International Journal of Advanced Biochemistry Research 2026; 10(1): 33-54

International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2026; 10(1): 33-54
www.biochemjournal.com
Received: 10-10-2025
Accepted: 13-11-2025

Vishal K Solanki
Senior Research Fellow (SRF), Ph.D. (Aquaculture), Fisheries Research Station, Kamdhenu University, Okha, Gujarat, India

Nilesh H Joshi
Associate Professor & Head, Fisheries Research Station, Kamdhenu University, Okha, Gujarat, India

Anjali R Baraiya
M.F.Sc. (Fish Processing Technology), College of Fisheries Science, Kamdhenu University, Veraval, Gujarat, India.

Corresponding Author:
Vishal K Solanki
Senior Research Fellow (SRF), Ph.D. (Aquaculture), Fisheries Research Station, Kamdhenu University, Okha, Gujarat, India

A review on status of global and Indian seaweed farming: Past and present scenario

Vishal K Solanki, Nilesh H Joshi and Anjali R Baraiya

DOI: https://www.doi.org/10.33545/26174693.2026.v10.i1a.6864

Abstract
The seaweed aquaculture has become the highest growing sector of global aquaculture, which presents a sustainable route to fulfilling the increasing resource demands whilst alleviating the strain on terrestrial agriculture and marine life. The review is based on synthesizing world and national data on seaweed production, trade and policies based on international agencies such as FAO, UNCTAD, and the World Bank and national sources such as ICAR-CMFRI and the Department of Fisheries, which refer to the last 20 years (2000-2022). The world seaweed harvested in the year 2021 was 35.2 million tons, of which more than 98 percent was produced in Asian countries, mainly China and Indonesia. The global market is estimated at about USD 17 billion in 2021 but will rise to close to USD 85 billion by 2026 because of the increasing demand of renewable, bio-based and environmentally sustainable products. Although this has been increased, commercial cultivation continues to be highly concentrated with eight dominant species predominantly *Laminaria japonica* and *Eucheuma spp.* producing 93.7% volume of the world output.
The seaweed segment is now broadening out of the food and hydrocolloid market into high-value market segments like bio-stimulants, methane-reducing livestock feed additives, bioplastics, alternative protein, nutraceuticals and biofuels. Bio-stimulants made out of seaweed in and of themselves form USD 1 billion market, which is expected to grow to USD 1.87 billion by year 2030. Nevertheless, international and national development is progressively limited by climate-related stressors such as increasing sea temperatures, reduced growing season, and diminished output.
The sector has been underutilized in India, even though it has 7517km of coastline, 844 reported seaweed species, and 317 of the possible sites of cultivation occupying 23970 hectares. The national production dropped by almost 20 percent, 34,922 tons in 2009 and 27,937 tons in 2018, as a result of mass mortality of farmed *Kappaphycus alvarezii* after 2013 and overharvesting of natural agarophyte stocks. As a result, processing industries in the country are running at a low level and India is mainly importing sodium alginate mainly the Chinese industries which are also supplying about 92 percent of the total imports. To curb this situation, the Government of India has put in place ₹640 crore in the Pradhan Mantri Matsya Sampada Yojana (PMMSY) with a production goal of 1.12 million tons by 2025.
To reach this target, the development of large-scale mariculture as an alternative to the wild harvest and the financial assistance of research in the field of the diversification of their species and the creation of strains with high yields is mandatory. The fortification of the seaweed industry will not only increase industrial independence and livelihood in the coast but also lead directly to the UN Sustainable Development Goals via climate change and carbon capture, coastal cleanup and the larger-scale transformation of the sea. Seaweed farming can be described as a bio engine of the green economy, which can sustainably address the needs of the environment and the economy at the same time.

Keywords: Seaweed farming, global status, Indian seaweed sector, aquaculture, mariculture

1. Introduction
Aquaculture has emerged as an effective strategy for meeting increasing global resource needs while reducing pressure on natural ecosystems (Costello *et al.*, 2020; Eikeset *et al.*, 2018; Jacquet and Pauly, 2007) [7, 12, 23]. Within this sector, seaweed cultivation stands out as the most rapidly expanding form of aquaculture, owing to its capacity to address a wide range of global environmental and socioeconomic challenges (National Oceanic and Atmospheric Administration Fisheries, 2020) [39]. Notably, seaweed farming contributes directly to the achievement of several United Nations Sustainable Development Goals (SDGs) (Mustafa *et al.*, 2018) [38].

Seaweeds are utilized across diverse sectors, including human food, livestock and aquafeed, agriculture as fertilizers, and the pharmaceutical industry for bioactive compounds and peptides. In recent years, increasing emphasis has been placed on their role in climate change mitigation, particularly through applications such as biofuel production from biomass, mitigation of coastal pollution, and long-term carbon dioxide sequestration (Chen *et al*., 2015; Food and Agriculture Organization of the United Nations (FAO), 2022b; Kraan, 2013; Krause-Jensen and Duarte, 2016; Makkar *et al*., 2016; Skjermo *et al*., 2014) [6, 16, 29, 30, 32, 49].

Seaweed farming is predominantly practiced in East and Southeast Asia, where its use for dietary and medicinal purposes dates back more than 1,500 years. The development of large-scale commercial cultivation systems began during the mid-20th century in countries such as Korea, Japan, and China, resulting in substantial industry growth (Hwang *et al*., 2019) [22]. Despite this progress, non-Asian regions contributed less than 2% of total global farmed seaweed production in 2020 (Seaweed Insights, Global Production Overview, 2022) [46], indicating considerable untapped potential for expansion beyond Asia.

At present, seaweed aquaculture occupies only a negligible fraction of the global coastal ocean area approximately 0.004% as recorded in 2017 (Duarte *et al*., 2017) [11]. Achieving global food security and climate mitigation targets will require a significant increase in the marine area allocated to seaweed cultivation (World Bank Group, 2016) [59]. Such expansion must also account for the impacts of climate change, including alterations in seasonal growth patterns and competition with other ocean-based activities (Bricknell *et al*., 2021) [3].

2. The Lucrative Potential of the Global Seaweed Market

The global seaweed industry, estimated to be worth nearly USD 17 billion by UNCTAD (2023a) [55], offers significant growth potential extending well beyond its conventional uses. New and rapidly developing applications—including biostimulants, livestock feed, pet nutrition, and methane-mitigating feed additives are projected to collectively generate revenues of about USD 4.4 billion by 2030. In addition, medium-term opportunities in areas such as dietary supplements, alternative protein sources, advanced biomaterials, bioplastics, and sustainable textiles are expected to contribute up to USD 6 billion in market value (Global Seaweed New and Emerging Markets Report, 2023) [20]. These forecasts highlight the strong economic potential of the seaweed sector, particularly within innovation-driven and sustainability-oriented markets. The expansion of this industry is further supported by increasing consumer preference for environmentally friendly and natural products, reinforcing seaweed's role as a key component of the emerging green economy.

3. Present Global Status of Seaweed Production

Seaweed farming has experienced extraordinary growth over the past several decades, expanding nearly one thousand times since 1950 (Cai, 2021) [4-5]. By 2021, global farmed seaweed production had risen to 35.2 million tonnes in live weight (UNCTAD and FAO, 2022) [53]. Similarly, the Food and Agriculture Organization of the United Nations reported that worldwide algae production reached 36 million tonnes in wet weight during 2020 (FAO, 2022b) [16] (Figure 1). Further highlighting the sector's potential, a World Bank assessment indicates that ten emerging seaweed markets alone could generate economic value of up to USD 11.8 billion by 2030. Despite these encouraging projections, a substantial proportion of the industry's prospective value remains unrealized, suggesting considerable scope for expansion beyond existing applications (Global Seaweed New and Emerging Markets Report, 2023) [20].

Projections indicate that an annual growth rate of approximately 14% in seaweed cultivation could yield nearly 500 million tonnes of dry biomass by 2050, potentially contributing to a 10% rise in global food availability, improved income opportunities, and enhanced quality of life (Bjerregaard *et al*., 2016) [22]. In addition to its economic importance, seaweed farming offers significant environmental advantages, including carbon capture, enhancement of water quality, and the creation of marine habitats, positioning it as a cornerstone of sustainable ocean-based food systems. Continued technological innovation in cultivation techniques and post-harvest processing is expected to further enhance productivity and efficiency. Moreover, combining seaweed farming with complementary marine activities such as shellfish aquaculture can generate synergistic ecological and economic gains. As international initiatives to address climate change accelerate, the seaweed sector is increasingly recognized as a vital contributor to sustainable development pathways.

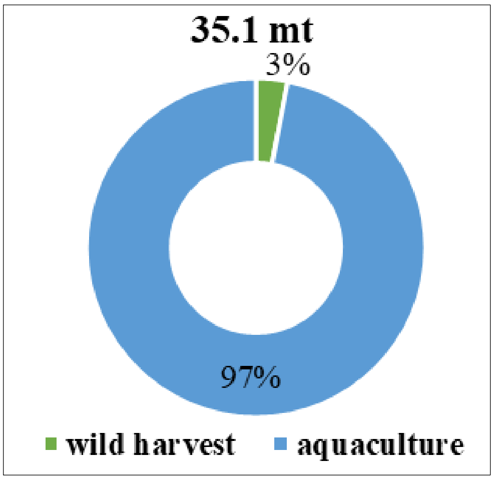

Fig 1: Global production of algae (Source: FAO 2022b) [16].

The Growth of the Global Seaweed Market

Between 2000 and 2021, the market value of the seaweed industry surged, more than tripling from $5 billion to $17 billion. According to UNCTAD (2024) [56], this trajectory is set to continue, with the market value projected to skyrocket seven-fold to $85 billion by 2026. This exponential growth underscores the immense potential and promising future of the seaweed industry on the global stage. As technological advancements and sustainability initiatives continue to drive innovation in seaweed cultivation and product development, the industry is poised for unprecedented expansion and economic prosperity.

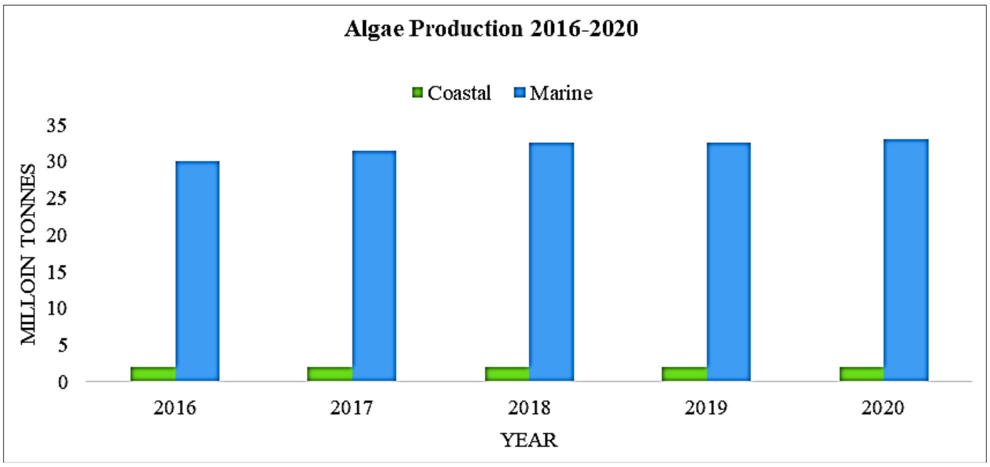

Fig 2: Composition of marine and coastal aquaculture production by algae.

Current Status of Seaweed Production in Asia

The global seaweed production landscape is heavily influenced by a select few East and Southeast Asian nations (FAO 2022b) [16]. These nations not only dominate in terms of volume and value but also collectively hold over 98% of the market share (FAO 2022b) [16]. In 2021 alone, Asian producers contributed a staggering 99.5%, equivalent to 35 million tons of the total global production volume (FAO 2023) [17]. China stands out as the primary contributor, accounting for 61% of the world's seaweed production. Indonesia follows closely behind, commanding 26% of the global market share, while other significant players include the Republic of Korea, the Philippines, the Democratic People's Republic of Korea, Japan and Malaysia. However, outside Asia, nations such as the United Republic of Tanzania, the Russian Federation and Chile play minor roles, collectively contributing just 0.34% to the global production (UNCTAD 2024) [56]. The dominance of Asian nations in seaweed production highlights their crucial role in meeting global demand for this resource. Collaborations and knowledge-sharing among Asian producers and emerging players worldwide are essential for sustainable growth. Increasing recognition of seaweed's potential in addressing food security and environmental challenges is driving innovation and investment in seaweed farming technologies and products across Asia and beyond.

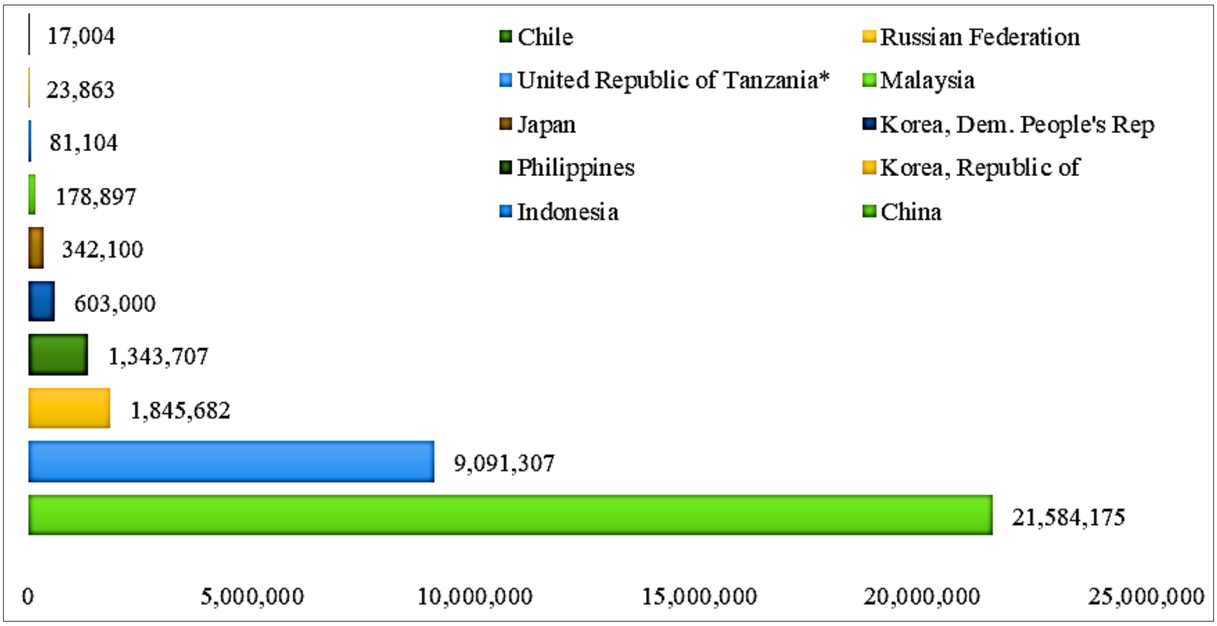

Fig 3: Top 10 seaweed producers 2021 (Source: UNCTAD 2024, based on (FAO 2023) [56]

6. Production Trends & Regional Dynamics

In 2020, global farmed seaweed production was heavily concentrated in Asia, with China contributing approximately 56% of total output and Indonesia accounting for a further 27%. South Korea and the Philippines followed at a distant level, each representing around 4% of worldwide production (Global Seaweed New and Emerging Markets Report, 2023) [20]. In contrast, countries outside Asia collectively produced less than 2% of farmed seaweed during the same year. Despite the dominance of leading producers, the period from 2015 to 2020 was marked by a deceleration in seaweed aquaculture growth across most regions. Analysis conducted by Hatch Innovation Services indicates that overall production volumes may be lower than previously projected, with several major producing areas facing stagnation or even declines in output in the near future (Hatch Innovation Services, 2023) [21].

These patterns are largely linked to mounting constraints within traditional seaweed farming systems, many of which are being intensified by climate change. Rising seawater temperatures and reduced cultivation windows have adversely affected productivity, resulting in lower commercial yields (Global Seaweed New and Emerging Markets Report, 2023) [20]. Consequently, the adoption of adaptive management strategies and technological innovations in cultivation practices has become increasingly critical to ensure the resilience, sustainability, and long-term growth of the seaweed aquaculture sector.

7. Growing Seaweed Production in Other Continents

Seaweed aquaculture is showing strong growth momentum in regions such as Europe and Oceania, largely supported by rising domestic demand (Cottier-Cook *et al*., 2016; Kim *et al*., 2017) [8, 28]. In Europe, seaweed production increased to approximately 23.8 thousand tonnes by 2021. Across the Americas, Chile and Peru remain the principal producers; however, output levels have varied considerably over time, reaching a high of 88 thousand tonnes in 2009 before declining to around 17 thousand tonnes in 2021. A comparable pattern is observed in Africa, where the United Republic of Tanzania recorded a production peak of 178 thousand tonnes in 2015, followed by a reduction to 81 thousand tonnes by 2021 (Global Seaweed New and Emerging Markets Report, 2023; World Bank, 2023).

Overall, these regional developments indicate increasing acknowledgment of seaweed's multifunctional applications and economic value. With demand continuing to rise, substantial opportunities exist to expand environmentally sustainable cultivation methods and to integrate seaweed more widely across diverse industrial sectors.

8. Global Seaweed Trade: Trends and Economic Impact

In 2019, microalgae and hydrocolloids exports earned 2.65 billion US dollars across 98 countries, with microalgae accounting for 909 million US dollars and hydrocolloids for 1.74 billion US dollars. Trade in algae surged from USD 65 million in 1976 to USD 1.1 billion in 2020, led by major exporters China, Indonesia and the Republic of Korea and top importers China, Japan and the United States of America (FAO 2022b) [16]. Seaweed exports reached approximately $943 million, while imports amounted to $1.2 billion in 2021. Global exports of seaweed and its by-products experienced a 40% growth between 2012 and 2021, largely attributed to Asia, indicating significant potential for the tradability of this emerging ocean economy sector. Additionally, due to the rising production of fishmeal and other aquatic animal by-products, trade in inedible by-products surged from USD 8 million in 1976 to USD 715 million in 2020 (FAO 2022b) [16]. The increasing global trade in seaweed products underscores the growing recognition of seaweed's economic value and versatility across industries. As demand rises, there's a notable opportunity for countries to further explore and capitalize on the potential of seaweed resources for economic growth and sustainability.

9. Asia's Dominance in Seaweed Trade: Exports and Imports

The dominance of Asian countries in the seaweed trade underscores the region's significance in the global market. As demand for seaweed products continues to grow, is potential for increased participation and collaboration among regions to foster sustainable development and economic growth. In 2021, Asian nations played a prominent role in both exporting and importing seaweed products, with exports totalling $590 million and imports reaching $762 million. The Americas and Europe exported $192 million and $143 million, respectively, while importing $165 million and $245 million in the same year. However, Africa and Oceania's contributions remained minimal, with exports amounting to $12.8 million and $3.8 million, respectively (UNCTAD 2023a & 2023b) [55, 52].

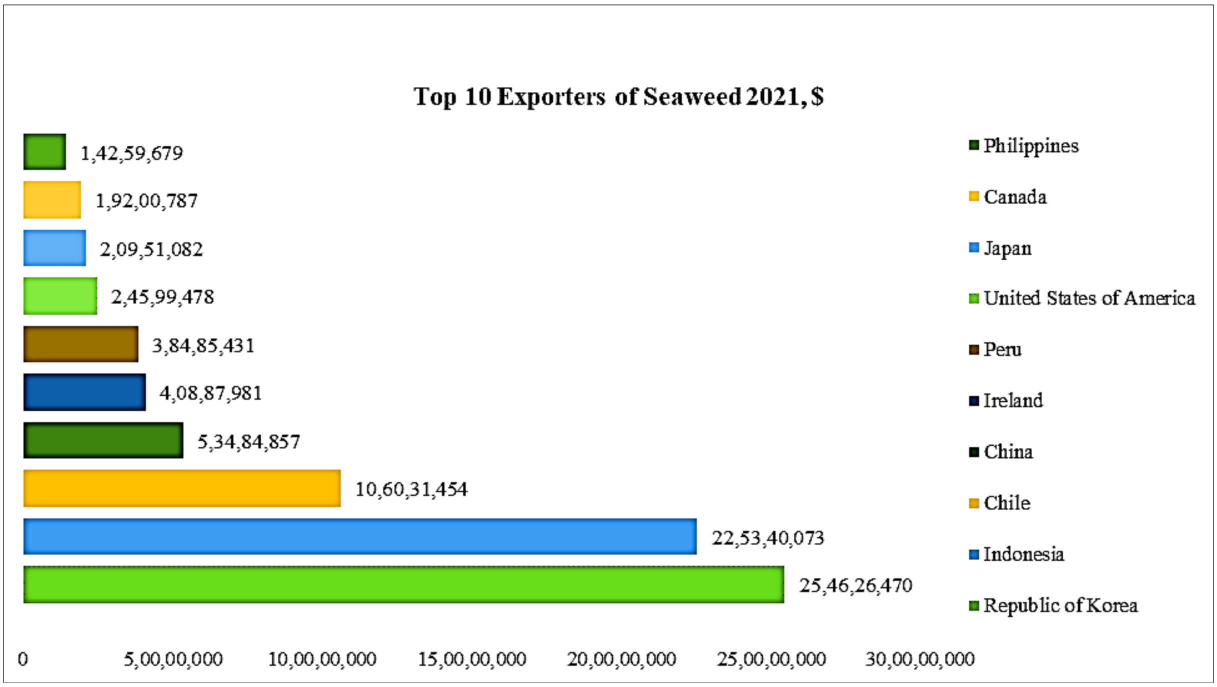

Fig 4: Top 10 exporters of seaweed 2021, US $ (Source: UNCTAD 2024 & 2022) [56]

Key Players in Seaweed Exports & Imports

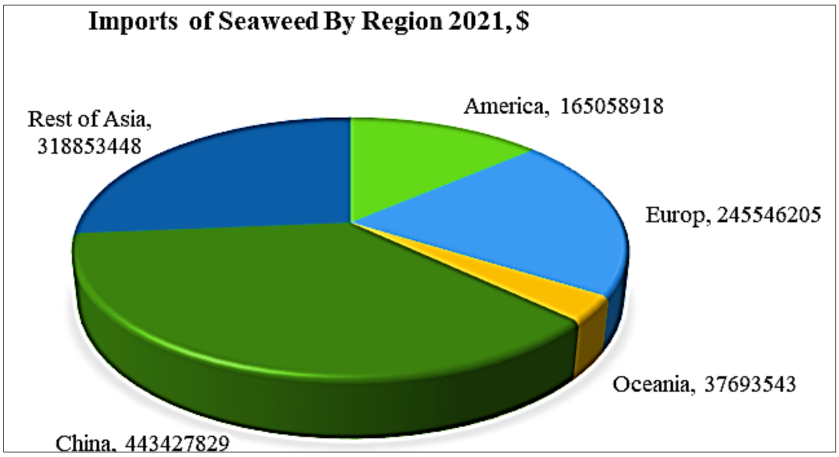

Fig 5: Imports of seaweed by region 2021, $ (Source: UNCTAD 2024) [56]

In 2021, mainland China dominated global imports, accounting for 41% of the total, making it the largest importer (UNCTAD 2023a & 2023b) [55, 52]. Japan followed as the second-largest importer with $193 million, trailed by the United States at $104 million. Among the top 1 0 importers, non-Asian countries included the Russian Federation ($51 million), France ($30 million) and Australia ($29 million). Notably, despite being significant seaweed producers, Indonesia and the Philippines had minimal import activity. These import dynamics highlight the varying degrees of reliance on seaweed imports among different countries, influenced by factors such as domestic production capacity and market demand.

Dominant Species in Commercial Seaweed Production

Table 1: World production of major aquaculture species (including species groups) (Source: FAO 2022b) [16]

Algae	2000	2005	2010	2015	2020	% of total, 2020
	live weight tonnes (Thousand)					
Japanese kelp (*Laminaria japonica)*	53,809	56,991	6,525.6	10,313.7	12,469.8	35.5
Eucheuma seaweeds (*Eucheuma spp).*	214.3	983.9	3472.6	10,182.1	8129.4	23.2
Gracilaria seaweeds (*Gracilaria spp.*)	55.5	933.2	1,657.1	3767	5,180.4	14.8
Wakame (*Undaria pinnatifida)*	311.1	2,439.7	1,505.1	2,215.6	2,810.6	8
Nori, (*Porphyra spp.*)	424.9	703.1	1,040.7	1,109,9	2,220.2	6.3
Elkhorn sea moss (*Kappaphycus alvarezii)*	649.5	1,283.5	1,884.2	1751.8	1,604.1	4.6
Fusiform sargassum (*Sargassum fusiforme)*	12.1	115.6	97	209.3	292.9	0.8
Spiny Eucheuma (*Eucheuma denticulatum)*	85.3	174.5	265.5	280.8	154.1	0.4
Subtotal of 8 major species	7,133.7	12,332.7	16,447.9	29,830.2	32,861.5	93.7
Subtotal other species	3,461.9	2,498.6	3,726.5	1,243.4	2,216.0	6.3
Total	10,595.6	14,831.3	20 174.3	31,073.5	35,077.6	100

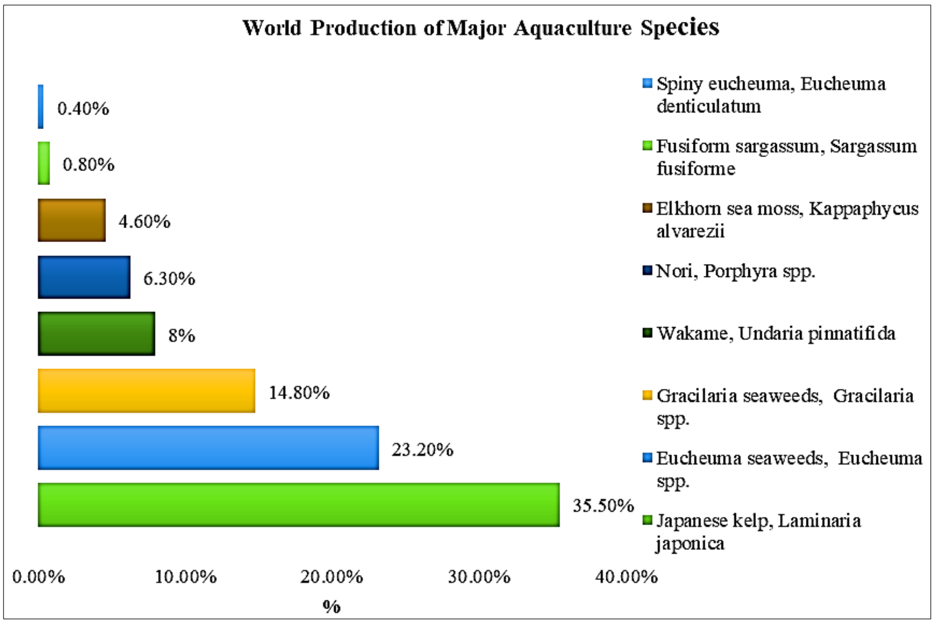

Fig 6: Contribution of major seaweed species to global production (Data source: FAO 2021) [14].

Although large-scale seaweed aquaculture has been established for only around the past fifty years, production has expanded rapidly, with global output nearly tripling over the last two decades. As wild seaweed stocks approach or exceed sustainable harvesting thresholds, future increases in supply are expected to rely predominantly on cultivated sources. At present, commercial production remains concentrated on a relatively small number of species (Global Seaweed New and Emerging Markets Report, 2023) [20]. Between 2000 and 2020, global seaweed production rose markedly from approximately 10.6 million tonnes to 35 million tonnes, with output largely driven by a limited group of taxa, including Undaria/Pyropia, Gracilaria / Eucheumatoids, and Saccharina (Hatch Innovation Services, 2023) [21]. Collectively, more than 95% of worldwide macroalgal production is accounted for by five genera: Laminaria / Saccharina (35.4%), Kappaphycus/Eucheuma (33.5%), Gracilaria (10.5%), Porphyra/Pyropia (8.6%), and Undaria (7.4%) (Table 1; Figures 6 and 7). Reliance on these dominant species has intensified steadily over the past twenty years (Global Seaweed New and Emerging Markets Report, 2023) [20].

Expanding research and development efforts toward the cultivation of a wider range of seaweed species could unlock new growth pathways for the sector, contributing to greater ecological resilience while enabling the identification of novel compounds with commercial and industrial value.

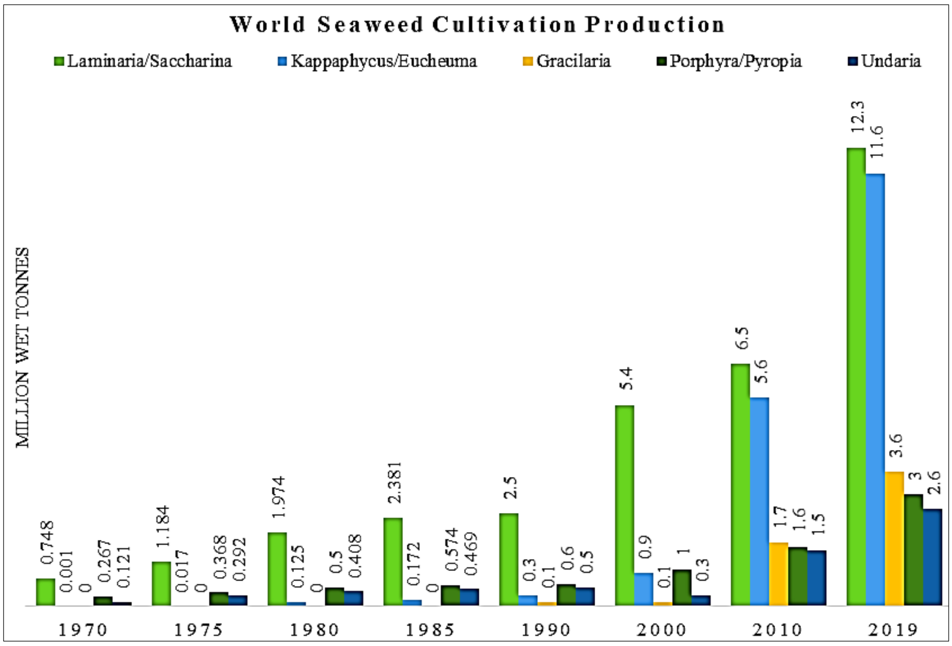

Fig 7: World seaweed aquaculture production by major species groups, 1970-2019 (Data source: FAO 2021) [14].

12. Global Wild Seaweed Collection

Global harvesting of wild seaweeds has shown a marked decline over recent decades, decreasing from 1.33 million tonnes in 1990 to approximately 1.08 million tonnes by 2019. Reductions were observed across all major macroalgal groups, with brown seaweed landings falling from 792,000 tonnes to 676,000 tonnes, red seaweeds declining from 349,000 tonnes to 190,000 tonnes, and green seaweeds decreasing from 53,000 tonnes to just 16,000 tonnes (Cai *et al*., 2021; FAO, 2021) [4-5, 14]. These trends underscore the growing pressure on natural seaweed stocks and reinforce the need to transition toward sustainable seaweed aquaculture systems to satisfy increasing market demand while safeguarding marine ecosystems.

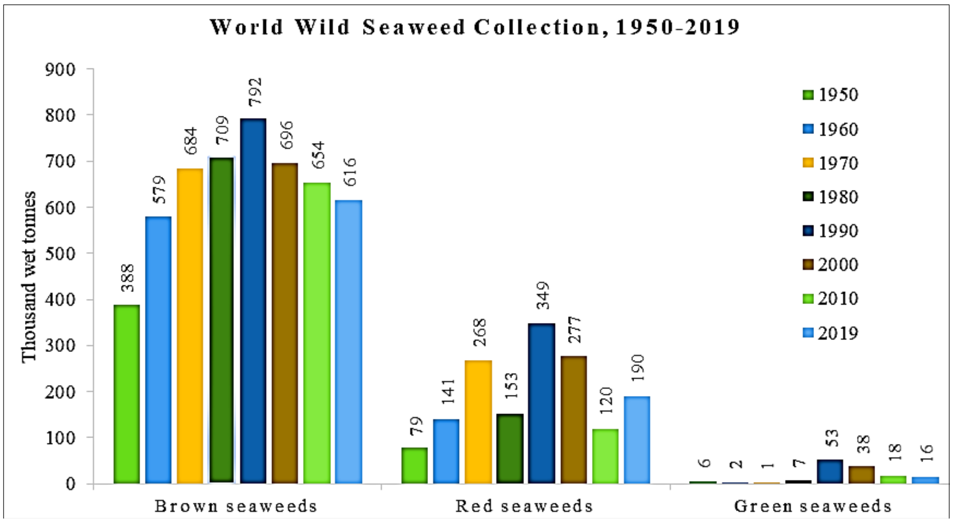

Fig 8: Global seaweed collection by 1950-2019 (Source: FAO 2021) [14].

13. Global Seaweed Cultivation: Trends and Shifts

Worldwide seaweed aquaculture has undergone rapid expansion over the past three decades, with production rising from approximately 4.2 million tonnes in 1990 to 34.7 million tonnes by 2019. This substantial increase has been driven primarily by intensified cultivation of brown and red seaweed species. Output of brown seaweeds grew from 3.1 million tonnes to 16.4 million tonnes, while red seaweed production expanded even more markedly, increasing from about 1 million tonnes to 18.3 million tonnes (Figure 9). In contrast, farmed green seaweeds experienced a decline over the same period, with production decreasing from 31,000 tonnes to 17,000 tonnes (Cai *et al*., 2021; FAO, 2021) [4-5, 14]. Overall, these trends illustrate the growing importance of seaweed across multiple industrial sectors and highlight its promise as a sustainable source of food and bio-based resources.

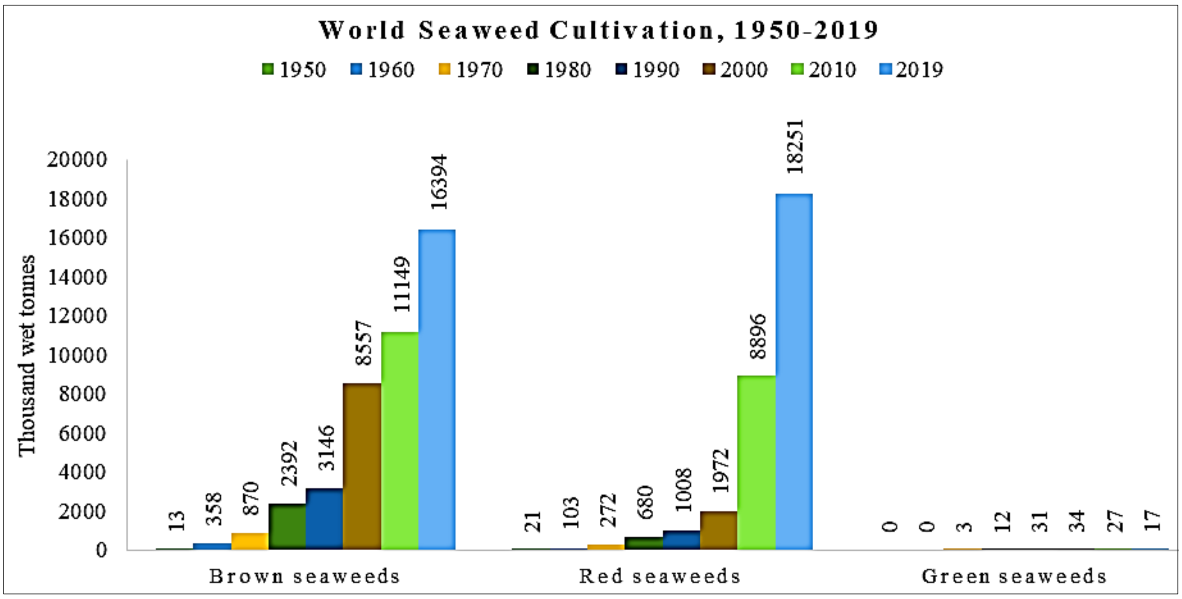

Fig 9: Global seaweed cultivation by, 1950-2019 (Data source: FAO 2021) [14].

14. Global Seaweed By-products Market

In 2021, the global market saw agar exports valued at $260 million and alginate exports at $161 million (UNCTAD 2024) [56]. The estimated value of carrageenan exports reached $1.5 billion in the same year. The increasing demand for natural and sustainable ingredients in food, pharmaceuticals and cosmetics continues to drive growth in the hydrocolloid sector. Advances in processing technologies and new applications in various industries further enhance the market's potential.

14.1 Hydrocolloids

Hydrocolloids are widely used in various industries and their market is highly commoditized. The majority of the supply comes from Asia, but companies like IFF (formerly DuPont Nutrition & Biosciences) are establishing supply partnerships in Norway and Iceland. Seaweeds play a vital role in this sector, providing the base for 40% of all hydrocolloids (Ferdouse *et al*. 2018) [18]. The seaweed-based hydrocolloid market is valued at approximately $610 million and is expected to reach nearly $1 billion by 2023 (Seaweed Hydrocolloid Market Share, Trend & Forecast 2023; Purcell & Quintero 2024) [45, 41]. Innovations in sustainable sourcing and production techniques are driving growth in this industry.

14.2 Bio stimulants: Biostimulants comprise a group of naturally derived products sourced from plants, seaweeds, microorganisms, and other organic materials that are applied to crops to promote growth, improve nutrient assimilation, and enhance tolerance to biotic and abiotic stress. Seaweed-based products represent a substantial share of this segment, accounting for roughly 40% of the global biostimulant market (Purcell and Quintero, 2024; Nozaki, 2023) [41, 40]. Despite forming an estimated USD 1 billion component of the crop nutrition industry, seaweed-derived biostimulants are currently applied to less than 0.5% of agricultural land worldwide, reflecting their relatively low adoption in large-scale farming systems. In 2022, these products held the largest share of the biostimulant market approximately 30-40% within a global market valued between USD 2.5 and 3.5 billion (Figure 10). With an anticipated compound annual growth rate (CAGR) of about 10%, the market value of seaweed-based biostimulants is projected to reach USD 1.87 billion by 2030 (Global Seaweed New and Emerging Markets Report, 2023) [20].

This rapid expansion is being driven by growing consumer demand for organically produced food and increasing emphasis on sustainable and environmentally responsible agricultural practices (Data Bridge Market Research, 2024). Projections suggest that by 2027, the biostimulant industry may require up to 1 million tonnes of seaweed annually, representing a 50% increase compared to current usage levels (Purcell and Quintero, 2024; Seaweed Markets Analysis, 2023). Continued improvements in formulation efficiency, along with the emergence of novel agricultural applications, are expected to further accelerate growth in this market segment (Figure 10).

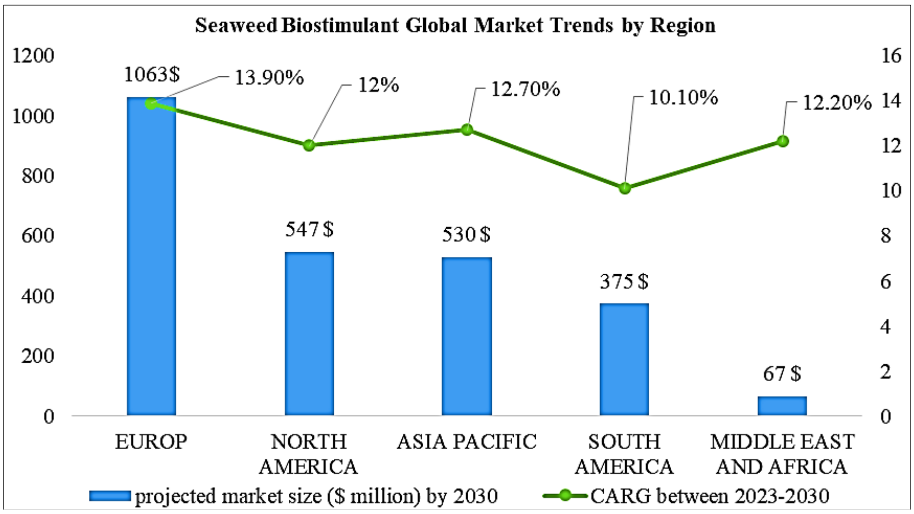

Fig 10: Seaweed bio stimulant global market trends by region (Source: Data bridge market research 2023)

14.3 Pet food

Pet food products incorporating seaweed are already on the market, though comprehensive data on their current market size is lacking. The global pet food market, dominated by bulk feeds and additives, was valued at $115.5 billion in 2022 and is expected to grow at a CAGR of 5.11% from 2023 to 2030 (Global Seaweed New and Emerging Markets Report 2023) [20]. The inclusion of seaweed in pet food is driven by its nutritional benefits, including essential vitamins, minerals and antioxidants that promote pet health. As consumers increasingly seek natural and sustainable ingredients for their pets, the demand for seaweed-based pet food products is anticipated to rise.

14.4 Feed additive

Seaweed is currently incorporated into animal nutrition systems both as a functional feed additive and as a direct feed component, although precise estimates of its present market share remain limited. The global feed additives sector was valued at approximately USD 38.86 billion in 2022 and is expected to expand at a compound annual growth rate (CAGR) of 3.9% through 2030. With the livestock feed industry progressively shifting from synthetic inputs toward natural alternatives, seaweed-based feed additives are anticipated to experience strong market growth between 2023 and 2028, with projections suggesting a market value of up to USD 1.122 billion by 2030 (Global Seaweed New and Emerging Markets Report, 2023) [20].

This increasing adoption is largely attributed to the nutritional and functional advantages of seaweed, including its high concentrations of essential vitamins, minerals, and bioactive compounds that support animal health, performance, and productivity. In addition, the emphasis on sustainable feed solutions and rising consumer preference for organically produced animal products are expected to further accelerate the uptake of seaweed-derived additives within the global feed industry.

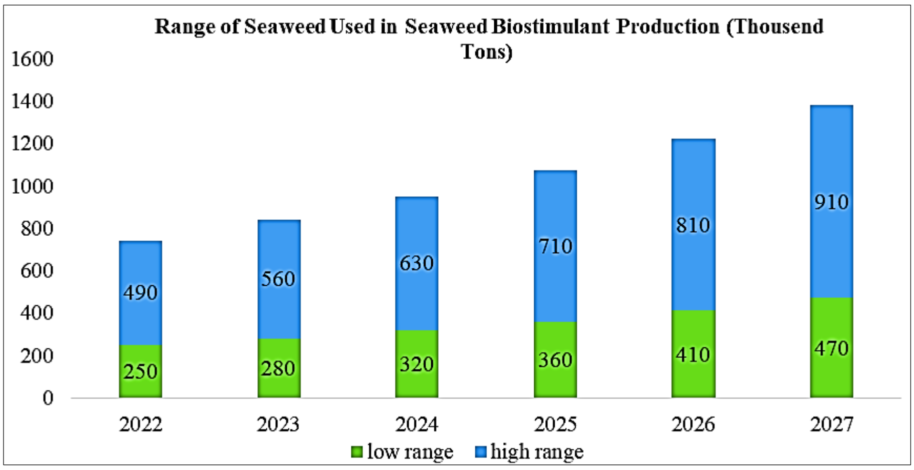

Fig 11: Range of seaweed used in seaweed bio stimulant production (Source: Seaweed markets analysis 2023)

14.5 Methane-reducing additives

Methane-mitigating feed additives represent a rapidly developing niche within the global animal nutrition market, with an estimated value of USD 47 million in 2022. Increasing commitments by governments and corporate entities to achieve net-zero emission targets are expected to drive exceptionally rapid expansion in this segment, with projected compound annual growth rates approaching 57% in the coming years. Seaweed-derived methane-reducing additives are anticipated to be key contributors to this growth, with market estimates suggesting they could attain a value of approximately USD 306 million by 2030 (Global Seaweed New and Emerging Markets Report, 2023) [20].

The growing adoption of these additives is primarily motivated by the urgent need to curb greenhouse gas emissions associated with livestock production, positioning seaweed-based solutions as a natural and environmentally sustainable alternative. Furthermore, ongoing improvements in seaweed farming systems and processing technologies are enhancing both the effectiveness and scalability of these innovative feed additives, supporting their wider commercial deployment.

14.6 Alternative proteins sourced

Seaweed-derived alternative proteins are now being commercialized across global markets. The worldwide alternative protein sector was valued at approximately USD 10.2 billion in 2022 and is projected to expand at a compound annual growth rate (CAGR) of around 36% through 2030. Growth in this industry is driven by increasing demand for non-animal protein sources, heightened awareness among consumers and product developers of the functional versatility of seaweed, and its potential to improve sustainability within food supply chains. Within this broader market, the seaweed-based alternative protein segment is expected to reach an estimated value of USD 448 million by 2030 (Global Seaweed New and Emerging Markets Report, 2023) [20]. As alternative protein markets continue to scale, seaweed is well positioned to contribute meaningfully to the global need for nutritious, sustainable food solutions.

14.7 Nutraceuticals

Commercial products containing seaweed-derived nutraceuticals are already in circulation, although reliable estimates of their present market share remain limited. The global nutraceutical sector was estimated at around USD 450 billion in 2022 and is forecast to expand at a compound annual growth rate (CAGR) of approximately 7.5% through 2030. Within this large and rapidly expanding market, ingredients sourced from seaweed offer a high-growth niche and are expected to generate revenues of up to USD 3.9 billion by 2030 (Global Seaweed New and Emerging Markets Report, 2023) [20].

14.8 Bioplastics: Seaweed-based bioplastics are currently used in niche applications, primarily in the form of biofilms and are in the early stages of market adoption. In 2022, the global bioplastics market was valued at $11.5 billion and is projected to grow at a CAGR of 20% through 2030. By 2030, the market potential for seaweed-based bioplastics could reach $733 million (Global seaweed new and emerging markets report 2023) [20]. This growth is fuelled by increasing demand for sustainable alternatives to traditional plastics, driven by environmental concerns and regulatory pressures. Seaweed offers a renewable and biodegradable source for bioplastics, which can significantly reduce the environmental impact compared to petroleum-based plastics. As technology advances and production scales up, seaweed-based bioplastics are expected to find broader applications in packaging, agriculture and consumer goods, further driving market expansion.

14.9 Textiles

Seaweed-based textiles are gaining attention as part of the broader trend toward biosynthetic textiles, which aim to replace fossil-based synthetics. While biosynthetic textiles are typically derived from crops or occasionally from forestry residues or agricultural waste, the global market for these textiles was valued at $17.18 billion in 2022. Despite constituting less than 1% of the overall textile market, biosynthetic textiles are forecasted to grow at an annual rate of 10% from 2022 to 2030 (Global seaweed new and emerging markets report 2023) [20].

14.10 Pharmaceutical

Within the pharmaceutical industry, the market for drugs derived from marine sources is currently valued at approximately USD 2.56 billion and is expected to expand at an annual rate of 5-10% through 2030. Sustained demand for novel and effective therapeutic solutions is a key driver of this growth, with seaweed-derived compounds showing considerable functional potential. Nevertheless, the majority of research on pharmaceuticals sourced from seaweed remains at the preclinical stage. As a result, it is likely that regulatory-approved products will require an additional 5-10 years to reach the market, alongside significant investment to support clinical development and commercialization (Global Seaweed New and Emerging Markets Report, 2023) [20].

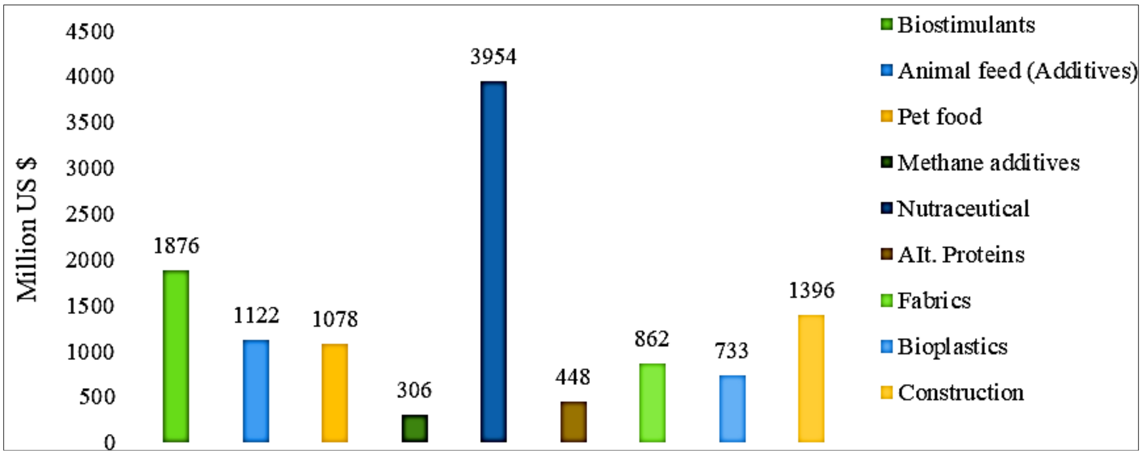

Fig 12: Predicted seaweed market size by 2030 ($ millions) (Global seaweed: New and emerging markets report 2023).

15. Present Scenario of Indian Seaweed Production

India possesses an extensive marine domain, with a coastline of 7,517 km distributed across its coastal states, an Exclusive Economic Zone (EEZ) of approximately 2.5 million km², and a continental shelf area of about 0.13 million km² (Mantri *et al.*, 2019a) [33]. This expansive marine environment supports rich seaweed diversity, comprising nearly 844 species that inhabit a wide range of ecological niches, including estuarine mangrove systems, rocky intertidal zones, and coral reef substrates (Megarajan *et al.*, 2021) [37]. With records documenting 841 seaweed species belonging to 216 genera and 68 families, India is recognized as an important biodiversity hotspot within the Indian Ocean region (Sahoo *et al.*, 2003) [44]. Species distribution varies geographically, with Tamil Nadu reporting the highest diversity, followed by Gujarat, Maharashtra, Lakshadweep, Andhra Pradesh, and other coastal regions (Venkataraman and Raghunathan, 2015) [57]. In Indian waters, seaweed biomass is dominated by green seaweeds (70%), followed by brown (16%) and red seaweeds (14%) (Joseph and Jayaprakash, 2023) [25].

Despite this considerable natural endowment, commercial-scale seaweed farming in India is largely confined to Tamil Nadu and Gujarat, while other coastal states remain at early stages of development, focusing mainly on experimental trials and demonstration activities. Although the country has an estimated annual harvest potential exceeding 0.26 million tonnes of wet seaweed biomass, realized production remains minimal. For instance, only about 3,000 tonnes were harvested in 2016, representing less than 0.1% of global seaweed output (Megarajan *et al.*, 2021) [37]. Traditionally, species such as *Gelidiella acerosa* and *Gracilaria edulis* have been exploited for agar extraction, whereas brown seaweeds including *Sargassum* and *Turbinaria* are primarily utilized for alginate production (Anilkumar, 2022) [1].

Although India has extensive coastal areas suitable for mariculture, large-scale commercial seaweed cultivation has yet to gain momentum. At present, nearly 25 seaweed-based chemical industries operate in the country, many of which function below capacity due to inadequate domestic raw material supply, resulting in reliance on imported seaweed. While seaweed consumption is not traditionally widespread in the Indian diet, the sector holds significant promise, offering ecosystem services such as carbon sequestration, habitat provision for marine organisms, and coastal pollution mitigation, in addition to applications in animal feed and agricultural fertilizers (Tandel *et al.*, 2016) [50]. Unlocking this potential will require coordinated efforts to expand seaweed farming, address infrastructural and policy constraints, and strengthen the value chain across the sector.

16. Seaweed Production in India: Market Dynamics

In India, seaweed harvesting is still largely dependent on natural stocks and is predominantly carried out by women from more than 2,000 coastal households. Harvesters collect seaweeds using small boats and transport the biomass to the shore, where it is purchased by agents or intermediaries and subsequently supplied to processing industries (Mathew and Ravishankar, 2018) [35]. Along the Tamil Nadu coastline, an estimated 500-600 tonnes of dry-weight wild agarophytes are harvested annually (Mantri *et al.*, 2019b), generating an approximate market value of ₹27 crores (Lok Sabha Secretariat, 2021) [31].

Total seaweed production in India, including both wild collection and aquaculture, declined from 34,922 tonnes in 2009 to 27,937 tonnes in 2018. This period was characterized by a gradual reduction in output until 2015, followed by a modest recovery in subsequent years (Figure 21). Despite this improvement, India's share in global seaweed production remained low, contributing only 0.08% by 2018. Output from wild harvesting alone fell from 28,000 tonnes in 2009 to 22,635 tonnes in 2018 (Figure 14). Over the past decade, India's contribution to global production of seaweeds and other aquatic plants from wild collection has consistently remained below 3%, declining slightly from 2.5% in 2009 to 2.4% in 2018 (FAO, 2020 [13]; Anilkum

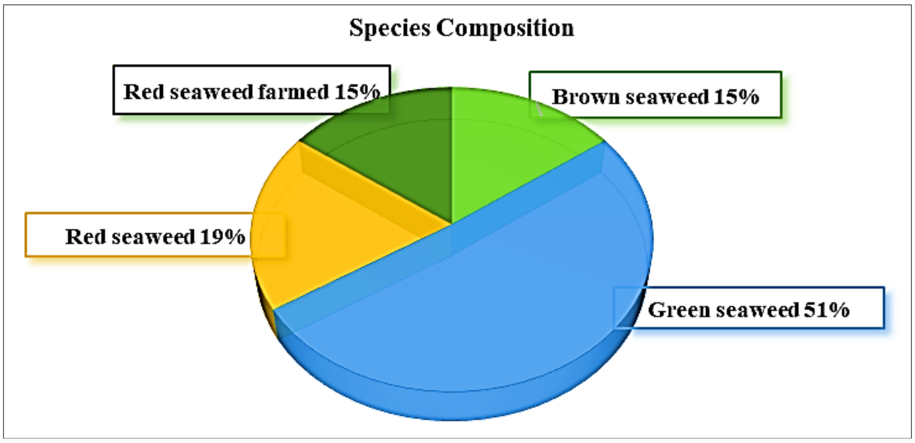

Fig 13: Seaweed production in India (Ranjan 2021) [43]

Annual estimates of seaweed harvest from wild sources, along with mariculture production along the east coast, are generated by ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), enabling systematic evaluation of India's seaweed production potential. Experimental seaweed mariculture trials focusing on *Gracilaria edulis* and *Gelidiella acerosa* were initiated as early as 1964. Subsequently, large-scale commercial cultivation of *Kappaphycus alvarezii*, a kappa-carrageenan-producing species, was launched in 2000 with support from PepsiCo India Holdings Ltd. across coastal regions of Tamil Nadu, Odisha, Gujarat, and Daman & Diu. This initiative was supported technically by the Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Bhavnagar (Kaladharan *et al.*, 2019b) [27].

Contract farming of *Kappaphycus alvarezii* by coastal fisher communities along India's east coast reached its peak in 2012, achieving approximately 1,500 tonnes of dry-weight production and yielding more than 70,000 tonnes of wet biomass between 2005 and 2015. During this period, procurement prices ranged from ₹4.5 to ₹35 per kilogram (dry weight), resulting in an annual turnover of nearly ₹2.0 billion. However, large-scale mortality events after 2013 led to a sharp decline in production, with recent annual outputs

averaging only about 200 tonnes of dry biomass (Kaladharan *et al*., 2019b) [27]. Current efforts are focused on revitalizing and sustaining commercial seaweed farming in India (Figure 15).
Historically, India's dependence on natural seaweed beds, combined with overexploitation and habitat degradation, has highlighted the urgent need for expanding seaweed cultivation practices (Anilkumar, 2022) [1]. Early aquaculture initiatives prioritized *Gracilaria edulis* because of its strong regenerative capacity (Kaladharan *et al*., 2019). The cultivation of *Kappaphycus alvarezii* was later introduced following its import from Japan by CSIR-CSMCRI (Anilkumar, 2022) [1]. At present, green seaweeds account for approximately 51% of overall production, while red seaweeds constitute the dominant group under farming systems in India (Ranjan, 2021) (Figure 13).

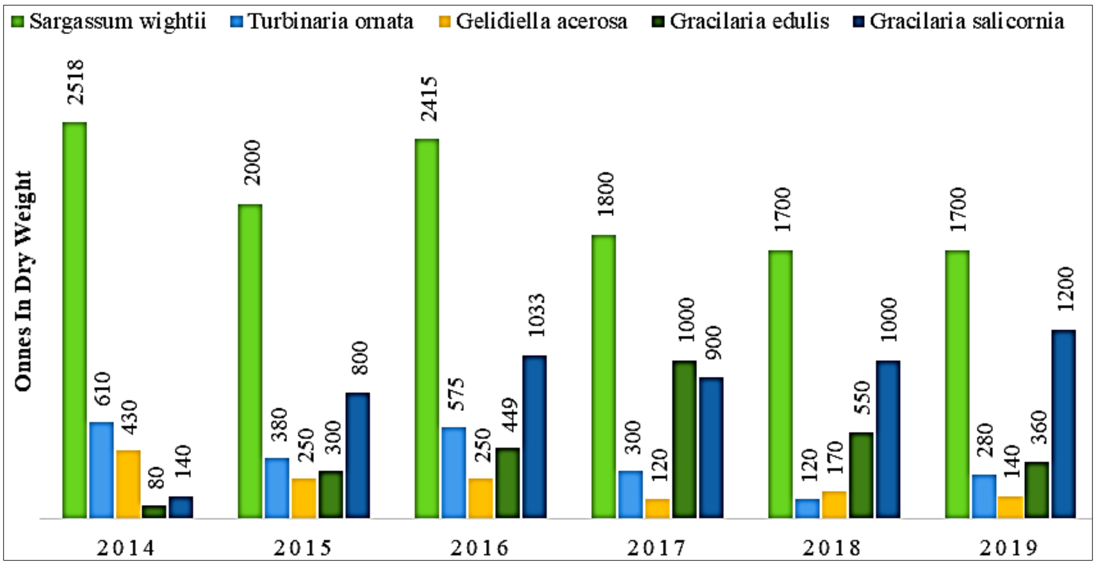

Fig 14: Production of seaweed through wild collection during the year 2014-2019 (Kaladharan *et al*. 2019b) [27].

Aquaculture production of aquatic plants, including seaweeds, in India experienced a decrease from 6,922 tons in 2009 to 5,302 tons in 2018. Despite the decline in quantity, the value of aquatic plants produced through aquaculture in India increased from USD 0.25 million in 2009 to USD 0.42 million in 2018. India's contribution to global farmed aquatic plants production remains negligible, accounting for 0.02% in terms of volume and 0.003% in terms of value in 2018 (FAO 2020) [13]. This decrease in aquaculture production highlights potential challenges or shifts in the industry Exploring innovative cultivation techniques or introducing new seaweed species with higher market demand could contribute to revitalizing the aquaculture sector and boosting its economic significance in India's agricultural landscape.
Among the diverse array of seaweeds found in India, nearly 60 species hold commercial significance. However, large-scale commercial farming is currently limited to only two to three species (Anilkumar 2022) [1]. Commercial seaweed aquaculture in India primarily occurs in Tamil Nadu and Gujarat, with smaller operations in Maharashtra and Odisha (Lok Sabha Secretariat 2021; Anilkumar 2022) [31, 1].
According to Johnson & Ignatius (2020) [24], approximately 23,970 hectares of coastal areas in India are deemed suitable for seaweed farming. Detailed state-wise information regarding potential cultivation sites is provided in Table 2.

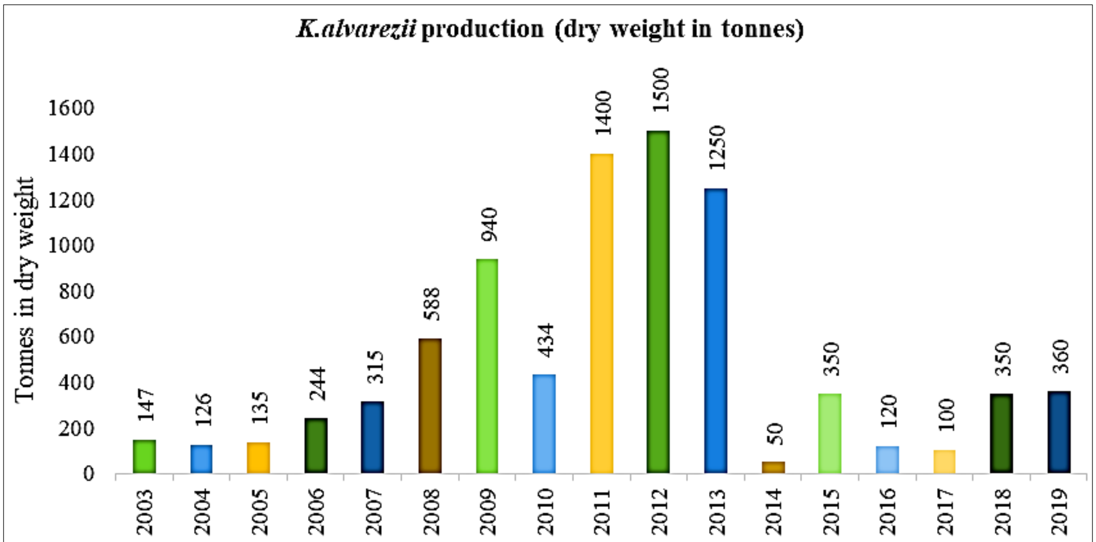

Fig 15: *K. alvarezii* production (dry weight in tonnes) (Kaladharan *et al*. 2019b) [27].

Table 2: Potential sites identified for seaweed culture along Indian coast (Source: Johnson & Ignatius 2020) [24]

State	No. of locations identified	Area of potential sites (Ha)
Gujarat	9	10,316
Diu	5	700
Maharashtra	12	2,724
Goa	4	120
Karnataka	14	1,579
Kerala	7	80
Lakshadweep Islands	11	213
Tamil Nadu	187	5,048
Andhra Pradesh	49	1,215
Odisha	14	1,525
West Bengal	5	450
Total (All India)	317	23,970

To meet the demand for seaweed products and enhance self-sufficiency in production, India requires approximately 400 tonnes per annum of agar and 1,000 tonnes per annum of alginate. However, only 30% and less than 40% of these respective requirements are currently produced domestically (Johnson & Ignatius 2020) [24]. Additionally, the annual demand for carrageenan ranges from 1,500 to 2,000 tonnes, with the food sector accounting for nearly 70% of the global market (Johnson & Ignatius 2020) [24].

Considering the demand for agar, alginate and carrageenan, the total annual seaweed requirement on a dry weight basis is estimated to be 4,000 tonnes for agar-producing algae, 5,000 tonnes for alginate-producing algae and 4,500 to 6,000 tonnes for carrageenan-producing algae. Therefore, promoting large-scale farming initiatives is crucial to improving self-sufficiency in seaweed-based products (Johnson & Ignatius 2020) [24]. Expanding seaweed cultivation efforts, particularly of species rich in agar, alginate and carrageenan, can contribute significantly to fulfilling domestic demand and reducing reliance on imports. Moreover, investing in research and development to optimize cultivation techniques and identify high-yield seaweed strains can further enhance production efficiency and support India's goal of achieving self-sufficiency in seaweed-based products.

17. Seaweed Trade Dynamics: Import Trends and Market Insights

17.1 Human consumption & other seaweeds Import

During the period from 2015-16 to 2021-22, India recorded a sharp reduction in imports of seaweeds intended for direct human consumption. Imports declined from 277.42 tonnes, valued at ₹983.49 lakhs in 2015-16, to just 0.02 tonnes worth ₹2.35 lakhs by 2021-22. In contrast, imports of other categories of seaweeds showed a notable increase over the same timeframe, rising from 27.68 tonnes valued at ₹33.27 lakhs in 2015-16 to 291.54 tonnes valued at ₹190.97 lakhs in 2021-22. Although the imported volume expanded substantially, the average import price per kilogram declined from ₹120 in 2015-16 to ₹66 in 2021-22. In the latter year, these other seaweed imports originated from six countries, with Sri Lanka, Indonesia, and Ireland emerging as the principal supplying nations.

Agarose import

The import of agarose to India remained minimal, ranging from 0.03 tons valued at Rs.3.30 lakhs in 2016-17 to 0.47 tons valued at Rs.844.96 lakhs in 2019-20 (Table 3, Figure 16, Table 4, Figure 17)).

17.2 Agar-agar import

The import of agar-agar showed a steady increase from 315.97 tons in 2015-16 to 437.82 tons in 2019-20, followed by a slight decrease to 410.30 tons in 2021-22. Despite the fluctuation in quantity, the import value rose from Rs.3,780.47 lakhs in 2015-16 to Rs.5,486.74 lakhs in 2021-22, with the cost per kg of imported commodity reaching Rs.1,337/- in 2021-22. Agar-agar imports originated from over ten countries in 2021-22, with China being the primary exporter, accounting for approximately 50% of the quantity and 35% of the value (Table 3, Figure 16, Table 4, Figure 17).

Table 3: Seaweed imports to India-quantity (2015-16 to 2021-22) (source: Tradestat 2022) [51]

Products	Quantity ('000kg)						
	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Seaweeds fit for human consumption	277.42	175.75	252.23	79.11	28.46	85.6	0.02
Other seaweeds	27.68	64.7	22.07	44.87	13.77	153.28	291.54
Agarose	0.39	0.03	N. A.	N. A.	0.47	N. A.	N. A.
Agar-Agar whether or not modified	315.97	339.87	366.36	389.5	437.82	412.94	410.3
Kappa Carrageenan	300.62	74.45	50.14	112.18	421.27	79.16	15.45
Sodium Alginate	2,450.3	2,686.8	3,232.6	2,629.7	2,148.2	1,665.8	1,361.5
Other alginic acid its salts and esters	324.76	1247.2	884.51	1384.1	1051.8	893.25	836.41

17.3 Kappa carrageenan import

The import of kappa carrageenan into India experienced a notable decline from 300.62 tons (valued at Rs.2, 236.47 lakhs) in 2015-16 to 15.45 tons (valued at Rs.177.72 lakhs) (Table 4, Figure 17) in 2021-22. Despite the decrease in quantity, the cost per kg of the imported commodity rose from Rs.744/- in 2015-16 to Rs.1,150/- in 2021-22 (Table 3, Figure 16). During 2021-22, kappa carrageenan imports originated from six countries, with China accounting for 48% of the quantity and 46% of the value, followed by the Republic of Korea with 26% contribution in both quantity and value (Tradestat 2022; Anilkumar 2022) [51, 1]. The shift in import dynamics of kappa carrageenan emphasizes potential changes in demand patterns or supply sources within the industry. Additionally, diversifying import sources and development domestic production capabilities may contribute to enhancing resilience and stability in the supply chain for kappa carrageenan and related products.

17.4 Sodium alginate import

Sodium alginate emerged as the predominant seaweed-based product imported into India both in terms of volume and value. Despite a declining trend in import quantity, from 2,450.31 tons in 2015-16 to 1,361.46 tons in 2021-22, the import value showed an increase from Rs. 6,011.52 lakhs to Rs.6,379.12 lakhs during the same period (Table 3, Figure

16). The cost per kg of the commodity also witnessed a rise from Rs.245/- to Rs.469/- over the years. In 2021-22, sodium alginate imports originated from fourteen countries, with the bulk coming from China (1,249.77 tons valued at Rs.4,094.01 lakhs) (Table 4, Figure 17), accounting for 92% of the quantity and 64% of the value (Tradestat 2022; Anilkumar 2022) [51, 1]. Exploring the factors contributing to the declining import trend of sodium alginate and analysing the implications of the increased import value could provide valuable insights into market dynamics and potential strategies to enhance domestic production or diversify import sources.

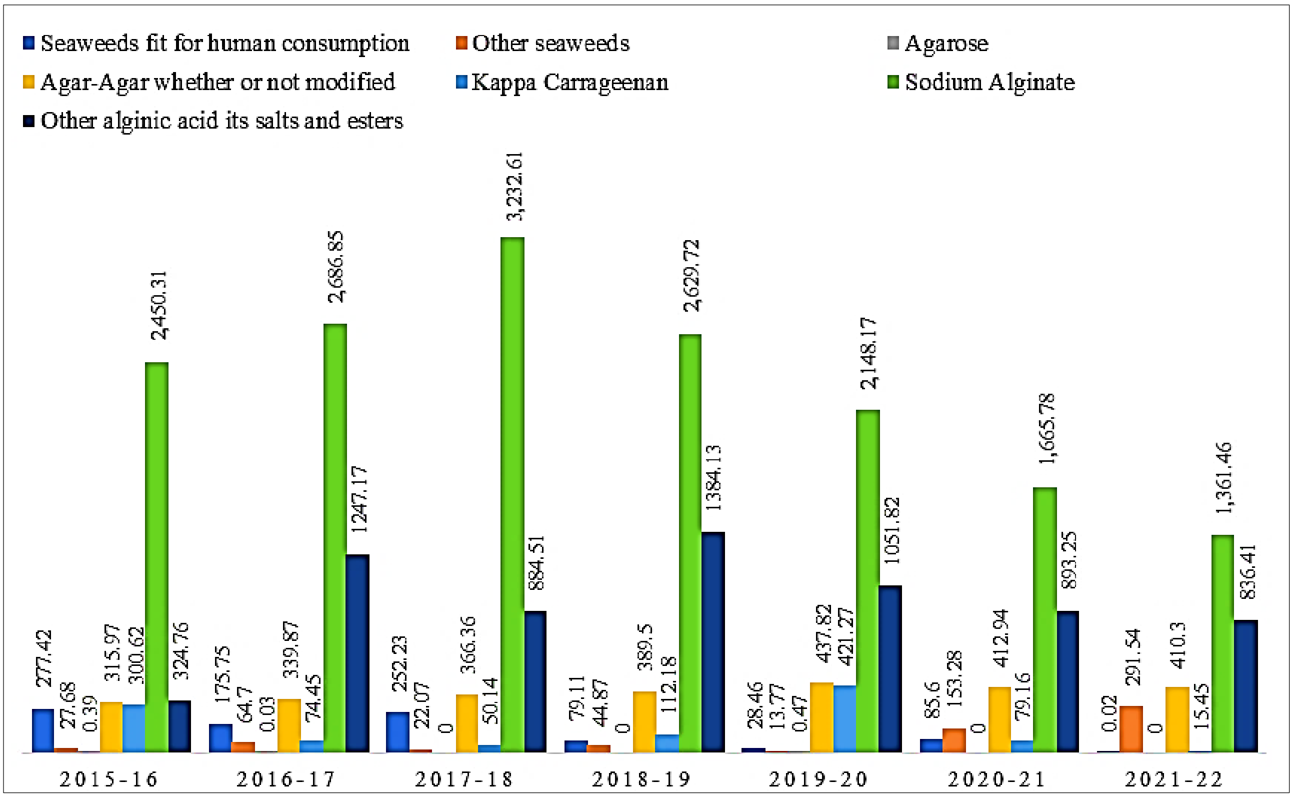

Fig 16: Seaweed imports to India-quantity (2015-16 to 2021-22) (Source: Tradestat 2022) [51]

Other alginic acid its salts and esters Imports

During 2021-22, India imported 836.41 tons of other alginic acid, its salts and esters, with a total value of Rs.3,979.63 lakhs. The cost of the commodity in that period amounted to Rs.476/kg. Imports originated from fourteen countries, with China leading both in volume (90%) and value (64%) (Tradestat 2022; Anilkumar 2022) [51, 1].

Table 4: Seaweed imports to India value (2015-16 to 2021-22) (source: Tradestat 2022) [51]

Products	Value (Rs. Lakhs)						
	2015-16	**2016-17**	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
Seaweeds fit for human consumption	983.49	331.77	432.6	108.2	47.45	98.84	2.35
Other seaweeds	33.27	57.8	9.22	24.11	16	88.57	190.97
Agarose	34.54	3.3	N. A.	N. A.	844.96	N. A.	N.A.
Agar-Agar whether or not modified	3,780.5	4,116.5	4,885.20	5,906.8	6,897.5	6,632.4	5,486.7
Kappa Carrageenan	2,236.5	533.74	504.3	1,083.4	4,100.1	687.75	177.72
Sodium Alginate	6,011.5	7,556.4	10,227.9	8,130.9	7,454.1	4,999.5	6,379.1
Other alginic acid its salts and esters	1,515.9	2,576.4	3,191.77	4,858.7	3,594.3	2,901.9	3,979.6

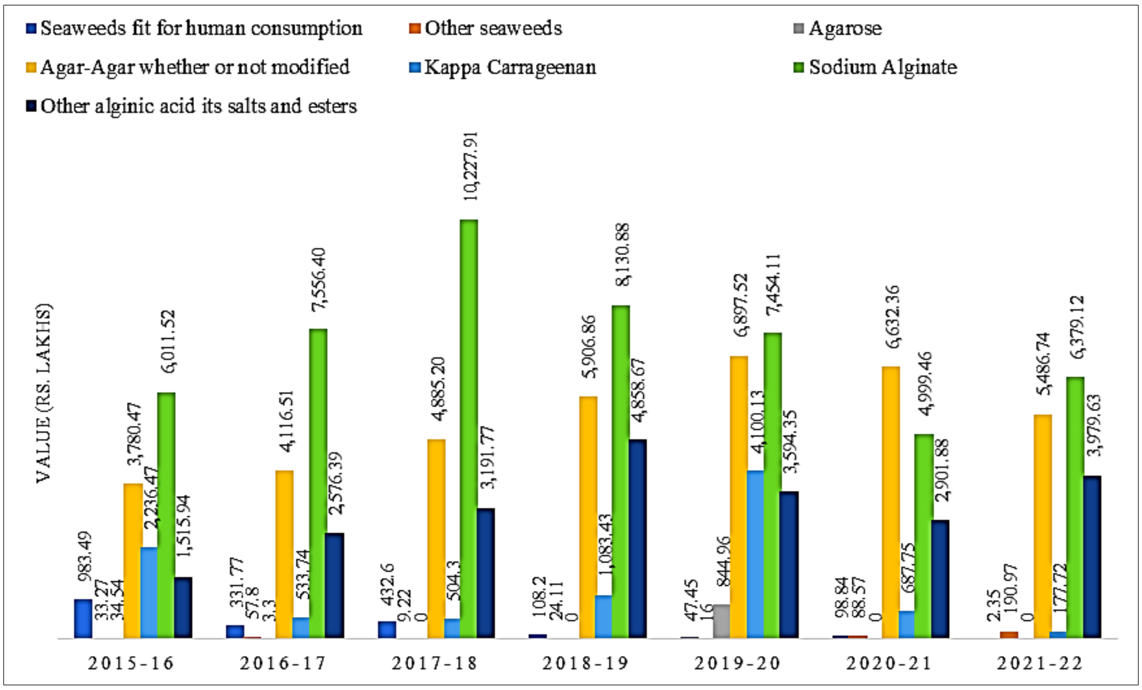

Fig 17: Seaweed imports to India-value (2015-16 to 2021-22) (Source: Tradestat 2022) [51]

17.5 Seaweed species export: Key seaweed species exported from India encompass *Kappaphycus alvarezii*, *Gracilaria spp.*, *Gelidiella acerosa*, *Sargassum spp.*, *Turbinaria spp.*, among others. These exports play a vital role in the global seaweed trade market, contributing to various industries such as food, pharmaceuticals and cosmetics. Detailed information regarding seaweed exports from India during the period spanning from 2015-16 to 2021-22, delineating both quantity and value, is presented in Table 5 and Table 6, respectively (Tradestat, 2022; Anilkumar 2022) [51, 1]. Understanding the export dynamics of these seaweed species can provide valuable insights into market trends and opportunities for further growth and development within the seaweed industry.

Table 5: Seaweed export from India-quantity (2015-16 to 2021-22) (Source: Tradestat 2022) [51]

Products	Quantity ('000 Kg)						
	2015-16	**2016-17**	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
Seaweeds fit for human consumption	N. A.	N. A.	0.64	14.09	N. A.	0.01	0.5
Other seaweeds	N. A.	0.13	0.2	N. A.	N. A.	0.73	52.47
Agarose	0.05	0.19	0.13	0.18	0.06	0.17	0.03
Agar-Agar whether or not modified	141.45	143.14	131.82	129.46	136.15	96.46	131.33
Kappa Carrageenan	2.65	1.65	0	4.03	1.58	1.99	103.47
Sodium Alginate	84.6	92.84	96.7	152.06	58.77	37.9	112.81
Other alginic acid its salts and esters	52.69	43.96	91.72	64.1	20.26	20.14	31.52

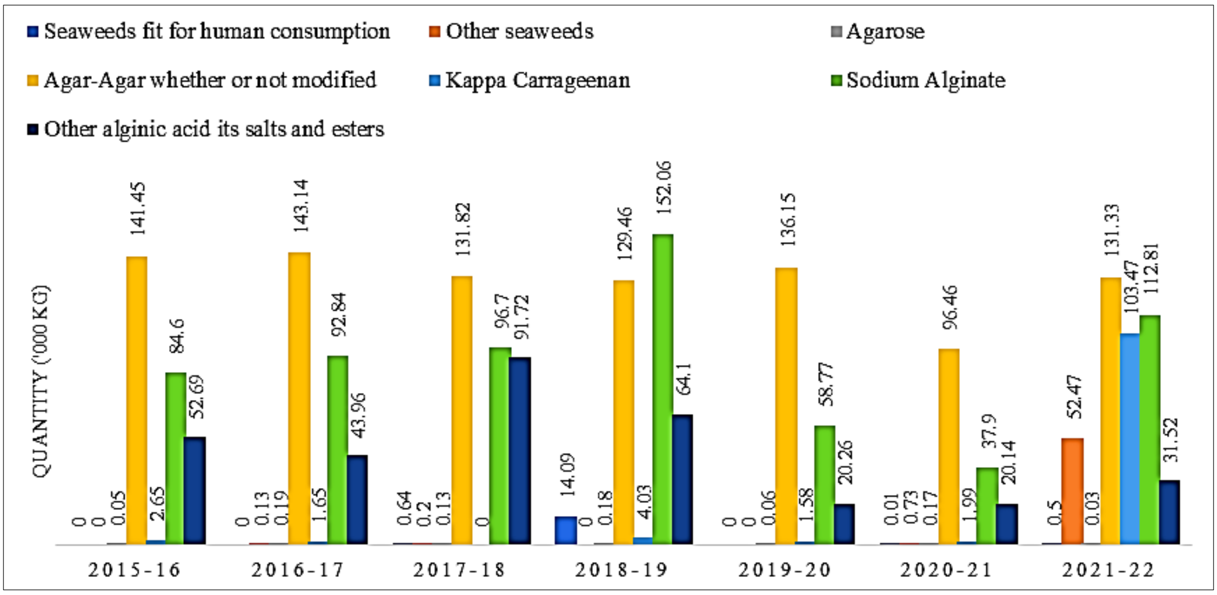

Fig 18: Seaweed export from India-quantity (2015-16 to 2021-22) (Source: Tradestat 2022) [51]

17.6 Human consumption & other seaweeds export
The quantity of seaweeds suitable for human consumption exported from India remained minimal. In 2021-22, a mere 0.50 tons valued at Rs.1.08 lakhs were exported, with a cost of Rs.216/kg. Meanwhile, 52.47 tons of other seaweeds were exported during the same period, totalling Rs.63.59 lakhs, at a cost of Rs.121/- per kg. These other seaweeds were sent to only three countries: the Netherlands (41.75 tons worth Rs.50.93 lakhs), Bangladesh (10.00 tons worth Rs.9.40 lakhs) and New Zealand (0.72 tons worth Rs.3.26 lakhs) (Table 5, Figure 18, Table 6, Figure 21). Agarose export from India remained minimal, with only 0.03 tons worth Rs.6.20 lakhs exported in 2021-22, mainly to Ethiopia (Tradestat 2022; Anilkumar 2022) [51, 1].

17.7 Agar-agar
Agar-agar emerged as the primary seaweed-based product exported from India. Despite a decline in volume from 141.45 tons in 2015-16 to 131.33 tons in 2021-22, the value of exports increased from Rs.1,681.32 lakhs to Rs.1,860.83 lakhs during the same period (Table 5, Figure 18, Table 6, Figure 21). The cost per kg fluctuated from Rs.1,189/- to Rs.1,417/- over the years. Agar-agar found its way to more than eighty countries in 2021-22, with the United Arab Emirates being the top destination, followed by Iran (Tradestat 2022; Anilkumar 2022) [51, 1].

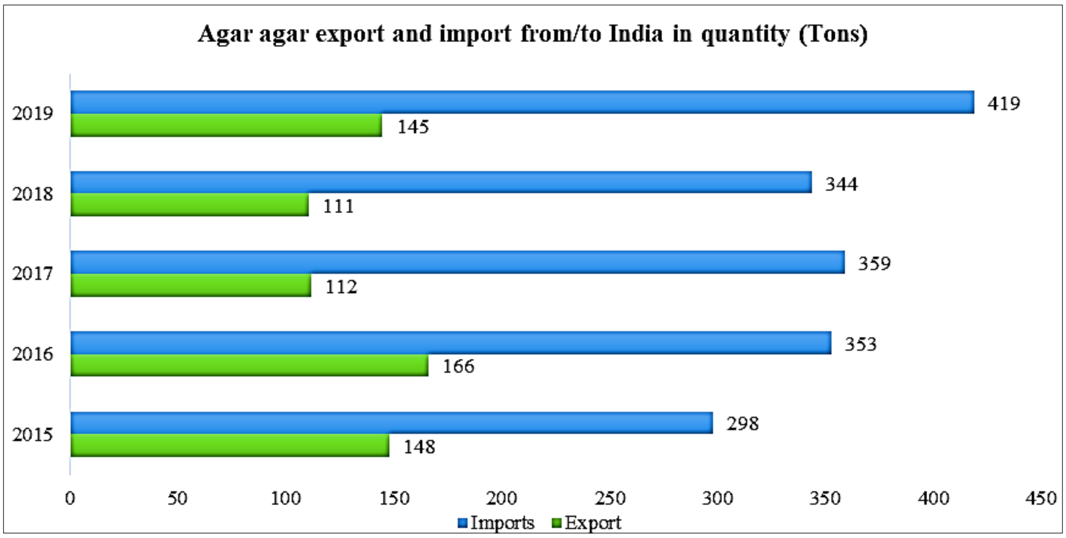

Fig 19: Agar agar export and import from/to India in quantity (tons) (Ranjan 2021) [43]

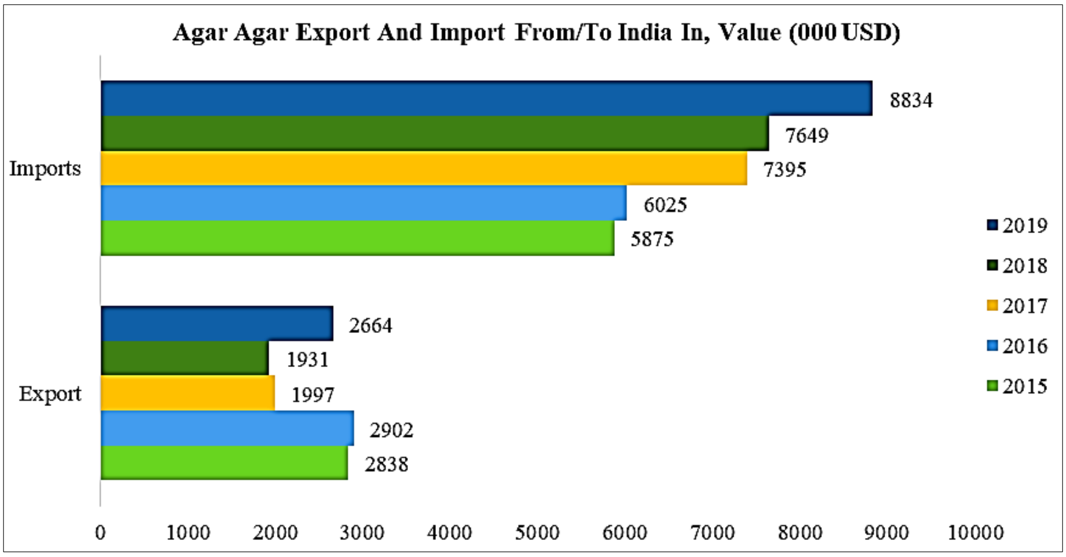

Fig 20: Agar agar export and import from/to India in, value (000 US$) (Ranjan 2021) [43]

17.8 Carrageenan export
The quantity of kappa carrageenan exported from India witnessed a significant surge, escalating from 2.65 tons valued at Rs.16.82 lakhs in 2015-16 to 103.47 tons valued at Rs.115.62 lakhs in 2021-22. Despite the substantial increase in exports, the price per kg of kappa carrageenan declined from Rs.635/- to Rs.112/-. Among the nine countries receiving exports, China emerged as the primary destination in 2021-22, accounting for 97% of volume and 67% of value (Table 5, Figure 18, Table 6, Figure 21).

17.9 Sodium alginate export: During 2021-22, India exported 112.81 tons of sodium alginate valued at Rs.849.57 lakhs, with a cost per kg of Rs.753/-. This product was exported to approximately forty countries, with Algeria being the principal destination, comprising 36% of volume and 39% of value (Table 5, Figure 18, Table 6, Figure 21).

17.10 Other alginic acid salts and esters export
Conversely, a decreasing trend was noted in the quantity of other alginic acid salts and esters exported from India. The

quantity declined from 52.69 tons in 2015-16 to 31.52 tons in 2021-22, while the value rose from Rs.205.04 lakhs to Rs.342.03 lakhs during the same period (Table 5, Figure 18, Table 6, Figure 21). The cost per kg surged from Rs.389/- to Rs.1, 085/-. This product found its way to over twenty countries, with Indonesia leading in terms of quantity (19%) and the Republic of Korea leading in terms of value (21%) (Anilkumar 2022) [1].

Table 6: Seaweed export from India-value (2015-16 to 2021-22) (Source: Tradestat 2022) [51]

Products	Value (Rs. Lakhs)						
	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Seaweeds fit for human consumption	N. A.	N. A.	11.28	13.03	N. A.	0.08	1.08
Other seaweeds	N.A.	1.26	1	N. A.	0.03	2.04	63.59
Agarose	0.43	0.97	1.56	1.28	1.77	2.6	6.2
Agar-Agar whether or not modified	1,681.3	1,742.9	1,470.6	1,580.1	1,749.5	1,342.6	1,860.8
Kappa Carrageenan	16.82	7.24	0.01	25.86	11.46	16.89	115.62
Sodium Alginate	352.15	578.64	709.63	997.2	304.32	271.17	849.57
Other alginic acid its salts and esters	205.04	181.95	338.28	306.33	219.62	181.26	342.03

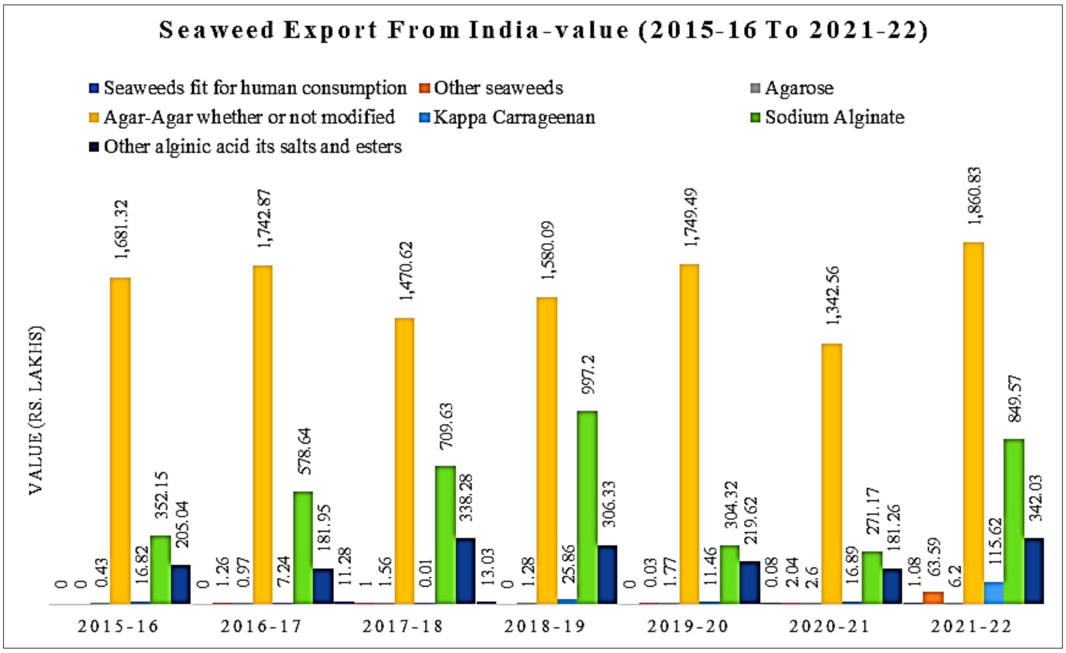

Fig 21: Seaweed export from India-value (2015-16 to 2021-22) (Source: Tradestat 2022) [51]

Trend in Indian Dried Seaweed Exports

India's dried seaweed exports totalled 836 tons in 2009-10, marking the onset of a consistent downward trend in exports there after (Table 7, Figure 22, 23). Over the past six years, export quantities have remained minimal.

Table 7: Export of dried seaweed from India (2009-10 to 2019-20) (Anilkumar 2022) [1]

Year	Quantity (Tons)	Value	
		Rs. lakhs	USD million
2009-10	836	338.55	0.71
2010-11	794	472.32	1.05
2011-12	605	361.22	0.76
2012-13	719	447.58	0.84
2013-14	591	497.36	0.83
2014-15	19	61.09	0.1
2015-16	35	228.01	0.35
2016-17	0	0	0
2017-18	0	0	0
2018-19	0.4	2.5	0.004
2019-20	0	0	0

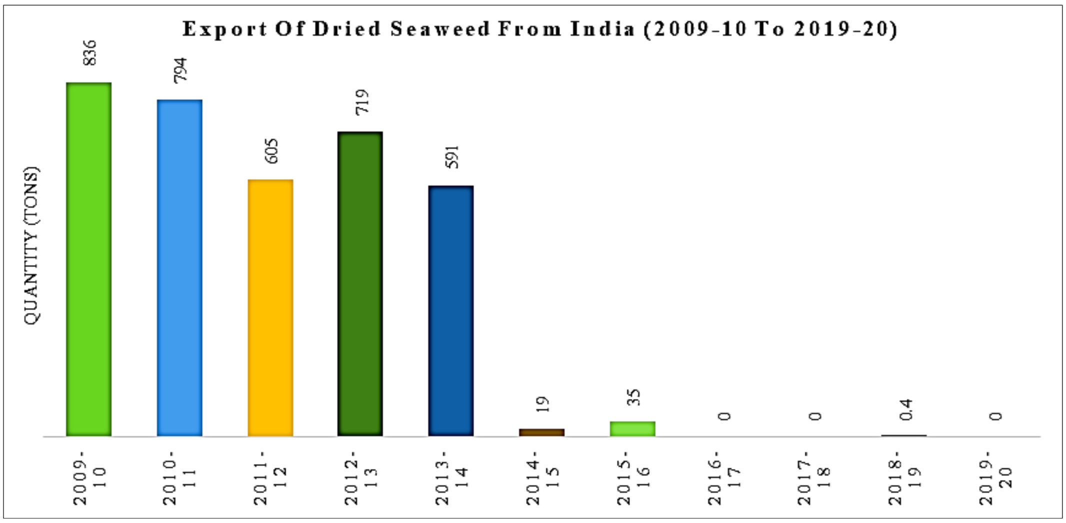

Fig 22: Export of dried seaweed from India (2009-10 to 2019-20) (Anilkumar 2022) [1].

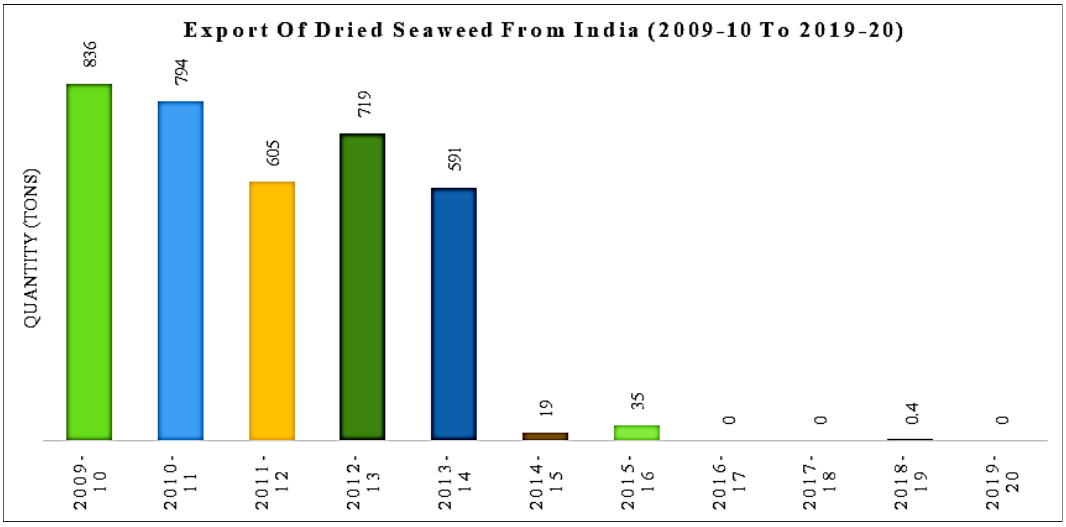

Fig 23: Export (Value Rs. Lakhs) of dried seaweed from India (2009-10 to 2019-20) (Anilkumar 2022) [1]

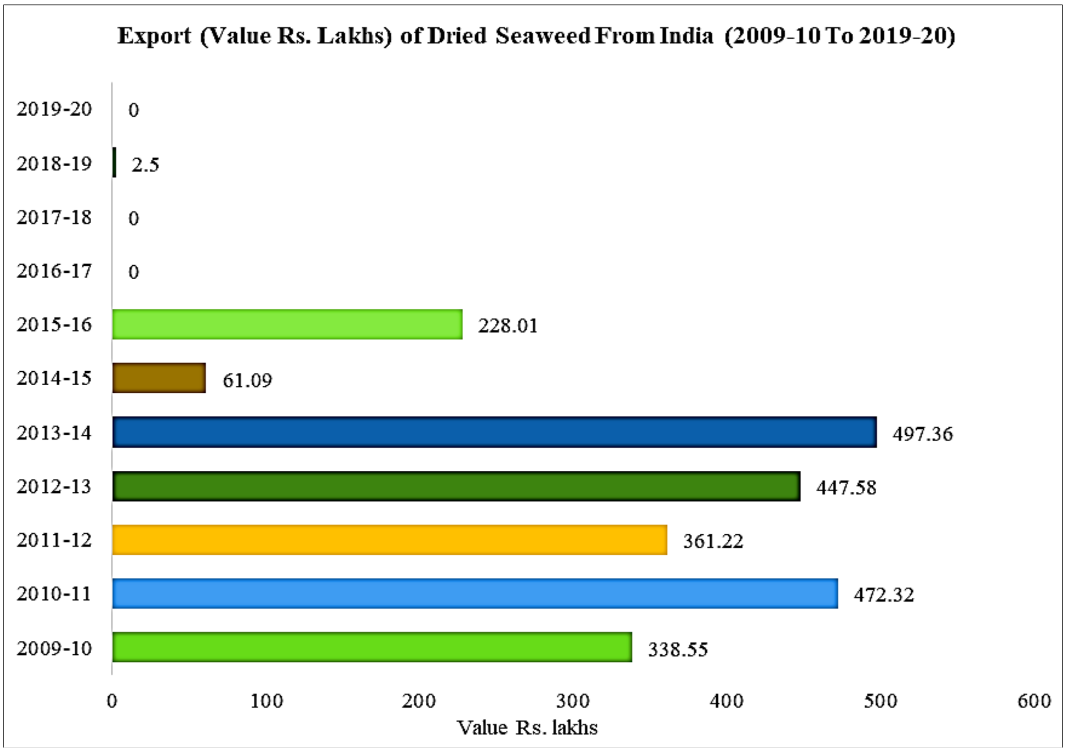

Fig 24: Export (USD million) of dried seaweed from India (2009-10 to 2019-20) (Anilkumar 2022) [1]

19. Seaweed Product Trade

19.1 Agar

Agar production in India originated in the 1940s as a small-scale cottage industry, with Gracilaria edulis serving as the primary raw material. This was later followed by the development of an industrial-scale agar extraction process that utilized Gelidium micropterum Kützing as the source material (Ganesan *et al*., 2019) [19]. The adoption of industrial processing techniques encouraged the establishment of multiple agar-processing units, many of which relied on either Gelidiella acerosa or G. edulis. Owing to the widespread availability of wild stocks of these species, the agar industry experienced substantial growth during the 1960s and 1970s. At present, approximately 25 agar-processing units are operational in India, collectively producing an estimated 300-400 tonnes annually (Ganesan *et al*., 2019) [19].

Food-grade agar accounts for nearly 67% of total domestic agar production, with output increasing steadily until reaching a peak during 2014-2015. However, during this same period, the availability of G. edulis declined markedly as a result of escalating demand from processing industries. This shortage prompted several agar manufacturers to import G. edulis from countries such as Sri Lanka and Indonesia. In addition, wild stocks of Gracilaria salicornia harvested from the Palk Bay region between 2012 and 2015 yielded an average of 400 dry tonnes annually. This biomass was used to produce food-grade agar with a gel strength of approximately 510 g cm^{-2}, meeting much of the domestic demand and commanding higher market prices compared to agar strips (Meena *et al*., 2008) [36].

Production of bacteriological-grade agar in India declined sharply after 2011-2012, reaching a minimum output of around 80 tonnes during 2012-2013. Marine Chemicals, Cochin, remains the dominant producer in this category, accounting for more than 70% of national bacteriological-grade agar production. The company relies entirely on imported raw materials and also procures crude agar from small-scale domestic processors, which is subsequently refined and exported to international markets (Ganesan *et al*., 2019) [19].

India imports agar from nearly 14 countries, with China being the leading supplier, providing approximately 78 tonnes valued at US$3,552,257. In contrast, India exported about 20 tonnes of agar worth US$18,826,473 to Morocco between January and December 2017. A comparison of current agar trade patterns with those from two decades earlier highlights a substantial rise in both import and export volumes and values. In 1997, agar imports were roughly seven times higher in volume (about 12.4 tonnes) and forty-two times greater in value (approximately US$163,342). Over the same period, export volumes increased nearly 198-fold (from about 0.55 tonnes in 1997), while export value rose approximately 149 times, reaching around US$1,907,915 in recent years (Mantri *et al*.)

19.2 Alginate

Alginate extraction takes place from *Sargassum spp*. and *Turbinaria spp*., sourced from wild stocks along the Gulf of Mannar coast. The production of alginate has shown a steady increase from 98 metric tonnes in 2003 to 200 metric tonnes in 2016. A significant player in this industry is SNAP Natural Products and Alginate (P) Ltd., known for producing various alginate products such as those for food, pharmacological, industrial, textile and welding purposes (Ganesan *et al*. 2019) [19].

20. Government Initiatives and Seaweed Sector Development in India

The **Government of India** has been placing increasing emphasis on the development of the seaweed sector to enhance production capacity and support industry growth. In 2018, India's wet seaweed output was approximately 5,300 tonnes, representing only about 0.02% of global production. However, with sustained policy support, national seaweed production is projected to rise sharply to nearly 1,120,000 tonnes by 2025 (Ranjan, 2020; Singh *et al*., 2022) [41, 48]. Since 2017, the Department of Fisheries, Government of India, has provided financial assistance to multiple research institutions for capacity building, farmer training, cultivation support, and the establishment of seaweed processing facilities. During the period from 2017 to 2020, cultivation of *Gracilaria* spp. and *Kappaphycus alvarezii* resulted in wet biomass production of 255.32 tonnes and 201.72 tonnes, respectively. The National Fisheries Development Board disbursed a total of ₹53.55 million under various projects, benefiting nearly 1,000 stakeholders (Ranjan, 2020; Singh *et al*., 2022) [48]. Additionally, under the Pradhan Mantri Matsya Sampada Yojana (PMMSY), an allocation of ₹640 crores has been earmarked for seaweed cultivation initiatives up to the financial year 2024-25.

Seaweed-based biostimulants currently account for approximately 25% of the Indian biostimulant market and are expected to expand significantly, reaching an estimated value of ₹8,500 crores by 2030 at a projected compound annual growth rate (CAGR) of 15%. Despite this growth potential, nearly 75% of biostimulant products used domestically are imported from North America and Europe, largely derived from cold-water marine algal species.

Between 2020 and 2022, approvals under PMMSY enabled the establishment of approximately 54,000 raft-based seaweed culture units across states such as Andhra Pradesh, Gujarat, Karnataka, Maharashtra, and Tamil Nadu. In addition, 63,531 monoline and tube-net seaweed farming units were sanctioned in Andhra Pradesh, Karnataka, Maharashtra, and Tamil Nadu. The National Fisheries Development Board has also played a pivotal role in promoting seaweed farming through training and demonstration programs targeted at fisher communities and women self-help groups, with cumulative financial support amounting to ₹55.173 crores between 2007-08 and 2018-19 (DOF, 2022) [10].

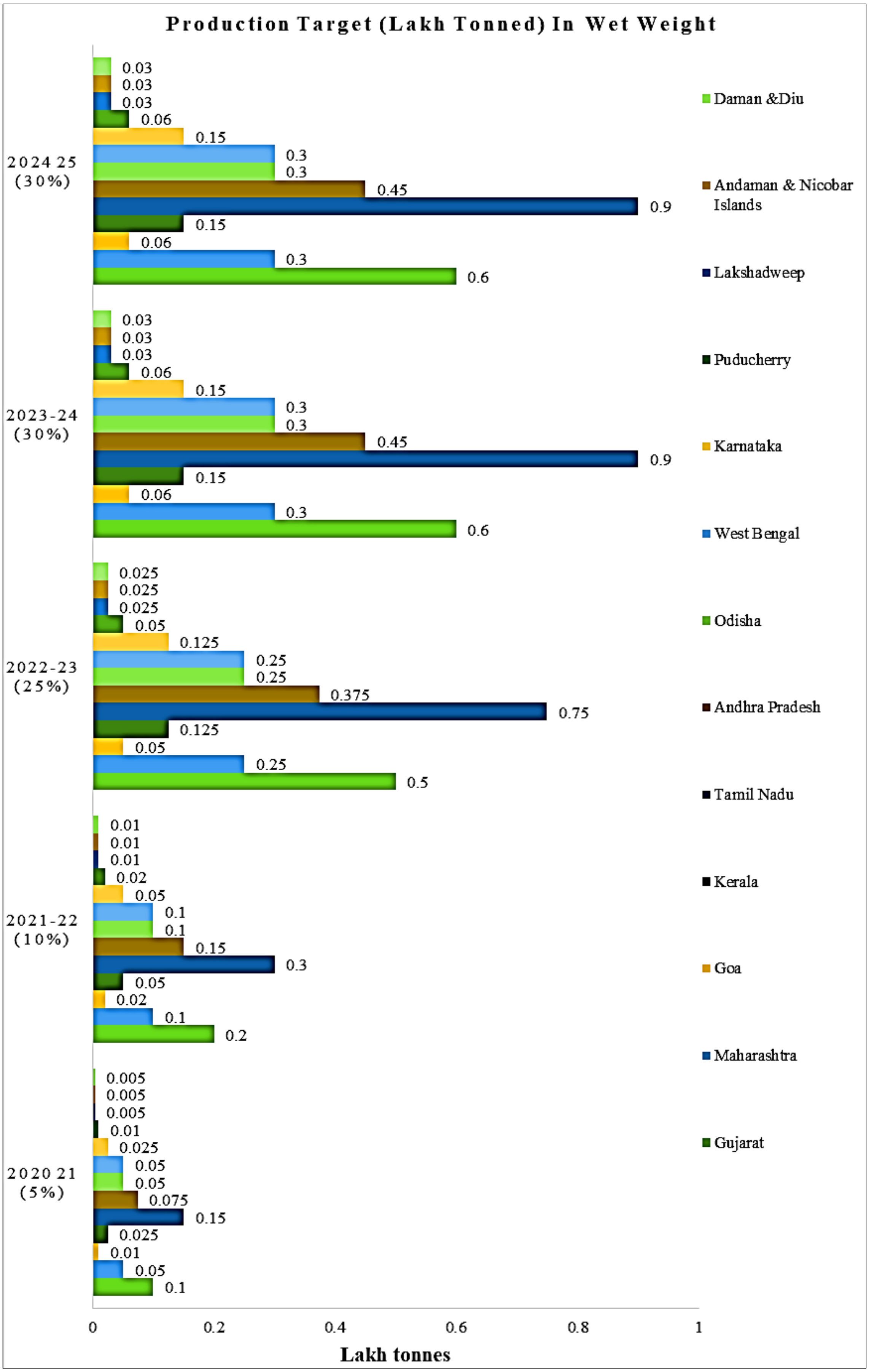

Fig 25: Production target (lakh ton) in wet weight (Source: Ranjan 2021) [43]

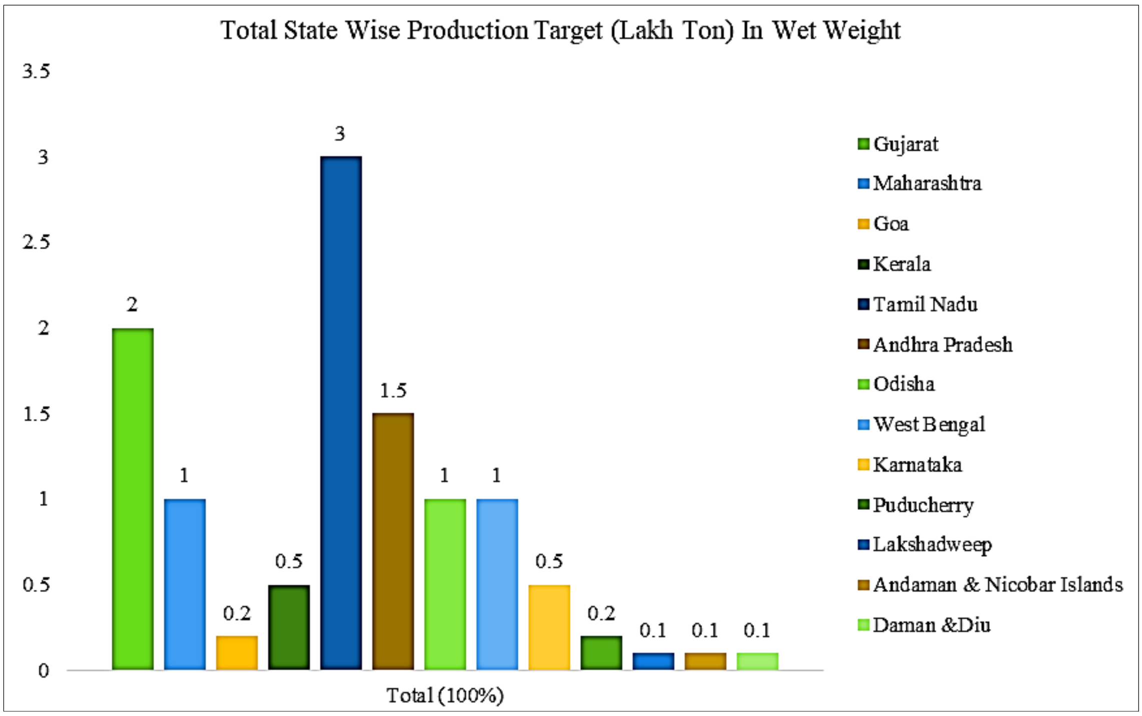

Fig 26: State wise production target (Source: Ranjan 2021) [43]

References

1. Anilkumar PK. Mapping of technologies for value-addition of seaweeds in India. New Delhi: Technology Information, Forecasting and Assessment Council; 2022. Available from: https://www.tifac.org.in/reports-publications/recent-publications/2-
2. Bjerregaard R, Valderrama D, Radulovich R, Diana J, Capron M, McKinnie CA, *et al*. Seaweed aquaculture for food security, income generation and environmental health in tropical developing countries. Washington (DC): World Bank Group; 2016. p.1-16. Available from: https://documents.worldbank.org
3. Bricknell IR, Birkel SD, Brawley SH, Van Kirk T, Hamlin HJ, Capistrant-Fossa K, *et al*. Resilience of cold-water aquaculture: a review of likely scenarios as climate changes in the Gulf of Maine. Reviews in Aquaculture. 2021;13(1):460-503. doi:10.1111/raq.12483
4. Cai J. Global status of seaweed production, trade and utilization. In: Seaweed Innovation Forum Belize. Rome: Food and Agriculture Organization of the United Nations; 2021. Available from: https://www.competecaribbean.org/wp-content/uploads/2021/05/Global-status-of-seaweed-production-tradeand-utilization-Junning-Cai-FAO.pdf
5. Cai J, Lovatelli A, Aguilar-Manjarrez J, Cornish L, Dabbadie L, Desrochers A, *et al*. Seaweeds and microalgae: an overview for unlocking their potential in global aquaculture development. FAO Fisheries and Aquaculture Circular. 2021;(1229). Available from: https://www.researchgate.net/publication/354638626_seaweeds_and_microalgae_an_overview_for_unlocking_their_potential_in_global_aquaculture_development_fao_fisheries_and_aquaculture_circular_nfiac1229_en
6. Chen H, Zhou D, Luo G, Zhang S, Chen J. Macroalgae for biofuels production: progress and perspectives. Renewable and Sustainable Energy Reviews. 2015;47:427-437. doi:10.1016/j.rser.2015.03.086
7. Costello C, Cao L, Gelcich S, Cisneros MA, Free CM, Froehlich HE, *et al*. The future of food from the sea. In: The Blue Compendium: From Knowledge to Action for a Sustainable Ocean Economy. Cham: Springer International Publishing; 2023. p.1-14. doi:10.1038/s41586-020-2616-y
8. Cottier-Cook EJ, Nagabhatla N, Badis Y, Campbell ML, Chopin T, Fang J, *et al*. Safeguarding the future of the global seaweed aquaculture industry. Hamilton: United Nations University Institute for Water, Environment and Health (UNU-INWEH); 2016. 12 p. Available from: https://inweh.unu.edu
9. Data Bridge Market Research. Seaweed extracts biostimulant market set to reach the valuation of USD 2,581.48 million by 2030, size, share, demand, future growth, challenges and competitive analysis. GlobeNewswire News Room. 2023 May 17. Available from: https://www.globenewswire.com
10. Department of Fisheries, Ministry of Fisheries, Animal Husbandry and Dairying, Government of India. Promotion of seaweed cultivation in India. Matsya Sampada Newsletter (Jul-Sep 2022):1-3. Available from: https://dof.gov.in
11. Duarte CM, Wu J, Xiao X, Bruhn A, Krause-Jensen D. Can seaweed farming play a role in climate change mitigation and adaptation? Frontiers in Marine Science. 2017;4:100. Available from: https://www.frontiersin.org/articles/10.3389/fmars.2017.00100
12. Eikeset AM, Mazzarella AB, Davíðsdóttir B, Klinger DH, Levin SA, Rovenskaya E, *et al*. What is blue growth? The semantics of sustainable development of marine environments. Marine Policy. 2018;87:177-179. doi:10.1016/j.marpol.2017.10.019
13. Food and Agriculture Organization of the United Nations. The state of world fisheries and aquaculture 2020: sustainability in action. Rome: Food and Agriculture Organization of the United Nations; 2020.

Available from: https://www.fao.org/3/cb1213t/cb1213t.pdf
14. Food and Agriculture Organization of the United Nations. FAO global fishery and aquaculture production statistics (FishStatJ). Rome: Food and Agriculture Organization of the United Nations; 2021. Available from: https://www.fao.org/fishery/statistics/software/fishstatj/en
15. Food and Agriculture Organization of the United Nations. Good hygiene practices and HACCP. Rome: Food and Agriculture Organization of the United Nations; 2022a. Available from: https://www.fao.org/food/food-safety-quality/capacity-development/haccp/en
16. Food and Agriculture Organization of the United Nations. The state of world fisheries and aquaculture 2022: towards blue transformation. Rome: Food and Agriculture Organization of the United Nations; 2022b. Available from: https://www.fao.org/documents/card/en/c/cc0461en
17. Food and Agriculture Organization of the United Nations. Global fisheries and aquaculture at a glance. Rome: Food and Agriculture Organization of the United Nations; 2023. Available from: https://www.fao.org/3/cc0461en/online/sofia/2022/world-fisheries-aquaculture.html
18. Ferdouse F, Holdt SL, Smith R, Murua P, Yang Z. The global status of seaweed production, trade and utilization. Rome: Food and Agriculture Organization of the United Nations; 2018. Available from: https://backend.orbit.dtu.dk/ws/portalfiles/portal/163078059/FAO_report_Global_seaweed_2018.pdf
19. Ganesan M, Trivedi N, Gupta V, Madhav SV, Radhakrishna Reddy C, Levine IA. Seaweed resources in India current status of diversity and cultivation: prospects and challenges. Botanica Marina. 2019;62(5):463-482. doi:10.1515/bot-2018-0056
20. World Bank. Global seaweed new and emerging markets report 2023. Washington (DC): World Bank; 2023. Available from: https://www.worldbank.org/en/topic/environment/publication/global-seaweed-new-and-emerging-markets-report-2023
21. Hatch Innovation Services. HATCH seaweed insights. 2023. Available from: https://seaweedinsights.com
22. Hwang EK, Yotsukura N, Pang SJ, Su L, Shan TF. Seaweed breeding programs and progress in eastern Asian countries. Phycologia. 2019;58(5):484-495. doi:10.1080/00318884.2019.1639436
23. Jacquet JL, Pauly D. The rise of seafood awareness campaigns in an era of collapsing fisheries. Marine Policy. 2007;31(3):308-313. doi:10.1016/j.marpol.2006.09.003
24. Johnson J, Ignatius B. Seaweed farming in India: progress and prospects. Indian Farming. 2020;70(11). Available from: https://www.indianfarming.org
25. Joseph MM, Jayaprakash AA. Status of exploited marine fishery resources of India. Kochi: Central Marine Fisheries Research Institute; 2003. 157 p. Available from: https://www.cmfri.org.in
26. Kaladharan P, Johnson B, Sulochanan B. Mariculture of *Kappaphycus alvarezii* in the coastal waters of Palk Bay: crisis due to climate change or carrying capacity? Journal of the Marine Biological Association of India. 2019a;61(2):105-108.
27. Kaladharan P, Johnson B, Nazar AA, Ignatius B, Chakraborty K, Gopalakrishnan A. Perspective plan of ICAR-CMFRI for promoting seaweed mariculture in India. Marine Fisheries Information Service: Technical and Extension Series. 2019b;(240):17-22.
28. Kim JK, Yarish C, Hwang EK, Park M, Kim Y, Kim JK, *et al*. Seaweed aquaculture: cultivation technologies, challenges and its ecosystem services. Algae. 2017;32(1):1-13. doi:10.4490/algae.2017.32.3.3
29. Kraan S. Mass-cultivation of carbohydrate-rich macroalgae, a possible solution for sustainable biofuel production. Mitigation and Adaptation Strategies for Global Change. 2013;18:27-46. doi:10.1007/s11027-010-9275-5
30. Krause-Jensen D, Duarte CM. Substantial role of macroalgae in marine carbon sequestration. Nature Geoscience. 2016;9(10):737-742. doi:10.1038/ngeo2790
31. Lok Sabha Secretariat. Twenty-seventh report of the Standing Committee on Agriculture (17th Lok Sabha) on the Demands for Grants (2021-2022) of the Ministry of Fisheries, Animal Husbandry and Dairying. New Delhi: Government of India; 2021. Available from: https://loksabha.nic.in
32. Makkar HP, Tran G, Heuzé V, Giger-Reverdin S, Lessire M, Lebas F, *et al*. Seaweeds for livestock diets: A review. Animal Feed Science and Technology. 2016;212:1-17. Available from: https://doi.org/10.1016/j.anifeedsci.2015.09.001
33. Mantri VA, Ganesan M, Gupta V, Krishnan P, Siddhanta AK. An overview on agarophyte trade in India and need for policy interventions. Journal of Applied Phycology. 2019a;31:3011-3023. Available from: https://doi.org/10.1007/s10811-019-01830-8
34. Mantri VA, Kavale MG, Kazi MA. Seaweed biodiversity of India: Reviewing current knowledge to identify gaps, challenges and opportunities. Diversity. 2020;12(1):13. Available from: https://doi.org/10.3390/d12010013
35. Mathew S, Ravishankar CN. Seaweeds as a source of micro and macro nutrients. Indian Journal of Geo-Marine Sciences. 2018;47(02):235-241. Available from: https://nopr.niscpr.res.in/handle/123456789/43230
36. Meena R, Prasad K, Ganesan M, Siddhanta AK. Superior quality agar from *Gracilaria* species collected from the Gulf of Mannar, India. Journal of Applied Phycology. 2008;20:397-402. Available from: https://doi.org/10.1007/s10811-007-9264-2
37. Megarajan S, Ranjan R, Xavier B, Suresh RD, Ghosh S, Edward L, *et al*. Seaweed farming potential and reality in Andhra Pradesh coast. Aquaculture Spectrum. 2021;3(10):31-35. Available from: https://aquaculturespectrum.com
38. Mustafa S, Estim A, Shaleh SRM, Shapawi R. Positioning of aquaculture in blue growth and sustainable development goals. Aquacultura Indonesiana. 2018;19(1):1-9. Available from: https://doi.org/10.21534/ai.v19i1.105
39. National Oceanic and Atmospheric Administration Fisheries. Seaweed aquaculture. NOAA Fisheries; 2020. Available from:

https://www.fisheries.noaa.gov/national/aquaculture/seaweed-aquaculture
40. Nozaki S. Seaweed: A high-profile material for decarbonization—signs of supply chain transformation. 2023. Available from: https://www.voltagreentech.com/solution/
41. Purcell E, Quintero JP. Kelponomics: A comprehensive analysis of the global seaweed industry with sustainable strategies for growth in the Icelandic market. 2024. Available from: https://www.kelponomics.com
42. Ranjan R. Pradhan Mantri Matsya Sampada Yojana to bring "Aatma Nirbhar Bharat" in fisheries and aquaculture. Indian Farming. 2020;70(11):54-56. Available from: https://icar.org.in
43. Ranjan DR. International webinar: Entrepreneurship development on seaweed business by cooperatives. Department of Fisheries, Government of India; 2021. Available from: https://www.youtube.com/watch?v=IIukHf5fbjY
44. Sahoo D, Sahu N, Sahoo D. A critical survey of seaweed diversity of Chilika Lake, India. Algae. 2003;18(1):1-12. Available from: https://www.e-algae.org
45. Seaweed hydrocolloid market share, trend and forecast. Future Market Insights; 2023. Available from: https://www.futuremarketinsights.com/reports/seaweed-hydrocolloid-market
46. Seaweed Insights. Global production overview. 2022. Available from: https://seaweedinsights.com/global-production/
47. Seaweed markets analysis: Farmed seaweed carbon crediting and novel markets. The Nature Conservancy; 2023. Available from: https://www.nature.org
48. Singh PM, Maity D, Saha S, Dhal NK. Seaweed utilization and its economy in Indian agriculture. Materials Today: Proceedings. 2022;65:63-69. Available from: https://doi.org/10.1016/j.matpr.2022.04.595
49. Skjermo J, Aasen IM, Arff J, Broch OJ, Carvajal AK, Christie HC, *et al*. A new Norwegian bioeconomy based on cultivation and processing of seaweeds. 2014. Available from: https://www.sintef.no
50. Tandel KV, Joshi NH, Tandel GM, Patel M, Tandel JT. Seaweed cultivation in India: A new opportunity of revenue generation. Advances in Life Sciences. 2016;5:2487-2491. Available from: https://www.advancesinlifesciences.net
51. Tradestat. Export Import Data Bank. Department of Commerce, Government of India; 2022. Available from: https://tradestat.commerce.gov.in/eidb/
52. United Nations Conference on Trade and Development. Plastic pollution: The pressing case for natural and environmentally friendly substitutes to plastics. UNCTAD; 2023b. Available from: https://unctad.org/publication/plastic-pollution-pressing-case-natural-and-environmentally-friendly-substitutes
53. United Nations Conference on Trade and Development, Food and Agriculture Organization. Building a sustainable and resilient ocean economy. 2022. Available from: https://unctad.org
54. United Nations Conference on Trade and Development. Ocean goods trade statistics. UNCTADStats; 2022. Available from: https://unctadstat.unctad.org
55. United Nations Conference on Trade and Development. Trade and Environment Review: Building a sustainable and resilient ocean economy beyond 2030. 2023a. Available from: https://unctad.org
56. United Nations Conference on Trade and Development. An ocean of opportunities: The potential of seaweed to advance the SDGs. 2024. Available from: https://unctad.org
57. Venkataraman K, Raghunathan C. Coastal and marine biodiversity of India. In: Marine faunal diversity in India. Academic Press; 2015. p.303-348. Available from: https://doi.org/10.1016/B978-0-12-801948-1.00019-7
58. World Bank. What is food security? 2023. Available from: https://www.worldbank.org/en/topic/agriculture/brief/food-security-update/what-is-food-security
59. World Bank Group. Seaweed aquaculture for food security, income generation and environmental health in tropical developing countries. World Bank; 2016. Available from: https://doi.org/10.1596/24919