Seaweed-Enriched Cookies: A Nutritional and Functional Perspective

Abstract:

Seaweed and seaweed-based products are gaining global attention due to their health-benefiting properties. For the last three decades, seaweeds have been used as nutraceutical food, as they provide dietary benefits. It offers a rich source of nutrients, including minerals, vitamins, and fibre, while also possessing unique functional properties such as water and oil absorption. Due to their functional characteristics, the incorporation of seaweed into bakery products is becoming a novel strategy to develop nutritionally enriched value-added products. Cookie is one of the popular bakery products, with high consumer preference. The incorporation of seaweed offers a promising avenue for enhancing the nutritional value of cookies. It improves the physical, sensorial, and nutritional properties of cookies. This review seeks to explore the significance of seaweed consumption, the development of value-added cookies incorporating seaweed, and the impact of seaweed on the overall quality of cookies.

(***Keywords:*** *Seaweed, Cookies, Bakery products, Nutritionally enriched cookies*)

Introduction

Seaweeds are marine, multicellular eukaryotes characterized by their photosynthetic nature, chlorophyll content, and distribution spanning from the intertidal zone to depths of approximately 300 meters (Kumar *et al.* 2018). It represents a valuable renewable resource within the marine ecosystem (Rao and Mantri, 2006). This macroalgae is classified into three primary groups: Rhodophyta (red algae), Phaeophyta (brown algae), and Chlorophyta (green algae). Globally, approximately 10,300 species of seaweed have been documented, with a total annual production of 38 million tonnes as of 2022 (Chakraborty *et al.* 2022; FAO, 2024).

The Indian coastline is characterized by a rich diversity of seaweed populations. In 2021, India's seaweed production reached 34,000 tonnes (CMFRI, 2022). The seaweed flora of India exhibits a high degree of diversity, thriving in various coastal habitats such as rocky beaches, mudflats, estuaries, coral reefs, and lagoons. Approximately 770 seaweed species have been identified along the Indian coastline, comprising 420 red algae, 184 green algae, and 166 brown algae (Rao and Mantri, 2006; Joshi *et al.* 2015).

The occurrence of seaweeds is recorded abundantly along the coastal regions of Tamil Nadu, Gujarat, Andhra Pradesh, Orissa, West Bengal, Kerala, Maharashtra, Lakshadweep and Andaman Nicobar Islands. Along the Maharashtra (Mumbai, Ratnagiri), Goa, Karnataka (Karwar), Kerala (Vizhinjam, Varkala), and Orissa (Chilika) rich seaweed beds are reported (Rao *et al.* 2018).

Traditionally seaweed has been used as food, folk remedies, dyes and fertilizers. For the last three decades, seaweeds have been used as nutraceuticals or functional foods, as they give dietary benefits (Shannon and Abu-Ghannam, 2019). Seaweeds are recognized as a significant source of nutrients and possess numerous health-promoting properties. Maybe due to their nutritional benefits, seaweeds have been regarded as a food of gods and kings (Escrig and Goni, 1999). At present, over 56 countries produce seaweed worldwide with 97% of the total production comes from aquaculture. Out of the total world's seaweed production, only 30-38% of seaweed is utilized for human consumption (FAO, 2024).

Though the Indian coastline is an abundant source of seaweed having a potential of 9.7 million tonnes with 342 production sites (CMFRI, 2022), it has very low share in global production. The commercial exploitation of seaweeds in India began in 1966, primarily for the production of agar and alginate (Escrig and Goni, 1999). While phycocolloids (agar, alginate, and carrageenan) have been widely utilized in various industries, the use of seaweeds as a direct food source remains limited within the country.

Bakery products are the oldest and traditional stable diet of many countries globally with huge contribution in the food processing industry. It comprises the third largest segment of the packaged and convenience food (ready-to-eat and ready-to-cook products) market (Kumar *et al.* 2020; Kulshreshta *et al.* 2023). The bakery made products contributes 1.14% to the country's gross domestic product and engages more than 1.6 million people directly and 120 million indirectly on its supply chains in India (GOI, 2018).

Cookie is one of the popular bakery products and can be defined as a chemically leavened product which is baked in an oven for usually a short time span. The nutrient availability, inexpensiveness, palatability, compactness and convenience makes cookies an ideal bakery product. In comparison with other baked products like bread, cakes, etc. cookies have low moisture content which makes it free from microbial spoilage and have a longer shelf life (Dinnah *et al.* 2020).

The integration of seaweeds into bakery products has emerged as a focal point of research given their established nutritional and functional attributes. Studies have consistently demonstrated that the addition of seaweeds can substantially enhance the phytochemical content, antioxidant activity, and dietary fiber in bakery products. Moreover, seaweed incorporation can positively influence the nutritional, textural, and sensory properties of a diverse range of bakery items (Cox and Abu-Ghannam, 2013; Roohinejad *et al.* 2017).

The primary objective of this study is to conduct a comprehensive review of the nutritional significance and health-promoting attributes of seaweeds, their integration into cookie formulations, and the subsequent impact of seaweed incorporation on the nutritional, physical, and sensory properties of cookies.

Benefits of seaweed consumption on human health:

Seaweed, a nutrient-dense marine plant, offers a wealth of health benefits due to its unique composition. It is a great source of vitamins (A, B1, B2, B9, B12, C, D, E, and K), essential minerals (calcium, iron, iodine, magnesium, phosphorus, potassium, zinc, copper, manganese, selenium, and fluoride), dietary fibres, protein, essential amino acids and polyphenols (Lomartire *et al.* 2021).

Rajapakse and Kim (2011) reviewed the effects of seaweed consumption on human digestive health. They stated that the presence of dietary fibres in seaweed helps in reducing the risk of colorectal cancer and suppressing gastrointestinal inflammation. According to global epidemiological studies, countries where seaweeds are regularly consumed have significantly fewer instances of obesity and dietary-related disease (Shannon and Abu-Ghannam, 2019).

Also, some health-promoting properties are shown by seaweeds, i.e., anticancer, antiviral, antifungal, antidiabetic, antihypertensive, immunomodulatory, anticoagulant, anti-inflammatory, antioxidant, UV protective, neuroprotective, dyslipidaemia, bone-health, heart-health and mental-health benefits (Kumar *et al.* 2018).

Challenges associated with seaweed bakery product

Though incorporation of seaweed into bakery products can be a novel and health-beneficial approach in food industry, some challenges are associated with the production and sale of the bakery products. These challenges are mentioned below:

Availability of seaweed: Seaweed is not as widely available as other ingredients, which can make it difficult to find and obtain.

Strong flavour: Seaweed has a strong flavor that can be overpowering for some consumers. This can be a challenge when creating seaweed bakery products that are palatable to a wide range of people.

Regulatory challenges: There may be regulatory challenges associated with the production and sale of seaweed bakery products, such as food safety regulations and labeling requirements.

Incorporation of seaweeds in bakery products:

Seaweeds have gained attention for their potential use in bakery products due to their nutritional and functional properties. Studies have shown that incorporating seaweed powder, typically from species like *Kappaphycus alvarezii*, *Ulva 4ornema*, and *Gracilaria corticata*, can enhance the nutritional profile of bakery products. Seaweeds increase dietary fibre, protein, polyphenols, and antioxidant capacity, making products like bread, cakes, cookies, and buns more nutritionally robust.

For instance, Mamat *et al.* (2014, 2016) demonstrated that incorporating red seaweed powder improves water absorption in dough and increases moisture and fibre content in buns, though higher seaweed levels may decrease protein content. Sensory evaluations suggest that products with moderate seaweed incorporation are more acceptable, as higher concentrations may negatively impact flavour. Turuk and Banerjee (2023) found that bakery products containing *G. corticata* seaweed tend to have better nutritional outcomes than those with *U. 4ornema*, further supporting the idea that seaweed-enriched bakery items are healthier alternatives to traditional ones. Overall, seaweeds offer a promising avenue for creating nutritionally enhanced bakery products with added health benefits.

Quitral *et al.* (2021) emphasized that finely ground seaweed can form stable emulsions in dough, enhancing the functional qualities of bakery products. However, the optimal incorporation levels are critical, as excessive seaweed can impair sensory qualities, particularly flavour. Commonly recommended levels are around 4–10% for various bakery products.

Seaweed enriched cookies:

The incorporation of seaweed into cookies has been explored as a means of enhancing their nutritional, functional, and sensory properties. Various types of seaweed, including

Caulerpa racemosa, *Bifurcaria 5ornemann*, *Ulva 5ornema*, and others, have shown potential to improve the quality of baked products by increasing protein, fibre, and antioxidant content, while also affecting dough and texture properties. Numerous studies have demonstrated the effectiveness of different seaweed species in cookie formulations, contributing to the development of healthier and more functional food products.

Incorporation of seaweed in cookies

- **Sea Grapes (*Caulerpa racemosa*)**: Kumar *et al.* (2018) prepared semi-sweet biscuits supplemented with seaweed (*Caulerpa racemosa*) powder under the institutional project of ICAR-CIFT to assess its impact on physical, functional, and antioxidant properties. The inclusion of *C. racemosa* significantly increased water and oil absorption capacities, as well as solvent retention capacities of the flour mix. Protein, fiber, phenolic content, and antioxidant activities were increased with the increasing level of seaweed powder. Hence, the incorporation of seaweed powder showed a positive effect on the overall quality of the cookies.
- ***Bifurcaria bifurcate*:** Arufe *et al.* (2019) incorporated *Bifurcaria sornemann* seaweed powder into chestnut flour dough at 3%, 6%, and 9%. The seaweed addition enhanced dough stability and reduced its mechanical weakening. Gelatinized starch, used during mixing, improved dough recovery properties.
- ***Ulva 5ornema***: Jenifer and Kanjana (2019) used *Ulva 5ornema* in seaweed-based biscuits to improve the anthropometric profile of malnourished children. Various formulations of *Ulva 5ornema* were tested, and the biscuits were supplemented to malnourished children for 2 months, resulting in improved nutritional status.
- **Korean Coastal Seaweeds**: Oh *et al.* (2020) studied the impact of seaweeds native to the Korean coast on cookies. They prepared seaweed flour using four different species, including *Sargassum fulvellum, Enteromorpha linza, Codium fragile* and *Hizikia fusiforme.* In the preparation of cookies, 5% wheat flour was replaced with seaweed flour. The study found that seaweed incorporation improved solvent retention capacities, and cookies with *Hizikia fusiforme* were highly preferred in sensory evaluations.
- ***Gelidium spinosum***: Poulose *et al.* (2021) used *Gelidium spinosum* seaweed to extract stigmasterol, which was nano-emulsified and incorporated into biscuit dough. The

resulting biscuits had higher nutritional content, reduced hardness, and were sensorily acceptable.

- ***Ulva intestinalis***: Mohibullah *et al.* (2023) prepared seaweed cookies with the inclusion of different percentages of powdered and fragmented forms of *Ulva intestinalis*. They found that all the studied parameters of cookies including moisture content, spread factor, baking loss, pH, cookie density, colour, texture properties and volatile basic nitrogen were found within acceptable limits. They mentioned that cookies prepared with the inclusion of 2.5% powdered and 5% fragmented forms of seaweed can be considered healthy nutritional diets due to their high sensorial and nutritional properties.
- ***Portieria hornemannii***: Sivaraman *et al.* (2023) combined *Portieria hornemannii* seaweed with Tilapia fish protein concentrate (FPC) in cookie formulations. Cookies with 2.5% seaweed and 5% FPC showed high overall acceptability, enhanced nutritional value, and sensory attributes.

Effect of seaweeds on physical, sensorial, and nutritional quality of cookies:

Sensorial properties:

Results of the sensory evaluation of seaweed cookies vary based on the species and concentration of incorporated seaweed.

Kumar *et al.* (2018) substituted refined wheat flour with seaweed powder at different levels, including 0, 1, 5, and 10%. A significant decrease in sensory attributes was observed at higher levels (5 and 10%) of seaweed incorporation as compared to 1% of seaweed powder-supplemented biscuits.

Similarly, Mohibbullah *et al.* (2023) prepared seaweed cookies with the inclusion of 1, 2.5, 5 and 10% of powdered and fragmented forms of *Ulva intestinalis*. Seaweed inclusion levels of 1-5% were acceptable to sensory panellists, with 2.5% powdered and 5% fragmented forms of seaweed concentrations selected for further studies due to their favourable properties.

Oh *et al.* (2020) conducted the sensory evaluation of cookies prepared by replacing 5% wheat flour with seaweed flour made up of four different seaweed species viz., *Sargassum fulvellum*, *Enteromorpha linza*, *Codium fragile* and *Hizikia fusiforme*. In sensory

evaluation they found that, cookies with the incorporation of 5% seaweed (*Hizikia fusiforme*) powder by replacing wheat flour were greatly preferred with the highest sensory scores.

Effect of seaweed (*Portieria hornemannii*) powder and tilapia fish protein concentrate (FPC) on cookies were studied by Sivaraman *et al.* (2023). Cookies were prepared using 5% FPC and different percentages of seaweed viz., 2.5%, 5%, 7.5% and 10%. Sensory evaluation showed that cookies prepared with 2.5% seaweed and 5% FPC obtained the highest overall acceptability.

Overall, cookies with lower seaweed content tend to score higher in sensory evaluation. The incorporation of high concentrations of seaweed into cookies can lead to a decrease in sensory scores due to the introduction of strong, characteristic marine flavours and textures. Seaweed's unique sensory attributes, including astringency and bitterness, can negatively impact the overall acceptability of the final product (Cassani *et al.* 2020). Quitral *et al.* (2021) mentioned that the incorporation of seaweed in cookies should be less than 5%.

Physical properties:

Seaweed incorporation generally enhances the water and oil absorption capacities of doughs (Kumar *et al*. 2018), increases dough stability (Arufe *et al.* 2019), and improves baking properties. For example, gelatinized starch mixed with seaweed improves dough recovery properties, and seaweed can increase the spread factor and reduce the baking loss (Sivaraman *et al.* 2023). Mohibullah *et al.* (2023) found that cookies with *Ulva intestinalis* had acceptable physicochemical characteristics, including moisture content, spread factor, texture, and baking loss. Arufe *et al.* (2019) noted that the hardness of cookies increased with more than 3% seaweed.

Nutritional quality:

Seaweed-enhanced cookies tend to have improved nutritional profiles, including higher protein, fiber, phenolic content, and antioxidant activities (Kumar *et al.* 2018; Arufe *et al.* 2019). The addition of seaweeds also increases dietary fiber (Sivaraman *et al*. 2023) and essential nutrients such as ash and lipid content (Mohibullah *et al.* 2023). Seaweed-based biscuits supplemented to malnourished children showed significant improvements in anthropometric measures (Jenifer and Kanjana, 2019). Additionally, Poulose *et al.* (2021) demonstrated that seaweed biscuits containing stigmasterol had anti-diabetic properties, making them a promising functional food for diabetic patients.

Table 1. *Summary of work conducted on seaweed incorporated cookies and their characteristics*

A. Incorporation of different levels seaweed in cookies by different authors, used baking temperature and time					
Authors	**Kumar *et al.* (2018)**	**Arufe *et al.* (2019)**	**Oh *et al.* (2020)**	**Poulose et al. (2021)**	**Mohibbullah et al. (2023)**
Species of seaweed	*Caulerpa racemosa*	*Bifurcaria bifurcate*	*Hizikia fusiforme*	*Gelidium spinosum*	*Ulva intestinalis*
Level of seaweed incorporation	0,1, 5 and 10%	3, 6 and 9%	5%	Extract of seaweed: Stigmasterol was incorporated	2.5% powdered and 5% fragmented form
Baking temperature (°C)	190	180	160	160	180
Baking time (minutes)	14-15	20	10	20 ± 5	12
B. Effect of seaweed incorporation on proximate composition of cookies when compared with control cookies used					
Moisture (%)	Not significantly changed (from 4.19 to 4.03)	--	--	Decreased	Decreased (from 3.57 to 3.02)
Protein (%)	Increased (from 7.69 to 9.01)	--	--	Increased	Increased (from 6.88 to 11.78)
Fat (%)	Not significantly changed (from 14.48 to 13.77)	--	--	Increased	Not significantly changed (from 25.39 to 25.04)
Ash (%)	Increased (from 1.28 to 2.23)	--	--	--	Increased (from 1.45 to 4.81)
Carbohydrate (%)	Decreased (from 71.7 to 68.75%)	--	--	Decreased	--

C. Effect of seaweed incorporation on physical parameters of cookies when compared with control cookies used						
Hardness (N)		Decreased (from 17.57 to 11.29)	Increased (from 0.82 to 1.01)	--	Decreased (from 12.80 to 8.87)	Not significantly changed (from 2.3 to 2.82 kg/cm^2)
Colour	**L* (lightness/ darkness)**	Decreased (from 66.6 to 41.1)	--	Decreased (from 70.69 to 45.18)	Decreased (44.68)	Increased
	a* (redness/ greenness)	Decreased (from 10.6 to 3.26)	--	Increased (from -3.73 to -0.08)	Not significantly changed	Decreased
	b* (yellowness/ blueness)	Decreased (from 32.0 to 22.9)	--	Decreased (from 20.85 to 11.76)	Increased	Decreased
Water absorption capacity		Increased (from 1.24 to 1.52)	Increased (in dough)	Increased (in dough)	--	--
Oil absorption capacity		Increased (from 0.87 to 1.11)	--	--	--	--
Solvent retention capacity	**Lactic acid**	Increased (from 1.52 to 1.56)	--	Decreased (from 110.3 to 91.20%)	--	--
	Na_2CO_3	Increased (from 1.37 to 1.59)	--	Decreased (from 80.62 to 78.11%)	--	--
	Sucrose	Increased (from 1.98 to 2.38)	--	Increased (from 122.4 to 124.7%)	--	--

Conclusion:

Seaweed is a nutrient-dense food source that exhibits several health-promoting properties. The incorporation of seaweed in cookies is an innovative approach for developing a nutritionally enhanced, value-added product. The inclusion of seaweed significantly enhances the nutritional, functional, and sensory properties of cookies. Seaweed can be incorporated into cookies in various forms, including fragmented, powdered, and extracted. Cookies with higher seaweed concentrations may exhibit lower sensory scores due to the introduction of strong marine flavours and textures. This suggests that a moderate level of seaweed incorporation, typically less than 5%, is optimal for maintaining sensory acceptability. Though the higher level of seaweed inclusion negatively affects the sensory properties, the incorporation of a proper amount of seaweed in cookies can enhance dough properties, improve baking outcomes, and significantly elevate the nutritional profile of cookies. These findings highlight the potential of seaweed as a functional ingredient for developing healthier and more nutritious baked goods.

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Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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1. NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

2.

3.

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