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# *Nurturing Natures Harvest: Biofortifying Seaweed for Health and Nutrition*

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## ABSTRACT

The global population is projected to reach 10 billion by 2050, necessitating sustainable food sources to combat malnutrition. Seaweed, with its rich nutritional content and rapid growth, has emerged as a promising biofortification option. This paper examines the current status of seaweed resources, nutritional composition, and strategies for biofortification, focusing on India's coastal waters. Seaweed biofortification offers a viable solution to global food security challenges by providing essential nutrients and bioactive compounds. However, challenges such as nutrient variability, environmental risks, regulatory concerns, and consumer acceptance must be addressed for successful implementation. Collaborative efforts among scientists, policymakers, and the food industry are essential for the widespread adoption of biofortified seaweed, aligning with Sustainable Development Goals (SDGs) related to hunger eradication, sustainable aquaculture, climate action, and marine ecosystem preservation. Integration of biofortified seaweed into national fisheries programs, such as India's Pradhan Mantri Matsya Sampada Yojana (PMMSY), further strengthens sustainable development objectives. Continued investment, innovation, and inclusive governance frameworks are essential for realizing the transformative potential of biofortified seaweed in advancing nutrition security and fostering resilient food systems on a global scale.

## KEYWORDS

Seaweed, Biofortification, Sustainable Development Goals (SDG), Nutrition

## Introduction:

According to the UN Population Division, the global population is growing at a rate of approximately 0.88% per year and is projected to reach 10 billion by 2050. As the need for sustainable food sources becomes more urgent, seaweed, a diverse marine algae that grows ten times faster than terrestrial plants, has gained attention for its abundant nutritional content. Biofortification, the process of increasing nutrient levels in crops, is seen as a solution to combat malnutrition, particularly in developing countries (Saltzman *et al*., 2013). It is a long-term strategy for developing sustainable nutrition. Seaweed biofortification offers a viable approach to contribute to global food security by providing essential nutrients and bioactive compounds. According to Bouis & Saltzman (2017), over 20 million people in developing countries who live in farm households are currently growing and consuming biofortified crops. However, while biofortification has proven to be cost-effective, scaling it up requires significant institutional support. Achieving the goal of providing nutrition security to one billion people by 2030 demands strong leadership and sustained support for the biofortification approach (Nestel *et al*.,2006).

## Current status of seaweed:

India's coastal waters harbour a remarkable array of seaweeds, boasting an impressive 844 species that collectively contribute to a standing stock estimated at around 58,715 tonnes (wet weight) (FAO 2018). Many types of green, red, and brown seaweeds that are grown for human consumption are considered edible seaweeds. According to department of fisheries, India is home to a diverse array of algae species, encompassing 434 variations of Red Algae, 194 species of Brown Algae, and 216 types of Green Algae. Some notable Red Algae species, such as Gelidiella acerosa, Gracilaria edulis, G. crassa, G. foliifera, and G. verrucosa, are deliberately cultivated for the purpose of Agar production. The most widely cultivated genus of red seaweed, known as Porphyra/Pyropia or commonly referred to as "Nori" and "Purple Laver," can also be found in India (Islam, 2023). Additionally, Brown Algae varieties such as Sargassum spp., Turbinaria spp., and Cystoseira trinodis play a crucial role in the production of alginates and liquid seaweed fertilizer. "Japanese kombu" (*Saccharina japonica*) and "Wakame" (*Undaria pinnafitida*) are the two brown seaweeds that are most commonly grown. The green seaweeds *Eucheuma* spp. and *Kappaphycus* spp. are the most often grown.

Despite the abundance of seaweed resources, the current quantity is insufficient to meet the demands of the Indian seaweed industries. Tamil Nadu, Gujarat, Lakshadweep, and the Andaman & Nicobar Islands are home to extensive seaweed beds. Seaweeds play a significant role in various industries, providing essential sources of agar, agarose, and carrageenan. These industries have applications in diverse sectors such as laboratories, pharmaceuticals, cosmetics, cardboard, paper, paint, and processed foods. In India, there are 46 seaweed-based industries, with 21 focused on Agar production and 25 on Alginate production. However, these industries often struggle to operate at their full capacity due to challenges in maintaining a consistent supply of raw materials.

## Nutritional Composition of Seaweed:

Diverse varieties of seaweed have unique nutritional profiles. The brown seaweeds (Phaeophyceae) that include kombu and kelp are high in fucoxanthin, alginate, and iodine. Protein, vitamins, and minerals like calcium and magnesium are abundant in red seaweeds (Rhodophyta) including dulse and nori. Vitamins A, C, and K, as well as antioxidants and dietary fibres, are rich in green seaweeds (Chlorophyta), which include sea lettuce and sea grapes (Kasimala *et al*., 2015)

## Biofortification:

Biofortification encompasses the deliberate enhancement of the nutrient content within food crops through conventional plant breeding, improved agronomic practices, and contemporary biotechnological methods. According to Bouis & Saltzman (2017 this approach stands as a viable and cost-effective strategy for enhancing global nutrition. However, the ambitious objective of reaching one billion individuals by 2030 necessitates robust institutional leadership and support. Plant breeding for biofortification of staple foods is technically feasible and cost-effective in controlling micronutrient deficiencies. However, it is crucial to gain acceptance and increase uptake by both producers and consumers (Nestel *et al.,* 2006; Meenakshi *et al*., 2010; Garg *et al*., 2010). Despite the potential of biofortified staple foods to augment the dietary intake of essential nutrients, realizing success mandates heightened public investment and active community involvement (Johns & Eyzaguirre, 2007).

## Strategies for Seaweed Biofortification:

**Selective Breeding:** Crops are currently undergoing breeding processes aimed at elevating micronutrient levels, employing both conventional and transgenic methods. Numerous conventional varieties have already been released, including some biofortified staple crops that have undergone significant improved variety of Orange sweet potato (OSP) by the International Potato Centre (CIP) and National Agriculture Research and Extension System (NARES), maize breeding led by International Maize and Wheat Improvement Centre (CIMMYT) and International Institute of Tropical Agriculture (IITA) employed selective breeding techniques to develop strains of increase Provitamin A (Saltzman et al.,2013). Several modified biotechnology advancements along with conventional and transgenic breeding have been used to increase micronutrient such as vitamins, carotenoid etc. The advantage of selective breeding is cost-effective. Seaweed with enhanced nutritional profiles, this method harnesses the selective of natural genetic variations with desirable traits, such as increased protein content or higher levels of specific vitamins and for propagation.

**Agronomic approach:** Agronomic practices involve altering growth conditions, such as nutrient availability, light exposure, and temperature, can influence the biochemical composition of seaweed. Seaweeds, being photosynthetic, require ample sunlight for growth, minimal water flow with mild wave activity, shallow water depth and temperature ranging between 20°C to 30°C. Controlled cultivation environments aim to optimize nutrient uptake and synthesis in seaweed. Along with the above parameters adding fertilizers and organic matter can improve nutrient availability.

**Genetic Modification:** Artificial selection techniques can efficiently produce genetically modified seaweeds for human consumption and raw material production (Charrier *et al*.,2015). While this technique is less commonly employed due to regulatory constraints and public perception, genetic modification techniques allow for the targeted enhancement of specific nutritional traits in seaweed. Scientists can introduce or modify genes responsible for nutrient synthesis to amplify their presence in seaweed species.

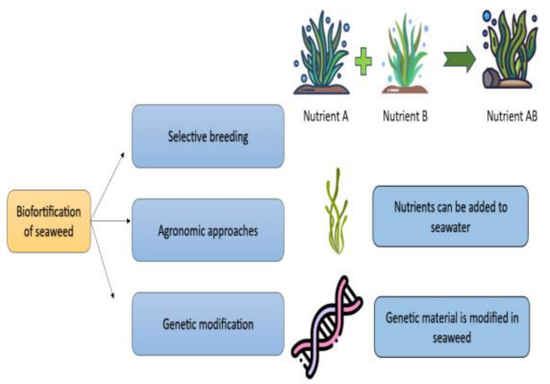


**Fig:1 Strategies for Seaweed Biofortification**

## Benefits

Seaweed biofortification has a number of possible benefits.

**Packed with Nutrients:** Biofortified seaweed is a natural source of numerous essential nutrients, such as minerals (such as calcium, iron, and iodine), vitamins (including A, C, and K), and trace elements (like zinc and selenium).

These nutrients are necessary for maintaining overall health as well as other bodily functions.

**Iodine Content:** seaweed is one of the best natural sources of iodine, a necessary mineral for the thyroid gland's proper function. An appropriate iodine intake is necessary for the production of thyroid hormone, which regulates metabolism and fosters growth and development.

**Potential Anti-Inflammatory Effects:** Seaweed contains bioactive substances with anti-inflammatory qualities, including polyphenols, flavonoids, and polysaccharides. These characteristics of seaweed may aid in reducing the body's inflammation.

**Potential Cardiovascular Benefits:** By assisting in the regulation of blood pressure and cholesterol levels, certain components of seaweed, such as peptides and fibres, may promote cardiovascular health.

## Challenges and Considerations:

Successful implementation of seaweed biofortification faces several challenges that necessitate addressing. Firstly, nutrient variability among seaweed species presents a significant obstacle. Factors such as species type, growth conditions, seasonal changes, and harvesting methods contribute to substantial differences in nutrient content, complicating efforts to standardize nutrient levels. Secondly, the absorption and accumulation of nutrients, including heavy metals and contaminants, by seaweed from its marine environment pose risks to biofortification efforts. Balancing the increase of essential nutrients with the prevention of harmful substance accumulation is imperative. Thirdly, cultivating seaweed in controlled environments or aquaculture settings is intricate due to factors such as temperature, water quality, light exposure, and nutrient availability, all of which require meticulous management for optimal growth and nutrient uptake. Moreover, regulatory and safety concerns must be addressed to ensure compliance with food safety standards and regulations, including monitoring and mitigating potential risks such as toxin presence or excess heavy metals. Furthermore, scaling up biofortification processes to meet commercial demands while maintaining cost-effectiveness is a significant challenge, requiring efficient and economically viable techniques. Finally, consumer acceptance and perception play a crucial role in the adoption of biofortified seaweed. Educating the public about the nutritional benefits while addressing concerns about safety and taste are essential factors influencing consumer acceptance. Thus, a comprehensive approach addressing these challenges is vital for the successful implementation of seaweed biofortification initiatives.

## Future Outlook:

Collaborative efforts among scientists, policymakers, and the food industry are indispensable for the advancement and widespread adoption of biofortified seaweed. Continuous interdisciplinary research, leveraging cutting-edge technological innovations such as genetically modification, agronomic approach, and adeptly addressing pertinent regulatory concerns are pivotal elements that will pave the way for the seamless integration of biofortified seaweed into the intricate fabric of global food systems. Establishing a robust framework for knowledge exchange, fostering synergies between stakeholders, and implementing evidence-based strategies will be imperative in ensuring the sustainable and scalable incorporation of this nutritional powerhouse into mainstream dietary practices.

## Conclusion:

Biofortification of seaweed is a promising strategy that aligns with the Sustainable Development Goals (SDGs). It has the potential to improve global nutrition, address climate change, promote sustainable ecosystems, and establish sustainable food sources. The use of biofortified seaweed supports SDG 2, which aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture. Additionally, this strategy contributes to SDG 13 - Climate Action and

SDG 14 - Life Below Water by cultivating seaweed that enhances climate resilience and utilizes marine resources (Guinea *et al*., 2020). In India, the Pradhan Mantri Matsya Sampada Yojana (PMMSY) scheme has invested Rs. 20050 crores in the overall fisheries sector development, which aligns with SDG 2 and SDG 14. A significant investment of Rs. 640 crores have been allotted for seaweed cultivation and marketing as part of this centrally sponsored scheme. Including biofortified seaweed in the PMMSY scheme would further strengthen sustainable development objectives by integrating diverse and nutritious marine resources into the national fisheries program. Ongoing research, technological advancements, collaboration with regulatory frameworks, and consumer education are crucial for the successful implementation of biofortified seaweed as a key component in achieving multiple SDGs.

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