

SEAWEED FARMING: A SUSTAINABLE SOLUTION FOR FOOD AND CLIMATE MITIGATION

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Introduction

India's seaweed production positioned at approximately 72,385 tonnes (wet weight) as of 2023. Seaweed farming, also known as seaweed aquaculture, is the practice of intentional cultivation of seaweed for nutritional and commercial purpose. Seaweed referred as a diverse group of macroscopic - multicellular marine algae found in oceans, seas and coastal waters. Contrary to land plants, seaweeds are devoid of true roots, stems and leaves but perform photosynthesis efficiently through thallus. Based on their pigmentation and biochemical properties, they exist in various colors and sizes which are classified into three main groups:

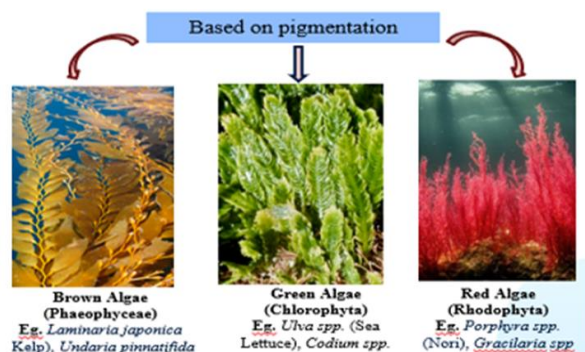


Fig. 1. Types of seaweed based on pigments

Seaweed farming is a low-input activity since seaweeds do not require freshwater, fertilizers, or pesticides. The seaweed farming process includes collecting and producing seedlings (spores or cuttings), planting them on structures and

harvesting the mature biomass some months. It is also considered as one of the most sustainable forms of aquaculture because of its minimal ecological footprint and high productivity.

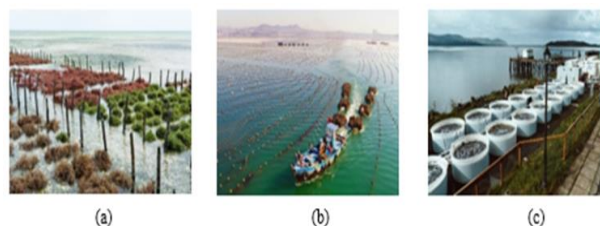
Types of Seaweed Farming

This farming categorized into three methods which is specific to local ecological and logistical conditions:

1. Nearshore Farming: This is the most frequently used method. Seaweed is tied to ropes, nets, or bamboo rafts anchored in shallow coastal zones. It is economically accessible and ideal for community-based farming.

2. Offshore Farming: It takes assistance of floating longline systems; this method is suited to deeper waters and higher wave energy environments. High volume production of species like kelp (*Saccharina*) is the characteristic feature of this farming.

3. Land-Based Systems: It occurs in controlled aquaculture tanks which are often are part of Integrated Multi-Trophic Aquaculture (IMTA). In this, seaweed acts as a bioremediator which helps in absorbing excess nutrients from finfish or shrimp tanks.



Types of seaweed farming: a) Nearshore farming b) offshore farming c) Land based farming

GLOBAL SEAWEED PRODUCTION



Fig. 2. Map of global seaweed production (Source: FAO Fisheries and Aquaculture)

These regions have developed advanced seaweed aquaculture systems supported by favorable coastal environments, large-scale infrastructure, and robust domestic and export

markets. A darker blue color and larger circle indicate a higher production value, with the highest recorded reaching approximately 9.7 million USD or more.

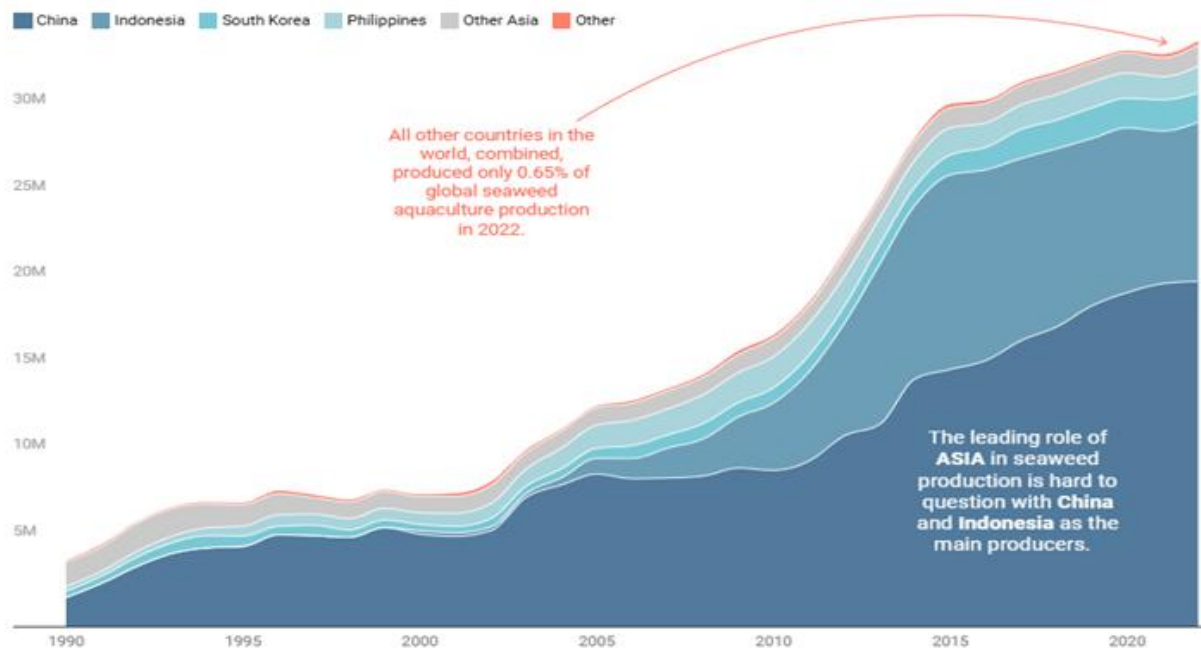


Fig. 3. Global production volumes 1990-2022 by country Source: FAO Fisheries and Aquaculture

The commercial seaweed market was estimated at USD 60.5 billion in 2023 and is speculated to grow at a 7.8% CAGR through 2032, driven by rising demand across industries. Asia Pacific commercial seaweed market size of

Asia Pacific is expected to surpass USD 75.7 billion by the end of 2032. Government policies in countries, such as China and Indonesia are giving boost to seaweed aquaculture through creating a market for personal care products containing

seaweed that are valued for their natural rejuvenating properties in the region for providing a sustainable and reliable domestic supply.

India's status on seaweed farming

In India (as of 2023), production of seaweed is positioned at approx. 72,385 tonnes (wet weight). The country has an immense potential in this farming sector with a capacity to produce near to 9.7 million tonnes annually (PIB, 2025). The Indian seaweed industry was valued at ₹200 crore in 2022 and is assumed to grow significantly, reaching a market value of ₹3,277 crore within the next ten years. Recognizing this potential, the Indian government has taken active steps to boost the sector. Through the Pradhan Mantri Matsya Sampada Yojana (PMMSY), an allocation of ₹640 crore has been made to support and facilitate seaweed farming initiatives by coastal population. One of the primary goals of this investment is to scale up national seaweed production to over 1.12 million tonnes by 2025, fostering both economic development and sustainable aquaculture practices.

Nutritional facts of seaweed

Seaweeds (red, brown, and green varieties) are very rich in primary and secondary metabolites that contribute immensely to human health.

These bioactive compounds give a multitude of health benefits. People recognize seaweed extracts for their neuroprotective properties which reduces the risk of neurodegenerative diseases and support brain health. They are full of anti-microbial, anti-fungal and anti-coagulant properties that combat infections and improves heart health. In addition to that, seaweeds have anti-carcinogenic and anti-inflammatory properties too which claimed to play a significant role in preventing chronic diseases and manages inflammation (Baghel et al., 2023). The industries use seaweeds for making nutraceuticals products,

cosmeceuticals products, pharmaceuticals, and functional foods products which has a wide range of benefits, therapeutic and commercial potential.

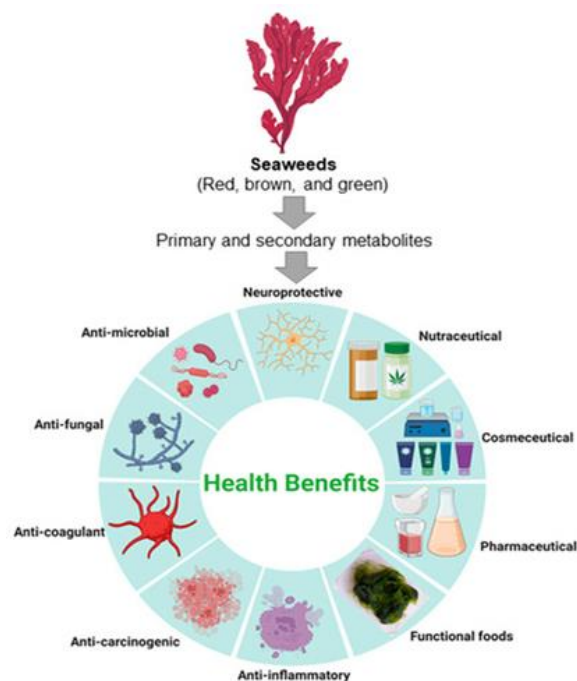


Fig. 4. Nutritional properties of seaweed

(Baghel et al., 2023)

Seaweed in human diets

Seaweed can be made a part of human diet in 3 ways:

- ♣ **For direct Consumption:** Seaweeds are commonly used and consumed in salads, soups, and snacks. For example, nori (*Porphyra* spp.) is used in making sushi while wakame (*Undaria pinnatifida*) is added to miso soup.
- ♣ **As food Additives:** Polysaccharides derived from seaweed for example, agar, carrageenan and alginate function as thickeners and stabilizers in food products such as dairy items and desserts.
- ♣ **As functional Foods:** Benefits of seaweeds are included to nutraceuticals and supplements because of its bioactive compounds such as polyphenols and omega-3 fatty acids which offer numerous health benefits like anti-inflammatory and antioxidant effects.

Seaweed as animal feed

Seaweed is emerging as a sustainable and nutritious addition to animal feed, offering benefits for both livestock performance and environmental impact. It is full of essential nutrients like amino acids, vitamins and minerals that sustains animal health and enhanced milk production (Beneitez, 2022). Although, some species like the red seaweed *Asparagopsis*

taxiformis can even cut methane emissions from ruminants by more than 80% when added in small quantities i.e., approximately 0.2% of dry matter intake, according to studies from CSIRO and UC Davis. Seaweed has natural prebiotic characteristics that may help the body absorb nutrients better and its usage reduces reliance on conventional feed ingredients that has higher environmental costs.

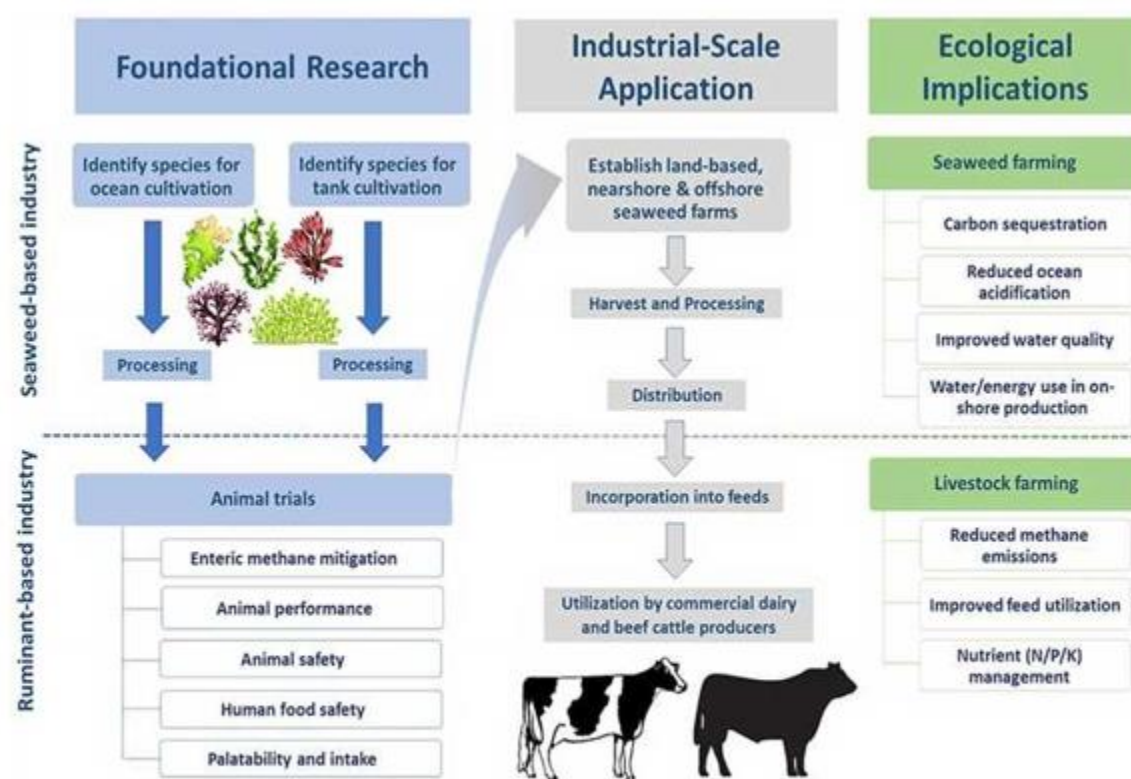


Fig.5. Seaweed incorporation into the livestock feed
(Beneitez, 2022)

Seaweed as biofuel

Seaweed is widely popular as a probable resource for biofuel production because of its colossal advantages. Seaweed stands out as a promising material for biofuel because of its unique characteristics. Some species grow outstandingly fast up to 60 centimeters a day making it possible to harvest them frequently and in large quantities.

It is also packed with carbohydrates which includes laminarin, mannitol and alginate that might be transformed into bioethanol or biogas via fermentation or anaerobic digestion (Baghel, 2023). A further advantage is that seaweed contains very little lignin unlike terrestrial plants making it far simpler and less energy-intensive to process into fuel.

Seaweed as a natural fertilizer

Seaweed has an inherent to be used as natural fertilizer because of important nutrients and natural compounds present in it which improve soil quality and make crops perform better. Contrary to synthetic fertilizers has only few nutrients such as nitrogen, phosphorus or potassium to provide, fertilizers made from seaweed provides a much wider variety of elements including magnesium, zinc, iodine and potassium. Plant growth hormones for example, cytokinins and auxins in seaweed also help roots grow well and give resistance to multiple types of stress. Numerous studies have also shown that

making the use of seaweed extracts help seeds germinate faster, increase the amount of chlorophyll in the leaves and also enhance the total yield of crops like tomatoes, wheat and potatoes. For example, a study published in *Scientia Horticulturae* in 2017 elucidated that tomato plants treated with seaweed extract produced 20 to 35 percent more fruit compared to untreated plants. Seaweed is also helpful in keeping soil healthy because it supports the growth of beneficial microbes and helps the soil hold more water, which means farmers can use less irrigation and fewer chemical fertilizers (Prasedya et al., 2023).

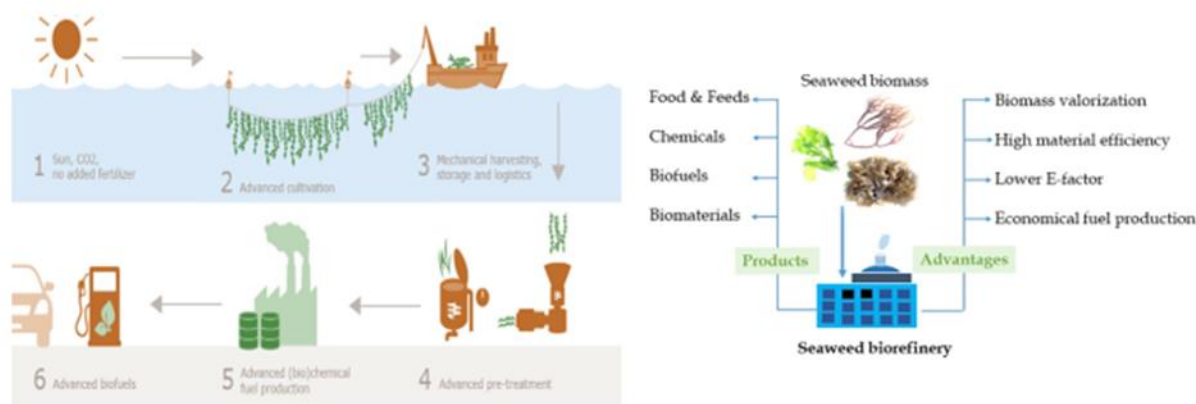


Fig.6. Biofuel production from seaweed
(Baghel, 2023)

Limitations of seaweed farming

Although seaweed farming demonstrates great potential for sustainable food production and climate change mitigation, it is not devoid of environmental and logistical challenges. Several key concerns must be addressed to ensure that seaweed aquaculture is both ecologically responsible and economically viable.

1. Environmental Impact Variability: The effects of seaweed farming on environment is widely based on the scale, species, and location of the farming operation. Farming operations may disrupt local marine ecosystems by altering natural light penetration, changing current patterns, or providing new substrates that

influence native species behavior, if practiced on the large scale. Cultivation of denser seaweed has a significant effect on water chemistry which makes it difficult in maintaining balance in the surrounding habitats (Lan et al., 2024).

2. Site-Specific Requirements: Seaweed farming is inherently dependent on specific environmental conditions. Optimal water temperature, salinity, nutrient concentrations, and light availability are major parameters for healthy seaweed growth. These requirements narrow down and restrict suitable farm sites to specific coastal zones. In addition to that, seasonal changes and regional variability can affect yield, making location selection and site

management critical components of farm success (Tasnim et al., 2024).

3. Climate Change Effects: Seaweed cultivation provides various tools to combat climate change like carbon sequestration and nutrient absorption. It also presents risks to the farms themselves. Ocean warming reduces growth rates of seaweeds.

4. Post-Harvest Handling Challenges: Seaweed is highly perishable and degrades quickly if not

handled properly (Azwar et al., 2024). This necessitates rapid drying, refrigeration and processing to sustain quality and prevent spoilage especially in coastal areas.

5. Potential for Invasive Species: The alien species introduction or selectively bred seaweed species can present a threat to local marine ecosystems that may outcompete native flora (Martinez et al., 2024).

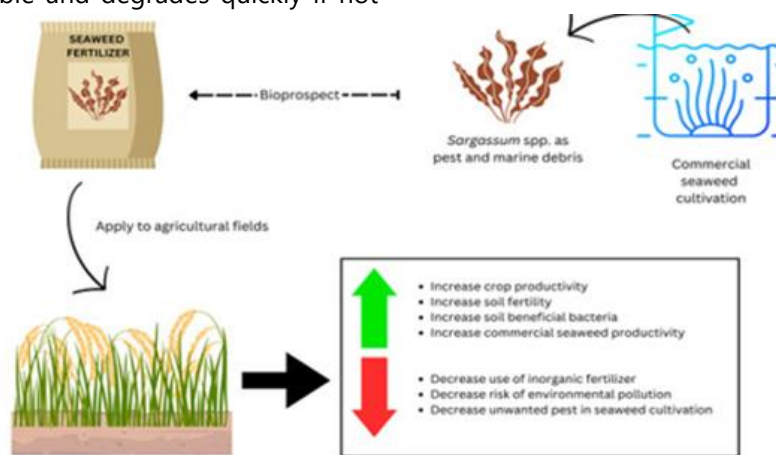


Fig.7. Illustration of sustainable potential of seaweed fertilizer in agricultural crop systems.
(Prasedya et al., 2023)

Conclusion

Seaweed farming is a sustainable practice for providing nutrient rich functional food, creating environment friendly product and sustaining marine biodiversity through habitat provision and ecosystem support. As being nature-based solution, it plays an important role in climate change mitigation by capturing atmospheric carbon dioxide, thereby reducing greenhouse gas concentrations, lowering ocean acidification, and enhancing the resilience of coastal ecosystems.

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