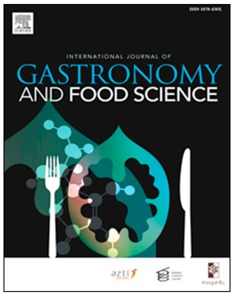

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SEAWEEDS IN BAKERY AND FARINACEOUS FOODS: A MINI-REVIEW

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SEAWEEDS IN BAKERY AND FARINACEOUS FOODS: A MINI-REVIEW

Seaweed is characterized by its nutritional composition. They contain protein and dietary fiber in high concentration, along with low fat and calorie intake. They also include bioactive compounds that are beneficial to health. For these reasons, it is incorporation in processed foods is interesting. In bakery and farinaceous foods, seaweed is incorporated as finely ground powder. The foods in which they have been incorporated are bread, noodles, cake, cookies, biscuits, and others. Thus, in general, foods with seaweeds incorporated, increase their content of protein, dietary fiber, total polyphenols, and antioxidant capacity.

Stable mixtures and emulsions are formed between the dough and the seaweed, furthermore, the functional properties improve in the products. Adding seaweeds into a bakery and farinaceous products decreases lightness, redness, and yellowness color parameters.

The sensorial quality is affected by the high concentration of seaweed, mainly flavor. It is being taken very carefully because sensory aspects are the most important for determining acceptability for consumers.

According to studies, the incorporation of seaweed in products should be a maximum of 10% for noodles, 4% for bread, 5% for biscuits, 5% for cookies, less than 10% for cake, and 3.55% in extruded maize.

Keywords: seaweeds, algae, bakery, farinaceous, sensory.

SEAWEEDS IN BAKERY AND FARINACEOUS FOODS: A MINI-REVIEW

1.- Introduction

Seaweeds are marine vegetables with nutrients and bioactive compounds, they constitute a renewable resource of the marine environment with conditions of application in the food, pharmaceutical, and cosmetic industries. Seaweeds are classified according to their predominant pigmentation as Chlorophyta or chlorophytes (green), Phaeophyta or phaeophytes (brown), and Rhodophyta or rhodophytes (red). The red and brown seaweeds are the most consumed directly into culinary preparations (Pereira, 2011).

Seaweeds can be incorporated as an ingredient in processed foods, providing nutrients, bioactive compounds and enhance food quality because they have antioxidant and antimicrobial action (Gupta & Abu-Ghannam, 2011; Syad et al., 2013). A study with 120 adult consumers evidenced that the most preferred forms of consuming seaweed were as snacks, bread, and in various dishes (Wendin & Undeland, 2020). The seaweeds used for this purpose are mainly brown and red (Gullón et al., 2020).

From the nutritional value, seaweed is characterized by high protein content, reaching similar concentrations to meats and dry legumes (Dawczynski et al., 2007). Red seaweed has higher protein content than brown and green ones (Fleurence, 1999; Fleurence et al., 2012; Cian et al., 2015). For example, protein concentration in seaweeds genera *Adenocystis* (brown) is 12.6 g/100 d.w.; in *Codium* (green) is 14.8 g/100 d.w., and in *Porphyra* (red) is 22.0 g/100 d.w. (Astorga-España et al., 2016). However, the digestibility of seaweed´s proteins is lower than those of animal origin because it has a high dietary fiber concentration that reduces the access of digestive and proteolytic enzymes (Urbano & Goñi, 2002).

The seaweed has a low contribution of fat, with distribution and ratio of fatty acids ω6/ω3 very beneficial for health, very low values of this relationship have been found, such as 0.5 and 0.02 in *Brongniartella australis* and *Gracilaria changii* respectively (Schmid et al., 2018; Gressler et al., 2011).

The seaweed´s caloric content is low, Ortiz et al. (2009) determined values of 324, 331, and 360 kcal / 100g in *Codium fragile*, *Gracilaria chilensis* and *Macrocystis pyrifera*, green, red, and brown algae respectively; Gamero-Vega et al. (2020) determined 223 kcal/100 as an average in red seaweed. This is mainly due to the low-fat content and high dietary fiber

The dietary fiber in seaweed reaches values over 50% d.m. (Ortiz et al., 2006) with soluble dietary fiber in high proportion. The content of insoluble fiber (IF) is higher than soluble fiber (SF) in all terrestrial vegetables, cereals, and legumes, however, it is found similar content of soluble and insoluble fiber in seaweed, and there are even some that have a higher content of SF than IF, such as *Himanthalia elongate* with 23.6 and 13.5g/100g of SF and IF respectively (Gómez-Ordóñez et al., 2010). SF has a greater effect on satiety, decreased postprandial glucose, insulin, and cholesterol levels (Ye et al., 2015; Fiszman & Varela, 2013). Further, seaweed contains minerals, vitamins, carotenoids, polyphenols, sulpholipids, sulfated polysaccharides (such as fucoidan), etc. (Parada et al., 2019; Belghit et al., 2017; Edelmann et al., 2019; Fernández-Segovia et al., 2018; Ganesan et al., 2019).

Seaweeds consumption has been linked to health effects by its nutrients and components. It has been reported on its biological activity in vitro as an antioxidant (Agregán et al., 2017; Wijesinghe & Jeon, 2012; Wang et al., 2009), anti-inflammatory (Kim & Himaya, 2011; Kim & Pangestuti, 2011; Rajapakse & Kim, 2011), anti-HIV (Sanniyasi et al., 2019), anti-Alzheimer's, and Parkinson diseases (Pereira & Valado, 2021), in addition to reducing the risk of chronic diseases such as metabolic syndrome (Rico et al., 2018), cancer (Rengasamy et al., 2020), osteoporosis, it influences the control of glycemic index (Parada et al., 2019), has antibacterial, potential therapeutic effect on calcium mineralization (Thi Nguyen et al., 2011). Its potential antidiabetic effect has been investigated through inhibition of enzymatic activity and control of anti-inflammatory and obesity response (Ganesan et al., 2019).

Rico et al. (2018) demonstrated that seaweed is a potential ingredient for the development of functional foods, to mitigate the risk factors for metabolic syndrome. Parada et al. (2019) showed that polyphenols from seaweed an ingredient in functional foods can low glycemic response.

When seaweeds are incorporated as an ingredient in food, they provide physicochemical and textural properties. Seaweeds contain sulfated polysaccharides, and these positively affect the structure and strength of food products. The principal sulfated polysaccharides present in seaweeds are fucoidans, laminaran, carrageenan, and ulvan. The carrageenans, present in red seaweeds, have gelling properties, emulsifying, thickening, and stabilizing; for this reason,

produce increased water absorption of the dough, reduced stickiness properties, increased firmness in bread (Mamat et al., 2014).

In consumers in countries where the consumption of seaweed is not common, neophobia towards them occurs, which affects the intention to consume seaweed. However, the qualifiers of "healthy" and the nutritional composition of seaweed, stimulate consumers more interested in health (Losada-López et al., 2021). Even so, it must be recognized that seaweed has a very characteristic and strong aroma and flavor, which affects the foods that contain them, so their incorporation into processed foods must be very well dosed and evaluated to obtain good results.

The incorporation of seaweeds in processed foods provides strong odors and characteristic marine flavors, they also produce, astringency and bitter taste (Cassani et al., 2020). More than 200 volatile compounds of different chemical groups have been identified in six species of seaweeds. The main volatile compounds correspond to hydrocarbons, ketones, aldehydes, alcohols, halogen or sulfur-containing compounds, acids, esters, furans, and phenols. It is necessary to identify that those most likely to impact sensory perception (Garicano Vilar et al., 2020).

The purpose of this study is to review the information regarding the effect of the incorporation of seaweed as an ingredient in bakery and farinaceous foods on nutritional properties, physical and sensory properties.

2.- Materials and methods

The literature search is done in databases: ScienceDirect, Web of Science, Scopus, PubMed, and Google Scholar. The search keywords included *seaweeds, bakery, bread, algae, noodles, cake, cookies, biscuit, pasta, farinaceous*. No restrictions were made regarding language (Articles in a language other than English or Spanish were translated with Google Translator) or date of publication. The included studies were published in food chemistry and bioenvironmental journals.

3.- Bioactive compounds in seaweeds

Seaweed contains different bioactive compounds such as polyphenols, including phenolic

Phlorotannins are present in brown seaweed, while red algae contain bromophenols, both compounds present in vitro activity to inhibit the proliferation of cancer cells, antidiabetic and antithrombotic properties, on the other hand, they inhibit the growth of tumors in vivo (Gullón et al., 2020; Liu et al., 2011). Phlorotannins have a strong antioxidant effect, they help to inhibit lipid peroxidation, an in vitro model system is more efficient than α-tocopherol (Ganesa et al., 2019). Seaweed polyphenol´s concentrations have different values, in green algae, *Ulva lactuca* 55.6 mg GAE/100g (Nunes et al., 2017) were quantified, while in brown algae *Himanthalia elongata* 1800 mg GAE/100g has been determined (Fernández-Segovia et al., 2018), in *Zonaira tournefortii* also brown, 2155 mg GAE/100g (Nunes et al., 2017) was determined, and the average in red algae was established at 542 mg GAE/100g (Gamero-Vega et al., 2020).

Dietary fiber and polyphenols have health benefits; however, benefits can be attributed to the association of both components (González-Aguilar et al., 2017). Saura-Calixto (1998) established the term "antioxidant fiber" to refer to bioactive compounds with antioxidant capacity associated with dietary fiber (Saura-Calixto, 2011). In the case of polyphenols, the same author differentiates extractable polyphenols (EP) (those extracted with solvents such as water, methanol, ethanol, etc.) from non-extractable polyphenols (NEP), the latter strongly associated with dietary fiber. This association between dietary fiber and polyphenols would modify the accessibility and bioavailability of the latter. Unabsorbed polyphenols are transported by dietary fiber to the colon, where they are released by the action of bacteria and there, they could exert beneficial health effects (Jakobek & Matić, 2019).

Further seaweed contains other compounds with antioxidant capacity such as carotenoids (carotenes, lycopene, fucoxanthin, zeaxanthin, lutein, neoxanthin, and violaxanthin) (Koizumi et al., 2018; Aryee et al., 2018), tocopherols (Ortiz et al., 2009), vitamin C (Bhattacharjee & Islam, 2014), and extracts of polysaccharides with sulfur groups with a significant antioxidant activity (Roohinejad et al., 2017). The antioxidant capacity of brown and red seaweed is very high (Devi et al., 2011).

About carotenoids, values of 199, 116, and 18 μg/g of [Lutein+β-carotene] have been reported in *Codium fragile*, *Gracilaria chilensis*, and *Macrocystis pyrifera* respectively

(Ortiz et al., 2009). Fucoxanthin in *Sargassum horneri* and *Cystoseira hakodatensis*, both

algae *Eucheuma denticulatum* (red) and *Sargassum polycystum* (brown), the concentration of [Lutein + zeaxanthin] was 109 and 26 mg/100g respectively (Palmieri & Forleo, 2020).

4.- Seaweed as food ingredients

In western countries, seaweed cannot be considered "new foods" strictly speaking, due to the presence of these for years in various preparations, however, processed foods that include seaweed as an ingredient can be considered "new" on the market. It is possible to promote the consumption of foods that use seaweed as an ingredient, highlighting healthy, ethical, and sustainable aspects (Palmieri & Forleo, 2020).

The incorporation of seaweed as an ingredient in processed foods shows advantages from the nutritional point of view, and the technological one, thanks to its functional properties such as water retention capacity, oil retention, swelling, and others. These properties depend mainly on the protein and dietary fiber content of the algae, allowing a positive interaction with other ingredients, as well as contributing to the stability against thermal processes and during food storage. (Elleuch et al., 2011; Quitral et al., 2019; Morales et al., 2019).

Further, the natural antioxidants of seaweed increase the shelf life of foods, since they delay the oxidation of the lipids present in them, thus Agregán et al. (2017) evaluated the antioxidant effect of extracts of the brown algae *Bifurcaria bifurcata* in canola oil, through of peroxide index, p-Anisidine, conjugated dienes, Totox value. The authors concluded that the inhibition of lipid oxidation is like that exerted by 200 ppm of BHT, which is why the extracts of the seaweed constitute a natural antioxidant potential.

Bakery and farinaceous foods (such as pasta, noodles, bread, or the like) have wheat flour or semolina as their main ingredient, their nutritional contribution is mainly carbohydrates.

There are many studies in which other ingredients ground as flour are incorporated into bread, pasta, and other farinaceous products, such as dried legumes (Bojnanska et al., 2012), pumpkin (See et al., 2007), and other dehydrated vegetables (Salehi & Aghajanzadeh, 2020; Arslan et al., 2019). Seaweed can also be incorporated into the bakery and farinaceous products, providing nutrients, dietary fiber, and bioactive compounds.

According to the studies presented in Table 1 and Table 2, mainly brown and red algae have

been added in concentration ranges of 0.5 to 8%; in noodles has been incorporated into a range of 3 to 30%; pasta in 5 to 20%; cake in 2.5 to 20%; biscuit in 5 to 60%; cookies in 3 to 9%; extrudes maize in 3.5%.

4.1.- Nutritional and bioactive compounds values

The incorporation of seaweed in the formulation of processed foods improves its nutritional quality due to the increase in the content of proteins, minerals, and dietary fiber (Prabhasankar et al., 2009), among others.

In this sense, Rodríguez de Marco et al., (2014) reported that the protein content increased significantly ($p <0.05$) when incorporating *Spirulina* in noodles, and their cooking did not cause significant losses in the content of this macronutrient. Concerning fiber content, this increased from 4.65% to 7.95% when *Himanthalia elongata* was incorporated by 17% in breadsticks (Cox & Abu-Ghannam, 2013). Similar effects were observed in bread with 4% of *Ascophyllum nodosum* incorporated, increasing the total dietary fiber by 34%, to control bread (Hall et al., 2012).

With micronutrients, it has been reported that the incorporation of the red algae *Porphyra columbina* significantly increased the content of phosphorus, calcium, and magnesium in extruded maize products, however, the bioaccessibility of these minerals decreased compared to the control sample. These effects could be attributed to the presence of dietary fiber, phenolic compounds, and phytic acid in seaweed, which could form insoluble complexes with minerals, affecting their bioavailability (Cian et al., 2014).

Moreover, it has been described that the incorporation of *Spirulina platensis* in noodles in different concentrations (5 to 20%) is capable of significantly reducing the fraction of total, soluble, and resistant starch at a biological level. The authors attribute these results to Spirulina provides a high amount of protein, which could limit the accessibility of α-amylase to starch, encapsulating its granules, thus reducing starch digestibility and the glycemic index (Rodriguez de Marco et al., 2014).

About the contribution of fatty acids, it has been described the incorporation of 10% *Undaria pannatifida* in noodles significantly reduces the ω-6/ω-3 ratio, due to the contribution of polyunsaturated fatty acids (PUFA) from the seaweed, such as octadecatetraenoic acid (18:

al., 2009). Lower ratios of ω-6/ω-3 are beneficial for health since they contribute to reducing the risk of metabolic syndrome (Jang & Park, 2020), depressive disorders in children and adults (Trebatická et al., 2020), neurodegenerative diseases (Shirooie et al., 2018), and others. Further, lipidic components such as fucoxanthin (xanthophyll that gives coloration to brown seaweed) and fucosterol (sterol), both with healthy properties, have also been reported in concentrations of 0.23 and 2.55 mg/g respectively, in noodles added with 30% *Undaria pannatifida* (Prabhasankar et al., 2009).

The incorporation of seaweed in farinaceous foods also improves the content of bioactive compounds, such as polyphenols and carotenoids, and therefore, of the antioxidant properties (Prabhasankar et al., 2009; Rodriguez de Marco et al., 2014). Over this, it has been described that the incorporation of seaweed in noodles produced a significant increase in the content of total polyphenols in raw and cooked samples, concerning the control. However, the cooking process decreased the content of polyphenols. This effect could be attributed to the fact that polyphenols are thermosensitive, also producing leaching in the cooking water (Pokorny et al., 2005; Gunathilake et al., 2018; Sengül et al., 2014; Mba et al., 2019). Higher polyphenol contents have also been observed in extruded maize added with *Porphyra columbina* (Cian et al., 2014), in noodles with *Spirulina* (Rodriguez de Marco et al., 2014), and breadsticks with 17% *Himanthalia elongata*. In this last study, the polyphenol content increased from 28 to 146 mg AGE/100g (Cox & Abu-Ghannam, 2013). Likewise, in most of these studies an increase in the antioxidant capacity of farinaceous products added with seaweed has been observed (Cox & Abu-Ghannam, 2013; Cian et al., 2014). Cox et al., (2012) also reported that thermal processes after dehydration could further increase the antioxidant capacity in farinaceous products added with seaweed. Furthermore, It has been described that antioxidant capacity induced by baking is related to the Maillard´s reaction; reaction products would cause an increase on polyphenols and antioxidant capacity (Zilic et al., 2016).

Arufe et al. (2019) determined an increase in antioxidant capacity in the mass of cookies before baking, however, in the cookies already made, in which the Maillard reaction has occurred, the antioxidant activity is overlapped by Maillard's products generated during baking.

Regarding shelf-life studies, in bread showed that the incorporation of 0.5 and 1% of [illegible]

of 0.5% *Myagropsis myagroides* was able to decrease the count of viable cells and molds (Lee et al., 2010). This property is due to its antimicrobial capacity and antioxidant effect against lipid oxidation.

Another aspect to consider when incorporating seaweed into a farinaceous and bakery product is to evaluate satiety, in this sense Hall et al., (2012) studied the satiety produced by samples of control and with 4% of *Ascophyllum nodosum* bread, in 12 healthy men and with overweight, observing that after 4 hours, all subjects reduced their energy consumption by 16.4%.

4.2.- Physical properties

From the technological vision, when incorporating seaweed in farinaceous products, some modifications are observed in certain parameters, such as an increase in their weight after cooking, what happened to add *Undaria pannatifida* in noodles at different concentrations (5 to 30%). This is explained by the hydration produced by the hydrocolloids (Prabhasankar et al., 2009). The seaweeds are raw materials for the production of hydrocolloids (polysaccharides), such as agar, alginate, and carrageenan. Hydrocolloids are characterized by their ability to form viscous solutions and/or gels when partially or dispersed in water (Li & Nie., 2016). Also, in this same farinaceous product added with *Spirulina* a shorter optimal cooking time was observed. This effect was attributed to the high protein content of these microalgae (60 to 70 g/100g), which would weaken the structure of the pasta because their proteins are not capable of developing gluten, and steric hindrance interferes in the network formation. (Rodriguez de Marco et al., 2014).

Besides, the addition of 4% protein hydrolysate of *Palmaria palmata* (a red seaweed) in bread, showed a lower specific volume ($p< 0.001$), that is, the dough did not manage to expand or “rise” as in the control. The authors attribute it to the amount of additional protein in bread that would compete with wheat starch for free moisture, restricting hydration and swelling of the starch granules (Fitzgerald et al., 2014). A similar result has been described in two studies, but in these the authors explained it by the antimicrobial effect of seaweed, affecting yeast, which is the leavening agent used in making bread, and also by the lower

Bread with 4% protein hydrolysate of *Palmaria palmata*, produced an increase in the hardness of the crumb, a decrease in cohesiveness and elasticity, and effects on the texture was observed. The authors agree with other studies, in that the cause of these modifications corresponds to the incorporation of vegetable protein (Fitzgerald et al., 2014).

According to the data in Table 2, in general, firmness increases in bread and pasta; chewiness increases in pasta and cake; hardness decreases in bread and increases in the cake. Specific volume decreases in bread. Cooking loss increases in noodles, pasta, and instant fried noodles.

Seaweeds are rich in pigments, mainly chlorophyll, carotenoids, phycoerythrin, and phycocyanin (Osorio et al., 2020), so their incorporation into food provides colorations depending on the type of algae. In Table 2 studies are presented in which the color parameters L* (lightness), a* (redness), and b* (yellowness) in foods are measured. The incorporation of seaweeds affects these parameters. In 5 out of 6 studies, L* decreased, meaning that the food darkened; the effect on the decrease of a* and b* was also greater, which means that the tones were more greenish and bluer. These color variations are attributed to the presence of pigments such as phycobillins, and chlorophylls in the seaweed (Kim et al., 2011). Darker colors have also been described in breadsticks with 17% Himanthalia elongata (Cox et al., 2012).

4.3.- Sensory properties

Sensory properties like appearance, color, texture, aroma, flavour, and overall quality in farinaceous and bakery products added with seaweed have different results. In noodles with 5 to 10% *Undaria pannatifida* did not present significant differences in sensory quality compared to the control sample. However, when the percentage of incorporation was increased to 20 and 30%, it presented a low sensory evaluation for appearance, strand quality, mouthfeel, and overall quality (Prabhasankar et al., 2009). In terms of texture, contradictory results were also observed in bread, with a variable degree of firmness. The color was affected by the incorporation of seaweed depending on the seaweed´s color and the level of its incorporation. In bread with 4% of protein hydrolysate from *Palmaria palmata*, a darker coloration was observed due to the greater availability of substrates for the Maillard reaction

Seaweed has a strong and characteristic aroma and flavor, which are not always highly acceptable to consumers. The flavor is attributed to specific amino acids, especially glutamate (glutamic acid), also guanylate, and inosinate, which provide an "umami" taste. Mannitol has been found in seaweed, over 30% in *Laminaria* and *Saccharina* species. Glutamate and mannitol combined can open a different flavor profile depending on the proportion of each component (Rioux et al., 2017). The seaweed´s aroma is derived from dimethyl sulfide [(CH_3) 2S], with notes of iodine, bromine, and other volatile compounds (Mouritsen et al., 2018). In this sense, extruded maize products added with 3.5% *Porphyra columbina*, results in the sensory evaluation kept the smell, taste, and crunchiness within the acceptable limit. Similar results were observed in bread with 4% *Ascophyllum nodosum* (Hall et al., 2012) and bread with 0.5, 1, and 2% extract *Sargassum fulvellum* (Kim et al., 2011). In contrast, the addition of 4% hydrolyzate protein from *Palmaria palmata* in bread, altered the taste for the control sample, producing a bitter taste, caused by the peptides of the seaweed protein hydrolysate (Fitzgerald et al., 2014).

The studies presented evaluate sensory acceptability using a hedonic scale. In most cases, this is reduced by incorporating seaweed, and the most affected attributes are flavor, taste, aroma, and aftertaste; as presented in Figure 1, which represents the variation of acceptability (measured on a 9-point hedonic scale) to the concentration of added seaweed, for different sensory attributes (Hall et al., 2012).

In some cases, the addition of seaweed causes increased acceptability, when concentrations are low, such as 0.5 to 1% in bread (Kim et al., 2011; Lee et al., 2010), 5% in biscuits (Pratiwi & Titik, 2019). In the case of the cake, the incorporation of algae greatly affects the acceptability of the product. Figure 2 presents the variation of overall acceptability (in percentage) versus the addition of seaweed in bread, biscuit, and cake. It is observed that adding 2% of seaweed in bread harms it a lot, and in cake over 4% addition is negative. However, in biscuits, the effect is milder.

5.- **Conclusion**

According to the studies reviewed, it is concluded that the incorporation of seaweed in

enriches them from a nutritional point of view, in texture properties and could prolong the useful life of these.

Seaweed has functional properties such as the ability to: water retention, oil retention, and swelling that allow them to interact with the other ingredients of the formulation, forming stable mixtures or emulsions.

Adding seaweeds into the bakery and farinaceous products decreases lightness, redness, and yellowness color parameters.

The incorporation of seaweeds in bakery and farinaceous products affects the sensory characteristics, mainly flavor. Considering the sensory characteristics, seaweed's level incorporation should be a maximum of 10% for noodles, 4% for bread, 5% for biscuits, 5% for cookies, less than 10% for cake, and 3.55% in extruded maize. Higher concentrations can negatively affect the sensory characteristics of the products.

It is possible to continue investigating the use of seaweed as an ingredient in bakery and farinaceous foods, varying types of seaweed, seaweed mixtures, concentrations, and other ingredients to improve sensory acceptability.

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Table 1. Incorporation of seaweed in bakery and farinaceous foods - Effect on nutrients, bioactive compounds, antioxidant capacity, and satiety

Food	**Seaweed - Addition%**	**Nutritional effects**	**Ref.**
Noodles	Brown *Undaria pinnatifida*. Wakame 5–10-20-30%	↑: moisture, fat, ash, raw fiber ($p<0.05$) ↑ proteins (18.7% to 21.7 % in 0 and 30% seaweed addition) ($p<0.05$) ↓ Carbohydrates Fucoxanthin: varies from n.d. to 0.23 mg/g in 0 and 30% seaweed addition respectively. Fucosterol: varies from n.d. to 2.55 mg/g in in 0 and 30% seaweed addition. ↑ Total phenolic content in raw and cooked simples ($p<0.05$) ↑ in vitro antioxidant activities (DPPH-radical scavenging, superoxide radical scavenging, metal chelating, reducing power) in raw and cooked simples ($p<0.05$) ratio ω-6/ω-3= 15.2 to 3.4 in 0 and 10% seaweed addition	Prabhasankar et al., 2009

Pasta	Green-blue *Spirulina platensis* 5 -10-20%	↑ Protein content ($p<0.05$) Raw pasta: varies from 12.9 to 23.5 g/100g d.s. in in 0 and 20% seaweed addition. Cooked pasta: varies from 13.1 to 23.7 g/100g d.s. in in 0 and 20% seaweed addition. ↑ Protein availability: from 10.3 to 12.9 g/100g d.s. in in 0 and 20% seaweed addition. ↑ Total phenolic content, antioxidant capacity (TEAC), (FRAP) ($p<0.05$) ↓ Total starch, soluble starch, resistant starch ($p<0.05$)	Rodriguez de Marco et al., 2014
Instant fried noodles	Red *Eucheuma cottonii* 5%	↑ Protein varies from 9.34 to 16.92 g/100g in 0 and 5% seaweed addition ↑ fat, ash, dietary fibre. ↓ carbohydrate, moisture moisture.	Kumoro et al., 2016
Bread	Brown *Ascophyllum nodosum* 4%	↑ Satiety No differences in relation to glycemic control and postprandial cholesterol	Hall et al., 2012

Breadsticks	Brown *Himanthalia elongata* 3-5-10-15-17%	↑: dietary fiber, total polyphenols, antioxidant capacity (DPPH). (greater effect at higher algae concentration).	Cox and Abu-Ghannam, 2013
Cake	Red *Eucheuma cottonii* 5-10-15-20%	↑ ash ($p<0.05$) Total dietary fibre is 1.5, 3.0, 5.4, 6.7 and 8.1% in 0, 5, 10, 15 and 20% addition seaweed ($p<0.05$) The increase in soluble fibre is greater than in insoluble fibre.	Huang & Yang, 2019.
Biscuits	Green *Ulva Lactuca* 30-40-50-60%	↓ essential amino acid content with increasing concentration of seaweed	Jenifer & Kanjana, 2018

Cookies	Brown *B. bifurcata.* *F. vesiculosus* *A. nodosum* 3-6-9%	↑ total polyphenolic content, proportional to the concentration of seaweed. The increase is: *A. nodosum* > *B. bifurcata* > *F. vesiculosus* Before baking: significant differences ($p<0.05$) After baking: significant differences ($p<0.05$) only with 6 and 9% ↑ antioxidant properties of doughs (before baking).	Arufe et al., 2019
Extruded maize.	Red *Porphyra columbina* 3.5%	↑: protein, ash, dietary fiber (total and insoluble), ($p<0.05$) ↑ lipid (n.s.) ↓ soluble dietary fiber, moisture, energy. Amino acids: ↑ aspartic acid, serine, alanine, methionine, proline ($p<0.05$) Minerals: ↑ Na, P, Ca, Mg. ($p<0.05$) Dializability %: ↑ Mg. ↓ Ca, Fe and Zn. ↑ total polyphenols, antioxidant capacity (TEAC and DPPH).	Cian et al., 2014

↑: increase; ↓: decrease.

n.d.: not detected

d.s.: dry sample

n.s.: no significant

Table 2. Sensory and physical properties

Food	Thermal treatment	Seaweed	Concentration	Technological and sensory effects	Ref.
Noodles	Extrusion: 75°C x 3 hr. Cooking: 100°C x 8 min	Brown *Undaria pinnatifida*. Wakame	5% 10% 20% 30%	↑: cooking loss ($p < 0.05$) ↓: Sensory quality (appearance, strand quality, mouth feel, overall quality) ($p < 0.05$).	Prabhasankar et al., 2009
Pasta	Dehydration	Green-blue *Spirulina platensis*	5% 10% 20%	↑: swelling index, water absorption, stickiness in 20% addition ($p < 0.05$). ↑ cohesiveness in 10% and 20% addition ($p < 0.05$). Springiness remains without significant differences ↑ cooking loss, fracturability, firmness, chewiness for all concentrations	Rodriguez de Marco et al., 2014

Noodles		Green *Monostroma nitidum*	4% 6% 8%	↑: cooking yields ($p < 0.05$)	Chang and Wu, 2008
Noodles		Green *Monostroma nitidum*	3% 6%	↑: cooking performance, softness and fluffiness ($p < 0.05$) ↓: tension and extensibility	Chang et al., 2011
Instant fried noodles	Frying in palm olein at 150-160°C x 1 min	Red *Eucheuma cottonii*	5%	↓ water absorption ($p < 0.05$) ↑ cooking loss (no significant) ↓ swelling index (n.s.) ↓ sensory evaluation of texture, aroma, flavour ↑ sensory evaluation of colour	Kumoro et al., 2016
Bread	---	Brown *Ascophyllum nodosum*	1% 2% 3% 4%	Sensory evaluation: appearance, aroma, texture (n.s.) ↓: flavor, aftertaste, total acceptability ($p < 0.05$)	Hall et al., 2012

Bread	---	Brown *Sargassum fulvellum* extracts	0.5% 1% 2%	↑: shelf life (less humidity). Color: ↓ L, ↓ a, ↑ b ($p < 0.05$) ↓: hardness, shear force, gumminess, chewiness, resilience ($p < 0.05$) Springiness: no difference Sensory evaluation: ↓: color-inside, color-outside, inner shape, smell (n.s.). Taste ↑ in 0.5%, 1% addition; ↓ in 2% addition (n.s.) Texture ↑ (n.s.)	Kim et al., 2011
Bread	---	Brown *Myagropsis myagroides* Ethanol extracts	0.5% 1% 2%	↓ viable cell and mold count. ↑ protection factor (n.s.) pH: ↑ 0 day (n.s.); ↓ 3 - 6 day ($p < 0.05$) Color: ↓ L ($p < 0.05$); ↓ a and ↑ b ($p < 0.05$) Sensory evaluation: ↓: color-outside (n.s. in 0.5%, 1%. $p < 0.05$ in 2%)	Lee et al., 2010

				↑: color-inside (n.s.), inner shape (n.s.), texture ($p<0.05$) No difference: smell, taste.	
Bread		Red *Kappaphycus alvarezii*	2 – 8%	↑ water absorption of the dough. ↓ stickiness properties of the dough. ↑ firmness of the bread	Mamat et al., 2014
Bread	220°C x 20 min Oven cooking	Red *Palmaria palmata* protein hydrolyzate	4%	↓: specific volume ($p < 0.001$); crust L (n.s.); crumb L*/b* ($p<0.01$) Digital image analysis: ↓ number of cells, wall thickness. ↑ cell volume. (n.s.) ↑ crumb hardness (n.s.) ↓ crumb cohesiveness, crumb springiness ($p<0.05$), moisture % (n.s.) Sensory evaluation: ↓ appearance, texture, flavor, and general acceptability.	Fitzgerald et al., 2014

Bread		Red *Kappaphycus alvarezii*	0,5% 1% 1,5%	↓: specific volume. By including 1 g of fresh garlic, they improve the sensory characteristics.	Komatsuzaki et al., 2019
Breadsticks	40°C x 24 h Dehydration 210°C x 20 min Oven cooking	Brown *Himanthalia elongata*	3% 5% 10% 15% 17%	↑: darker bread Sensory evaluation: ↓ aroma, appearance, texture, taste, overall acceptability.	Cox and Abu-Ghannam, 2013
Cake	180°C x 30 min Oven cooking	Red *Eucheuma cottonii*	5% 10% 15% 20%	Batters: ↑ specific gravity, consistency coefficient ($p<0.05$) ↓ flow behavior index ($p<0.05$). Cakes: ↑ weight; ↓ volume ($p<0.05$) ↓ L*; ↑ a* and b* ($p<0.05$)	Huang & Yang, 2019.

				↑ hardness, chewiness. (n.s. in 5% and 10%; p<0.05 in 15% and 20%) Springiness, cohesiveness, resilience: does not vary ↓ Sensory evaluation: appearance, colour, odour, flavour, overall accepotability. 5% and 10% substitution were acceptable to the consumers.	
Cake		Red *Eucheuma cottonii*	2.5% 5% 7%	↓ color, flavour, taste with 5 and 7% of seaweed. ↓ texture with 7% of seaweed.	Ningsih & Anggraeni, 2021.
Cake	160°C x 35 min Oven cooking	Red *Gracilaria sp*	2.5% 5% 7.5%	L* is higher in 2.5 and 5% than 0 and 7.5% (p<0.05) ↓ a* ↓ b* in 5 and 7.5% (p<0.05) Sensory evaluation: appearance, flavor, taste, texture, total ↑ sensory acceptability in 2.5% addition. ↓ sensory acceptability in 5 and 7.5% addition.	Chiciani & Titik, 2019.

Biscuit	150°C x 15 min Oven cooking	Red *Eucheuma cottonii*	5% 10% 15%	Sensory evaluation: appearance, flavor, taste, texture, total ↑ sensory acceptability in 5% addition (all attributes). ↓ sensory acceptability in 10 and 15% addition (all attributes). ↓ L*, b* ($p<0.05$) ↑ a* ($p<0.05$)	Pratiwi & Titik, 2019
Biscuits	170-180°C x 20-25 min Direct fired oven	Green *Ulva lactuca*	30% 40% 50% 60%	↓: sensory attributes (appearance, colour, aroma, texture, taste, flavour, overall).	Jenifer & Kanjana, 2018
Cookies	160°C x 10 min Oven cooking	Brown *Sargassum fuilvellum* *Hizikia fusiforme*	5%	Dough pH ↓ with *E. linza, C. fragile, H. fusiforme.* Dough density ↑ ↑ cookie moisture, height, spread factor, breaking stress, distance ($p<0.05$) ↓: baking loss (n.s.), diameter ($p<0.05$)	Oh et al., 2020

		Green *Enteromorpha linza* *Codium fragile*		Colour: ↓ L*, b*. Sensory evaluation: ↓: color, flavor, hardness, fishy, overall (p<0.05).	
Extruded maize.	175°C	Red *Porphyra columbina*	3.5%	Color: ↓ L* , a*, b* (p<0.05) ↑: Greens tones. Sensorially without differences: smell, taste, and crispness. ↑ flavor, adherence	Cian et al., 2014

↑: increase; ↓: decrease.

n.s.: not significant difference to 5%

Figure 1. Effect of seaweed concentration on sensory attributes of bread containing *Ascophyllum nodosum*

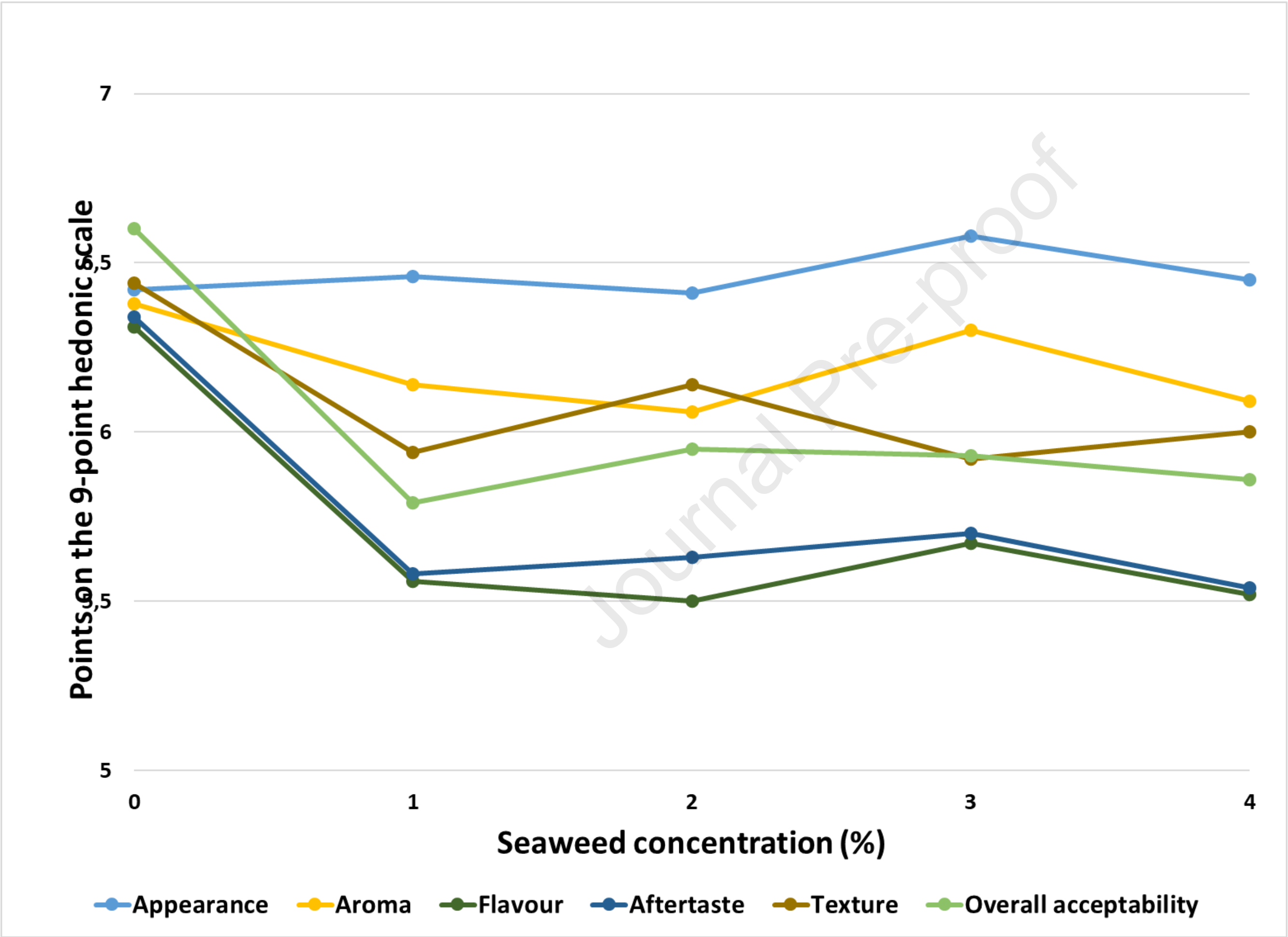
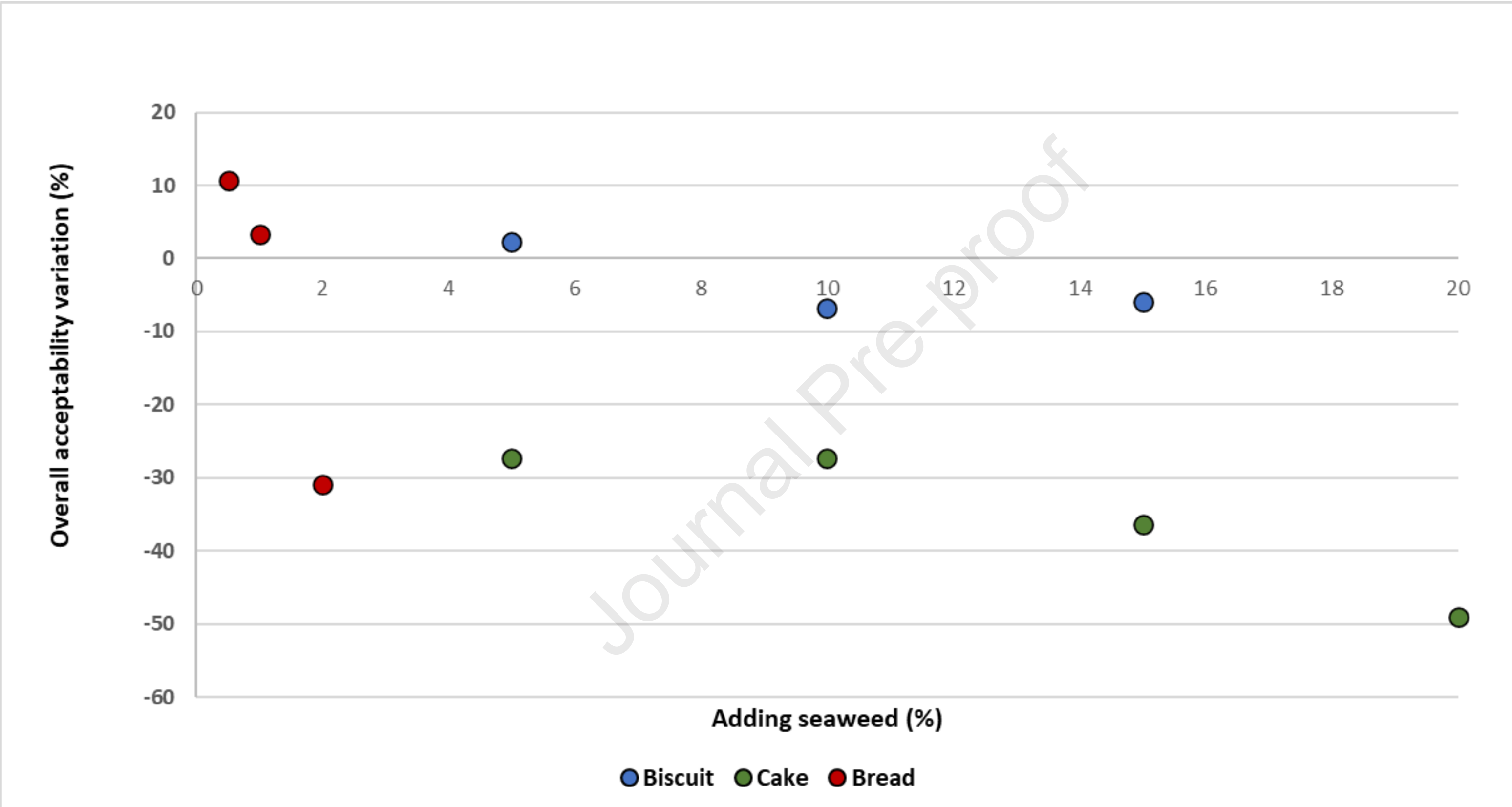


Figure 2. Effect of seaweed concentration on variation of acceptability for biscuit, cake and bread



IMPLICATIONS FOR GASTRONOMY

Bakery and farinaceous foods such as bread, cookies, noodles, and others are widely consumed by the western population of all ages. They are enjoyed for breakfast, lunch, dinner and as snacks between meals. These foods provide mainly carbohydrates, which contribute to weight gain. If ingredients with a high content of dietary fiber, such as seaweed, are incorporated, bakery foods will be healthier; in addition, seaweed provide bioactive compounds of great interest to health.

The researchs revieweded in the present study reports on the benefits of incorporating seaweed, such as increased shelf life, increased softness and fluffiness in noodles, increased protein content, dietary fiber, minerals, polyphenols in the foods, and produce greater satiety when eating food. However, sensory quality was affected in some products. Seaweed have a characteristic flavor and aroma, so their incorporation cannot be in very high concentrations, however, using additives and other ingredients the sensory quality of the products can be improved.

This study serves as the basis for future research in the culinary area, such as incorporation in other farinaceous and bakery products such as pizza doughs, other doughs, incorporation of different types of algae, combination of algae, different concentrations, incorporation of other ingredients or additives to improve sensory quality, etc.

CONFLICTS OF INTEREST

The authors are university academics, dedicated to teaching research.

The authors declare that they have no conflicts of interest.