis (d.w.). More details of the analytical methodologies are in Ortiz et al. (2006).

Lexicon development

Panel

Nine panelists were selected among individuals that actively participated in the development and tasting of seaweed products during the three previous years (Figueroa et al. 2021). All panel members (6 women and 3 men, all Chileans and aged between 25 and 74 y.o.) were food technologists with previous training in sensory evaluation and familiar with local dishes containing the three seaweeds.

Sample preparation

Due to the Covid-19 pandemic, development of the sensory vocabulary was performed with coded dry samples sent to the homes of seven panelists, along with detailed instructions of the hydration, cooking and tasting of samples. Two of the panelists living on the outskirts of Santiago de Chile and familiar with products and procedures bought similar dried seaweeds at local markets and followed the preparation instructions. All panelists were present in these online sessions. Portions of approximately 200 mL dry seaweed were hydrated in 1 L of water for 3 h and part of them were also cooked in water at 100 °C for 20 min (traditional method to cook seaweed).

Descriptor generation

Test sessions took place by videoconference. Panelists participated in four preliminary sessions led by a sensory evaluation expert (A.B.), each of approximately 90 min. In the first three sessions, the panelists tasted raw and cooked seaweed and described the samples in as many terms as possible regarding their appearance, aroma, taste, mouthfeel, texture, and residual sensation. In a fourth session, the descriptors were commented on, discussed, and redundant or irrelevant terms were eliminated, resulting in a consensus classification of 25 words or key terms for sensory descriptors.

Sensory evaluation

The sensory evaluation activity aimed at qualitatively assessing the seaweed samples according to the selected descriptors and took place in the premises of our laboratory in the Gastronomic Unit of the Pontificia Universidad Católica de Chile. This evaluation consisted of two sessions, one to verify that all panelists (present in both sessions) understood the descriptors and the evaluation method, and the other for sensory evaluation itself.

Sample preparation for sensory evaluation

The traditional way to prepare the seaweeds was adapted to avoid the loss of flavor compounds in the cooking water, thus to better evaluate the natural sensory characteristics. Samples were presented in two formats: raw-rehydrated and hydrated-cooked (six samples in total). The rehydrated samples were prepared and standardized as follows: *D. antarctica*, 1 g dry weight: 3 g water; *Pyropia* spp., 1 g dry weight: 2.5 g of water; and *U. lactuca*, 1 g dry weight: 2 g water. All the samples were rehydrated for 1 h. For the cooked seaweed, the same hydration treatment was followed, but then *U. lactuca* and *Pyropia* spp. were cooked inside sealed plastics bags for 15 min and *D. antarctica* for 20 min in water at 100 °C. The hydrated and cooked samples were prepared the day before, stored at 5 °C until used and served to the panel in closed white plastic cups at room temperature (20 °C), identified with a randomly selected 3-digit code.

Final training for the evaluation of samples

Each panelist received six samples (three seaweed species and two treatments of each) and an answer sheet with the 25 sensory descriptors obtained from the vocabulary development meetings. The objective of this session was to confirm that the panelists understood the sensory descriptors of appearance, aromatic and taste components, texture, and aftertaste of the newly standardized samples. The panelists first tasted the *D. antarctica*, both hydrated and cooked, and commented on the descriptors presented in the sensory descriptor guide. The attributes were condensed and discussed in the following order: appearance, aroma, flavor, mouthfeel, texture, and aftertaste. Later, the same attributes were discussed for *Pyropia* spp. and *U. lactuca* (hydrated and cooked).

Ranking descriptive analysis

In the sensory evaluation session, the six seaweed samples were analyzed by the RDA method in a sequential monadic order (Richter et al. 2010). The instruction was to evaluate and compare each sample with the other samples and record the impressions. Every panelist received deionized water to clean the palate between tastings. The comparative evaluation consisted in ranking the six samples for each descriptor, using a ranking order from 1 to 6. Results are expressed as the sum of rankings by the nine panelists for each descriptor: the smaller the sum, the smaller the intensity of the descriptor.

Physico-chemical analysis

Umami compounds

Free amino acids were determined by a modification of the method of Segura-Campos et al. (2011). For hydrated seaweed, 35 mL of water was added to 1 g of ground dried seaweed and allowed to hydrate for 1 h. For the cooked samples, hydrated *U. lactuca* and *Pyropia* spp. were cooked in boiling water for 15 min and *D. antarctica* for 20 min. In both cases, the aqueous extract was separated, filtered, and used for analysis.

A sample of 200 μL of the aqueous extract was dissolved in 2.8 mL of borate buffer (1 M, pH 9.0) and derivatized with 2.4 μL of diethyl ethoxymethylene malonate at 50 °C for 50 min under agitation. Quantification of free amino acids was performed in a UHPLC UltiMate 3000 system (Thermo Scientific, USA) following the procedures for the separation of derivatives by Segura-Campos et al. (2011). Results are expressed in mg (100 g) $^{-1}$ of dry seaweed.

Nucleotides were extracted with water and hydrochloric acid, after centrifugation (Peinado et al. 2014). For hydrated samples, dry seaweed (0.6 g) was weighed into a falcon tube and distilled water (10 mL) was added and allowed to hydrate for 1 h. For cooked seaweed, the samples were hydrated following the previous steps and cooked at 100 °C for 15 min (*U. lactuca* and *Pyropia* spp.) and 20 min (*D. antarctica*). Then hydrochloric acid (10 mL, 0.01 N) was added followed by stirring at 90 °C for 90 min. The mixture was allowed to stand for another 20 min and then filtered through a gauze. The supernatant was centrifuged at 8500 × *g* for 15 min. Quantification was performed by UHPLC UltiMate 3000 system (Thermo Scientific) with a C18 column (4.6 × 100 mm, 5 μm particle size) at 30 °C. The mobile phases were A: 20 mmol L^{-1} KH_2PO_4: 20 mmol L^{-1} K_2HPO_4 (v:v 1:1), adjusted to pH 5.8 with phosphoric acid and B: Methanol at a flow rate of 0.7 mL min^{-1}. The gradient program used was as follows: 0–9 min 8% B. A period of 6 min with initial conditions was sufficient time for a subsequent analysis run. UV detection was at a wavelength of 254 nm. Results are expressed in mg (100 g) $^{-1}$ of dry seaweed.

Equivalent umami concentration (EUC)

The EUC value reflects the impact on umami flavor intensity given by a mixture of the free amino acids glutamic acid and aspartic acid (L-Glu and L-Asp) and free nucleotides IMP (disodium inosinate) and GMP (disodium guanylate), and is represented by the following equation (Yamaguchi 1991).

$$EUC = \sum a_i b_i + 1218\left(\sum a_i b_i\right)\left(\sum a_j b_j\right)$$

EUC is expressed as g of monosodium glutamate in 100 g of sample (dry weight). Values of a_i and a_j denote the concentrations (g (100 g)$^{-1}$) of amino acids (L-Asp or L-Glu) and nucleotides (GMP or IMP), respectively. Parameter b_i represents the relative concentration of umami (RUC) for each amino acid (L-Glu: 1; L-Asp: 0.077) and b_j is the RUC for the 5'-nucleotides (IMP: 1; GMP: 2.3). The coefficient 1218 is a synergistic constant based on the concentration (g (100 g)$^{-1}$) used (Chen and Zhang 2007).

Texture profile analysis

The mechanical behavior of seaweed samples was assessed by the texture profile analysis (TPA) protocol after adapting the assay to the morphological characteristics of each seaweed (cylindrical shape or extended sheets). *Durvillea antarctica* (around 1.5 cm diameter) was cut into pieces 2 cm long while the foliose seaweeds *U. lactuca* and *Pyropia* spp. were weighed (8 g) and placed directly in a cylindrical sample holder (4 cm diam.; 3 cm height). Compression testing was done with a stainless-steel flat probe 3 cm in diameter. TPA test parameters were pre-test and post-test speed, 3.0 mm s^{-1}; test speed, 1.0 mm s^{-1}. *U. lactuca* and *Pyropia* spp. were compressed twice for 8 mm and *D. antarctica* to 50% deformation (ten replicates each). Six parameters were generated from the force–deformation graph: hardness (N), the maximum load applied to the samples during the first compression cycle; adhesiveness (N s), the negative force area for the first bite; cohesiveness (dimensionless), ratio of the area under the second peak to that under the first peak; springiness (dimensionless), the reversed sample deformation in the second compression obtained as the ratio of the distance of the detected height of sample on the second compression to that of the original compression; and, chewiness (N mm), the product of gumminess and springiness (Ansari et al. 2014).

Color

Color of hydrated and cooked seaweeds was measured with a computer vision system (DVS-Lab, Digital Vision Solutions, Chile) and expressed according to the CIE coordinates of lightness (L*), redness (a*), and yellowness (b*) (Luna and Aguilera 2014).

Data analysis

The statistical analysis of instrumental data was performed using the SPSS version 19.0 (SPSS, IBM, USA). Seaweed samples were grouped for analysis according to the

Table 2 Chemical composition of raw seaweeds

Seaweed	*D. antarctica* g (100 g)$^{-1}$ d.w	*Pyropia* spp. g (100 g)$^{-1}$ d.w	*U. lactuca* g (100 g)$^{-1}$ d.w
Moisture	8.1 ± 0.3	9.3 ± 0.0	18.2 ± 0.2
Ash	15.2 ± 0.1	18.8 ± 0.2	20.2 ± 0.7
Protein	7.0 ± 0.1	23.3 ± 0.4	19.6 ± 0.1
Carbohydrates	69.6 ± 0.2	48.5 ± 0.5	41.6 ± 0.1
Crude fiber	53.0 ± 1.5	21.7 ± 1.1	33.7 ± 0.9
Fat	0.1 ± 0.0	0.2 ± 0.0	0.4 ± 0.0

Values are expressed as mean ± standard ($n = 2$)

treatment (raw or cooked seaweed). The normality of results was analyzed by the Shapiro–Wilk test, and the Levene test was applied to determine the homogeneity of the variance. Significance of instrumental data ($p = 0.05$) was evaluated by the t-Student or Mann–Whitney U method. Results of the ranking descriptive analysis (RDA) were analyzed using the Generalized Procrustes Analysis (GPA) and the XLSTAT 2015.6 software (Mamede and Benassi 2016). Data were arranged as nine individual matrices (one per judge) of six lines (corresponding to sample treatments) and 25 columns (descriptors). Correlations of instrumental and sensory data were performed using SPSS version 19.0 (SPSS, IBM, USA), by the Spearman method with a significance of $p = 0.05$.

Results

Chemical characterization of seaweeds

Proximate analysis of samples provides a valuable chemical characterization of the materials in the study given the high variability exhibited by the same seaweed species depending on location, time of harvest, part of the frond, etc. *Pyropia* spp. and *U. lactuca* exhibited a high protein content, 19.6 and 23.3 g (100 g)$^{-1}$ d.w., respectively (Table 2) while the protein content in *D. antarctica* was approximately 7 g (100 g)$^{-1}$ d.w. Seaweeds contained only a small amount of lipids (Table 2). *U. lactuca* had the highest fat content, 0.41 g g (100 g)$^{-1}$ d.w. while the lipid content of *Pyropia* spp. and *D. antarctica* were 0.1- 0.2 g (100 g)$^{-1}$ d.w., respectively. Regarding carbohydrates, *U. lactuca* had the lowest carbohydrate content (41.6 g g (100 g)$^{-1}$ d.w.) while *D. antarctica* exhibited the highest amount (69.6 g (100 g)$^{-1}$ d.w.) (Table 2). Seaweeds are known for their ability to accumulate minerals and their high ash content compared to land plants, e.g., 8- 40% (Rupérez 2002; Munoz and Díaz 2022). *Ulva lactuca* had the highest ash content (20.2 g (100 g)$^{-1}$ d.w.) and *D. antarctica* the lowest (15.2 g (100 g)$^{-1}$ d.w.) (Table 2).

Development of a sensory vocabulary and definition of descriptors

From the online evaluation session, 25 descriptors were generated for aroma, flavor, mouthfeel, texture, and residual sensation. Table 3 shows some examples of sensory descriptors and terms used in the food science literature that allowed the panelists guide and compare the descriptors selected for seaweeds (Table 4).

Evaluation of sensory attributes

Color and appearance

Color is an important visual trait appreciated by seaweed consumers (Zhu et al. 2022). Independent of treatment, all three seaweed species showed different L*, a* and b*color parameters (Table 5). The a* value of *U. lactuca* varied significantly ($p = 0.05$) between the hydrated and cooked samples, meaning that it shifted from bright green to a more reddish color (Table 5). In the case of *Pyropia* spp., the cooked sample was significantly different in all parameters from the hydrated seaweed, and visually it became darker. The color of *D. antarctica*, did not change significantly after cooking (Table 5).

Taste and aroma

Regarding the taste and aroma, the hydrated *U. lactuca* showed more herbal notes and earthy/mouldy aroma than other seaweeds (Table 4 and Fig. 1). *Pyropia* spp., showed a high marine aroma and a sweet, salty and umami taste (Table 4). Finally, *D. antarctica* was characterized by a caramelized marine aroma, a sweet and umami taste and had the lowest value in the ranking for the salty descriptor (Table 4). Mineral aroma and residual mineral flavor were not significantly different between seaweeds independent of treatments.

A significant correlation ($p = 0.05$) was observed between flavor descriptors and some chemical components. There was a strong positive correlation between umami taste and sweet taste perceived by the panel ($r = 0.829$), and a positive correlation between the sweet taste and the caramel aroma ($r = 0.771$) of *D. antarctica* and *Pyropia* spp.

Umami compounds

The content of umami compounds varied between seaweeds. The seaweed with the highest content of L-Glu was *Pyropia* spp., between 310.06 (hydrated) and 324.27 (cooked) mg (100 g) $^{-1}$ d.w. Instead, the seaweed with the lowest value was *U. lactuca* with values ranging between

Table 3 Definition of selected sensory descriptors for seaweeds

Descriptor	Definition	Suggested references	References
Appearance			
Shiny	Light is reflected from the surface	Brilliant: tomato, candy Opaque: cookies, bread	Meilgaard et al. 2016
Translucent/ opaque	Light goes through sample, but clear images cannot be seen through it	Translucent: apple juice, fried onion Opaque: cookies, cheese	FAO 1999
Rough	Contains irregularities, bumps, or grains on the surface	Mild: apple peel Rough: peel of Hass avocado	Meilgaard et al. 2016
Turgid	The surface appears swollen or stretched (tense) due to hydrated cells underneath	Flaccid: raisins, dehydrated fruits Turgent: fresh grape, celery	Taniwaki and Sakurai 2010
Aroma			
Marine	Related to the smell of the sea, wet rocks, fresh fish, shellfish	Nori, fresh fish	Baker et al. 2014; Chapman et al. 2015; Stévant et al. 2020
Herbal	Reminds of freshly cut grass and fresh green leafy vegetables	Fresh spinach, matcha tea, parsley, freshly cut grass	Smyth et al. 2012; Talavera-Bianchi et al. 2010
Earthy /mouldy	Associated with humus, including moist soil, decaying of vegetation or basement scent	Fresh mushrooms	Talavera-Bianchi et al. 2010
Mineral	Associated with an aromatic and mouthfeel of metallic aroma and sea salts	Blood, metal cans, Al foil, salt solution	Sharma et al. 2020; Talavera-Bianchi et al. 2010
Caramel	Associated with the impression of sweet substances, aromas of caramel. Sweet, honey, toasted	Honey, caramel	Chun et al. 2020; Wu et al. 2017
Taste			
Sweet	Sensation stimulated by sucrose and low-calorie sweeteners	Honey, candies, sugar	Bueno de Godoy et al. 2020; Galán-Soldevilla et al. 2005
Bitter	Taste stimulated by substances like quinine, caffeine, and hop bitters	Ristretto coffee, IPA beers, grapefruit, tonic water	Chapman et al. 2015; Talavera-Bianchi et al. 2010
Salty	Taste stimulated by sodium salts, such as sodium chloride and sodium glutamate	Salty snacks, jerky, salt-packed anchovies	Chapman et al. 2015; Talavera-Bianchi et al. 2010
Acid	Taste stimulated by acids, such as citric, acetic, malic, phosphoric, etc	Lemon juice, vinegar, sour apples	Chapman et al. 2015; Talavera-Bianchi et al. 2010
Umami	The basic taste produced by monosodium glutamate or disodium inosinate	Soy sauce, aged cheeses, soup broths	Chapman et al. 2015; Talavera-Bianchi et al. 2010
Mouthfeel			
Astringent	Produces the shrinkage or puckering of the tongue's surface	Red wine, immature fruit	Bueno de Godoy et al. 2020; Wu et al. 2017
Slimy	The textural property that produces the sensation of wet. Slipperiness at the surfaces of the oral cavity	Natto (fermented soybeans), okra	ISO 2008
Texture			
Sticky	During chewing the food adheres to surfaces in the palate, teeth and tongue	Okra	ISO2008
Elastic	The degree to which the sample returns to its original shape after exerting a force	Plastic: butter Elastic: squid, marshmallows, gummies	Jowitt 1974; Meilgaard et al. 2016
Crunchy	Food emits noise while it breaks or fractures, characterized by few significant breaks	Raw carrot, apple, celery, pig's ear	Aguirre et al. 2018; Wu et al. 2017
Cohesive	Difficult to break/cut and bite resistant requires chewing	Low: muffin Medium: cheeses High: chewing gum	Aguirre et al. 2018; Wu et al. 2017

Table 3 (continued)

Descriptor	Definition	Suggested references	References
Cartilaginous	Associated with cartilage- a combination of hardness and crispness	Pig's ear, chicken cartilage	Texture Analysis Professionals Blog 2017
Hard	Requires force to compress between the molars to bring the teeth together	Soft: cream cheese Medium hard: peanuts Hard: hard candies	Jowitt 1974; Stévant et al. 2020; Wu et al. 2017
Residual sensation			
Toothstick	Amount of product that sticks to the teeth and palate after swallowing	Low level: mushrooms Intense: chewy candy	Meilgaard et al. 2016
Bitter	Lingering bitter sensation remaining in the mouth after the product is swallowed	Ristretto coffee, high-hops beers, grapefruit, tonic water	Talavera-Bianchi et al. 2010
Mineral	Lingering salty or metallic sensation remaining in the mouth after swallowing	Blood, some mineral waters	Talavera-Bianchi et al. 2010

Table 4 Characterization of samples by RDA

Descriptor	Descriptor	DH	DC	PH	PC	UH	UC
Appearance	Brilliant	51 ^{a}	41 ^{a,b}	38 ^{a,b}	27 ^{b,c}	18 ^{c}	14 ^{c}
	Translucent	20 ^{b,c}	15 ^{c}	47 ^{a}	47 ^{a}	28 ^{b,c}	32 ^{a,b}
	Rough	47 ^{a}	48 ^{a}	20 ^{b}	25 ^{b}	24 ^{b}	25^{b}
	Turgid	53 ^{a}	42 ^{a,b}	35 ^{b}	28 ^{b,c}	19 ^{c,d}	12 ^{d}
Aroma	Marine	46 ^{a}	27 ^{b}	42 ^{a}	23 ^{b}	21 ^{b}	25 ^{b}
	Herbal	23 ^{b,c}	15 ^{c}	34 ^{a,b}	30 ^{a,b}	41 ^{a}	40 ^{a}
	Earthy/mouldy	16 ^{c}	12 ^{c}	25 ^{b,c}	35 ^{a,b}	38 ^{a,b}	42 ^{a}
	Mineral	35 ^{a}	20 ^{a}	38 ^{a}	38 ^{a}	29 ^{a}	29 ^{a}
	Caramel	37 ^{b}	54 ^{a}	25^{b,c,d}	35 ^{b,c}	17 ^{d}	21 ^{c,d}
Taste	Sweet	35 ^{a}	43 ^{a}	39 ^{a}	41 ^{a}	17 ^{b}	14 ^{b}
	Salty	25 ^{b,c}	18 ^{c}	42 ^{a}	37 ^{a,b}	33^{a,b,c}	34 ^{a,b}
	Acid	21 ^{c,d}	14 ^{d}	31 ^{b,c}	31 ^{b,c}	45 ^{a,b}	47 ^{a}
	Umami	33 ^{a}	36 ^{a}	43 ^{a}	48 ^{a}	15 ^{b}	14 ^{b}
	Bitter	21 ^{b,c}	13 ^{c}	26 ^{b,c}	30 ^{b}	49 ^{a}	50 ^{a}
Mouthfeel	Astringent	19 ^{b}	16 ^{b}	28 ^{b}	27 ^{b}	49 ^{a}	50 ^{a}
	Slimy	50 ^{a}	45 ^{a,b}	33 ^{b,c}	29 ^{c,d}	16 ^{d}	16 ^{d}
Texture	Sticky	45 ^{a}	48 ^{a}	21 ^{b}	27 ^{b}	22 ^{b}	26 ^{b}
	Springy	53 ^{a}	44 ^{a,b}	36 ^{b}	29 ^{b,c}	18 ^{c}	9 ^{d}
	Crunchy	54 ^{a}	45 ^{a,b}	35 ^{b,c}	28 ^{c,d}	16 ^{d,e}	11 ^{e}
	Hardeness	52 ^{a}	43 ^{a,b}	38 ^{a,b}	29 ^{b,c}	15 ^{c,d}	12 ^{d}
	Cohesiveness	52 ^{a}	43 ^{a,b}	38^{a,b,c}	29 ^{b,c,d}	14 ^{d,e}	13 ^{e}
	Cartilaginous	52 ^{a}	43 ^{a,b}	36 ^{b,c}	31 ^{b,c}	15 ^{d}	12 ^{d}
Residual sensation	Tooth adhesion	12 ^{d}	15 ^{d}	32 ^{b,c}	35 ^{a,b,c}	45 ^{a,b}	50 ^{a}
	Bitter	14 ^{d,e}	13 ^{e}	29 ^{c,d}	34 ^{b,c}	48 ^{a,b}	51 ^{a}
	Mineral	26 ^{a}	26 ^{a}	36 ^{a}	35 ^{a}	35 ^{a}	31 ^{a}

Different superscripts in the same row indicate significant differences

Sum of rankings of the nine panelists (higher values mean more intensity)

Nomenclature: *DH* hydrated *D. antarctica*, *DC* cooked *D. antarctica*, *PH* hydrated *Pyropia* spp., *PC* cooked *Pyropia spp*, *UH* hydrated *U. lactuca, UC* cooked *U. lactuca*

37.07 (hydrated) and 35.60 (cooked) mg (100 g) $^{-1}$ d.w. (Table 6). The seaweed that obtained the highest content of L-Asp was *D. antarctica* with values between 71.09 (hydrated) and 78.57 (cooked) mg (100 g)$^{-1}$ d.w. Regarding free nucleotides, the seaweed with the highest content of nucleotides was *Pyropia* spp., followed by *D. antarctica.* No nucleotides were identified for cooked or hydrated *U. lactuca.*

Table 5 Color parameters of hydrated and cooked seaweeds

Sample	DH	DC	PH	PC	UH	UC
L*	26.98 ± 0.61 [a]	27.05 ± 1.64 [a]	50.86 ± 2.02 [b]	40.93 ± 3.10 [c]	49.83 ± 1.39 [d]	47.36 ± 2.32 [d]
a*	3.06 ± 0.35 [a]	3.09 ± 0.17 [a]	4.60 ± 0.77 [b]	9.05 ± 2.60 [c]	-7.27 ± 0.78 [d]	-0.77 ± 0.34 [e]
b*	4.41 ± 0.5 [a]	4.17 ± 0.63 [a]	12.19 ± 12.19 [b]	3.43 ± 0.78 [c]	30.29 ± 1.48 [e]	24.33 ± 1.71 [e]

Different superscripts in the same row indicate significant differences between treatments in each seaweed. Values are expressed as mean ± standard deviation ($n = 10$)

Nomenclature: *L** lightness, *a** redness, *b** yellowness, *DH* hydrated *D. antarctica*, *DC* cooked *D. antarctica*, *PH* hydrated *Pyropia* spp., *PC* cooked *Pyropia spp*, *UH* hydrated *U. lactuca, UC* cooked *U. lactuca*

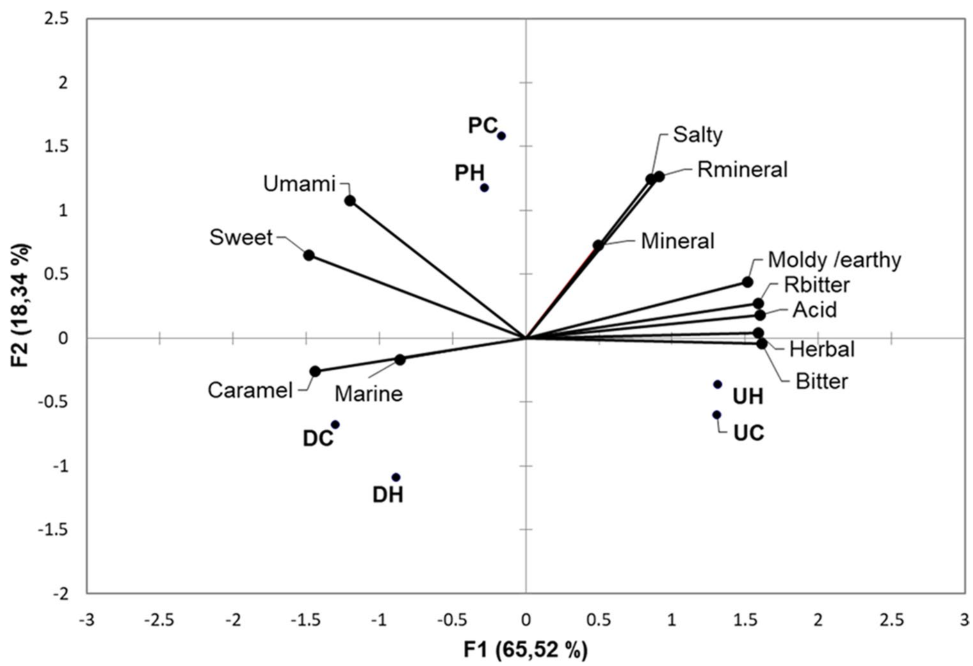

Fig. 1 Generalized Procrustes Analysis (GPA) plot of descriptors for taste, aroma and residual flavour obtained by Ranking Descriptive Analysis. Rbitter and Rmineral refer to residual sensations. Nomenclature: DH: hydrated *D. antarctica*; DC: cooked *D. antarctica*; PH: hydrated *Pyropia* spp.; PC: cooked *Pyropia* spp; UH: hydrated *U. lactuca*; UC: cooked *U. lactuca*

Table 6 Amino acid and 5′-nucleotides content in hydrated and cooked seaweed, and equivalent umami concentration EUC

Sample	DH	DC	PH	PC	UH	UC
L-Asp [a]	71.09 ± 2.15	78.57 ± 2.07	51.45 ± 0.86	58.54 ± 1.89	53.10 ± 3.19	36.81 ± 0.40
L-Glu [a]	209.09 ± 6.98	209.98 ± 2.07	310.06 ± 4.89	324.27 ± 11.75	37.07 ± 0.31	35.60 ± 0.61
IMP [a]	0.963 ± 0.01	1.328 ± 0.04	7.809 ± 0.07	7.333 ± 0.76	N.D	N.D
GMP [a]	0.014 ± 0.15	0.044 ± 0.14	0.071 ± 0.05	0.764 ± 0.19	N.D	N.D
EUC [b]	3.19	3.06	4.60	5.34	0.04	0.04

Values are expressed as mean ± standard deviation ($n = 3$)

Nomenclature: *DH* hydrated *D. antarctica*, *DC* cooked *D. antarctica*, *PH* hydrated *Pyropia* spp., *PC* cooked *Pyropia spp*, *UH* hydrated *U. lactuca, UC* cooked *U. Lactuca, L-Asp* Aspartic acid, *L-Glu* Glutamic acid, *N.D.* not detected

[a]mg (100 g)$^{-1}$ d.w

[b]gMSG (100 g)$^{-1}$ d.w

EUC varied between seaweed species, but not between cooking conditions (Table 6). The seaweed with the highest EUC value was *Pyropia* spp., 4.60 and 5.34 (g MSG (100 g)$^{-1}$ d.w.) for hydrated and cooked samples, respectively, followed by *D. antarctica* (4.60 and 5.34 g MSG (100 g)$^{-1}$ d.w., respectively). The lowest EUC value corresponded to *U. lactuca* for both sample treatments 0.04 (g MSG (100 g)$^{-1}$ d.w.). These results are consistent with those reported by the sensory panel (Table 4). The correlation analysis using Spearman's bivariate method, showed a significant ($p = 0.05$) and positive

Table 7 Texture parameters determined by the TPA method

Sample	DH	DC	PH	PC	UH	UC
Hardness(N)	10.20 ± 1.52 [a]	2.72 ± 1.24 [b]	1.01 ± 0.22 [c]	0.91 ± 0.13 [c]	2.43 ± 0.77 [d]	1.85 ± 0.78 [d]
Adhesiveness (g*sec)	–19.11 ± 9.19 [a]	–25.83 ± 16.23 [a]	–4.53 ± 2.68 [b]	–7.39 ± 4.73 [b]	–3.61 ± 2.35 [c]	–9.08 ± 5.62 [d]
Springiness	0.95 ± 0.08 [a]	0.98 ± 0.07 [a]	0.98 ± 0.01 [b]	1.00 ± 0.07 [b]	0.95 ± 0.03 [c]	0.89 ± 0.06 [d]
Cohesiveness	0.90 ± 0.10 [a]	0.92 ± 0.04 [a]	0.84 ± 0.35[b]	0.79 ± 0.09 [c]	0.83 ± 0.05 [c]	0.74 ± 0.08 [d]
Chewiness	8.83 ± 2.30 [a]	2.45 ± 1.17 [b]	0.83 ± 0.18 [c]	0.71 ± 0.10 [c]	1.91 ± 0.60 [c]	1.23 ± 0.56 [d]
Resilience	0.77 ± 0.10 [a]	0.45 ± 0.03 [b]	0.32 ± 0.02 [b]	0.26 ± 0.02 [c]	0.24 ± 0.03 [c]	0.18 ± 0.04 [d]

Different superscripts in the same row indicate significant differences between treatments in each seaweed. Values are expressed as mean ± standard deviation ($n = 10$)

Nomenclature: *DH* hydrated *D. antarctica*, *DC* cooked *D. antarctica*, *PH* hydrated *Pyropia* spp., *PC* cooked *Pyropia spp*, *UH* hydrated *U. lactuca, UC* cooked *U. Lactuca*

correlation (r = 0.943) between the umami taste perceived by the sensory panel and the EUC values.

Texture analysis

The sensory panel evaluated the difference in textural properties. The hardness of all the seaweeds decreased with cooking. Hydrated *D. antarctica* and *Pyropia* spp. decreased their hardness by approximately 10 points with respect to their respective cooked samples, and the hydrated *U. lactuca* only decreased by 3 points with respect to the cooked sample. Other important parameters were crunchy, cartilaginous and springy sensation that together with hardness decreased with cooking. The only parameter that seemed to increase with cooking was stickiness. The seaweed with highest values for all texture parameters was *D. antarctica* and the lowest score was obtained by *U. lactuca*.

Texture profile analysis

Cooking of *U. lactuca* generated significant differences ($p < 0.05$) in all texture parameters except for hardness (Table 7). In the case *Pyropia* spp., the descriptors cohesiveness and resilience presented a significant difference between uncooked and cooked samples. For *D. antarctica*, significant differences were detected in hardness, chewiness, and resilience. Since the physical testing method was different for *D. antarctica* (i.e., compression rather than puncture) comparisons with the other two seaweed species cannot be made, however, cooking induced textural changes to diverse extents for the three seaweeds.

Discussion

Chemical characterization of seaweeds

The protein content of seaweeds varies with the species. High contents of proteins are reported for green and red seaweeds, and some of these species can reach up to 40% of their dry weight in protein (Holdt and Kraan 2011). Results of protein content for *Pyropia* spp. (23.3%) and *U. lactuca* (19.6%) were similar to those reported by Cian et al. (2013), 24.61 g (100 g)$^{-1}$ d.w. for the red seaweed *Porphyra columbina* while Ortiz et al. (2006) and Rasyid (2017) reported a protein content for *U. lactuca* ranging between 13.6 and 27.2 g (100 g)$^{-1}$ d.w. The protein content in brown seaweeds in generally low; *D. antarctica* was the seaweed with the lowest protein content, about 7% of its dry weigh, a value similar to that of Mateluna et al. (2020). Regarding lipids, seaweeds have low contents of triglycerides that vary between species, season, and environmental factors. Our results agree with previous studies (Anantharaman et al. 2013; Pirian et al. 2020), confirming that green seaweeds, in general, contain higher concentrations of lipids than red and brown seaweeds. The values obtained for *Pyropia* spp. and *D. antarctica* were in accordance with those reported by Cian et al. (2013) and Mateluna et al. (2020).

Carbohydrates, particularly polysaccharides, are in high concentration in seaweed as they fulfil important structural, storage and functional functions (Quitral et al. 2012). Values for *Pyropia* spp. and *D. antarctica* were similar to those obtained by Cian et al. (2013) and Ortiz et al. (2006). In the case of *U. lactuca*, Rasyid (2017) and Ortiz et al. (2006), reported a higher amount of carbohydrates, a difference that could be due to environmental conditions or growth stage of the seaweed.

Mineral content in this studio differs from those reported by Ortiz et al. (2006), who found that *D. antarctica* contained a higher ash content (17.9 g (100 g)$^{-1}$ d.w.) than *U. lactuca* (11.0 g (100 g)$^{-1}$ d.w.). In the case of *Pyropia* spp., the ash content (18.8 g (100 g)$^{-1}$ d.w.) was higher than the value reported by Cian et al. (2013). Seaweeds vary greatly in their ash and mineral content due to factors such as geographical origin and seasonal, environmental, and physiological variations (Rupérez 2002).

In summary, results of the proximate analysis of seaweeds were consistent with those of other authors and any differences may be attributed to factors such as environmental conditions, geographical location, stage of development and morphological characteristics of seaweeds, among others (Circuncisão et al. 2018; Figueroa et al. 2021).

Development of a sensory vocabulary and definition of descriptors

A common way to develop a sensory vocabulary is to start by asking members of a panel to write down an attribute list for a food and then the panel leader promotes a group discussion to agree on the definitions (Mc Donnell et al. 2001). Thus, a preliminary sensory vocabulary is open to improvements and validation by expert panelists and it may lead to the creation of formal lexicons for specific foods or beverages (Baker et al. 2014). In our case, with the aid of a vocabulary, research chefs and consumers will be able to speak the same language when it comes to describing the sensory characteristics of seaweeds, seaweed products, and dishes. In fact, a detailed analysis of research articles suggesting the incorporation of seaweeds in any form (i.e., flours, extracts, etc.) into traditional food products (breads, pasta, meat products, etc.) show that addition of seaweed ingredients is limited at around 10% by undesirable sensory effects (Birch et al. 2018; Prager 2020; Figueroa et al. 2021).

Evaluation of sensory attributes

Color and appearance

The three seaweeds species are very different in terms of appearance and color. Morphologically, *U. lactuca* is a foliose seaweed with a laminar thallus with blades around 15 cm in size, of light green to dark green color; *Pyropia* spp. is a foliose seaweed with translucent fronds of a color that varies between pink and purple, and having blades approximately 10 cm in size; *D. antarctica*, on the other hand, is a brown seaweed with cylindrical fronds that can measure up to 15 m in length. In cross-section, the outer part consists of a hard cortex and the interior looks like a honeycomb (Mateluna et al. 2020). Its color varies from dark brown to greenish brown (Santelices 1989).

Cooking modifies the structure of seaweeds, and this change is more evident in some species than in others (Chen and Roca 2018). Panelists did not recognize major differences in the appearance of raw and cooked seaweeds (Table 4). In the case of *D. antarctica* its tubular shape became flattened after cooking and the alteration was expressed by the sensory panel as being less turgid (Table 4). These changes may be attributed to the solubilization of structural polysaccharides in hot water leading to collapse of the honeycomb inner structure (Mouritsen 2013; Bruhn et al. 2019).

Color was different between seaweeds and treatments. These color changes after cooking are probably due to degradation of pigments (e.g., chlorophylls, xanthophylls, and carotenes) leading to the formation of secondary-colored substances (Stévant et al. 2018). Pina et al. (2014) and Amorim et al. (2012) pointed out that the presence of β-carotene and lutein increased in the red seaweed *Chondrus crispus*, the brown seaweed *Undaria pinnatifida* (Wakame), and *Laminaria* spp. (Kombu) after hot culinary treatments, probably by their release from an obliterated cellular matrix.

Taste and aroma

Flavor of seaweeds, or the sensory impression determined by the chemical senses of taste and smell, depends on the species, geographical origin, time of harvest, and the processing method, among other factors (López-Pérez et al. 2017). The green seaweed *U. lactuca* had more herbal notes and earthy/mouldy aroma among seaweeds because it contains high levels of dimethyl sulfide (DMS) which provides "cabbage sulfur" and "seaside fresh" aromas (López-Pérez et al. 2017; Francezon et al. 2021). Sugisawa et al. (1990), pointed out that the herbaceous aroma was mainly due to the high content of aldehydes that are perceived as herbaceous, green and cucumber aromas. Regarding red seaweeds, *Porphyra* spp., belonging to the same family as *Pyropia* spp., have high contents of DMS and other sulfur compounds that provide a strong marine flavor in the seaweed (Francezon et al. 2021). Furthermore, this seaweed contains high amounts of free glutamate and 5' ribonucleotides that enhance the umami flavor in some dishes such as sushi (Mouritsen et al. 2012). In addition, it contains a great diversity and abundance of halogenated compounds that contribute to marine and shellfish aromas (Francezon et al. 2021). These compounds could be responsible for the marine aromas and the sweet, salty and umami taste. In the case of *D. antarctica*, there is limited information on the volatile composition and flavor compounds. Moraes et al. (2021) found that *D. antarctica* contained a large amount of 1-octen-3-ol, a mushroom-like aroma.

Mineral and residual sensations were not different between treatments. Regarding residual sensations, Sanchez-García et al. (2021), point out that cooked samples of *Ulva rigida* exhibited low values of several aroma descriptors, including seaside and seaweed notes. The earthy/mouldy aroma and bitter taste of *U. lactuca* remained after cooking. *Pyropia* spp., however, experienced noticeable changes in flavor, particularly, in marine aroma. The caramel and marine aromas changed significantly for *D. antarctica* after cooking. It should be stressed at this point that sensory perceptions depend on the origin of samples and cannot be generalized to the particular species.

Figure 1 shows how samples and descriptors distributed in the different quadrants of the GPA graph. *D. antarctica* exhibited most of the desirable descriptors, such as caramel, umami and marine aromas while *U. lactuca* turned out to have undesirable bitter and earthy/mouldy descriptors. *Pyropia* spp. was almost equidistant from the other two samples where umami and salty were the closest descriptors. Also evident from Fig. 1 is that cooking changed only slightly the position of samples in the graph.

There is an interesting correlation between the enhancement of sweetness perception and umami taste (Woskow 1969). This relationship is evidenced in the results obtained. Furthermore, these results stimulate further research on the content of sugars and umami components of seaweeds and harvesting conditions that optimize a positive sensory perceptions by consumers.

Umami compounds

There is limited information on the content of amino acids responsible for the umami taste of most edible seaweeds (Mouritsen et al. 2019). Often these free amino acids precipitate forming a white layer on the surface of the dried seaweeds (Mouritsen et al. 2012). Umami taste in seaweeds is mainly a result of the synergistic presence between glutamic acid and aspartic acid with 5' ribonucleotides (Yamaguchi 1991). Milinovic et al. (2020) reported that green seaweed, in general, has a low content of free umami compounds compared to other edible macroalgae, which is consistent with results obtained in this study. Moreover, they pointed out that of twelve different species of seaweeds, the Rhodophyta containd the highest concentration of L-Glu and L-Asp. The authors also suggested that red seaweeds are a good option to introduce the umami taste in culinary recipes. Kawashima et al. (2018) identified the components of the umami taste of nori (*Porphyra* spp.) and reported concentrations of the free amino acids L-Glu and L-Asp of 261 mg (100 g) $^{-1}$ and 56 mg (100 g) $^{-1}$, respectively, similar to those of *Pyropia* spp. in Table 6. Regarding brown seaweed, the glutamate content is highly variable depending on the species. Mouritsen et al. (2019) studied the MSG content in dashi broth from 20 different species of brown seaweed and found out that it ranged from 0.015 to 37 mg mL^{-1}.

Umami components and nucleotides were determined in seaweed extracts (as described in Sect. 2.5.1) so they correspond to the free form of these compounds (Peinado et al. 2014; Kawashima et al. 2018). Thus, the reported concentrations may not represent the actual contents in hydrated and cooked seaweeds used in sensory evaluation, but they are a good proxy of the free forms of compounds in solution inside the hydrated and cooked seaweeds. Regarding the nucleotide content of seaweeds, some studies indicate that the presence of 5'GMP and 5'IMP is very low, often imperceptible (Milinovic et al. 2020). Values in Table 6 show that the total concentration of the nucleotides 5'IMP and 5'GMP are low, ranging from 0.97 to 8.0 mg (100 g) $^{-1}$ d.w. and not detectable in *U. lactuca*. Tashiro et al. (1991), reported 5'IMP concentrations in the range of 9 to 10 mg (100 g) $^{-1}$ in dried nori On the other hand, Peinado et al. (2014) reported total nucleotide concentrations similar to those existing in tomatoes, potatoes

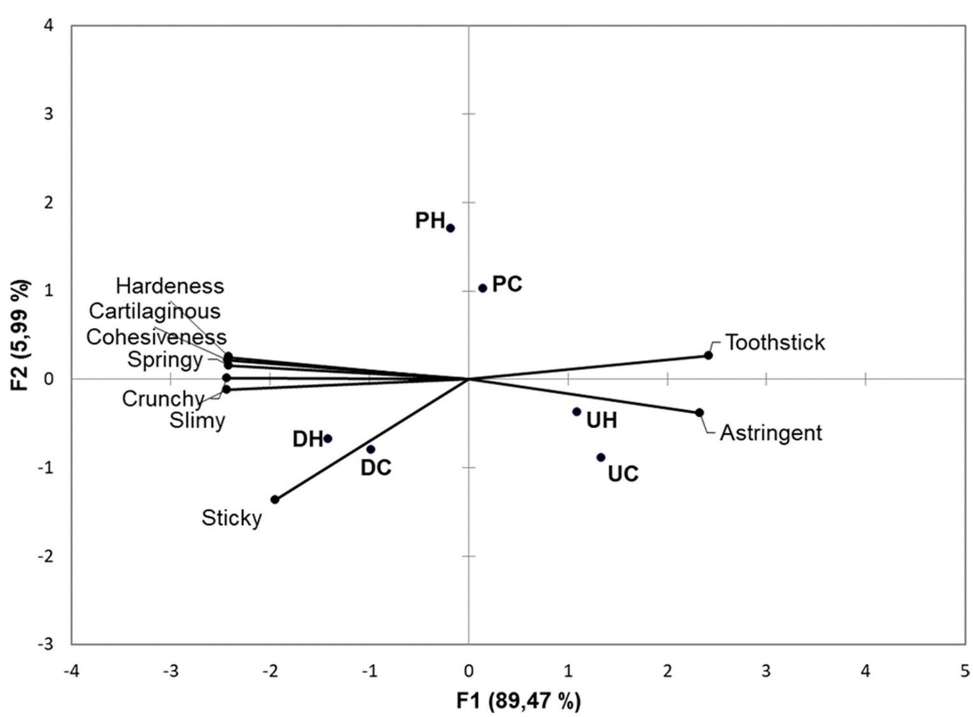

Fig. 2 Generalized Procrustes Analysis (GPA) plot of descriptors for texture obtained by Ranking Descriptive Analysis. Nomenclature: DH: hydrated *D. antarctica*; DC: cooked *D. antarctica*; PH: hydrated *Pyropia* spp.; PC: cooked *Pyropia* spp; UH: hydrated *U. lactuca*; UC: cooked *U. lactuca*

and fungi (of the order of 500 mg (100 g) $^{-1}$) in *Pelvetia canaliculata* and *Fucus vesiculosus*. Further work should be undertaken regarding the nucleotide content of seaweeds and their variability between species.

Texture analysis

Texture is a critical attribute in the acceptance of seaweeds. Table 4, shows that the three seaweeds were different in terms of stickiness, elasticity, crispness, hardness, cohesiveness, and cartilaginous sensation. *Ulva lactuca* obtained the lowest values in the RDA, which means that it was the softest seaweed, the least sticky, elastic, crispy, cartilaginous, and cohesive. In the case of *Pyropia* spp., the values obtained from RDA are intermediate between those *U. lactuca* and *D. antarctica*, which means that texture is not a distinctive parameter for this seaweed. Finally, *D. antarctica* obtained the highest RDA values in all attributes and was perceived as hard elastic, cohesive and cartilaginous. The texture difference between the three seaweeds is also appreciated in the GPA graph in Fig. 2. *D. antarctica* and *U. lactuca* are in opposite quadrants along the X-axis, meaning that they possessed contrasting textural characteristics.

Panelists did not find much difference in textural descriptors between hydrated and cooked samples of the same species (Table 4 and Fig. 2). For *U. lactuca*, the perception of springiness decreased significantly with cooking. Results are similar to those obtained by Sanchez-García et al. (2021), in that the descriptors of hardness, stickiness and elasticity did not change significantly for *Ulva rigida*. In the case of *Pyropia* spp. and *D. antarctica*, the elastic, crunchy, hardness, cohesiveness, and cartilaginous descriptors tend to decrease when the seaweeds are cooked. Bruhn et al. (2019) found that cooking decreases the viscous appearance of *Saccharina japonica* due to the dissolution or washing in water of polysaccharides such as laminarin or fucoidan. In this study, just enough water was used to hydrate, therefore an increase in viscosity is perceived in the treated seaweed. Therefore, one option to remove this often unpleasant characteristic is to wash the seaweed, but unfortunately some flavor compounds such as umami compounds will be lost in the broth.

Texture profile analysis

Seaweeds have tough and elastic cell walls reinforced with polysaccharides (Mouritsen 2013). When these polysaccharides contact the hot water, some of them dissolve and weaken the cell structures, generating changes in texture, a phenomenon observed in Table 7 that also occurs in land plants. This change in texture was demonstrated by Mateluna et al. (2020), who studied the microstructural and textural changes of *D. antarctica* after cooking. According to Vervoort et al. (2012), hydrothermal processing of carrots generates a loss of turgor that translates into textural softening. Adhesiveness increases when the seaweeds are cooked at 100 °C (Table 7) but the effect is not significant. Alginates, carrageenans and ulvans are the main structural components of cell walls of brown, red and green seaweeds, respectively, and these polysaccharides are solubilized by hot water (Xu et al. 2017). This may explain that upon cooking the cell walls break down releasing polymers that generate a viscous or slippery sensation in the mouth.

Correlation between sensory analysis and TPA

Instrumental analysis of foods saves time and costs while providing a guide to design and implement sensory trials (Ross 2009). In general, only a few correlations exist between sensory and instrumental textural measurements by TPA. This is attributed to the complexity of the chewing process compared to mechanical tests (Saldaña et al. 2015). However, some correlations existed between data from the sensory panel and the TPA. The hardness and cartilaginous descriptors obtained from the sensory analysis correlated with the hardness measured by TPA ($r = 0.543$). The linear correlation is statistically not very strong, but it was sensed by the panel, and it may be due to the fact that the ranking method does not reveal the magnitude of the differences between descriptors of samples. Another correlated parameter was sensory stickiness and TPA adhesiveness ($r = -0.886$). Meullenet et al. (1998) studied 21 foods from various origins by sensory analysis and TPA and found acceptable linear correlations only for hardness and springiness. We agree with their conclusion that the instrumental testing conditions should closely represent phenomena perceived during sensory evaluation.

Conclusions

This work reports on the development of a preliminary vocabulary to evaluate the sensory properties of local seaweeds consumed in Chile. It provides a basic terminology that can be adapted and complemented to other seaweed species and locations. The chemical composition of the three edible seaweeds in this study (*D. antarctica*, *Pyropia* spp., and *U. lactuca*) was comparable to that of similar seaweeds reported in the literature. The nine-member sensory panel agreed after several sessions on a 25-descriptor vocabulary. During sensory analysis of raw and cooked samples, these descriptors managed to differentiate the sensory properties of the seaweeds with the Ranking Descriptive Analysis (RDA) method as demonstrated by Generalized Procrustes Analysis (GPA). Although it was not possible to obtain the true intensity of the descriptors (as would be achieved using Quantitative Descriptive Analysis), a ranking profile of the main characteristic descriptors for each seaweed was obtained. *Ulva lactuca* was characterized as a bitter seaweed, with an herbaceous aroma and the softest of the three seaweeds. *Pyropia* spp., was the most umami seaweed although it did not have a distinctive texture and cooking increased the aroma of caramel, and earthy/mouldy and the umami taste. *Durvillea antarctica* was the least salty, with a caramel aroma and the hardest, and most cartilaginous and sticky seaweed. In general, cooking did not greatly modify the sensory attributes of seaweeds. Physical and chemical analyses corroborated the sensations perceived by the panel in terms of umami taste and texture. Part of the sensory differences observed between the samples investigated may be attributed to their different morphologies, microstructures, and chemical composition.

This work should inspire further research that accurately defines the meanings of the descriptors by an expert panel and the determination of their quantitative sensory values on a numerical scale, superseding the ranking method used in this work. Another aspect requiring further study is the implementation of instrumental testing conditions in TPA that closely relate to phenomena perceived during the sensory evaluation of seaweeds.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflicts of interest The authors declare that they have no conflicts of interest.

References

Aguilera JM (2021) Seaweeds from Chile on the Table. Pontificia Universidad Católica, Santiago

Aguirre ME, Owens CM, Miller RK, Alvarado CZ (2018) Descriptive sensory and instrumental texture profile analysis of woody breast in marinated chicken. Poult Sci 97:1456–1461

Amorim K, Lage-Yusty M, López-Hernandez J (2012) Changes in bioactive compounds content and antioxidant activity of seaweed after cooking processing. CYTA J Food 10:321–324

Anantharaman P, Parthiban C, Saranya C, Girija K, Hemalatha A, Suresh M (2013) Biochemical composition of some selected seaweeds from Tuticorin coast. Adv Appl Sci Res 4:362–366

Ansari S, Maftoon-Azad N, Farahnaky A, Hosseini E, Badii F (2014) Effect of moisture content on textural attributes of dried figs. Int Agrophysics 28:403–412

AOAC (2012) Official Methods of Analysis. AOAC, Gaithersburg

Baker AK, Vixie B, Rasco BA, Ovissipour M, Ross CF (2014) Development of a lexicon for caviar and its usefulness for determining consumer preference. J Food Sci 79:2533–2541

Birch D, Skallerud K, Paul NA (2018) Who are the future seaweed consumers in a Western society? Insights from Australia. Br Food J 121:603–615

Bruhn A, Brynning G, Johansen A, Lindegaard MS, Sveigaard HH, Aarup B, Fonager L, Andersen LL, Rasmussen MB, Larsen MM (2019) Fermentation of sugar kelp (*Saccharina latissima*) - Effects on sensory properties, and content of minerals and metals. J Appl Phycol 31:3175–3187

Bueno de Godoy RC, Chambers E, Yang G (2020) Development of a preliminary sensory lexicon for mate tea. J Sens Stud 35:e12570

Chapman A, Stévant P, Larssen WE (2015) Food or fad? Challenges and opportunities for including seaweeds in a Nordic diet. Bot Mar 58:423–433

Chen K, Roca M (2018) Cooking effects on chlorophyll profile of the main edible seaweeds. Food Chem 15:368–374

Chen DW, Zhang M (2007) Non-volatile taste active compounds in the meat of Chinese mitten crab (*Eriocheir sinensis*). Food Chem 104:1200–1205

Chizoti TS, Cruz MF, Benassi MT, Brugnaro C, de Medeiros SDS, Bordi PL Jr, Verruma-Bernardi MR (2018) Sensory analysis of chocolate milk for college students. J Obesity Overweight 4:107

Chun S, Chambers E, Han I (2020) Development of a sensory flavor lexicon for mushrooms and subsequent characterization of fresh and dried mushrooms. Foods 9:980

Cian RE, Fajardo MA, Alaiz M, Vioque J, González RJ, Drago SR (2013) Chemical composition, nutritional and antioxidant properties of the red edible seaweed *Porphyra columbina*. Int J Food Sci Nutr 65:299–305

Circuncisão AR, Catarino MD, Cardoso SM, Silva AMS (2018) Minerals from macroalgae origin: Health benefits and risks for consumers. Mar Drugs 16:400

FAO (1999) Guidelines for the sensory evaluation of fish and shellfish in laboratories. https://www.fao.org/faowhocodexalimentarius/shproxy/es/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXG%2B31-1999%252FCXG_031e.pdf. Accessed 27 Dec 2021

Figueroa V, Farfán M, Aguilera JM (2021) Seaweeds as novel foods and source of culinary flavors. Food Rev Int. https://doi.org/10.1080/87559129.2021.1892749

Francezon N, Tremblay A, Mouget JL, Pasetto P, Beaulieu L (2021) Algae as a source of natural flavors in innovative foods. J Agric Food Chem 69:11753–11772

Galán-Soldevilla H, Ruiz-Pérez-Cacho MP, Serrano S, Jodral M, Bentabol A (2005) Development of a preliminary sensory lexicon for floral honey. Food Qual Prefer 16:71–77

Giboreau A, Dacremont C, Egoroff C, Guerrand S, Urdapilleta I, Candel D, Dubois D (2007) Defining sensory descriptors: Towards writing guidelines based on terminology. Food Qual Prefer 18:265–274

Guerrero I, Romero A, Tous J (2001) Importance of Generalised Procrustes Analysis in sensory characterisation of virgin olive oil. Food Qual Prefer 12:515–520

Hayakawa F, Kazami Y, Wakayama H, Oboshi R (2010) Sensory lexicon of brewed coffee for Japanese consumers, untrained coffee professionals and trained coffee tasters. J Sens Stud 25:917–939
Holdt SL, Kraan S (2011) Bioactive compounds in seaweed: Functional food applications and legislation. J Appl Phycol 23:543–597
ISO (2008) Sensory analysis-vocabulary. https://www.iso.org/obp/ui#iso:std:iso:5492:ed-2:v1:en. Accessed 23 Dec 2021
Jowitt R (1974) The terminology of food texture. J Texture Stud 5:351–358
Kato K, Hayashi M, Umene S, Masunaga HA (2015) Novel method for producing softened edible seaweed kombu. Food Sci Technol 65:618–623
Kawashima T, Shirai T, Matsuda H, Osako K, Okazaki E (2018) Identification and roles of the taste-active components of dried nori. Japan J Food Eng 19:121–127
Kreischer L, Schuttelaar M (2016) Ocean greens: Explore the world of edible seaweed and sea vegetables. The Experiment, New York
Lawless LJ, Civille GV (2013) Developing lexicons: A review. J Sens Stud 28:270–281
López-Pérez O, Picon A, Nuñez M (2017) Volatile compounds and odour characteristics of seven species of dehydrated edible seaweeds. Food Res Int 99:1002–1010
Luna MP, Aguilera JM (2014) Kinetics of colour development of molten glucose, fructose and sucrose at high temperatures. Food Biophys 9:61–68
Mamede MEO, Benassi MT (2016) Efficiency assessment of Flash Profiling and Ranking Descriptive Analysis: a comparative study with star fruit-powdered flavored drink. Food Sci Technol 36:195–203
Mansilla A, González L, Astorga MS, Ávila M, Ojeda J, Rosenfeld S, Marambio J (2012) Uso de algas marinas en la gastronomía Magallánica. Universidad de Magallanes, Punta Arenas
Mateluna C, Figueroa V, Ortiz J, Aguilera JM (2020) Effect of processing on texture and microstructure of the seaweed *Durvillaea antarctica*. J Appl Phycol 32:4211–4219
Mc Donnell E, Hulin-Bertaud S, Sheehan E, Delahunty C (2001) Development and learning process of a sensory vocabulary for the odor evaluation of selected distilled beverages using descriptive analysis. J Sens Stud 16:425–445
Meilgaard MC, Civille GV, Carr BT (2016) Sensory evaluation techniques. CRC Press, Boca Raton
Meullenet JF, Lyon BG, Carpenter JA, Lyon CE (1998) Relationship between sensory and instrumental texture profile attributes. J Sens Stud 13:77–93
Milinovic J, Campos B, Mata P, Diniz M, Noronha JP (2020) Umami free amino acids in edible green, red, and brown seaweeds from the Portuguese seashore. J Appl Phycol 32:3331–3339
Moraes L, Carapina C, Ferrerira L, Mansilla A, Ziemann MA, Pereira CM (2021) Evaluation of volatile organic compounds in brown and red sub-Antarctic macroalgae. Rev Bras Bot 44:79–84
Mouritsen OG (2013) Seaweeds: Edible, Available, and Sustainable. The University of Chicago Press, London
Mouritsen OG, Williams L, Bjerregaard R, Duelund L (2012) Seaweeds for umami flavour in the new Nordic cuisine. Flavour 1:4
Mouritsen OG, Duelund L, Petersen MA, Hartmann AL, Frøst MB (2019) Umami taste, free amino acid composition, and volatile compounds of brown seaweeds. J Appl Phycol 31:1213–1232
Munoz IL, Díaz NF (2022) Minerals in edible seaweed: Health benefits and food safety issues. Crit Rev Food Sci Nutr 62:1592–1697
O'Connor K (2017) Seaweed a global history. Reaktion Books, London
Ortiz J, Romero N, Robert P, Araya J, López-Hernández J, Bozzo C, Navarrete E, Osorio A, Rios A (2006) Dietary fiber, amino acid, fatty acid and tocopherol contents of the edible seaweeds *Ulva lactuca* and *Durvillaea antarctica*. Food Chem 99:108–104
Osborne DR, Voogt P (1986) Análisis de los Nutrientes de los Alimentos. Acribia, Zaragoza
Peinado I, Girón J, Koutsidis G, Ames JM (2014) Chemical composition, antioxidant activity and sensory evaluation of five different species of brown edible seaweeds. Food Res Int 66:36–44
Pérez-Lloréns JL, Hernández I, Vergara JJ, Brun FG, León A (2017) ¿Las Algas se Comen? Un Periplo por la Biología, la Historia, las Curiosidades y la Gastronomía. Editorial UCA, Cádiz
Pina AL, Costa AR, Lage-Yusty MA, López-Hernandez J (2014) An evaluation of edible red seaweed (*Chondrus crispus*) components and their modification during the cooking process. Food Sci Technol 56:175–180
Pirian K, Jeliani ZZ, Arman M, Sohrabipour J, Yousefzadi M (2020) Proximate analysis of selected macroalgal species from the persian gulf as a nutritional resource. Trop Life Sci Res 31:17
Porto-Muiños (2021) Porto-Muiños. www.portomuinos.com. Accessed 23 Dec 2021
Prager HR (2020) What can be done to increase acceptance of seaweed into the western diet. University of Science and Technology, Norway. https://www.ntnu.edu/documents/139799/1273574286/TPD4505.Henry.Prager.pdf/bcb465ea-79e3-45c0-b1d2-1775b3d1852f. Accessed 20 Dec 2021
Quitral V, Morales C, Sepúlveda M, Schwartz MM (2012) Nutritional and health properties of seaweeds and its potential as a functional ingredient. Rev Chil Nutr 39:196–202
Rasyid A (2017) Evaluation of nutritonal composition of the dried seaweed *Ulva lactuca* from Pameungpeuk Waters. Indonesia Trop Life Sci Res 28:119–125
Richter VB, Avancini de Almeida TC, Prudencio SH, Benassi M (2010) Proposing a ranking descriptive sensory method. Food Qual Prefer 21:611–620
Ross CF (2009) Sensory science at the human–machine interface. Trends Food Sci Technol 20:63–72
Rupérez P (2002) Mineral content of edible marine seaweeds. Food Chem 79:23–26
Saldaña E, Behrens JH, Serrano JS, Ribeiro F, de Almeida MA, Contreras-Castillo CJ (2015) Microstructure, texture profile and descriptive analysis of texture for traditional and light mortadella. Food Struct 6:13–20
Sanchez-García F, Mirzayeva A, Roldán A, Castro R, Palacios V, Barroso CG, Durán-Gerruero E (2021) Effect of different cooking methods on sea lettuce (*Ulva rigida*) volatile compounds and sensory properties. J Sci Food Agric 101:970–980
Santelices B (1989) Algas marinas de Chile: Distribución, ecología, utilización y diversidad. Ediciones Universidad Católica de Chile, Santiago
Santos MT, Narendra N (2018) Volatile components in seaweeds. Oceanogr Mar Biol 2:195–201
Sato H, Koizumi R, Nakazawa Y, Yamazaki M, Itoyama R, Ichisawa M, Negishi J, Sakuma R, Furusho T, Sagane Y, Takano K (2017) Data on the sensory evaluation of potatoes (*Solanum tuberosum*) from different areas of Hokkaido, Japan, performed by untrained young adults. Data Brief 15:397–400
Segura-Campos M, Ruiz-Ruiz J, Betancur-Ancora D, López-Rodríguez K, Chel-Guerrero L, Alaiz-Barragan M (2011) Implementación y validación de un método de análisis de aminoácidos por cromatografía de líquidos de alta resolución. Rev Facult Ing Quím 51:32–40
Sharma C, Chambers E, Jayanty SS, Rajakalyan VS, Holm DG, Talavera M (2020) Development of a lexicon to describe the sensory characteristics of a wide variety of potato cultivars. J Sens Stu 4:e12577
Smyth HE, Sanderson JE, Sultanbawa Y (2012) Lexicon for the sensory description of Australian native plant foods and ingredients. J Sens Stud 27:471–481
Stévant P, Indergård E, Ólafsdóttir A, Marfaing H, Larssen WE, Fleurence J, Roleda MY, Rustad T, Slizyte R, Nordtvedt TS (2018) Effects of drying on the nutrient content and physico-chemical and

sensory characteristics of the edible kelp *Saccharina latissima*. J Appl Phycol 30:2587–2599

Stévant P, Olafsdottir A, Deleris P, Dumay J, Fluence J (2020) Data on the sensory characteristics and chemical composition of the edible red seaweed dulse (*Palmaria palmata*) after dry and semi-dry storage. Data Brief 33:1–15

Sugisawa H, Nakamura K, Tamura H (1990) The aroma profile of the volatiles in marine green algae (*Ulva pertusa*). Food Rev Int 6:573–589

Suwonsichon S (2019) The importance of sensory lexicons for research and development of food products. Foods 8:27

Talavera-Bianchi M, Chambers E IV, Chambers DH (2010) Lexicon to describe flavor of fresh leafy vegetables. J Sens Stud 25:163–183

Tan HSG, Tibboel CJ, Stieger M (2017) Why do unusual novel foods like insects lack sensory appeal? Investigating the underlying sensory perceptions. Food Qual Prefer 60:48–58

Tanaka M (1986) Texture of Japanese foods. Food Rev Int 2:247–265

Taniwaki M, Sakurai N (2010) Evaluation of the internal quality of agricultural products using acoustic vibration techniques. J Jpn Soc Hortic Sci 79:113–128

Tashiro T, Fujita E, Tamai M, Higashi J (1991) High-performance liquid chromatographic determination of 5’- and 2’(3’)-mononucleotides in seaweeds and fishes (Analysis of nucleic acid related substances by ion- exchange chromatography Part VII). Nippon Shokuhin Kogyo Gakkaishi 38:1–16

Texture Analysis Professionals Blog (2017) Food Texture around the World. https://textureanalysisprofessionals.blogspot.com/2017/10/food-texture-around-world.html

Tuorila H, Hartmann C (2019) Consumer responses to novel and unfamiliar foods. Curr Opin Food Sci 33:1–8

Vervoort L, Van der Placken L, Grauwet T, Verlinde P, Matser AM, Hendrickx A, van Loey A (2012) Thermal versus high pressure processing of carrots: A comparative pilot-scale study on equivalent basis. Food Tech 15:1–13

Woskow MH (1969) Selectivity in flavor modification by 5’-ribonucleotides. Food Tech 23:32–37

Wu G, Ross CF, Morris CF, Murphy KM (2017) Lexicon development, consumer acceptance, and drivers of liking of quinoa varieties. J Food Sci 82:993–1005

Xu SY, Huang X, Cheong KL (2017) Recent advances in marine algae polysaccharides: Isolation, structure, and activities. Mar Drugs 15:388

Yamaguchi S (1991) Basic properties of umami and effects on humans. Physiol Behav 49:833–841

Yang J, Lee J (2019) Application of sensory descriptive analysis and consumer studies to investigate traditional and authentic foods: A review. Foods 8:54

Yang G, Chambers E, Wang H (2020) Flavor lexicon development (in English and Chinese) and descriptive analysis of Sichuan pepper. J Sens Stud 26:e12636

Zhu X, Healy LE, Sevindik O, Sun DW, Selli S, Kelebek H, Tiwari B (2022) Impacts of novel blanching treatments combined with commercial drying methods on the physicochemical properties of Irish brown seaweed *Alaria esculenta*. Food Chem 369:1–19

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