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Blue gold: How seaweed farming in modern agriculture supports a sustainable planet

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Abstract

Seaweeds are macroscopic marine algae with significant ecological, nutritional, and economic importance. Rich in bioactive compounds, they offer various health benefits and are classified into brown, red, and green algae. They play key roles in marine ecosystems by supporting food webs, improving water quality, and aiding carbon sequestration. Besides, seaweeds are widely used as food, fertilizers, animal feed, and industrial raw materials, and their cultivation provides a sustainable livelihood for coastal communities. However, challenges such as limited technical knowledge, environmental factors, and heavy metal accumulation restrict large-scale adoption in India. Government initiatives like PMMSY and support from research institutions aim to promote this sector. Overall, seaweed cultivation holds strong potential for sustainable development, environmental conservation, and economic growth.

Keywords: Bioactive compounds, carbon sequestration, coastal livelihoods, marine algae, marine ecosystem, seaweeds, sustainable agriculture

Introduction:

The name ‘seaweed’ itself explains that the weeds which are from the sea. Basically, seaweed is a broad group of macroscopic, multicellular marine algae grown in oceans, seas, or coastal waters (Joshi *et* al., 2015). The marine ecosystem depends on seaweeds a lot. Seaweeds do not have any universally accepted definition, but seaweeds generally live in the ocean and are macroscopic, i.e., visible to the naked eye.

Seaweeds are known for their significant number of antioxidants and other nutrients and bioactive compounds, which have novel medicinal properties, a high proportion of carbohydrates and proteins, and a low amount of fats (Khalid *et* al., 2018). Besides, it also has

vitamins, minerals, and pigments. According to the properties of seaweeds, it is reported that it has anti-oxidant, anti-viral, anti-inflammatory, anti- tumour, anti-cancer, and immunomodulatory effects (Sharanagat *et* al., 2019).

Humans have been cultivating seaweeds for centuries, valuing them for their many practical uses. Nowadays, seaweed farming has expanded worldwide and is increasingly known for its important agricultural activity (Zhang *et* al., 2022). Seaweeds are not only used as food, but also it is used as industrial raw materials, cattle feed, and natural fertilizer. In addition to their economic importance, seaweeds play a vital role in maintaining healthy marine ecosystems

There are three groups of seaweeds based on their pigment. These are green algae (Chlorophyceae), brown algae (Phaeophyceae), and red algae (Rhodophyceae) (Neto & Pinto, 2019). The appearance of seaweeds looks like non-woody terrestrial plants.

These macroscopic marine algae are found in clear water to ensure adequate sunlight penetration. The optimum temperature for the growth of seaweeds is 26 to 30 degrees Celsius, and the salinity range must be above 30 ppt. Maintaining nutrient flow and oxygen supply, it requires mild water currents.

Types of seaweeds:

There are mainly three types of seaweeds. These are-

1. Brown algae
2. Red algae and
3. Green algae.

1. **Brown algae:** These brown algae are multicellular seaweeds belonging to the class of Phaeophyceae, mainly found in marine circumstances (Abdel-Kareem & ElSaied, 2022). They are most abundant in temperate and polar regions, especially in colder water, and often grow along rocky seashores. This type of algae plays a vital role by serving as food and habitat for other marine life. Large species, like *Macrocystis,* form underwater kelp forests that support high biodiversity. *Sargassum* creates floating mats that provide habitat in tropical waters. Some brown algae, particularly kelps, are also used by humans as food
2. **Red algae:** Red seaweeds are primarily characterized by the red colour due to the presence of phycoerythrin. The red seaweeds are predominantly found in marine water, attached to the rocks and other shore plants, and extending to the deeper water. They are rare in freshwater. It has significant ecological, culinary, and industrial importance. Some red algae are valuable as food, like laver, dulse, etc. Irish moss (*Chondrus*) is widely used

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as gelatine substitute in foods and personal care products. *Corallina*, a special type of red seaweeds forms coral reefs and islands along with corals. Additionally, *Agar*, which is used as a culture medium for bacteria and fungi, is derived from Gracilaria and Gelidium (Yadav *et* al., 2023).

3. **Green algae:** Chlorophyll-containing green algae are autotrophic in nature and include both microscopic and macroscopic forms, consisting of chlorophyta and carophyta (Xu *et* al., 2023). The green seaweeds are nutritionally rich and widely used in food, cosmetics, and fertilizer. Ecologically green seaweeds play an important role on aquatic ecosystem by producing oxygen and serving as a food source for many marine creatures.

Significance of seaweed cultivation:

Seaweeds play a vital role in maintaining marine ecology. Seaweeds can generate up to 50% of the Earth's oxygen. Carbon sequestration, one of the most important ecological functions of seaweeds. By absorbing carbon dioxide, seaweeds help to maintain the atmospheric carbon level. They also help to reduce ocean acidification by lowering carbon dioxide concentrations in the marine water (Gao *et* al., 2022).

Seaweeds are normally primary producers. So, they can create the base of the coastal food web by converting sunlight into energy.

Besides, seaweeds act as a habitat-forming species by providing shelter, breeding grounds, and feeding areas foe fishes and other marine creatures. Making dense seaweed beds and kelp forests helps to enhance biodiversity.

Additionally, seaweeds improve the water quality by absorbing excess nutrients. For this reason, it helps to reduce nutrient pollution and prevent harmful algal blooms. By reducing wave energy and preventing shoreline erosion, they can help to stabilize coastal surroundings. Due to their eco-friendly nature and nutrient-enriched profile, seaweeds act as a promising resource for the future of natural farming. As seaweeds contain essential macro and micro nutrients, plant growth regulators, and bio-active compounds, they support healthy plant growth without harming the environment.

It can also be used as a bio-stimulus, fertilizers, and a soil conditioner by improving soil health, increasing stress tolerance. Instead, the use of chemical fertilizers and seaweeds acts as a promising solution for natural and sustainable farming.

Besides all of these, seaweeds can be utilized for medicinal purposes. Having the anti-oxidant capabilities, it helps to lower the risk of oxidative stress. Due to their anti-inflammatory properties, seaweeds inhibit chronic inflammation. In addition to all of these,

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seaweeds have cardio-protective effects by lowering blood cholesterol levels, improving lipid metabolism, and reducing the risk of cardiovascular diseases.

Along with these, seaweeds have been consumed as a food for centuries, especially in the coastal regions of Asia. As it is highly nutritious, rich in vitamins, minerals, dietary fibre, and protein, edible seaweeds like nori, kelp, wakame, and kombu can be taken in soups, salads, snacks, and seasonings. It can be consumed in various form including fresh, dried, powered or as extracts. That is why seaweeds are gradually recognized as a healthy food source for the future.

Seaweeds can be utilized as packaging materials by being made into a rigid plastic alternative. Seaweed pulp can be used for making paper.

Seaweeds cultivation is an important source of income, especially for the coastal people. By using low investment, minimal inputs, and simple farming methods, it is accessible to small-scale farmers and Self-Help Groups. As seaweeds grow quickly and can be harvested multiple times in a year, provide a regular and reliable income. In addition to direct income, seaweed cultivation gives employment opportunities in processing, marketing, and value addition.

Apart from these, seaweeds are processed for bio-ethanol and bio-gas as a renewable fuel alternative (Mohapatra & Padhi, 2019). The compounds of seaweeds act as a binding agent in toothpaste, jelly, and organic cosmetics. Seaweed cultivation helps to support the marine food chain and reduce eutrophication in the ocean.

Challenges for seaweed cultivation:

In India, seaweed cultivation faces some challenges. Limited awareness and technical knowledge among coastal communities restrict the large-scale adoption. The availability of good quality seed materials and standardised cultivation techniques are still inadequate in some areas.

Environmental factors like seasonal changes, cyclones, rough sea conditions, and water pollution affect the growth and yield of seaweed.

Post-harvest challenges like a lack of proper drying, storage, processing facilities, and market linkages can reduce the profitability of farming communities.

Limited access to credit, insurance, and governmental support may create further constraints.

Along with these, labour shortage, disease threats, and harmful algal blooms are the other challenges in seaweed cultivation.

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A significant concern is the accumulation of heavy metals such as arsenic and cadmium in seaweeds. If the seaweeds are not properly treated, these metals can enter the soil as fertilizer, be taken up by the crops, and ultimately pose a risk to soil health, food safety, and human health.

Governmental initiatives:

Pradhan Mantri Matsya Sampada Yojana (PMMSY) sanctioned 195 crores rupees for sea weed cultivation sector.

A multipurpose seaweed park was approved in Tamil Nadu with 127 crores rupees in support.

NITI Aayog has proposed a comprehensive strategy to extend seaweed farming in India by expanding crop and infrastructure insurance schemes, forming steering communities to support the farming sector, and establishing technical panels for seed and planting materials imports.

The Ministry of Fisheries has released guidelines to allow the import of disease-free, high quality of sea weed germplasm with quarantine and biosecurity measures.

The ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), Mandapam Regional Centre, has been created as a national hub for seaweeds research and development. Lakshadweep has also been identified as a key seaweed farming cluster to boost production and livelihoods.

Conclusion:

In conclusion, it must be said that seaweeds are a versatile marine resource-supporting bio-diversity, supplying nutritional food and industrial raw materials, and helping mitigate climate change through carbon uptake. Seaweed farming offers low-input livelihood and circular economy opportunities, but it sustainably requires improved seed technology, processing infrastructure, making links, and supportive policies. With responsible cultivation, research, and value-chain development, seaweed can play a vital role in resilient coastal ecosystems and sustainable food and economic systems.

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