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.
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 bilingial 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, cartilaginous, slightly plastic | Fresh, slightly bitter, reminiscent of green and wild herbs | Pérez-Llorén et al. 2017; Porto-Muiños 2021    |
|                                | Thin and transparent sheet          | Roasted: crispy                   |                                             |                                                |
| Durvillaea antarctica          | Fresh: green                        | Fleshy, elastic, and firm consistency. | Intense taste of the sea; flavor of wild mushrooms | Mansilla et al. 2012; Pérez-Llorén et al. 2017 |
|                                | Dried: reddish brown                | Crunchy, damp, and spongy        |                                             |                                                |
| Macrocystis pyrifera           | Olive green, with rough fronds along their length | Fresh: slightly slimy             | Smooth taste of the sea                     | Mansilla et al. 2012                          |
|                                |                                     | Dried: crunchy                    |                                             |                                                |
| Pyropia spp.                   | Thin and transparent sheet          | Fine and cartilaginous            | Dried: mushrooms                            | Pérez-Llorén et al. 2017; Porto-Muiños 2021    |
|                                | Fresh: violet                       |                                   | Toasted, cooked: roasted sardines          |                                                |
|                                | Toasted, cooked: green              |                                   |                                             |                                                |
| 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              | Intense, with hints of crustacean           | Mansilla et al. 2012                          |
|                                |                                     | Dried: crunchy                    |                                             |                                                |
| 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-Llorén et al. 2017; Porto-Muiños 2021 |
| Chondrus crispus               | Small and ramified                  | Cartilaginous                      | Crustacean flavor                           | Peinado et al. 2014; Pérez-Llorén et al. 2017 |
|                                | Fresh: red                          |                                   |                                             |                                                |
|                                | Cooked: green                       |                                   |                                             |                                                |
| Undaria pinnatifida            | Elongated and wavy sheets           | Fine, crispy, and somewhat meaty  | Fishy, marine; reminds oysters, sweet        | Kreischer and Schuttelaar 2016; Mouritsen et al. 2019; Porto-Muiños 2021 |
|                                | Fresh: yellow to brown              |                                   |                                             |                                                |
|                                | Cooked: green                       |                                   |                                             |                                                |
| Palmaria palmata               | Palm shape                          | Cartilaginous, soft, and dissolves easily | Sweet and slightly iodised flavour; strong marine aroma | Kreischer and Schuttelaar 2016; Mouritsen et al. 2012; Pérez-Llorén et al. 2017 |
|                                | Deep red, brown or purple           |                                   |                                             |                                                |
| Saccharina japonica/Saccharina lattissima | Slimy                           | Fleshy and slightly cartilaginous | Mild taste of sea, sweet; intense umami, mushroom aroma | Mouritsen et al. 2019; Pérez-Llorén et al. 2017 |
|                                | Yellow green                        |                                   |                                             |                                                |
| Himanthalia elongata           | Narrow strips                       | Crunchy and fleshy                | Soft, reminds a land vegetable              | Porto-Muiños 2021                             |
|                                | Fresh: brown                        |                                   |                                             |                                                |
|                                | Cooked: green                       |                                   |                                             |                                                |
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 rpm for another 20 min and then filtered through a gauze. 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 rpm for another 20 min and then filtered through a gauze.

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). *Durvillaea 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; chewiness (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, springiness (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
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 *Ulva 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 (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 (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...
| Descriptor       | Definition                                                                 | Suggested references                                                                 | References                          |
|------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------------------|-------------------------------------|
| **Appearance**   |                                                                            |                                                                                        |                                     |
| Shiny            | Light is reflected from the surface                                       | Brilliant: tomato, candy                                                               | Meilgaard et al. 2016               |
|                  |                                                                           | Opaque: cookies, bread                                                                 |                                     |
| Translucent/     | Light goes through sample, but clear images cannot be seen through it     | Translucent: apple juice, fried onion                                                  | FAO 1999                            |
| Opaque           |                                                                           | Opaque: cookies, cheese                                                                 |                                     |
| Rough            | Contains irregularities, bumps, or grains on the surface                 | Mild: apple peel                                                                       | Meilgaard et al. 2016               |
|                  |                                                                           | Rough: peel of Hass avocado                                                            |                                     |
| Turgid           | The surface appears swollen or stretched (tense) due to hydrated cells    | Flaccid: raisins, dehydrated fruits                                                    | Taniwaki and Sakurai 2010           |
|                  | underneath                                                                | Turgent: fresh grape, celery                                                           |                                     |
| **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    | Fresh mushrooms                                                                       | Talavera-Bianchi et al. 2010        |
|                  | basement scent                                                            |                                                                                        |                                     |
| 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.    | Honey, caramel                                                                        | Chun et al. 2020; Wu et al. 2017     |
|                  | Sweet, honey, toasted                                                     |                                                                                        |                                     |
| **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      | Salty snacks, jerky, salt-packed anchovies                                              | Chapman et al. 2015; Talavera-Bianchi et al. 2010 |
|                  | glutamate                                                                 |                                                                                        |                                     |
| 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  | Natto (fermented soybeans), okra                                                       | ISO 2008                            |
|                  | the surfaces of the oral cavity                                           |                                                                                        |                                     |
| **Texture**      |                                                                            |                                                                                        |                                     |
| Sticky           | During chewing the food adheres to surfaces in the palate, teeth and     | Okra                                                                                    | ISO 2008                            |
|                  | tongue                                                                    |                                                                                        |                                     |
| Elastic          | The degree to which the sample returns to its original shape after        | Plastic: butter                                                                        | Jowitt 1974; Meilgaard et al. 2016   |
|                  | exerting a force                                                          | Elastic: squid, marshmallows, gummies                                                  |                                     |
| Crunchy          | Food emits noise while it breaks or fractures, characterized by few       | Raw carrot, apple, celery, pig’s ear                                                   | Aguirre et al. 2018; Wu et al. 2017  |
|                  | significant breaks                                                        |                                                                                        |                                     |
| Cohesive         | Difficult to break/cut and bite resistant requires chewing                | Low: muffin                                                                            | Aguirre et al. 2018; Wu et al. 2017  |
|                  |                                                                          | Medium: cheeses                                                                       |                                     |
|                  |                                                                          | High: chewing gum                                                                      |                                     |
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*.

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*. 

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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 5  Color parameters of hydrated and cooked seaweeds

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

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  | 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  | 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    | 0.963±0.01 | 1.328±0.04 | 7.809±0.07 | 7.333±0.76 | N.D  | N.D |
| GMP    | 0.014±0.15 | 0.044±0.14 | 0.071±0.05 | 0.764±0.19 | N.D  | N.D |
| EUC    | 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.
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 columnina* 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 carotenoids) 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/muddy 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-Garcia 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/muddy 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 contained 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*.](image-url)
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. Alginites, 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.

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