HIGH-VALUE UTILIZATION OF MARINE BIOMASS IN THE BAKERY INDUSTRY: CASE STUDY – SACCHARINA LATISSIMA

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Abstract. *The study explores the use of Saccharina latissima seaweed as an innovative functional ingredient in the bakery industry, particularly in products such as bread and savory snacks. The research was conducted within the SuMaFood project and aims to sustainably valorize marine raw materials, with a focus on expanding the range of food products by integrating ingredients with high nutritional value. The seaweed used was organically cultivated and processed through microwave vacuum drying, followed by fine milling. It was incorporated into bread and snack recipes, replacing white wheat flour in varying proportions (from 1.5% to 6%). Detailed nutritional analyses, rheological tests, and sensory evaluations were performed on a group of 205 consumers. The results highlight that seaweed flour has a high content of minerals and fiber, which supports its use as a functional ingredient with potential nutritional and health claims according to European legislation. However, the specific aroma—associated with a fish-like taste—was perceived as a limiting factor for product acceptance. To improve the sensory profile, researchers added ingredients such as cumin, garlic, or flax seeds to the recipes, which proved effective in masking the characteristic seaweed taste and allowed for higher substitution levels to be better accepted. This research demonstrates the viability of using Saccharina L. in bakery products and opens up prospects for the development of innovative food products with nutritional and functional benefits, in line with current trends toward sustainable and healthy consumption.*

Keywords: *Saccharina latissima*, seaweed flour, functional bread, sensory evaluation, consumer acceptability

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1. Introduction

The exploration of marine resources for innovative, functional, and sustainable food ingredients has intensified in recent years, responding to the need for healthier diets and resilient food systems [9, 10].

The brown macroalga *Saccharina Latissima* (formerly *Laminaria saccharina*) has emerged as a promising candidate for diversifying sustainable food sources and developing functional bioactive ingredients for food systems. Traditionally exploited in Asian diets for its nutritional richness and palatability, *S. latissima* is now increasingly cultivated in European aquaculture systems, including integrated multi-trophic aquaculture (IMTA), thanks to its high productivity, ease of farming, and valuable biochemical profile [7, 22]. This species is rich in polysaccharides (e.g., alginates, fucoidans, laminarans), dietary fibers, minerals, vitamins, and phenolic compounds, with potential health-promoting effects such as antioxidant, anti-inflammatory, and immunomodulatory activities [5, 6, 16]. Polyphenols and phlorotannins in particular are recognized for their radical scavenging capacity, while fucoxanthin, its dominant carotenoid pigment, contributes to photoprotection and may have anti-obesity, anti-cancer, and UV-protective effects [3, 12].

Research has also demonstrated that the physicochemical composition and antioxidant capacity of *S. latissima* are highly variable, influenced by environmental factors such as seasonal light and nutrient availability, as well as processing conditions like drying and storage [7, 13]. These parameters must therefore be carefully considered to harness its full potential as a food ingredient or nutraceutical. Moreover, projects such as SUMAFOOD are increasingly focusing on seaweed integration in local food chains, recognizing *S. latissima* as an underutilized yet sustainable marine resource with potential contributions to food security, circular bioeconomy, and healthier diets (www.sumfood.eu).

Seaweed incorporation in bakery products has been proposed as a promising valorization pathway, aligning with current consumer demand for functional and natural foods with enhanced health benefits [5]. Fortification of bakery products with seaweed biomass may improve their fiber content, mineral profile, antioxidant capacity, and functional properties while supporting local blue-biobased economies. However, challenges remain regarding sensory acceptance, processing compatibility, and stability of bioactive compounds [4, 8].

This study aims to investigate the high-value potential of *Saccharina latissima* in the bakery sector by assessing its composition, functional properties, and possibilities for incorporation into bread and other baked products. In this context, the research further seeks to clarify the biofunctional properties of *S. latissima* to support evidence-based applications within safe, traceable, and sustainable food systems.

2. Background on *Saccharina Latissima* and Functional Potential

Saccharina Latissima is a brown macroalga from the *Laminariaceae* family, widely distributed in the North Atlantic. It is characterized by high levels of laminarin, fucoidan, alginates, essential minerals (such as iodine, calcium, iron), vitamins, and bioactive polyphenols with antioxidant activity [12, 13]. The seasonal and environmental variability of its composition has been well-documented, with significant effects on phenolic content, carotenoids like fucoxanthin, and antioxidant activity [7].

In addition to its nutritional and health-promoting attributes, *S. latissima* has functional technological potential due to its hydrocolloids, which can contribute to water retention, emulsification, and textural improvements in baked goods [6]. These features can help reformulate bread, biscuits, or gluten-free products with enhanced functional quality.

3. Materials and Methods

For determining the physicochemical composition, standard methods were used, namely:

- the moisture content was verified to be conformant to SR ISO 712:2009 [17].

- the method of determining the ash content according to SR ISO 2171:2009 [18].

- the protein content of the samples was established in accordance with SR ISO 20483:2007 [19].

- the total fat content was determined by continuous flow extraction according to SR 90:2007 [20].

- a method for the determination of crude fiber was realized according to Oprea O. et al. (2023) [9].

- the content of potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), copper (Cu), selenium (Se), manganese (Mn), chromium (Cr), molybdenum (Mo), iron (Fe), zinc (Zn), phosphorus (P), and iodine (I) from the marine algae S. latissima, was determined using the ICP-OES method (inductively coupled plasma—optical emission spectrometry) [9].

- the total content of polyphenolic compounds was determined by the Folin-Ciocalteau (FC) method [14].

- the DPPH method, as described by Shekhar et al. (2021) [15], is used worldwide in terms of free radical scavenging quantification.

- the sensorial analysis was realised accordidng with ISO 8586:2012 [21]. The acceptance tests applied the nine-point hedonic scale, with nine possible qualifications to be given to the evaluated product: 9—I like it extremely; 8—I like it very much; 7—I like it moderately; 6—I like it slightly; 5—indifferent; 4—I dislike it slightly; 3—I dislike it moderately; 2—I dislike it very much; 1—I dislike it extremely.

4. Results

4.1. Nutritional enrichment

Saccharina Latissima is a valuable source of dietary fiber, particularly alginates, which may improve the nutritional profile of baked products and support satiety [16]. Its mineral content can also contribute to addressing micronutrient deficiencies, including iodine and iron, which are relevant in many European populations [7].

Table 1. Fizico-chemical characteristics of *Saccharina Latissima* flour [9]

Parameter	***Saccharina Latissima* flour**
Moisture content (%)	7.170 ± 0.22
Ash (%)	38.92 ± 4.25
Protein (%)	14.34 ± 1.02
Fat (%)	0.706 ± 0.03
Raw fibre (%)	6.367 ± 0.46
Potasium (mg/kg d.m.)	62,088 ± 1949
Magnesium (mg/kg d.m.)	6,041 ± 166.0
Calcium (mg/kg d.m.)	8,236 ± 636.0
Iron (mg/kg d.m.)	35.23 ± 6.20
Na (mg/kg d.m.)	15,205 ± 35.00
Zinc (mg/kg d.m.)	30.06 ± 0.33
Copper (mg/kg d.m.)	0.846 ± 0.03
Selenium (mg/kg d.m.)	0
Manganese (mg/kg d.m.)	3.967 ± 0.50
Chromium (mg/kg d.m.)	0
Molybdenum (mg/kg d.m.)	0
Phosphorus (mg/kg d.m.)	2,263 ± 129.0
Iodine (mg/kg d.m.)	12,530 ± 2076

4.2. Antioxidant activity of *S. Latissima*

The presence of polyphenols, phlorotannins, and carotenoids (fucoxanthin) confers potential antioxidant and anti-inflammatory properties to *S. latissima*, which could be transferred to functional bakery products [13]. However, these compounds can be sensitive to baking temperatures, so encapsulation or gentle incorporation techniques may be needed to preserve their activity [22].

Table 2. Antioxidant activity of *S. Latissima* flour

Parameter	***Saccharina Latissima* flour**
Total polyphenols (mg GAE/100g)	283.5 ± 13.79
DPPH (mg Trolox/100g; µmol T/100g)	13.10 0.20

4.3. Technological functionalities

Seaweed-derived hydrocolloids (alginates, laminarans) may positively influence dough rheology, bread texture, and moisture retention, potentially extend shelf life and improve crumb softness [6].
The technological parameters used in the production technologies for bakery and pastry products were optimized through repeated experiments and direct observations of the resulting doughs.

Table 3. Snacks type products with *S. Latissima* flour addition

No. crt.	Products developed with *Saccharina Latissima* flour addition	Nutritional facts *Nutritional values in 100 g*
1.	Salty snacks with seaweed (1.5%) and mix of seeds 	ENERGY: 365.45 Kcal PROTEIN: 11.89 g FAT: 8.22 g CARBOHYDRATES: 58.97 g FIBERS: 3.36 g SUGAR: 0.43 g
2.	Biscuits with seaweed (1.5%) and cheese 	ENERGY: 277.15 Kcal PROTEIN: 8.46 g FAT: 7.59 g CARBOHYDRATES: 41.4 g FIBERS: 1.55 g SUGAR: 0.05 g
3.	Bake rolls with seaweed (1,5%) and garlic powder	ENERGY: 358.14 Kcal PROTEIN: 10.77 g FAT: 5.29 g CARBOHYDRATES: 63.98 g

		FIBERS: 3.09 g SUGAR: 4.5 g
4.	Salty snacks with seaweed (1.5%) and cumin seeds 	ENERGY: 266.22 Kcal PROTEIN: 7.16 g FAT: 1.9 g CARBOHYDRATES: 47.12 g FIBERS: 1.72 g SUGAR: 0.05 g
5.	Salty snacks with seaweed (3%) and cumin seeds 	ENERGY: 263.79 Kcal PROTEIN: 7.22 g FAT: 1.89 g CARBOHYDRATES: 46.69 g FIBERS: 1.76 g SUGA R: 0.04 g

4.4. Technological functionalities

Seaweed inclusion may affect sensory characteristics such as color, aroma, and taste. Studies suggest acceptable incorporation levels range between 1–5% in flour basis to balance sensory acceptance and functional benefits [5, 16]. Targeted consumer education and marketing, as explored in SUMAFOOD, can enhance acceptance of marine-based bakery innovations. In the case of the bread samples, the control recorded a score of 7.9, the sample with 1.5% *S. latissima* scored 7.1, followed by the sample with 3% S.L. at 6.1, the sample with 4.5% S.L. at 5, and finally, the sample with 6% S.L. recorded a score of 3.6. For the snack-type products, recipe and process parameter optimization was carried out with the involvement of consumers, who also took part in the manufacturing processes.

5. Discussions. Consumer Acceptance and Product Development Considerations

Successfully launching newly developed food products requires a deep understanding of how consumers accept and adopt such products, a process strongly influenced by consumer attitudes and beliefs. These are relevant, and sometimes decisive, factors affecting the acceptance or rejection of novel foods, including functional bakery products, which are proposed as alternatives to traditional or conventional foods [1, 2, 11]. Preliminary studies carried out at Transilvania University of Brașov evaluated consumer acceptance of bread products (with 1.5%, 3%, 4.5%, 6% replacement levels) and salty snacks (2%, 3%, 4%, 6%) incorporating seaweed flour (*Saccharina latissima*) as a partial flour substitute. In order to improve consumer acceptance at higher replacement levels (4% and 6%), the recipes for salty snacks were successfully supplemented with 2% caraway seeds, flax seeds, and garlic powder. Favorable results were reported especially for caraway and garlic additions.

The acceptability studies involved a sample of 205 respondents, aged 18 to 65 years, and revealed the following key sensory characteristics:

- **For bread products:** bitter taste, salty taste, sour taste, crust color, crumb color, crumb pore uniformity, crumb flexibility, crumb friability, specific aroma, aftertaste.
- **For salty snacks:** color, bitter taste, salty taste, sour taste, specific aroma, aftertaste.

In bread-type products, the main challenges identified were excessive salty and sour taste, a specific "fish-like" aroma (noted by most respondents), and increased hardness, which intensified with higher levels of seaweed flour. Adjusting the base recipe ingredients could moderate excessive sourness and saltiness. The specific flavor and persistent aroma could be masked by incorporating caraway or rosemary, with encouraging results from initial trials. Hardness issues, related to reduced crumb porosity, were shown to limit the feasible seaweed flour inclusion to about 3%, as confirmed by overall acceptability scores and standardized rheological tests. Crust or crumb color changes were not considered negative by consumers.

In salty snack products, there was no limitation related to porosity, and the hardness could be mitigated by using flours with lower gluten content or by reducing product thickness. The main limiting factor was the specific seaweed aroma, which was successfully masked by adding 2% caraway in products with 4% and 6% seaweed flour.

These findings suggest that *Saccharina latissima* flour represents a promising ingredient for the bakery and snack industry due to its high content of minerals and dietary fiber. Sensory and technological limitations can be minimized by using aromatic seeds and spices and by limiting seaweed flour additions to 1.5–3% for optimal consumer acceptance.

6. Conclusions

(1). *Saccharina latissima* shows high potential as a functional ingredient in the bakery industry thanks to its valuable content of minerals, dietary fiber, and bioactive compounds with potential antioxidant and anti-inflammatory effects.

(2). Consumer acceptance remains a key challenge because of the characteristic seaweed taste and aroma, which were perceived as undesirable at higher inclusion levels; however, these sensory limitations can be successfully mitigated through recipe adjustments, such as adding spices or aromatic seeds.

(3). Technological functionality of *Saccharina latissima* — including its hydrocolloids and fiber content — can improve dough properties, water retention, and shelf life of bakery products, supporting its practical use in bread, biscuits, and snacks.

(4). Optimized formulations with seaweed flour additions of around 1.5–3% achieved a good balance between nutritional benefits and consumer acceptability, highlighting the feasibility of introducing such innovative products to the market.

(5). Future research and development should focus on improving sensory profiles, encapsulation of bioactives, and integrating *Saccharina latissima* within sustainable, traceable food chains to contribute to blue bioeconomy strategies and healthier diets.

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