Sensory evaluation of seaweed – A scoping review and systematic assessment of sensory studies

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Sensory evaluation of seaweed – A scoping review and systematic assessment of sensory studies

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ABSTRACT

Introduction: Seaweed, i.e. macroalgae, are nutritious marine seafood encompassing benefits from a sustainability perspective. In order to utilize seaweed as food, their sensory traits must be explored. The aim of this scoping review was to map and characterize sensory studies of seaweed and food products containing seaweed with regards to their sensory findings and methodological quality.

Methods: Scopus, Web of Science, and PubMed were searched, using the terms "sensory", "descriptive analysis", "QDA", "descriptive evaluation", "seaweed", "algae" and "macroalgae", which generated 1666 records. After removing duplicates, 1,004 unique records remained for screening of title/abstract. Application of eligibility criteria resulted in 91 final articles. Two authors extracted data from the articles. The quality of sensory methodologies were assessed separately.

Results: Seventeen articles were categorized as analytical and 74 articles as hedonic. The evaluated seaweed was mostly dried. Seventy articles used vehicles, e.g. baked goods and processed meat products with 1-5 % dry weight being the most common inclusion levels of seaweed. Nutritional improvement was generally the purpose of adding seaweed to food products.

Post-harvest treatments (e.g. drying or cooking) affected the sensory quality of the samples. Quality scores for sensory methodologies varied.

Conclusion: Increasing seaweed content in food products was associated with lower liking in consumer tests. Other post-harvest treatments than drying, such as blanching before further processing for stabilization purposes, should be explored, in order to allow higher inclusion levels than 1-5 % and thus, attain nutritional benefits by increasing the consumption of seaweed. 20 % of the studies were considered fully reproducible.

1. Introduction

Seaweed, i.e. macroalgae, grow in marine environments, requiring no more than seawater with its naturally occurring nutrients, CO_2, and sunlight. There are thousands of different species of seaweeds across the world, divided into three main groups based on their pigmentation: red, brown, and green (Lopez-Santamarina et al., 2020). Seaweed, namely red and brown, has long been consumed as a food source by humans, but its utilization remains limited across different regions. Today, the East Asian countries account for the vast majority of the global seaweed consumption (Murai et al., 2021); The Japanese population has an estimated average intake of 25.5 g fresh weight (fw) or 2.5 g dry weight (dw) per day per person (Trigo et al., 2023). Apart from certain coastal areas of Ireland and Scotland, where red seaweeds are consumed more regularly, the common application for seaweeds in Europe is for the extraction of hydrocolloids to be used as food-thickening agents (Murai et al., 2021; Polat et al., 2023). The consumption of whole seaweed in Europe is currently limited to a few dishes and food products (Mendes

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et al., 2022). At least 150 seaweed species are estimated to be consumed regularly, of which the European Union Novel Food legislation has approved 30 species as novel foods (Mendes et al., 2022).

Seaweed can be rich in micronutrients, such as various elements and vitamins. For instance, *Saccharina latissima*, commonly known as sugar kelp (a brown seaweed), *Ulva* sp., commonly known as sea lettuce (a green seaweed), and *Palmaria palmata,* commonly known as dulse (a red seaweed), are sources of calcium, magnesium, iron, selenium, and vitamin B12 (Cian et al., 2015; Stedt et al., 2022a; Steinhagen et al., 2024; Trigo et al., 2023). However, absolute levels vary substantially between and within the brown, green and red seaweed groups (Peñalver et al., 2020). When it comes to macronutrients, reported protein levels generally rank the seaweeds as red > green > brown species (Cian et al., 2015), with red and green seaweeds being the most abundant (Trigo et al., 2023). Recent cultivation regimes have also raised the crude protein content of sea lettuce to >30 % on a dry weight (dw) basis, thus making it a promising complementary protein source if consumed according to the daily dose mentioned above (Stedt et al., 2022a).

Since seaweed sequester carbon and contribute to mitigating water eutrophication, they are considered a climate-friendly source of nutrients as exemplified above, potentially equivalent to traditional land-grown crops (Yong et al., 2022). Thus, increased consumption of seaweed could be beneficial both from an environmental and nutritional perspective, as long as intake levels are balanced against potentially excessive levels of iodine (mainly an issue in kelp species) and heavy metals (Jacobsen et al., 2023).

An important aspect that we consider should receive more attention from the scientific community is the sensory profiles of seaweed, i.e. their perceived appearance, flavor, and texture. This is because seaweed may have different sensory profiles, distinct from those of land-grown vegetables. However, both seaweed and land-grown vegetables share similar intrinsic and extrinsic factors affecting their sensory profiles, such as species type, cultivation modes, harvest time, and post-harvest processing methods, like drying, cooking, and freezing (Fredriksson et al., 2023). Introducing new flavors, as those typically found in seaweed, to a population of consumers can encounter certain barriers, such as the fear of tasting unfamiliar foods, also known as food neophobia - especially common in young children (Białek-Dratwa et al., 2022). In fact, previous studies have specifically suggested that food neophobia might be a barrier when it comes to consuming seaweed (Losada-Lopez et al., 2021), which supports the importance of evaluating the sensory characteristics of whole seaweed and seaweed-containing products. To successfully increase seaweed consumption, important steps towards this goal include exploring possible sensory limitations such as smell, flavor and texture (Fredriksson et al., 2023).

Sensory evaluation can be defined as a method that is "used to measure, analyze, evoke, and interpret the reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch, and hearing" and is a fundamental part of the food development process (Stone & Sidel, 1993; Lawless & Heymann, 2010). Traditionally one can distinguish between two main types of sensory evaluation methods: analytical and hedonic. Analytical tests provide objective information about food products, such as what sensory traits are present and to which degree, and are conducted by trained assessors (Quantitative descriptive analysis). Rapid methods are also available where predefined traits can be selected by the assessor (e.g. check-all-that-apply), rated on intensity scales, or used for ranking based on differences between products (Ranking descriptive analysis). Hedonic tests, on the other hand, are subjective and measure acceptance (e.g., degree of liking), preference, and involve consumers (Lawless & Heymann, 2010). While the idea of creating a tasty, ready-to-eat product might be simple, it can be challenging to introduce new food products that not only meet the needs and preferences of consumers but also will change their eating and cooking habits (Fredriksson et al., 2023). These factors must be acknowledged in order to enable new products to compete with existing, regularly consumed ones and to last on the market (Stone & Sidel, 1993). Therefore, the industry often implements sensory evaluations with trained panels as well as preference- or acceptability testing with untrained consumer panels before proceeding to the marketing of new food products to the public (Lawless & Heymann, 2010). However, when using humans as measurement instruments, natural variations are to be expected. Therefore, following methodological guidelines and best practices is of great importance, such as the standards from the International Organization for Standardization (ISO).

To facilitate the choice of raw materials and processing techniques in future research as well as product development, the body of literature should be gathered and presented in a concise and comprehensible manner. While four previously published reviews have focused on utilization of seaweed as food including sensory aspects, they mainly targeted seaweed-containing bakery products (Quitral et al., 2022), potential gastronomic utilization of seaweed (Rioux et al., 2017), nutrition related aspects (Kumar et al., 2023), and safety (Gupta & Abu-Ghannam, 2011). A comprehensive scoping review focusing on the sensory scientific evaluation of seaweed is, to the best of our knowledge, still to be reported.

Therefore, the aim of this scoping review is to map and characterize published sensory studies of seaweed and food products containing seaweed, both with regards to their sensory findings and methodological quality.

2. Methods

2.1. Literature search

Before conducting this scoping review, all authors agreed to search the field for sensory evaluation, analytical and hedonic, of seaweed. This scoping review was registered by SRD in INPLASY (registration no. 202410098), reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis with extension for scoping reviews (PRISMA-ScR) (Fig. 1), and conducted according to the PRISMA checklist (Tricco et al., 2018). Scopus, Web of Science and PubMed were searched from initiation to December 14, 2023. The search strategy was formed by SRD in collaboration with a librarian at Uppsala University (Uppsala, Sweden), and included the following terms: "sensory", "descriptive analysis", "QDA", "descriptive evaluation", "seaweed", "algae" and "macroalgae". The search yielded 1,666 records, which were exported from the databases to the web-based software for systematic- and scoping reviews, Rayyan. After automatically resolving duplicates with Rayyan, 1,004 records remained. An additional two records were identified by SRD through alerts from Google Scholar a posteriori (Trigo et al., 2024; Wirenfeldt et al., 2024), which resulted in 1,006 unique records for screening (Fig. 1).

2.2. Design

The choice of conducting a scoping review instead of a systematic review was motivated by the juvenescence and scarceness of literature in the field of sensory evaluation of seaweed. While the search strategy for both systematic reviews and scoping reviews are systematic, there is a key difference between them: a systematic review requires a specific research question to be answered by its included articles, whereas a scoping review has a broader comprehension, allowing previously unknown research gaps to be defined. This makes a scoping review suitable for familiarizing with a research area, and thus forerunning future systematic reviews.

2.3. Study selection/screening

Two members of the research team (SRD and PS) screened title/abstract of 1,006 records. The inclusion criteria when screening title/

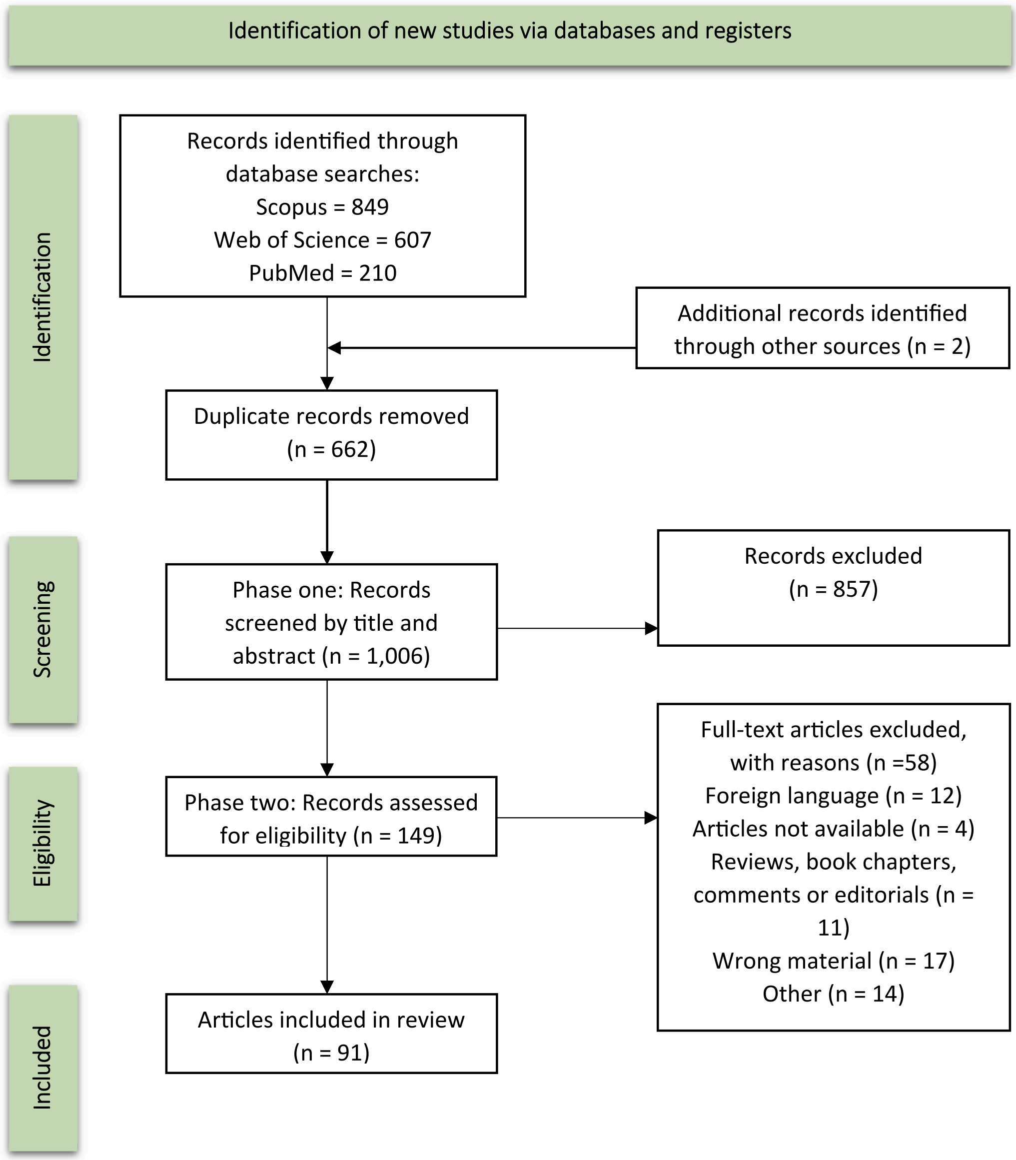

Fig. 1. PRISMA-ScR (PRISMA extension for scoping reviews).

abstract were the following: (1) sensory evaluation of seaweed biomass and (2) sensory evaluation - descriptive and hedonic - of seaweed as an ingredient in food products. The exclusion criteria were: (1) Sensory evaluation of meat from animals that had been fed seaweed; (2) sensory evaluation of microalgae; (3) book chapters; (4) reviews; (5) sensory evaluation of food products with isolated compounds of seaweed used for purposes other than sensory characteristics, such as improved chemical and/or microbial stability; (6) sensory evaluation of seaweed as an ingredient in non-edible products, such as plastic packaging and cosmetics; and (7) articles in other languages than English (Table 1). After applying the inclusion criteria, 149 records remained. When SRD and PS disagreed on a record, a third member (JPT or KS) was brought in to decide. SRD, JPT, PS, and KS proceeded to read the full texts and assessed the records for eligibility. Twelve records were excluded for not being in English, 4 records could not be retrieved due to missing full-text articles, 11 records were excluded due to being reviews, book chapters, comments, or editorials, 17 records were excluded for sensory evaluation of other materials than seaweed, and 14 records were finally excluded for other reasons. After applying the exclusion criteria, a total of 91 records remained and were thus included in the final review (Fig. 1).

Table 1
Inclusion- and exclusion criteria.

Inclusion criteria	Exclusion criteria
I.1. Biomass of seaweed/macroalgae	E.1. Meat from animals that have been fed seaweed/macroalgae
I.2. Biomass of seaweed/macroalgae as part of a food product	E.2. Microalgae
	E.3. Book chapters
	E.4. Reviews
	E.5. Isolated single compounds (e.g. proteins or polysaccharides) as an additive for shelf life or stability purposes
	E.6. Non-edible products
	E.7. Articles in languages other than English

2.4. Data charting

SRD and JPT jointly developed a data charting form with relevant variables. The developed form was then used by SRD and JPT, who independently retrieved the data from the articles. The data charting was an iterative process and when inconsistencies or misinterpretations occurred, these were resolved with discussion between SRD and JPT. After charting the data, SRD verified the data by reading each article a third time, and, if necessary, revising it after consulting JPT.

2.5. Data items

The data was conceptualized, focusing on methodologies and sensory findings; seaweed species; food vehicles; seaweed incorporation levels; sensory test methods; sensory attributes (Table 2); treatment and processing of seaweed prior to sensory evaluation; evaluation scales; sensory scores in relation to amounts of seaweed; and number of assessors. Furthermore, the purpose of evaluating pure seaweed or incorporating seaweed into other food products was categorized as follows: nutritional improvement, sodium reduction, ingredient replacement, sensory profiling, shelf-life and storage, processing techniques, food waste utilization, geographical comparisons, functional improvement, improvement of physicochemical properties, sensory improvement, functionality, and plant-based protein substitution (Tables 3 & 4).

2.6. Evaluation of sensory methodologies in the articles

All 91 studies were subject to a critical evaluation by CJBR via a quality-assessment tool for sensory methods used in the literature (Appendix 1). The tool consisted of a scoring sheet designed to assess sensory methodological aspects: these pertained to the (1) appropriate use of participants (e.g., trained assessors for analytical tasks and consumers for hedonic tasks); (2) suitability of evaluation scales according to the used sensory method (Lawless & Heymann, 2010; Meilgaard et al., 2016; Vidal et al., 2014); (3) practical aspects of the experiments (e.g., number of samples, control sample, sample serving size, serving temperature, replicates, randomization of serving order, randomization of sample codes, use of palate cleansers, controlled testing environment); and (3) whether ethical requirements (e.g., participants' consent, prior approval by a research committee) were fulfilled. Relevant methodology data was extracted and translated to numeric scores, based on the amount of information available in the articles. In case of missing information, the specific data item was given the score of 0. A score of 1 was given for each item that was fulfilled in the paper, whereas a 0 was assigned for requirements not disclosed by the research paper. For every paper included in the review, the values in each item were summed, with the highest possible score being 14 points/paper (Tables 3 & 4). The sum of scores was converted to final quality grades, ranging from the lowest quality, "f", to the highest quality, "a". The quality scores were given, based on level of information provided and thereby the reproducibility of the study. Grade "a" (11-14 points) reflects excellent quality that meets most quality criteria, with expected high reproducibility. Grade "b" (9-10 points) indicates high-quality studies with minor weaknesses but sufficient detail for reproduction. Grade "c" (7-8 points) corresponds to average-quality studies meeting at least half the criteria, with partially reproducible methods. Grade "d" (5-6 points) represents fair quality with minimal criteria met, limited reporting, and expected low reproducibility. Grade "e" (3-4 points) denotes low-quality studies with severely underreported methods, thus hampering reproducibility. Grade "f' (0-2 points) applies to the lowest-quality studies, which lack sufficient information for reproducibility. Studies with multiple tests received one quality score per test.

3. Results

3.1. Overview of eligible studies

During the past three decades, seaweed has been subject to sensory scientific evaluation across different parts of the world (Figs. 2 & 3). Seaweed is consumed and has been studied regularly in many Asian countries, thus the studies were primarily conducted in Southeast Asia (51.6 % of the total number of studies), followed by Western Europe, and North America (Fig. 2). The studies were published during years 1991 to 2023, with a notable increase in the past decade (Fig. 3). Studies involving seaweeds and their sensory attributes in Europe and the Americas are few but nonetheless increasing – with ten publications during the last two years compared to two publications ten years ago

Table 2
Reported sensory attributes of the seaweed species evaluated in the descriptive analyses included in the scoping review.

Seaweed pigmentation and species		Appearance	Odor	Taste/Flavor	Texture
Brown	*Saccharina latissima*	Yellow-green, green, slimy	Fresh sea, fermented, hay	Fresh sea, fermented, hay, salt, umami, bitter, sour, sweet, boiled vegetables, iron, intense taste	Crispy, tough, dissolves, viscous, bite, hard
	Fucus vesiculosus	Yellow-green, thick, uniform color	Seaweed, sea, green, hay, fresh fish	seaweed, salty, green, umami, sweet, bitter, metal	firm, crispy, adhesive, astringent, bite
	Durvillaea antarctica	N/A	Caramel, marine	Caramel, marine	N/A
	Alaria esculenta	Green	Grass	Salty, intense taste	Crispy, hard
	Undaria pinnitifida	N/A	Sea	Salty, umami	Bite
Green	*Ulva* sp.	Thick, crumpled, transparent, green	Seaweed, sea, green, hay, fresh fish, grass	Seaweed, salty, green, umami, sweet, metal, bitter, intense taste	Firm, crispy, adhesive, clotted, astringent, soft
	Ulva lactuca	N/A	N/A	Bitter, acid, moldy/earthy, herbal, mineral, salty	N/A
	Ulva fenestrata	Blue-green	N/A	Umami, fresh grass	Oily
	Ulva rigida	Intense green, bright	Fresh grass, raw vegetables, cooked vegetables, fungi, mold, sludge, cooked fish, dry fish, mollusk, coast rock, seaweed, seaside	Fishy, vegetable	Chewy, hard, elastic, sticky, persistent
Red	*Pyropia* and *Porphyra* spp.	Slimy, light, red	Sea, caramel, marine, earthy, moldy, herbal	Boiled green vegetables, sweet, bitter, iron, umami, salty, mineral	Chewy, hard, firm, tough, adhesive, dispersible
	Palmaria palmata	Magenta colored	Seaweed, sweet, hay, fish skin, shellfish, sea	Salty, seaweed, rich flavor, bitter, dried fish, intense taste	Crunchy, tough, chewy, hard

Table 3
General characteristics reported in articles that used analytical sensory methods and calculated quality score for sensory methodology ($n = 17$).

Article	Purpose of seaweed evaluation (Quality score*)	Sensory study design	Seaweed species	Post-harvest treatment	Sensory findings
Wirenfeldt et al. (2024)	Nutritional improvement (d)	Descriptive analysis	*Fucus vesiculosus* and *Ulva* sp. (brown)	Dried	Freeze-dried (FD) seaweed had odors of seaweed, sea, and fresh fish. Significant differences in appearance, odor, flavor, and texture attributes between *F. vesiculosus* and *Ulva* sp. after different drying methods were also detected.
Bruhn et al. (2019)	Nutritional improvement (c)	Quantitative descriptive analysis	*Saccharina latissima* (experimental), *Undaria pinnatifida, Fucus vesiculosus*, and *Pyropia* sp. - dried (brown)	Multiple	Fermentation changed fresh sugar kelp into a product with a milder, less salty taste, a reduced sea smell and a less slimy visual appearance.
Chang & Wu (2008)	Nutritional improvement (c)	Descriptive analysis	*Monostroma nitidum* (green)	Dried	The addition of seaweed affected color, stickiness and wetness as well as firmness which was higher.
Chang et al. (2011)	Nutritional improvement (c)	Texture profile	*Monostroma nitidum* (green)	Dried	Color intensity, stickiness, wetness and softness increased with seaweed addition
Cittadini et al. (2023)	Sodium reduction and salt replacement (a)	Sensory profiling	*Laminaria ochroleuca* (brown)	Dried	The use of seaweed powder (T2) as a salt substitute, decreased the saltiness, while the other sensory properties were unaffected.
Figueroa et al. (2022)	Sensory profiling (c)	Ranking descriptive analysis	*Durvillaea antarctica* (brown), *Pyropia* spp. (red), and *Ulva lactuca* (green)	Dried	*U. lactuca* was characterized as bitter, with an herbaceous aroma and the softest of the three seaweeds. *Pyropia* spp., was the most umami seaweed and cooking increased the aroma of caramel, earthy/moldy flavor and umami taste. *D. antarctica* was the least salty, with a caramel aroma and the hardest, most cartilaginous, and sticky seaweed.
Jönsson et al. (2023)	Sensory profiling (b)	Descriptive analysis	*Saccharina latissima, Alaria esculenta* (brown), *Palmaria palmata* (red), *Ulva* sp. (green).	Dried	Seaweed species had varying sensory attributes like taste, color, and texture. P. palmata stood out with red color, umami taste, and firm texture. *Ulva* sp. was saltiest with lemon odor, light color, and less crispy than the other species.
Krook et al. (2023)	Nutritional improvement (b)	Generic descriptive analysis and tetrad test	*Saccharina latissima* (brown)	Dried	Seawater-treated *S. latissima* had the highest saltiness and umami intensity, making it more flavorful compared to freshwater-treated samples, which had lower scores across all sensory attributes and a greater loss of flavor-active compounds
Ogawa et al. (1991)	Sensory profiling (f)	Ranking test for texture	*Porphyra* spp. (red)	Commercially dried	N/A
Ribeiro et al. (2021)	Shelf-life and nutritional improvement (d)	Difference from Control Test	*Fucus vesiculosus* (brown) and *Ulva rigida* (green)	Dried, milled	The sensory quality was maintained during storage to a larger extent in the seaweed-enriched pasta compared to the control.
Sanchez-Garcia et al. (2019)	Shelf-life and storage (e)	Descriptive analysis	*Ulva rigida* (green)	Fresh	Storage time and temperature significantly affected the intensity of these odor descriptors, indicating a loss of freshness over time
Sánchez-García, et al. (2021)	Shelf-life and storage (e)	Descriptive analysis	*Ulva rigida* (green)	Fresh	Storage time mainly affected texture and quality of the samples, which indicated loss of quality and freshness
Sánchez-García et al. (2021)	Processing techniques (e)	Descriptive analysis	*Ulva rigida* (green)	Heated	Cooking decreased the intensity of seaside- and seaweed attributes, while increasing the attributes of cooked-, dry, salty fish and crustacean.
Stedt et al. (2022b)	Nutritional improvement (c)	Quantitative Descriptive Analysis	*Ulva fenestrata* (green)	Dried	Herring production process waters gave a higher yield, and a higher protein content compared to seawater control. The process waters did not affect the sensory attributes.
Stévant et al. (2018)	Processing techniques (d)	Descriptive test	*Saccharina latissima* (brown)	Dried	Drying temperature did not significantly alter the aroma or flavor of the seaweed. The texture was affected by the drying method, with freeze-dried samples having a higher swelling capacity and better rehydration properties compared to air-dried samples.
Stévant et al. (2020)	Shelf-life and storage (c)	Generic descriptive analysis	*Palmaria palmata* (red)	Dried	During storage under controlled conditions, marine and fishy flavors and odors of the dried seaweed faded, as described for the maturation of kombu in Japan, while sweet, rich and complex notes arose during storage of semi-dry material.
Trigo et al. (2024)	Processing techniques (c)	Quantitative Descriptive Analysis	*Ulva linza, Ulva fenestrata* (green)	Dried	Saltiness emerged as the primary distinction between emulsions with unwashed *U. linza* and *U. fenestrata*; washing *U. fenestrata* retained sensory qualities.

*Quality score of the sensory methodology equals the sum of points received for each reported item (Appendix 1). Studies with multiple tests received a quality score for each test.
a = 11-14 points (excellent quality), b = 9-10 points, c = 7-8 points, d = 5-6 points, 4 = 3-4 points, f = 0-2 points (lowest quality).

Table 4
General characteristics reported in articles that used affective or combined (analytical and affective) sensory methods and calculated quality score for sensory methodology ($n = 74$).

Article	Purpose of seaweed incorporation (Quality score*)	Seaweed species	Seaweed treatment	Seaweed inclusion level	Vehicle	Sample preparation	Sensory findings
Akomea-Frempong et al. (2021)	Nutritional improvement (a)	*Saccharina latissima* (brown)	Fresh and frozen	N/A	kelp salad and kelp sauerkraut	Salad: Blanched for 1 or 3 min, unblanched. Sauerkraut: raw, raw/ frozen, blanched, blanched/frozen, fermented	The salad with the 1 min (100°C) blanched kelp and the control sauerkraut without kelp received higher scores compared to unblanched kelp
Ana et al. (2022)	Sensory and nutritional improvement (e)	*Pyropia* spp. (red)	Dried	2.6 %	choux pastry	Seaweed powder was blended with choux-pastry mix	The enriched pastry scored the highest on the preference scale.
Astuti et al. (2023)	Nutritional improvement (d)	*Caulerpa racemosa* (green)	Dried and fermented	0 %,25 %, 0.5 %, 0.75 %	Instant oat drink	The fermented seaweed was mixed with oats, boiling water and sugar.	No significant difference was found between the formulations.
Balbas et al. (2015)	Geographical comparison (b, c)	*Undaria pinnatifida* (brown)	Blanched, cured, dried	Not reported	Mixed with chicken stock	Dry seaweed was served in a chicken soup	New Zealand wakame was lighter, thinner, and softer - due to higher water concentration than the commercial Korean samples.
Blouin et al. (2006)	Food waste utilization (e)	*Wildemania amplissima* (formerly *Porphyra amplissima*), *Porphyra umbilicalis*, *Pyropia yezoensis* (formerly *Porphyra yezoensis*) (red)	Sun-dried	Not reported	Rice cracker/ Popcorn	The flakes were mixed with safflower oil and sprinkled over rice crackers and popcorn	Both children and adults found the native seaweed species, *W. amplissima* and *P. umbilicalis*, to be acceptable in food products.
Chapman et al. (2015)	Nutritional and functional improvement (d, e, e)	*Saccharina latissima, Alaria esculenta, Laminaria digitata* (brown), *Palmaria palmata* (red)	Dried	5 %	Fish cake	Commercially dried or dried, rehydrated, and micro-wave steamed	The inclusion of 5 % dried *S. latissima* in fish cakes did not negatively affect the sensory acceptability of the product
Choi et al. (2012)	Fat replacement (c, c)	*Saccharina japonica* (formerly *Laminaria japonica*) (brown)	Dried	0 %, 1 %, 3 %, 5 %	Reduced-fat pork patties	Commercially dried and milled < 0.5mm	The 1 % and 3 % addition of seaweed to reduced fat pork patties received the highest overall scores, whereas the patties with 10 % fat and no seaweed received the lowest sensory score.
Choi et al. (2012)	Shelf-life and storage (d, f)	*Undaria pinnatifida* (brown)	Not reported	N/A	N/A	Not reported	All sensory scores decreased with storage time (up to 5 days)
Choi et al. (2014)	Exploring health benefits (e)	*Saccharina japonica* (formerly *Laminaria japonica*) (brown)	Dried	0 %, 2.5 %, 5 %, 7.5 %, 10 %, 12.5 %	Rice wine	Dried and milled seaweed was added during fermentation of the rice wine	5 % and 7,5 % had the best anti-diabetes activity with acceptable seaweed flavor
Choi et al. (2015)	Sensory improvement (a, b)	*Saccharina japonica* (formerly *Laminaria japonica*), *Undaria pinnatifida, Sargassum fusiforme* (brown), *Salicornia europaea* (Vascular plant)	Dried	1 %	Frankfurter sausages	Dried seaweed was ground and mixed with the rest of the ingredients.	Frankfurters with 1 % sea tangle or 1 % sea mustard did not differ significantly from the control, which had the highest acceptability scores.
Choi et al. (2017)	Improvement of physicochemical and sensory properties (b, c)	*Undaria pinnatifida* (brown)	Dried	0 %, 0.5 %, 1 %, 1.5 %, 2 %	Frankfurter sausages with varying levels of transglutaminase and NaCl	Seaweed powder was mixed with the rest of the ingredients of the Frankfurters.	Increasing levels of sea mustard resulted in lower color scores.
Cofrades et al. (2011)	Nutritional improvement (c, d)	*Himanthalia elongata* (brown)	Dried	3 %	Restructured poultry steaks	Seaweed powder was added to the poultry steaks in two stages to ensure even distribution	Adding seaweed did not affect the sensory properties of the steaks negatively.

(continued on next page)

Table 4 (*continued*)

Article	Purpose of seaweed incorporation (Quality score*)	Seaweed species	Seaweed treatment	Seaweed inclusion level	Vehicle	Sample preparation	Sensory findings
						throughout the mixture	
Cox & Abu-Ghannam (2013)	Nutritional improvement (c)	*Himanthalia elongata* (brown)	Dried	10 %, 17.07 %	Breadsticks	Seaweed powder was mixed with breadstick dough	Incorporating *H. elongata* significantly enhanced the breadsticks' phytochemical content without negatively affecting the sensory properties.
Cox & Abu-Ghannam (2013)	Shelf life and nutritional improvement (c)	*Himanthalia elongata* (brown)	Dried	20 %, 40 %	Beef patties	Dried, milled, and mixed with beef-patty ingredients	The seaweed patties were found overall to be acceptable by the sensory panel, particularly in terms of texture. Seaweed had a positive effect on shelf-life, dietary fibre, phenolic content and antioxidant activity.
Damat et al. (2021)	Algae-based analogue (f)	*Gracilaria* spp. (red)	Fresh	0.8 %, 1.5 %, 2.3 %	Analog rice	Soaked in brine for 24 h, blended with water, extrusion-cooked to a rice analogue	Increasing seaweed amounts (F1 vs F4 vs F7) negatively affected aroma and overall acceptability.
Damayanti et al. (2021)	Nutritional improvement (e)	*Sargassum hystrix* (brown)	Fresh	10 %, 20 %, 30 %, 40 %, 50 %	Functional drink	Seaweed was immersed with the other ingredients, until the samples reached different pH-levels	The flavor preference for seaweed was at 20 %, which scored the highest.
Debbarma et al. (2017)	Nutritional improvement (e, f)	*Ulva reticulata* (green)	Fresh	10 %, 20 %	Noodles	Ground and mixed with noodle dough	20 % *U. reticulata* incorporation received the highest acceptability score after the control. Firmer and rougher compared to the other samples.
del Olmo et al. (2018)	Nutritional improvement (b, c)	*Himanthalia elongata, Laminaria ochroleuca, Undaria pinnatifida* (brown), *Porphyra umbilicalis* (red), and *Ulva lactuca* (green)	Dried	1 %	Cheese	Dehydrated seaweeds were minced to small flakes and mixed with cheese curds prior to being poured into molds.	*P. umbilicalis* and *U. lactuca* cheeses had the most distinct flavor and received the lowest scores. *H. elongata, L. ochroleuca* and *U. Pinnatifida* got the highest scores.
Dewi & Purnamayati (2021)	Nutritional improvement (e)	*Caulerpa racemosa* (green)	Fresh	30 %	fermented yoghurt drink	C. racemosa was mixed with milk, sucrose, water, and pasteurized and fermented	The panelists preferred the 30 % *C. racemosa* yoghurt fermented with a combination of Lactobacillus bulgaricus and Streptococcus thermophilus
Egodavitharana et al. (2023)	Nutritional improvement (d)	*Ulva* sp. (green)	Dried	0 %, 2 %, 4 %	Crackers	Seaweed powder was mixed with dough, and oven-baked into crackers	4 % of both species had a positive effect on the sensory traits of the crackers
Fellendorf et al. (2016)	Sodium reduction and fat replacement (c)	*Undaria pinnatifida* (brown)	Not reported	3.3 %	Black pudding	Not reported	No significant difference in sensory characteristics between control and the seaweed-containing samples.
Gorman et al. (2023)	Sodium reduction (a)	Not reported	Dried	0.4 %	Whole wheat bread	Seaweed powder was mixed with the ingredients of the bread loaves	The addition of 10 % or 20 % to whole wheat bread was similar to control and acceptable to consumers

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Table 4 (*continued*)

Article	Purpose of seaweed incorporation (Quality score*)	Seaweed species	Seaweed treatment	Seaweed inclusion level	Vehicle	Sample preparation	Sensory findings
Hanjabam et al. (2017)	Nutritional improvement (e)	*Sargassum wightii* (brown)	Dried	3 %, 5 %	Fish jerky	Seaweed powder was mixed with jerky ingredients, sliced and oven-dried	Jerky with 3 % or 5 % seaweed received the highest acceptability, following the control.
Hentati et al. (2019)	Sensory and nutritional improvement (c)	*Jania pedunculata var. adhaerens* (formerly *Jania adhaerens*) (red) and *Cystoseira compressa* (brown)	Dried	0 %, 0.5 %, 1 %, 1.5 %	Fish burgers	Seaweed powder was mixed into fish burgers.	The most significant improvements were observed at 1 % seaweed concentration
Huang & Yang (2019)	Nutritional improvement (c)	*Euchema* sp. (red)	Dried	1.2 %, 2.3 %, 3.5 %, 4.6 %	Sponge cake	Seaweed powder was mixed with cake batter, baked, and served at room temperature in small cubes.	Flour replacement increased the dietary fibre content without affecting consumer acceptance negatively
Jeong et al. (2022)	Nutritional improvement (d)	*Pyropia* sp. (red)	Dried	6.4 %, 14.3 %, 20.0 %, 23.1 %, 24.5 %	Rice paper	Seaweed powder was mixed with rice powder and tapioca starch, spread out and dried to rice paper	The optimal amount of laver powder used in the enriched rice paper samples was 24.5 %
Jiménez-Colmenero et al. (2010)	Ingredient replacement (d)	*Himanthalia elongata* (brown)	Dried	3.3 %	Frankfurters	Seaweed powder was blended into sausages, smoked at 70°C	The addition of seaweed resulted in a lower acceptance of the frankfurters
Kim et al. (2010)	Physicochemical improvement (d, d)	*Saccharina japonica* (formerly *Laminaria japonica*) (brown)	Dried	1 %, 2 %, 3 %, 4 %	Breakfast sausages	Seaweed powder was mixed with the rest of the sausage ingredients.	The breakfast sausage with 1 % sea tangle powder received the highest score for tenderness and juiciness.
Koh et al. (2022)	Nutritional improvement (b, b)	*Eucheuma denticulatum* (red)	Dried	0 %, 5 %, 7.5 %, 10 %, 12.5 %, 15 %	Instant wheat noodles	Seaweed powder was mixed with the noodle ingredients.	7.5 % and 15 % seaweed content received the highest sensory score
Kumar et al. (2018)	Nutritional improvement (e)	*Caulerpa racemosa* (green)	Dried	0 %, 0.7 %, 3.3 %, 6.5 %	biscuit	Seaweed powder was mixed into biscuit dough	Seaweed-incorporated biscuits maintained acceptable taste, texture, and overall quality
Kumar et al. (2019)	Nutritional improvement (e)	*Sargassum wightii* (brown)	Dried	1 %, 2.5 %, 4.2 %	coffee beverage with milk	Seaweed powder was mixed with coffee powder, sugar, and toned milk, strained and served to the assessors.	the beverage infused with 1 % of seaweed had the highest score on the hedonic scale.
Lamont & McSweeney (2021)	Nutritional improvement (b)	*Ascophyllum nodosum* (brown) and *Chondrus crispus* (red)	Dried	2 %, 4 %, 6 %, 8 %	Whole wheat bread	Seaweed powder was mixed with dough	2 % and 4 % seaweed were the most accepted.
Lee et al. (2014)	Processing techniques (d, d)	*Kappaphycus alvarezii* (red)	Dried	N/A	Dehydrated seaweed snack	The seaweed pieces were put in an osmotic solution with sucrose and citric acid t different concentrations and temperatures and then dried to create a seaweed snack	40°C for the osmotic dehydration and the highest sucrose concentration received the highest score.
Lee et al. (2022)	Processing techniques (d)	*Undaria pinnatifida* (brown)	Dried	Not reported	Sea mustard seasoning mix	Seaweed powder was extrusion-cooked together with other ingredients (milk, soybean, etc.), dried, and milled. The powder was mixed with hot water, and served as soup to the panelists.	Extrusion cooking increased the pleasant taste of the seasoning mix
López-López et al. (2009)	Fat replacement (d)	*Himanthalia elongata* (brown)	Not reported	5 %	Frankfurter sausages	Not reported	5 % seaweed resulted in stronger off-flavor, and thus, lower overall acceptability

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Table 4 (*continued*)

Article	Purpose of seaweed incorporation (Quality score*)	Seaweed species	Seaweed treatment	Seaweed inclusion level	Vehicle	Sample preparation	Sensory findings
López-López et al. (2010)	Fat replacement (d)	*Undaria pinnatifida* (brown)	Dried	3.3 %	Beef patties	Seaweed powder was mixed with the rest of the beef-patty ingredients.	There was no significant difference in the sensory characteristics between the seaweed-containing sample and the control.
López-Pérez et al. (2021)	Shelf-life and storage (d)	*Undaria pinnatifida, Himanthalia elongata* (brown), *Codium fragile, Ulva lactuca* (green), and *Chondrus crispus* (red)	Frozen	N/A	N/A	Thawed and high-pressure processed	High-pressure processing significantly improved the sensory quality and shelf life of the seaweeds compared to untreated samples.
Mamat et al. (2018)	Functionality (d)	*Kappaphycus alvarezii* (red)	Dried	0 %, 2 %, 4 %, 6 %, 8 %, 10 %	Muffins	Seaweed powder was mixed with wheat flour, used for baking the muffins, sliced and served to the assessors	Muffins with up to 6 % seaweed powder were accepted by the panelists, while the muffins with 2 % seaweed powder were the most preferred.
Mamat et al. (2021)	Nutritional improvement (c, c)	*Kappaphycus alvarezii* (red)	Dried	0.6 %, 1.3 %, 1.9 %, 2.6 %, 3.2 %, 3.9 %, 4.5 %, 5.2 %	Soft wheat rolls	Seaweed powder was mixed with wheat flour. Soft rolls were then baked, cooled, and sliced to 2-cm pieces for sensory evaluation	The wheat rolls with 0.6 % seaweed powder was the most preferred by the panelists
Mamat et al. (2023)	Nutritional and functional improvement (c)	*Kappaphycus alvarezii* (red)	Dried	0 %, 1.5 %, 3 %, 4.5 %, 6 %, 7.5 %, 9 %	steamed bun	Seaweed powder was mixed with the other ingredients of the steamed bun, baked, cooled, reheated and served to the assessors.	1.5 % did not differ significantly from control. 7.5 %. 9 % scored significantly lower in liking than 1.5 %
Mamatha et al. (2007)	Nutritional improvement (f, f)	*Ulva compressa* (green)	Dried	0 %, 5 %, 7.5 %, 10 %	Pakoda (fried snack)	Seaweed powder was mixed with the ingredients of the batter.	5 % and 7.5 % addition of *U. compressa* received similar scores as the control sample. up to 7.5 % of *U. compressa* was acceptable.
Menezes et al. (2015)	Nutritional improvement (f)	*Cladophora* spp. and *Ulva* spp. (green)	Dried	2.5 %, 5 %, 7.5 %	Bread	Dried, milled, and mixed into dough	No significant difference between 2.5 %, 5 %, and 7.5 % seaweed, which were all accepted by consumers
Metin & Baygar (2018)	Nutritional improvement (d)	*Ulva intestinalis* (green)	Dried	1 %, 3 %, 5 % (tea) - 10 %, 15 %, 20 % (soup)	Tea, soup and spice mix on toast	Seaweed powder was mixed with tea, soup and sunflower oil, spread on toast for sensory evaluation.	10 % seaweed content was not significantly different from control
Mohammad et al. (2019)	Nutritional improvement (e)	*Kappaphycus alvarezii* (red)	Dried	10 %, 20 %, 30 %	fish sausage, chicken soup with flat rice noodles, Yellow Alkaline noodles	Soaked, blended with water (puree), and boiled, prior to being mixed with noodle dough and fish-sausage mixture. Noodles were served in chicken soup and sausages were sliced 1.5 cm.	The fish sausages with seaweed scored higher than the controls, whereas the noodles with seaweed scored lower than the controls.
Mohammed et al. (2022)	Functionality (a)	*Himanthalia elongata, Alaria esculenta* (brown), *Palmaria palmata, Porphyra umbilicalis* (red)	Dried	1 %, 2.5 %, 5 %	Pork sausage	Seaweed powder was mixed with minced meat prior to the sausage making	Sausages with 1 % Nori were the most accepted (score 6.98)
Mohibbullah et al. (2023)	Nutritional improvement (c)	*Ulva intestinalis* (green)	Dried	Not reported	Cookies	Dried and fragmented seaweed was then mixed into cookie dough, baked and stored at room temperature.	Inclusion-levels of 1 %, 2.5 %, and 5 % seaweed were the most acceptable to the panelists

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Table 4 (*continued*)

Article	Purpose of seaweed incorporation (Quality score*)	Seaweed species	Seaweed treatment	Seaweed inclusion level	Vehicle	Sample preparation	Sensory findings
Monzón et al. (2022)	Unknown (e)	*Pyropia columbina* (red)	Dried	6 %, 9 %	Gluten-free pasta	Seaweed powder was mixed with pasta dough	Pasta with 6 % seaweed received higher scores for acceptability, flavor and mouth feel in the consumer test compared to the control.
Munsu et al. (2021)	Nutritional improvement (c)	*Kappaphycus alvarezii* (red), *Sargassum polycystum* (brown), *Caulerpa lentillifera* (green)	Dried	0 %, 2 %, 4 %, 6 %	Chicken sausages	Seaweed powder was mixed with sausage ingredients, cooked in water and served to the assessors in pieces.	The panelists found the chicken sausages with up to 4 % *K. alvarezii* and 2 % *S. polycystum* to be acceptable in terms of taste and texture
Nayyar & Skonberg (2019)	Shelf -life and storage (d)	*Palmaria palmata, Gracilaria tikvahiae* (red)	Fresh	N/A	N/A	Fresh seaweed was stored at two different refrigerator temperatures for a number of days.	*P. palmata*, stored at 2°C, received higher scores than 7°C, while the scores for *G. tikvahiae* stored at 2°C vs 7°C did not differ.
Nuñez & Picon (2017)	Nutritional improvement (b, c)	*Saccharina latissima, Himanthalia elongata, Undaria pinnatifida* (brown), *Porphyra umbilicalis* (red), and *Ulva lactuca* (green)	Dried	0 %, 0.5 %	yoghurt and quark	Seaweed powder was mixed with yoghurt and quark.	*S. latissima* received the highest odor- and flavor quality scores. The seaweed-containing products had lower acidity and more distinct fishy aromas.
Oh et al. (2020)	Nutritional improvement (c)	*Sargassum fulvellum, Sagassum fusiforme* (formerly *Hizikia fusiformis*) (brown), *Ulva linza* (formerly *Enteromorpha linza*), and *Codium fragile* (green)	Dried	0 %, 2.4 %	Cookies	The different SW-powders replaced 5 % of the flour in the cookie dough, which were baked according to the recipe	Cookies made with *S. fusiforme* were the most preferred among the different seaweed species used
Pandi et al. (2023)	Nutritional improvement (e)	*Caulerpa racemosa* (green)	Dried	2.5 %, 5 %, 10 %, 15 %	Pasta	Seaweed powder was mixed with the rest of the pasta ingredients.	The nutritional value of the 5 %-seaweed pasta was higher than the one of the control, while there was no significant difference in the sensory quality of the samples.
Patil et al. (2023)	Plant-based protein substitution (f)	*Pyropia* spp. (red) and brown seaweed (unknown species)	Dried	0 %, 2 %, 4 %, 6 %, 8 %, 10 %	Breaded and fried Fish-analogue balls	Dried sheets of Kombu and Nori were rehydrated, minced, and rolled into balls	No significant difference in sensory quality between seaweed-containing samples and control.
Perry et al. (2019)	Shelf -life and storage (b)	*Alaria esculenta* (brown)	Fresh	N/A	Salted seaweed salad	Rinsed in tap water and treated with different amounts of salt	Consumer acceptability was high for the salted seaweed with a 90-day shelf life (180 g salt/kg seaweed)
Pindi et al. (2023)	Improvement of physicochemical and sensory properties, salt replacement (c)	*Kappaphycus alvarezii* (red)	Dried	0 %, 2 %, 4 %	Chicken patties	Seaweed powder was mixed with chicken-patty ingredients.	The incorporation of 4 % seaweed received the highest sensory scores.
Pindi et al. (2023)	Improvement of physicochemical properties and nutrition, fat replacement (c)	*Kappaphycus alvarezii* (red)	Dried	0 %, 2.5 %, 5 %, 7.5 %	Chicken patties	Seaweed powder was mixed with chicken-patty ingredients.	Adding *K. alvarezii* to chicken patties increased the overall phenolic content and showed acceptable sensory results.
Pongpichaiudom & Songsermpong (2018)	Nutritional improvement (d)	Not reported (*Porphyra* is mentioned in the introduction)	Dried	0 %, 1.6 %	Instant noodles	Seaweed powder was mixed with the rest of the ingredients of the noodles	The addition of seaweed was accepted by the panel although it affected the texture negatively compared to the control.

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Table 4 (*continued*)

Article	Purpose of seaweed incorporation (Quality score*)	Seaweed species	Seaweed treatment	Seaweed inclusion level	Vehicle	Sample preparation	Sensory findings
Rahman et al. (2023)	Nutritional improvement (d)	Not reported	Not reported	0 %, 10 %, 25 %, 50 %, 75 %, 100 %	Sweet potato biscuits	Not reported	Seaweed-flour addition decreased the consumer acceptance. The control sample received the highest score
Ribeiro et al. (2022)	Improvement of physicochemical properties (c)	*Fucus vesiculosus* (brown)	Dried	1 %, 5.5 %, 10 %	Wheat pasta	Seaweed powder was mixed with semolina in the making of pasta.	The sensory traits of the pasta with low inclusion of seaweed was the most preferred. Inclusion levels at 1 % did not change the sensory traits of the pasta.
Salgado et al. (2023)	Unknown (d)	*Saccharina japonica* (brown), *Ulva rigida* (green), *Porphyra dioica* (red)	Dried	4 % SJ. 3 % UR, 3 % PD	Milk-, white- and ruby chocolates	Seaweed powder was mixed into tempered and molded chocolates	Milk chocolate with *S. latissima* received the highest score, followed by ruby chocolate with *P. dioica*, and white chocolate with *U. rigida* as the least favored
Sasue et al. (2023)	Nutritional improvement (b)	*Kappaphycus alvarezii* (red)	Dried	0 %, 3 %, 6 %, 9 %, 12 %	High fibre bun	Not reported	3 % seaweed addition had was the most accepted by the consumers and similar to control, but with increased softness of the bun, whereas 12 % seaweed addition was significantly different and had the lowest acceptability among consumers
Senthil et al. (2005)	Functionality (e, e)	*Euchema* sp. (red)	Dried	5 %, 7.5 %, 10 %, 12.5 %, 15 %	Fish cutlet	Seaweed powder was mixed into fish-cutlet mix.	Increasing levels of *Euchema* sp. up to 10 %, resulted in more hardness and higher overall quality compare to the other inclusion levels.
Senthil et al. (2011)	Shelf -life and storage (d, f)	*Euchema* sp. (red)	Dried	2 %, 2.5 %	Cooked rice with spice adjunct mix	Seaweed powder was mixed with other powdered spices and vegetable oil.	Incorporation of up to 20 % *Eucheuma* sp. did not affect the acceptability of the spice adjunct mix.
Sivaraman et al. (2023)	Nutritional improvement (d)	*Portieria hornemannii* (red)	Dried	2.5 %, 5 %, 7.5 %, 10 %	Wheat cookies	Seaweed powder was mixed with cookie-dough, baked, cooled and served to the assessors.	The cookies with the lowest level of seaweed incorporation (2.5 % powdered and 5 % fragmented) had the highest acceptability score.
Skonberg et al. (2021)	Shelf life and nutritional improvement (c)	*Saccharina latissima, Alaria esculenta* (brown)	Fresh	25 %, 50 %, 75 %	fermented sauerkraut-style product with cabbage	the seaweed was shredded to 2 cm, mixed with cabbage and salt, followed by inoculation and fermentation. Thereafter stored at 3°C for 60 days.	The overall liking was not significantly affected by the addition of seaweed to the sauerkraut
Song et al. (2012)	Functionality (f)	*Undaria pinnatifida* and *Saccharina japonica* (formerly *Laminaria japonica*) (brown)	Dried	Not reported	Freeze-dried Mieyok and aqueous soup	Seaweed powder was mixed with beef stock, then separated as Miyeokguk, which was freeze-dried and mixed with hot water and served as soup	The study found that gamma irradiation at doses above 15 kGy significantly changed the flavor, taste, texture, and overall acceptance of freeze-dried miyeokguk, making the texture of 15 kGy-irradiated samples and the

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Table 4 (*continued*)

Article	Purpose of seaweed incorporation (Quality score*)	Seaweed species	Seaweed treatment	Seaweed inclusion level	Vehicle	Sample preparation	Sensory findings
							overall acceptance scores of 20 kGy-irradiated samples fall below acceptable levels for consumption
Sugimura et al. (2012)	Unknown (e)	*Undaria Pinnatifida* (brown)	Dried	0.5 %, 1 %, 2 %	Scones	Seaweed powder was mixed into the dough.	Up to 2 % wakame powder in the scones was considered acceptable.
Turuk & Banerjee (2023)	Nutritional improvement (c)	*Ulva lactuca* (green), *Gracilaria corticata* (red)	Dried	0 %, 1.1 % (bread), 0.6 % (cake), 0.8 % (cookies)	bread, cake, cookie	Seaweed powder was mixed with cake batter, bread-, and cookie dough	Not reported
Vieira EF et al. (2020)	Sensory and nutritional improvement (b)	*Fucus spiralis* (brown) and *Chondrus crispus* (red)	Fresh seaweed was either frozen or dehydrated	0 %, 25 %	Canned chub mackerel	Fresh seaweed was either frozen or dehydrated, added to the brine and fish before canning it or only to the fish when canning it.	Canned chub mackerel with *C. crispus* and *F. spiralis* was preferred for its ability to improve taste and texture over the other seaweed types and the control sample. Dehydrated seaweed was preferred over frozen.
Vilar et al. (2020)	Improvement of physicochemical and sensory properties (c)	*Himanthalia elongata, Undaria pinnatifida* (brown), *Porphyra umbilicalis*, and *Palmaria palmata* (red)	Dried	0 %, 1 %	Frankfurter sausages	Seaweed powder was mixed into sausages, which were cooked, sliced to 3-cm cylinders, and served to the panelists at room temperature.	Sensory scores were lower in seaweed-containing frankfurters compared to control samples, although the ones with *H. elongata* were the most accepted (score 5.78)
Wiander & Palva (2011)	Sodium reduction and salt replacement (e)	*Undaria pinnatifida* (brown)	Not reported	1 %	Sauerkraut	Not reported	the best sensory quality was obtained by fermentation with 1 % algae and 0.8 % mineral salt
Widati et al. (2021)	Nutritional improvement (c, d)	*Kappaphycopsis cottonii* (fomerly *Eucheuma cottonii*) (red)	Semi-dried	2.5 %, 5 %, 7.5 %	Beef meatball	Semi-dried seaweed was mixed with the rest of the ingredients for the meatballs.	The addition of 2.5 % seaweed did not negatively affect the acceptability of the meatballs.
Widiyanti & Purnamayati (2021)	Sensory improvement (e)	*Kappaphycopsis cottonii* (fomerly *Eucheuma cottonii*) (red)	Dried	20 %, 30 %, 40 %	Minced fish- and seaweed rolls	Seaweed powder was soaked and ground to a puree. This was then mixed with the fish mince and other ingredients, wrapped in tofu skin and steamed, and cooled before sensory evaluation	The addition of seaweed puree positively affected the acceptability.
Yang et al. (2022)	Processing techniques (b, c)	*Pyropia yezoensis* (formerly *Porphyra yezoensis*) (red)	Roasted	N/A	Fermented seaweed sauce (Seaweed + water)	Roasted scraps of seaweed were milled into powder and then mixed with water and sterilized at 121°C. After this, the samples were fermented at 40°C for 0, 3, 7, 14, and 21 days	Fermentation with *L. casei* enhanced the acceptability of the *P. yezoensis* sauce, regardless of the fermentation duration.

*Quality of the sensory methodology score equals the sum of points received for each reported item (Appendix 1). Studies with multiple tests received a quality score for each test.
a = 11-14 points (excellent quality), b = 9-10 points, c = 7-8 points, d = 5-6 points, 4 = 3-4 points, f = 0-2 points (lowest quality).

(Figs. 2 & 3), probably as a result of the attention to climate change and related food-production challenges as reported (Fredriksson et al., 2023).

Table 2 shows reported sensory attributes of some of the seaweed species in the articles. The articles included were grouped into two categories based on sensory methods used: analytical methods (Table 3) and hedonic methods (Table 4). Seventeen articles used analytical methods, 49 articles used hedonic methods, and 25 articles used a combination of both methods. The latter ones were categorized as hedonic due to the focus of their findings. We were able to extract all

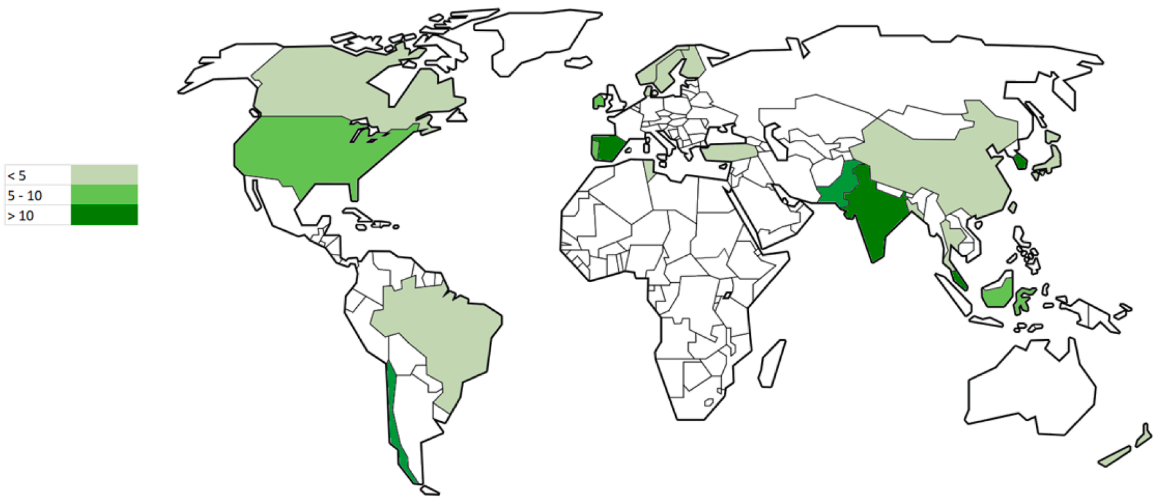

Fig. 2. Number of the eligible publications included in the present review, organized by country ($n = 91$ in total).

Fig. 3. Non-cumulative number of new publications per year ($n = 91$ in total).

relevant data from the included articles with the following exceptions: two studies did not report any sensory findings (Ogawa et al., 1991; Turuk & Banerjee, 2023), four studies did not specify seaweed species (Gorman et al., 2023; Koh et al., 2022; Pongpichaiudom & Songsermpong, 2018; Rahman et al., 2023), five studies did not report inclusion levels of seaweed into food vehicles (Balbas et al., 2015; Blouin et al., 2006; Lee et al., 2022; Mohibbullah et al., 2023; Song et al., 2012), and six studies did not report information about seaweed processing or sample preparation (Choi et al., 2012; Fellendorf et al., 2016; López-López et al., 2009; Rahman et al., 2023; Ribeiro et al., 2021; Wiander & Palva, 2011) (Fig. 1). More than half of the studies ($n = 51$, 56 %) stated that they aimed to improve nutritional properties of the seaweed biomass or their food vehicles by increasing fiber content, protein content, or partially replacing sodium and animal fat (Table 4). Only 9 of the 91 studies stated sensory improvement as part of their aim, for example by utilizing the well-known water-holding capacity (WHC) of seaweeds to increase the juiciness of different food matrices (Ana et al., 2022; Choi et al., 2017; Choi et al., 2015; Hentati et al., 2019; Pindi et al., 2023; Vieira et al., 2020; Vilar et al., 2020; Widiyanti & Purnamayati, 2021). The remaining studies ($n = 32$, 35 %) aimed to improve storage properties, shelf-life and physicochemical properties beyond WHC (Table 4). All analytical studies were conducted with adult subjects – similar to the hedonic studies, except for one study which included both adults and children (age 6-10 years) (Blouin et al., 2006).

In total, 47 different seaweed species were evaluated in the eligible articles. When classified based on their pigmentation, 18 of the included species were brown, 16 species were red, and 13 were green seaweed species (Tables 3 & 4). Brown seaweed species were the most prevalent overall, evaluated in 52 % of the 91 studies.

Comparing analytical and hedonic studies, green seaweed (Chlorophyta) was evaluated in 10 (59 %) of the analytical studies, brown seaweed (Heterokontophyta, Phaeophyceae) was evaluated in 7 (41 %), and red seaweed (Rhodophyta) was the least commonly evaluated in analytical studies, only present in 5 (29 %) of them (Table 3). Brown seaweed species were most commonly used in hedonic studies ($n = 39$, 53 %), followed by red seaweed species ($n = 34$, 46 %), while green seaweed species were evaluated by consumer panels in one fourth of the hedonic studies ($n = 18$, 24 %).

3.2. *Seaweed post-harvest treatments and food vehicles chosen for seaweed incorporation*

Two out of 17 articles using analytical methods evaluated fresh whole *Ulva rigida* (green seaweed) immediately after washing it in seawater or fresh water (Sanchez-Garcia et al., 2019; Sánchez-García et al., 2021). Nine articles used dried and rehydrated seaweeds

(Cittadini et al., 2023; Figueroa et al., 2022; Jönsson et al., 2023; Krook et al., 2023; Ogawa et al., 1991; Stedt et al., 2022b; Stévant et al., 2018, 2020; Wirenfeldt et al., 2024); three articles out of 17 evaluated seaweed-enriched noodles (Chang et al., 2011; Chang & Wu, 2008; Ribeiro et al., 2021); and three articles used other treatments, including fermentation of brown seaweed *Saccharina latissima, Undaria pinnatifida, Fucus vesiculosus (*Phaeophyceae), and *Pyropia* sp. (Rhodophyta) (Bruhn et al., 2019), and boiling of *U. rigida* (Chlorophyta) in water prior to serving (Sánchez-García et al., 2021).

In the majority of the hedonic articles, treatment of seaweeds pre-vehicle incorporation encompassed various methods of drying. Fifty-six articles reported that they had used either commercially dried seaweeds or seaweeds in their fresh form and subsequently dried as part of the study. Among those 56 articles, one reported blanching the seaweed prior to drying it (Balbas et al., 2015). The second most common stabilization method was freezing or fermentation, proceeded by washing the seaweeds in either seawater or tap water, followed by freezing or fermenting the seaweeds (Table 4). In the only study that involved children in two hedonic tests, the assessors evaluated rice crackers sprinkled with powders from two dried red seaweed species, *Porphyra umbilicalis* and *Pyropia yezoensis* in the first test. In the second test, *Wildemania amplissima* (formerly *Porphyra amplissima*) and *P. umbilicalis* were dried, powdered, and sprinkled on plain popcorn for evaluation (Blouin et al., 2006).

Of the 74 articles in the hedonic category, three evaluated pure seaweed (Choi et al., 2012; López-Pérez et al., 2021; Nayyar & Skonberg, 2019), whereas 70 articles used different food product as vehicles incorporated with seaweed (Table 4), and one article evaluated a dehydrated and seasoned seaweed snack (Lee et al., 2014). The most common vehicles were processed meat- or fish products ($n = 23$, 33 %), namely sausages and patties, followed by bakery products ($n = 18$, 26 %), namely bread, muffins, and crackers. Less common vehicles were beverages ($n = 5$, 7 %), noodles ($n = 6$, 9 %), and salads, soups, chocolates, rice analogues, cheese, rice paper, as well as sauce ($n = 18$, 25 %) (Table 4).

Among the included food vehicles, the proportions of incorporated seaweed in the products ranged from 0.5 % to 75 % of the total weight of the formulation; the most common proportion being 1 %, followed by 5 %, 2 %, 3 %, and 4 % (Table 4). Note in the table that the percentages reported sometimes were dw/fw, and sometimes fw/fw.

3.3. Sensory findings

The 17 analytical studies investigated how sensory characteristics of different seaweed species were influenced by post-harvest treatments such as drying, freezing, storage, and milling (Table 3). The 74 hedonic studies evaluated how different post-harvest treatments and levels of seaweed incorporation affected the sensory perception of food products containing seaweed (Table 4).

3.3.1. Analytical studies

The sensory attributes varied between species and indicated that the green seaweed *Ulva* sp. had a more herbaceous aroma and bitter taste, whereas the red seaweed *Pyropia* spp., was perceived to have a stronger umami taste (Figueroa et al., 2022). Adding herring-production process water to tank-cultivated *Ulva fenestrata* did not affect its sensory attributes (Stedt et al., 2022b) (Table 3).

The two articles analyzing seaweed-incorporated noodles in their analytical methods concluded that the addition of seaweed changed the noodles' texture, water-holding capacity, and color (Chang et al., 2011; Chang & Wu, 2008). In other studies, lower drying temperatures (Wirenfeldt et al., 2024) and lower moisture content (Stévant et al., 2020) retained stronger fishy- and marine odors (Stévant et al., 2020; Wirenfeldt et al., 2024). In one study, different drying temperatures, 25°C, 40°C, and 70°C did not result in significantly different aroma attributes of fresh sea for *Saccharina latissima* (Stévant et al., 2018), whereas in another study, the freeze-dried samples of *Fucus vesiculosus* and *Ulva* sp. had significantly stronger odors of seaweed, fresh fish and sea compared to their convection- and microwave-oven dried counterparts (Wirenfeldt et al., 2024). Washing *S. latissima* with seawater preserved umami- and salty taste, compared to washing it with tap water or freshwater (Krook et al., 2023). In another study, the absence of washing *Ulva* sp. resulted in stronger salty taste compared to washing it with seawater (Trigo et al., 2024). Fermentation of *S. latissima* and long-term storage of *U. rigida* affected their sensory attributes, mainly reducing their marine- and fishy aromas (Bruhn et al., 2019; Sanchez-Garcia et al., 2019; Sánchez-García et al., 2021), although long-term storage resulted in overall loss of other quality traits, such as color and texture as well as freshness.

Only one study explored the effects of cultivation strategies, such as adding herring production process waters to tank-cultivated *Ulva fenestrata* (Stedt et al., 2022b), and another assessed the effects of cooking (i.e., boiling) as seaweed treatments (Figueroa et al., 2022).

3.3.2. Hedonic studies

Of the 70 hedonic consumer studies using food products as vehicles, 14 studies (20 %) reported that adding seaweeds to commonly available food products had a positive effect on consumer acceptance (Ana et al., 2022; Astuti et al., 2023; Choi et al., 2012; Dewi & Purnamayati, 2021; Egodavitharana et al., 2023; Jeong et al., 2022; Koh et al., 2022; Kumar et al., 2019; Lee et al., 2014; Mamat et al., 2018; Monzón et al., 2022; Pindi et al., 2023; Vieira et al., 2020; Widiyanti & Purnamayati, 2021). In 32 of the studies (46 %) acceptance of seaweed-incorporated products was reported to be similar to the control products. These included food products both familiar and unfamiliar to the consumers (Blouin et al., 2006; Chapman et al., 2015; Choi et al., 2014; Choi et al., 2015; Cofrades et al., 2011; Cox & Abu-Ghannam, 2013a, 2013b; Debbarma et al., 2017; del Olmo et al., 2018; Fellendorf et al., 2016; Gorman et al., 2023; Hanjabam et al., 2017; Huang & Yang, 2019; Kumar et al., 2018; Lamont & McSweeney, 2021; López-López et al., 2010; Mamatha et al., 2007; Menezes et al., 2015; Metin & Baygar, 2018; Mohibbullah et al., 2023; Munsu et al., 2021; Oh et al., 2020; Pandi et al., 2023; Patil et al., 2023; Pindi et al., 2023; Pongpichaiudom & Songsermpong, 2018; Salgado et al., 2023; Senthil et al., 2011; Skonberg et al., 2021; Sugimura et al., 2012; Wiander & Palva, 2011; Widati et al., 2021). In 17 studies (24 %), there was a negative relationship between the seaweed-incorporation level and the hedonic liking scores, i.e. as the seaweed levels increased, the liking scores decreased (Choi et al., 2017; Damat et al., 2021; Damayanti et al., 2021; Hentati et al., 2019; Jiménez-Colmenero et al., 2010; Kim et al., 2010; López-López et al., 2009; Mamat et al., 2021, 2023; Mohammed et al., 2022; Nuñez & Picon, 2017; Rahman et al., 2023; Ribeiro et al., 2022; Sasue et al., 2023; Sivaraman et al., 2023; Song et al., 2012; Vilar et al., 2020). Two studies that used dried seaweed found that the presence of seaweed flavor and odor was associated with lower liking scores (del Olmo et al., 2018; Salgado et al., 2023). In 3 studies, heat-treated (high-pressure cooked, blanched, and extrusion-cooked) seaweed, both in pure form and incorporated into food vehicles, received higher liking scores than fresh seaweeds, which was especially pronounced for kelp and to a lower extent for green and red seaweeds (Akomea-Frempong et al., 2021; Lee et al., 2022; López-Pérez et al., 2021).

3.4. Critical evaluation of the sensory-methodologies

Of the 91 studies, one conducted three different sensory tests, 18 conducted two different sensory tests, and 72 studies conducted one test, resulting in a total of 111 grades (Tables 3 and 4). Six (5.4 %) studies received the highest grade i.e., "a", 17 (15.3 %) received grade "b", 30 (27 %) received grade "c", 27 (24.3 %) received grade "d", 22 (19.8 %) received grade "e", and 9 (8.1 %) studies received the lowest possible grade, "f" (Fig. 4). Of the 111 grades, 100 (90.1 %) used an appropriate evaluation scale, 64 (58 %) used the appropriate participants for their

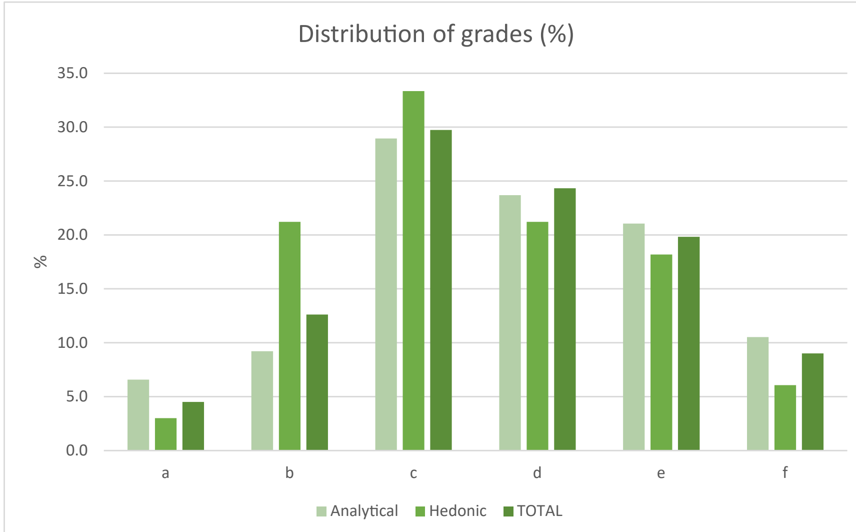

Fig. 4. Percentage of studies graded based on the quality of used sensory methodologies. a = highest grade, f = lowest grade.

chosen sensory method (trained panels for analytical tests and consumers for hedonic tests), and 33 (29.7 %) used an appropriate consumer-/panel size for their chosen sensory method. The other 78 (70.3 %) either did not use appropriate participants for the study type nor reported report sufficient information about the participants. This was especially common, in 69 out of 73 studies, in the hedonic evaluation category (90.4 %), some of which involved only five participants. Only nine (11.8 %) of the hedonic studies used an appropriate consumer-/panel size (Appendix 1).

4. Discussion

This scoping review aims to provide a comprehensive overview of studies that used sensory scientific evaluation to investigate seaweeds. In total, 91 papers were identified and divided into two main categories: analytical and hedonic.

Only 10 % of the studies using vehicles mentioned "sensory effect" or "sensory improvement" in their aims when incorporating seaweed into them, whereas nutritional improvement, as claimed by the authors, was more commonly the aim of the studies (Table 4). Positive sensory effects were rarely considered when incorporating seaweed into a food vehicle. Instead, the general approach in those studies was to achieve acceptance levels similar to the controls without seaweed (Table 4). Thus, based on these findings, we consider seaweeds to have largely been used as a nutrition-promoting ingredient rather than for their culinary potential. At the same time, our findings suggest that marine and fishy odors and flavors are associated with lower acceptance levels (Table 4). Therefore, we consider future research should focus on gastronomic utilization of seaweeds, such as adding unique texture- and flavor properties, especially to dishes with natural seafood notes, which could be enhanced by seaweed (Rioux et al., 2017). Further, their gastronomic utilization could leverage the umami taste present in most seaweeds - mainly due to glutamic acid, aspartate, and several peptides (Milinovic et al., 2021). Umami is known to be a driver of liking, regardless of cultural background and age (Figueroa et al., 2023), and is a frequently occurring descriptor in the sensory evaluation of seaweeds (Bruhn et al., 2019; Figueroa et al., 2022; Jönsson et al., 2023; Krook et al., 2023; Sánchez-García, et al., 2021; Sánchez-García, et al., 2021; Stedt et al., 2022b; Stévant et al., 2018, 2020; Trigo et al., 2024; Wirenfeldt et al., 2024).

Some studies focused on different post-harvest treatments, and particularly different drying techniques showed relevant findings from a sensory perspective. Results from the studies that used analytical methods suggest that drying seaweed at higher temperatures reduced marine or fishy odors compared to drying at lower temperatures (Sanchez-Garcia et al., 2019; Stévant et al., 2020). However, the findings were not entirely coherent: one study did not find significant differences in marine- or fishy odors when air-drying *S. latissima* at three different temperatures (Stévant et al., 2018), while another study reported that freeze-drying *Ulva* sp. and *F. vesiculosus* influences the sensory outcomes, specifically intensifying the fishy- and marine odors in the final product (Wirenfeldt et al., 2024). This indicates that lower drying temperatures better maintain the structure of the volatile odor-generating compounds in the seaweed (Wirenfeldt et al., 2024). At higher drying temperatures, secondary oxidation products such as aldehydes can react with proteins and form Schiff bases or furans (Li-Chan, 2017), which subsequently replace the fishy- and marine odors.

Besides drying temperatures, some papers found that drying techniques can affect the WHC differently, which in turn might have an impact on the sensory attributes of the seaweed. For instance, convective drying vs. freeze-drying vs. microwave-vacuum drying resulted in similar WHC levels for *F. vesiculosus*, while convective drying resulted in significantly higher WHC than freeze-drying in *Ulva* sp. Furthermore, freeze-dried *Ulva* sp. exhibited the lowest water activity, while also displaying the strongest marine odors (Wirenfeldt et al., 2024). This is supported by another study that compared effects from storage of fully-dried and semi-dried (20 % moisture content) *Palmaria palmata* (*Rhodophyta*) and found that the semi-dried seaweeds developed sweeter, richer and more complex notes than the fully-dried seaweeds, which had a stronger marine odor (Stévant et al., 2020). This is supported by other analytical studies showing that drying – especially at lower temperatures – preserves the marine- and fishy odors in seaweeds (Bruhn et al., 2019; Sanchez-Garcia et al., 2019; Wirenfeldt et al., 2024).

4.1. Seaweed-containing food products and consumer perceptions

An important aspect of hedonic studies is the selection of the food vehicle for incorporating seaweed, as it significantly influences consumer acceptance. This is especially crucial in Western countries, where seaweed consumption is less common, making the choice of an appropriate vehicle essential for integrating its unique flavors and textures into familiar foods. In the studies compiled in this review, often traditional and familiar foods, such as bakery products - both sweet and savory - and processed fish- or meat products, such as sausages and patties, were the most common vehicles (Table 4). Less common vehicles, such as fermented kelp products and whole wheat bread were evaluated in studies from Western countries (Akomea-Frempong et al., 2021; Balbas et al., 2015; Gorman et al., 2023; Lamont & McSweeney, 2021; Perry et al., 2019; Skonberg et al., 2021; Wiander & Palva, 2011), and may be perceived by consumers as "healthy" foods (Bisogni et al., 2012; Mete et al., 2019). The latter studies were in minority compared to the studies conducted in countries where seaweed is frequently consumed (Fig. 2). This suggests that perceived health benefits are possibly a motivational factor for encouraging an increased seaweed consumption in Western countries where seaweed are not eaten as regularly as in other countries. However, only highlighting potential health benefits of seaweed may not be enough to increase seaweed consumption for the larger population.

4.2. Seaweed incorporation levels: The more the better?

Studies have shown that the perceived benefits of healthy food products are often able to outweigh taste preferences of adults (Shepherd & Raats, 2006; Wendin & Undeland, 2020). However, a large number of the hedonic studies found that increasing concentrations of dry seaweed above 1-5 % in food products correlated with lower liking scores (Choi et al., 2017; Damat et al., 2021; Damayanti et al., 2021; Hentati et al., 2019; Jiménez-Colmenero et al., 2010; Kim et al., 2010; López-López et al., 2009; Mamat et al., 2021, 2023; Mohammed et al., 2022; Nuñez & Picon, 2017; Rahman et al., 2023; Ribeiro et al., 2022; Sasue et al., 2023; Sivaraman et al., 2023; Song et al., 2012; Vilar et al., 2020), suggesting that these concentrations may fall outside the optimal balance between perceived healthiness and taste preferences. In fifteen studies, the addition of seaweeds to food products (0.75-30 %) had positive effects on liking (Table 4). Of the 15 studies, which found that adding 0.75-30 % seaweed into food products resulted in positive effects on liking, 14 were conducted in South Eastern Asia (Ana et al., 2022; Astuti et al., 2023; Choi et al., 2012; Dewi & Purnamayati, 2021; Egodavitharana et al., 2023; Jeong et al., 2022; Koh et al., 2022; Kumar et al., 2019; Lee et al., 2014; Mamat et al., 2018; Mohammad et al., 2019; Monzón et al., 2022; Pindi et al., 2023; Widiyanti & Purnamayati, 2021), and one in Western Europe (Vieira et al., 2020), the latter being canned fish. However, as the seaweed concentration increased above the optimum levels, the liking decreased in those 15 studies (Table 4). It is, therefore, essential to detect and recognize the "sweet spot" that emerges before the trend crosses over to a negative correlation (Stone & Sidel, 2009). Moreover, the treatment's effect on the sensory characteristics of the seaweeds, is an important aspect of consumer perception of the finished product. Different seaweed species and treatments are likely to result in different acceptable inclusion levels in the end products. This aspect is also of importance when motivating an increased seaweed consumption with health-related claims.

The reviewed studies suggest that post-harvest treatment is a factor that affects sensory perceptions of the food products as well. In the studies that investigated consumer perceptions of products containing cooked seaweed, higher liking scores were reported (Akomea-Frempong et al., 2021; Lee et al., 2022; López-Pérez et al., 2021). However, the most common treatments were different forms of drying and inclusion levels were predominantly 1-5 % – with the exception of fish-and seafood-based vehicles containing larger amounts of seaweed (Table 4). Although only two of the hedonic studies explored and found a correlation between the presence of marine – and fishy odors and lower liking scores (del Olmo et al., 2018; Salgado et al., 2023), investigating other treatments than drying, such as heating without dehydration, can be of relevance. Of note is that only one of the studies involved children in the consumer tests (Blouin et al., 2006), and children's drivers of liking and perceptions of sensory qualities of food differ from the ones of adults (Waddingham et al., 2018).

4.3. Safety considerations of seaweed consumption

Seaweed, especially sugar kelps, often have a high content of the essential element iodine, which, if ingested in quantities exceeding the recommended upper intake level, may lead to adverse health effects (Nordic Nutrition Recommendations 2023/Integrating Environmental Aspects, n.d, 2024). Heavy metals, such as lead, mercury, cadmium, and inorganic arsenic can also be present in amounts limiting seaweed consumption to a greater extent (Guo et al., 2023). Taking these factors into account, the safety aspect is important to address, especially if the target group includes children and women of reproductive age (Hahn et al., 2022; Murai et al., 2021). Seaweeds have the capacity to efficiently absorb both nutrients and harmful substances from their surroundings, where the latter can entail a health risk when encouraging the large population to increase their consumption of seaweeds. The level, form and/or bioavailability of both nutrients and unwanted elements in seaweeds can however be affected by post-harvest processing (Guo et al., 2023; Jacobsen et al., 2023; Trigo et al., 2023). For instance, blanching *S. latissima* can reduce the content of iodine (Nielsen et al., 2020) content as well as of some of the heavy metals (Jacobsen et al., 2023). Given that different species and growth environments can result in varying initial levels of iodine and heavy metals, it is difficult to predict whether blanching consistently reduces these contents to safe intake levels (A Nordic approach to food safety risk management of seaweed for use as food. (n.d.), 2024).

4.4. Methodological considerations

This scoping review was conducted according to the PRISMA-guidelines for scoping reviews, and included both analytical studies exploring the sensory profiles of seaweeds as well as consumer perceptions of seaweeds and seaweed-containing products. The included studies were overall well-reported and -executed, although more efforts should be put into reporting methods to make the studies fully reproducible. It is important to point out that the sensory findings of the included articles should be interpreted cautiously, since only five out of 91 studies received the highest grade, "a" denoting high quality and reproducibility, with further 16 studies received the second highest grade" b". However, the majority of the studies received the grade "c" or lower and could thereby be considered of limited quality and reproducibility (Fig. 4). While the evaluation tool used in this study is still under development, the specific grades assigned to each paper are less important than the fact that our findings broadly align with previous assessments of sensory studies highlighted in the literature, which emphasize similar methodological challenges (Djekic et al., 2021; Song et al., 2022).

5. Conclusion

In total, 91 scientific articles were identified where seaweed or food products containing seaweed were evaluated using sensory methodology. The methodological quality varied in the evaluated papers, and while some of the studies received average to high grades, less than 20 % of the studies were found to be fully or mostly reproducible. The majority of the studies were hedonic evaluations conducted in Asia with adult panelists. Thus, more research is needed on other populations and age-groups such as European populations and children. The aims of the studies were mainly related to seaweeds contributing to nutritional improvement, focusing on post-harvest treatments in the analytical articles and seaweed-incorporation into food vehicles in the hedonic articles, rather than using seaweed as a means for sensory improvement.

The sensory findings suggest that seaweed dried at lower temperatures, with low moisture content was associated with stronger marine- and fishy descriptors. Furthermore, increasing inclusion levels of seaweed correlated with lower liking scores in adult consumers. Attention should be given to the inclusion levels, as it is unclear whether these are sufficient to qualify the food product as a source of specific nutrients, such as iron, vitamin B12, and protein.

To create food products with higher inclusion levels of seaweed that appeal to consumers' sensory preferences, more culinary research as well as exploring other post-harvest treatments, such as heating without dehydration and other cooking methods, is important. However, the bioavailability of the micronutrients as well as the safety aspects of the products, including minimizing the iodine content and staying within the safety levels of potentially harmful elements in seaweed, must be considered when aiming to increase their seaweed content.

Ethical statemnet

This scoping review is based solely on previously published data and thus, no ethical approval has been required.

CRediT authorship contribution statement

Sermin Rauf Dahlstedt: Writing – original draft, Visualization, Validation, Methodology, Investigation, Conceptualization. **João P. Trigo:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Kristoffer Stedt:** Writing – review & editing, Investigation, Conceptualization. **Fredrik Rosqvist:** Writing – review & editing. **Ingrid Undeland:** Writing – review & editing. **Henrik Pavia:** Writing – review & editing. **Christina J.B. Rune:** Writing – review & editing, Methodology, Investigation. **Davide Giacalone:** Writing – review & editing. **Pernilla Sandvik:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

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

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.afres.2025.101057.

Data availability

Data will be made available on request.

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