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Research Article

An Appraisal of Seaweed Industry in India at Global Level: Impact on Livelihood and Environment and Future Prospects

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ABSTRACT

The rapid growth of the global population has emphasized the necessity of searching the existing resource for novel bioactive compounds. Seaweeds are marine macroalgae reported to possess pronounced bioactive compounds ascertained with remarkable properties that attributes to their biological functionality. The market demand of seaweed has spurred in light due to their impeccable properties to act as gelling, emulsifying and stabilising agents which are widely exploited in the field of food, pharmaceutics, biomedicine and cosmetics. There exists a requisite to expand seaweed cultivation on a larger scale globally to explore their bioactive constituents which significantly contribute to raise global economy. Seaweed industry emerged as a fast-growing sector and provides livelihood to millions of people around the world. Moreover, the incorporation of seaweed in functional foods and nutraceuticals can pave the way for diminishing the concerns of malnutrition, especially in developing countries. Consequently, the development of the seaweed industry sheds new insights in the field of pharmaceutics and biomedicine. In this review, the utilisation of seaweeds, the growth of seaweed industry, production trends of seaweeds are cited. It also gives a comprehension about the consumer perception of seaweed-based products, the role played by women in the cultivation of seaweeds along with the future research aspects and challenges in the seaweed industry.

Keywords: Challenges, Livelihood, Production, Seaweed industry, Seaweed resources

INTRODUCTION

Seaweed market is a rising domain that's projected to hit $26 billion globally by 2025. Seaweeds, the promising herbs of the millennium (Dhargalkar and Pereira, 2005) are marine macroalgae residing exclusively in oceanic realm which are harvested world-wide and are sourced for a variety of purposes, comprising food for humans (McHugh, 2003). Being regarded as an assuring source for food, fodder, and bio-based economy, seaweeds are

utilised widely in the field of food, pharmaceutics, biomedicine and cosmetics industries. Being the primary producers in the ecosystem, they are ubiquitously distributed from the tropics to the polar. The four main classes of seaweeds include Chlorophyta (green algae), Phaeophyta (brown algae), Rhodophyta (red algae), and Cyanophyta (blue-green algae). Seaweeds provide a means of economic as well as ecological importance (Rameshkumar and Rajaram, 2019).

Seaweeds are one of the recent renewable sources as food, energy, chemicals and medicines. They act as an important resource of raw material for various diligences such as health food, medicines, pharmaceuticals, textiles, fertilizers and fodder. The main utilisation of seaweed is for the production of agar, alginates and carrageenan. The important polysaccharides extracted from seaweeds are agar, algin and carrageenan. Agar is extracted from red algae such as Gracilaria, Gelidium, Gelidiella and Pterocladia. Carrageenan is extracted from Eucheuma, Gigartina and Hypnea. Algin is obtained from brown algae like Sargassum and Turbinaria, Ascophyllum, Cystoseira, Laminaria, Macrocystis. These polysaccharides are found to have more than 200 industrial uses. Alginic acid, mannitol, laminarin, fucoidan and iodine are some of the chemicals commercially extracted from brown seaweeds. The alginates having an excellent range of viscosity, gelling properties and non-toxicity are used in the manufacture of the pharmaceuticals, cosmetics, paper and processed foods. Some of the substances extracted from red seaweeds include agar-agar, agarose and carrageenan which are used extensively in many industries. One of the greatest uses of agar is in the food preparation and as a purgative or as an outer cover of capsules in the pharmaceutical industry. Seaweeds are considered as one of the important marine living resources which occurs in the intertidal, shallow, and deep waters of the sea, up to 150m in depth and also in estuaries.

For centuries, seaweeds have been alleged only as a food source mainly for the coastal communities unaware of the wide range of properties and benefits possessed by the marine algae. But as time evolved both the medicinal and industrial properties of seaweeds were perceived and they found a prominent position in many applications for human welfare. Apart from the various industrial uses, seaweeds possess a renowned place in improving the nutritional status of communities due to the richness in antioxidants, micronutrients, macronutrients and vitamin (B12, A, K) in higher concentrations than land plants. The protein content of the seaweeds varies from species to species. The brown seaweeds account for a lesser protein content whereas the green and red seaweeds have a higher protein content. In red seaweeds like *Palmaria palmata* (dulse) and *Porphyra tenera* (nori), it was found that 35 and 47% of the dry matter were composed of protein. Thus, these two species are used extensively and exploited to a great extent. Recent research points out new opportunities in the field of medicines associated with bioactive molecules extracted from seaweed. Being rich in minerals, vitamins, trace elements and bioactive substances, seaweeds are called the medicinal food of the 21st century.

Seaweed Utilisation: A Historical Approach

In the seventeenth century, Japan marked the origin of intensive cultivation of seaweed when the rising demand could not be met by the supply of Nori (*Porphyra yezoensis*), a flat blade-like red seaweed which had been in use in Japan as a staple food source over two thousand years and more. The increased requirement for culture of seaweed was observed with development of the latest cultivation methods followed after World War II. The prevalent marine aquaculture industry in Japan is represented by the cultivation of Nori (*Porphyra yezoensis*). A value of US$1.5 billion has been fetched for a total of 350,000 tons which were cultivated every year in Japan. the 1950s marked the cultivation of seaweeds in China. *Laminaria japonica* or the ribbon seaweed was among the first species to be cultivated in China. The production of them had risen from 62 tons in 1952 to a current harvest in excess of 3.5 million MT. Asia is considered as the leading producer of seaweeds in which about 80% is being funded by China, Korea and Japan. The Philippines and South East Asia (SEA) initiated the farming

of eucheuma seaweeds in 1969 and was subsequently initiated in Indonesia (Valderrama *et al.,* 2013). Tanzania accounts for the commercial harvest of Eucheuma seaweeds in East Africa (Mshigeni, 1984).

The year 1966 marked the exploitation of seaweeds in India on a commercial basis (Silas and Kalimuthu, 1987). The coast of Tamil Nadu and Gujarat and around Lakshadweep and Andaman and Nicobar Islands has an abundant growth of seaweeds in India. Mumbai, Ratnagiri, Goa, Karwar, Varkala, Vizhinjam and Pulicat in Tamil Nadu and Chilka in Orissa also account for the rich seaweed sources found in the coastal areas. About 60 species of commercially important seaweeds were found important among 700 species of marine algae found in intertidal and deep-water regions of the Indian coasts. *Gelidiella acerosa* and *Gracilaria* sp. are the agar yielding red seaweeds which are collected throughout the year and *Sargassum* and *Turbinaria* are the algin yielding seaweeds which are gathered seasonally from August to January on the Southern coast. The intertidal and sub tidal regions in Gujarat harbours are abundant seaweed resources on the west coast which possibly have a great potential for the development of seaweed-based industries in India (Mohamed, 2015). In Tamil Nadu, about 30-40% of the coastline has drift seaweeds (Subba Rao and Mantri, 2006). The seaweed industry, thus has evolved into a prominent industry by almost doubling its production of approximately 30 billion tons per year (Mac Monagail *et al.,* 2017). The two species of tropical red algae namely *Eucheuma denticulatum and Kappaphycus alvarezii*, cultured for carrageenan, accounts for a substantial part of the global seaweed production (Buschmann *et al.,* 2017).

Seaweed Industries

The coastal zones worldwide are being exploited to a greater extent to meet the developing demands for marine foods, commodities and other products. The flourishing population in the world has put pressure on the need for creating alternative sources of fish production. Along with procuring wild seaweeds, aquaculture has evolved as a steadily and rapidly growing industry to meet these demands for seaweed. It was in the last decade when the seaweed industry increased its production to two-fold and had transformed into a prosperous industry in which the yearly production accounted for approximately 30 billion tons (Mac Monagail *et al.,* 2017).

The red algal species like *Kappaphycus* and *Eucheuma* are mainly cultivated and exploited for the extraction of carrageenan from them which is used extensively in processed food and cosmetics (Rimmer *et al.,* 2013). Seaweed farming to support the industry is considered as one of the most environmentally friendly forms of culture methods since it involves an insignificant amount of fertilizers. Seaweed farming for production of agar, alginates and carrageenan is usually endorsed as an efficient method for sustainability in aquaculture for coastal folks especially in the developing countries (Sievanen *et al.,* 2005).

Seaweeds can be utilized for biofuel production. In a study by Sondak *et al*. (2017), Seaweed Aquaculture Beds (SAB) are used extensively to mitigate carbon dioxide in many Asian countries including China, India, Indonesia, Japan, Malaysia, Philippines, Republic of Korea Thailand, and Vietnam, and is in an early stage in Australia and New Zealand. The study clearly detailed on the aspect of carbon accumulation by increasing the area for seaweed beds and emphasised that a subsequent reduction of fossil fuels and reduction of carbon dioxide emissions can be made possible by converting the biomass of seaweeds to biofuels.

The monoculture of seaweed has flourished over the years since they are at the bottom in the food chain, relatively low input is required for the extraction of their nourishment from the sea. *Laminaria japonica*, which constitutes over half of the world's aquatic plant production is cultured on long-line ropes in the coastal waters of China (Fei *et al.,* 1999). It was only towards the culmination of the 20th century, the idea of utilising algae as the nutrient scrubbers in the integrated culture of finfish, shellfish and crustaceans became recommenced and hence was later realized the importance of recycling waste by algae as one of the efficient and

economical measures to improve world mariculture sustainability. The removal of the wastes from seaweeds is usually sided with the help of two categories namely the open water and land-based cultivation system wherein the disposal and removal of wastes are difficult to control in the open water systems. The cultured as well as wild seaweeds are effectively utilized for human consumption or in industries.

One of the recent advancements from seaweeds is the area of development of ecological and sustainable feeds. Hence the aspect of the co-culture system between the seaweed and the shrimp is gaining worldwide acceptance. In this outlook, a study was conducted in which the green seaweeds were provided as food source on *Penaeus vannamei* intestinal bacterial communities. The bacteria were fed with different kinds of diet formulations as a trial for a period of 4 weeks. The diet formulations included only pellet, only *Ulva clathrate, Ulva clathrate* and pellet, only *Ulva lactuca* and *Ulva lactuca* and pellet. After the trial, a significant increase in final weight, weight gain and SGR were obtained for those fed with the green seaweeds rather than the pellet alone and a higher abundance of gut microbes were also found in them. This shows the growing importance of seaweeds in aquaculture integrated systems (González *et al.,* 2020).

In India seaweeds are naturally found and grown across the coasts of Tamil Nadu and Gujarat coasts. The seaweed culture in India provides occupation for various coastal communities. Farming of seaweed is mainly done by single rope floating raft method, fixed bottom long line method and Integrated Multi Trophic Aquaculture (IMTA) method. The seaweed farming in India is mainly initiated by Central Salt and Marine Chemical Research Institute (CSMCRI) and Marine Algal Research Station (MARS), Mandapam, Tamil Nadu. They developed sustainable methods for the cultivation of seaweeds like *Gracilaria edulis* and *Gelidiella acerosa* which are widely used in food and pharmaceutical industries and have good demand in the market. The current seaweed cultivation in India originally emerged from a strain of *Kappaphycus alvarezii* (Doty) from the Philippines that was obtained by Central Salt and Marine Chemical Research Institute (CSMCRI) in 1984 (Mantri *et al.,* 2017). Gujarat initiated outdoor culture with out-planting experiments at Port Okha during 1989-1996. Consequently during 1995-1997, various experimental trials were carried out at Mandapam, Tamil Nadu (Eswaran *et al.,* 2002). One of the main difficulties confronted in the agar industry in India is the poor quality of raw material (Kaladharan and Kaliaperumal, 1999).

Seaweed Production

In 2005, global seaweed production totalled 14.7 million tonnes, of which the culture sector contributed 13.5 million tonnes, while the harvest from the wild was vaguely above 1.2 million tonnes. After a decade in 2015 the total production was multiplied to 30.4 million tonnes, with the culture and capture sectors contributing 29.4 million tonnes and 1.1 million tonnes respectively. Apart from wild harvest of seaweed from open seas and waterbodies, seaweed also is cultivated on a wide scale in many regions of the world. The red seaweeds namely *Kappaphycus* and *Eucheuma* dominates the worldwide seaweed culture followed by the brown algae *Laminaria*. The cultivation of *Kappaphycus* and *Eucheuma* on a global extent started in Philippines during the 1960's with the first commercial production in 1970's. In 2018, the top 10 countries produced 96% of the global total of 2,165,675 metric tons. Asia stands as the world leader in seaweed cultivation and more than 80% is contributed by China, Korea and Japan.

Seaweeds dominate the production of aquatic plants. In the recent scenario, the global seaweed processing industry is one of the major growing industries in the world. It is estimated that about 27 million tonnes of seaweeds are utilised annually, collected either as wild harvest or cultivated in onshore or offshore farms, where the bulk production is mainly contributed from aquaculture. In 2015, the production of seaweeds was about less than five percent from wild harvest, done by harvesting of seaweeds by hand or collection of beach cast/ drift algae. The macroalgal products have a large and diverse range of applications. The seaweed hydrocolloid industry, mainly agar, alginate and carrageenan, showed 2-3% growth per year wherein the

raw material and production aspects were dominated by Asia-Pacific region. The seaweed industry is estimated to have an annual value of US$4.8 billion, in which human food products contribute the largest share and US$1.058 billion is mainly based on seaweed hydrocolloids (Porse and Rudolph, 2017). Globally, about 221 species of seaweeds are utilised, with 145 for food and 101 for phycocolloid production which includes 32 chlorophytes, 125 rhodophytes and 64 phaeophyta (Zemke-White and Ohno, 1999). The most intensively cultivated seaweeds include the brown algae *Laminaria japonica, Undaria pinnatifida* and the red algae namely *Porphyra* spp., *Euchema* spp., *Kappaphycus alverezi* and *Gracilleria* spp.

Seaweed Resources in India

It has been reported that from Indian waters a standing crop of 16,000 MT of Sargassum and Luminaria has been produced every year. The total production of seaweed from India was 6 lakh tonnes in 2000. The annual production of dry agar ranges from 110 to 132 MT whereas the algin production ranges between 360 to 540 MT.

Indian seaweed industry suffers from absence of infrastructure facilities at commercial level and lack of policy support hinders augmenting production with high yielding varieties. The potential annual production of seaweed from India is 87,000 MT and the nation can be one among the highest producers in the world. However, the present production is only 2.5% of the estimated potential. The dispensation of macro-algae is limited to agar-agar and factories are working at 50% capacity. Seaweeds are found in abundance along the Tamil Nadu and Gujarat coasts, Lakshadweep and Andaman and Nicobar Islands. Rich seaweed beds are found around Mumbai, Ratnagiri, Goa, Karwar, Varkala, Vizhinjam and Pulicat in Tamil Nadu and Chilka in Orissa. Out of approximately 700 species of marine algae found in both inter-tidal and deep-water regions of the Indian coast, nearly 60 species are commercially important.

The seaweed industry in India is mostly a cottage industry centred only on the natural stock of agar-yielding red seaweeds, mainly *Gelidiella acerosa* and *Gracilaria edulis*, and algin yielding brown seaweeds species like *Sargassum* and *Tubineria*. Agar yielding red seaweeds such as *Gelidiella acerosa* and *Gracilaria* sp. and algin yielding brown algae such as *Sargassum* and *Turbinaria* are collected throughout the year and seasonally from August to January on Southern coast, respectively. Natural stocks of seaweed are usually insufficient to congregate the industrial demand. Seaweed cultivation on a commercial scale can help to reduce the demand-supply gap. Joining hands with CSMCRI, research organisations like Central Marine Fisheries Research Institute (CMFRI), Gujarat Livelihood Promotion Company (GLPC) and other institutes are engaged in research and development of seaweed farming. Small farmers residing near the coast are motivated to take up seaweed cultivation, thus benefiting from not just high value-added incomes but nutrition. ICAR-Central Institute of Fisheries Technology, Cochin is engaged in active research on value added products from seaweeds.

Role of Women in Seaweed Sector

Wild harvesting of seaweed

Manual collection/harvesting of seaweed from the natural habitat is a source of livelihood especially for coast-based women. Around 5000 women in coastal villages of Ramanathapuram, Tuticorin, Kanyakumari. In Ramanathapuram district of Tamil Nadu coast, women venture into the sea for harvesting indigenous seaweed – Gelidium or Marikoluthupaasi and Gracilaria or Korai paasi. These are red seaweeds used in the manufacture of agar – a gelatinous substance which is sourced as a thickener in foods like jellies and desserts – as well as to make a liquid fertiliser. Seaweed harvesting is the only source of livelihood for women living in the state's remote fishing villages, which have little, if any, access to metalled roads and public transportation. The women venture into the sea at least 12 days a month except during the fish breeding season in April, May and June. Around 2000 women are involved in the wild harvest of seaweed from Pamban to Tuticorin stretch in Tamil Nadu.

Women carry protective gear, clothes and a net bag, and join a group of women – aged between 30 years and 60

years head towards the sea, where they catch boats to take them to the nearby islands. These are goggles for their eyes, strips of cloth wound around their fingers, and rubber slippers to prevent their feet from being cut on sharp rocks. Braving strong winds and powerful currents, they stay in the water for nearly six hours till they have filled their bags with seaweed. In the winter, the women choose to work off the islands of Appatheevu, Paliyamani, Mullitheevu, Vazhatheevu and Yanaparavai that are just a few hours away. In the summer, they risk venturing farther away, to three islands called Nallatheevu, Challi, Upputhanni that are two days away by boat. When going to more distant islands, sometimes they have to stop over at an island mid-way for the night. Each harvester can collect at least 25 kg of wet seaweed in a day. They earn Rs 15 per kg for dry Korai paasi and Rs 80 per kg for dry Marikoluthu seaweed. On average, each woman earns Rs 3,000 a month. There has been a drastic fall in the growth of seaweed, which has been attributed to overexploitation, a rise in the surface temperature of the sea and increased trawler movement. Another concern is that the women are operating illegally. The 21-odd islands from where they harvest seaweed are protected under the Gulf of Mannar Marine National Park, which comes under jurisdiction of the Forest Department. Each harvesting trip carries with it the risk that the women will be spotted by officials of this department and fined Rs. 10,000.

Seaweed Cultivation

Women play an important and complex role in seaweed farming in many developing countries ranging from small scale farming activities as well as mini-scale development of value-added products centred on the seaweed species cultured. In SE Asia seaweed cultivation is mainly a family-oriented business which encompasses all members of the family, whether nuclear or extended. Economic gains from seaweed farming has offered progressive and constructive vagaries in the quality of life of the family members concerned. Seaweed collection and cultivation is a significant livelihood choice for the coastal fisherwomen of India which augments their household income. As the farming areas are intertidal zones, women and children are able to safely access seaweed plots. These factors allow women, in particular, a vital chance to acquire income for themselves and their families while the men work as fishermen and in other sectors.

Women have contributed immensely to the seaweed farming sector playing a significant role in the sustainability of this sector with their perseverance, endurance and resilience and have illustrated persistence in the time of crises. With such women spearheading the seaweed industry, the advances will be shared with whole families and also other community members, since mothers are powerful anchors of the families in various countries. Anon (2003) emphasizes encouragement of a unified culture of seaweeds and shrimps in aquaculture as seaweeds enact as scrubbers in easing nutrient load and refining the environment.

Seaweed Based Product Development

The presence of functionally bioactive compounds in seaweeds has paved the way for the development of nutraceuticals/functional foods and various other value-added products from different seaweed species and is a remedy for addressing the malnutrition problem prevailing in young children and pregnant women of our country. The daily iodine requirement for adults (150 µg/day) can be easily met by small quantities of seaweed especially by kelps with an iodine content of about 1500-8000 parts per million. For the development of the products the biochemical characterisation of seaweed species is important. ICAR-CIFT has the expertise to carry out the process with the aid of sophisticated equipment available. The institute has carried out several imperative works in the area of development of value-added products from seaweeds. Seaweed based biscuit, for example, was prepared by incorporating green seaweed (*Caulerpa racemose*) at various levels and its sensory evaluation yielded a 9-point Hedonic scale. The increase in seaweed concentration in the biscuits increased the anti-oxidative nature of the biscuits and the total phenolic content which ranged from 30.1- 41.4 µg/ml. The production technology was transferred to an Indian Entrepreneur and the product is available in the market. Seaweed based ice cream, seaweed nutridrink, seaweed based extruded snacks and

dried *Ulva* powder as one of the ingredients in pasta are some of the products developed successfully by ICAR-CIFT, Cochin which has gained an affirmative recognition to the institution. Apart from the edible products, gelatin-seaweed polysaccharides edible films and carrageenan-based ointment incorporating *Kappaphycus alvarezii* were developed. The carrageenan-based hand sanitizer using carrageenan, isopropyl alcohol and aloevera gel was prepared. The antiviral property of carrageenan makes the hand sanitizer unique. The technology has been transferred to Kerala Nutraceutical Pvt Company LTD. Other products developed based on seaweed were the alginate based composite scaffolds, which was advanced by a combination of two techniques such as vacuum drying followed by freeze drying and seaweed extract-based bioplastic prepared with varying combinations of agar and sodium alginate.

Consumer Perception Towards Seaweed-based Products

By the turn of 2020, it is expected that the world food and grocery retail market will reach 12.24 trillion US$ from 8.77 trillion US$ in 2015. Globally, there is a growing trend for value added, convenient and fresh foods. Items including packaged food and drinks are poised to acquire a considerable share in the food market. NSSO surveys on per capita household expenditure on various goods and services point out that urban households spend more (around 80%) a month than their rural counterparts.

Departures from established food patterns have been observed on type of food consumed, where and with whom consumers prefer to consume food and even in the perception of acceptability or appropriateness of given food items. Even the quantum of eating has been observed to be changed like having snacks instead of a main meal. Rising population and improved expenditure power of people has enhanced the accessibility of premium food products. Changing consumer lifestyle, has forced the consumers to go for nutrient rich food with fibre content as he/she cannot afford an elaborate diet due to paucity of time. Food manufacturers around the world are

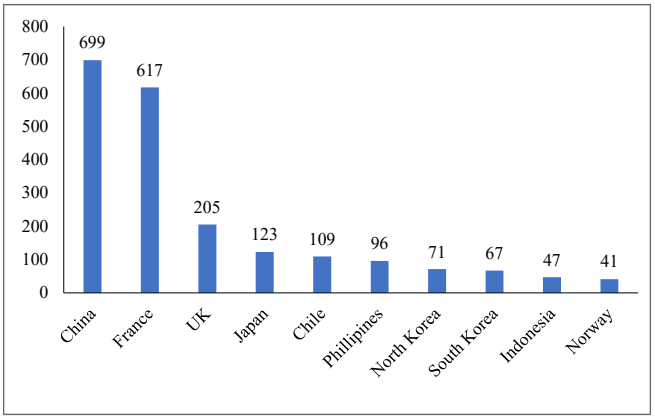

Figure 1: Top ten global seaweed producers ('000 MT/yr)
Source: FAOSTAT

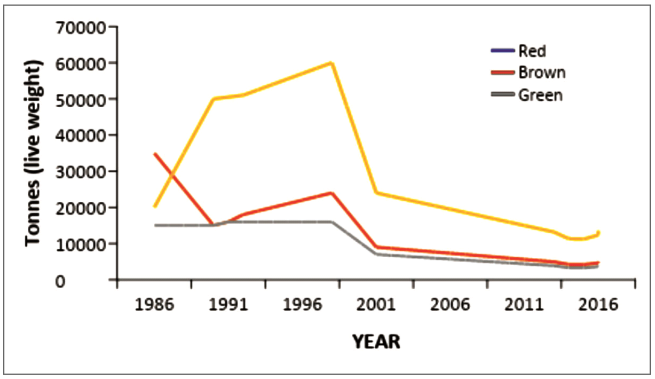

Figure 2: Seaweed capture production in India
Source: FAOSTAT

experimenting with new, nutritious and niche products which will suit the requirements of today's younger generation. Taking into consideration the changing consumer behavior, and market orientation towards healthy foods, through an ongoing research project on seaweed, ICAR-CIFT has formulated diversified products from seaweed, like biscuits, health drinks and nutribar. Consumer preference and willingness to buy such food products was tested from a wide consumer base in Kerala.

The effect of consumer distinctiveness on the recognition of new seaweed products was studied by collecting responses from a sample of 112 consumers in Ernakulam district. The sampling adopted was convenience sampling from consumers belonging to Low, Medium and High-income groups based on their annual income. The variables 'consumer innovativeness' to try new products, 'consumer

Table 1: Factor analysis of the variables

Variable	Dimension	Component scores
Consumer innovativeness	Know more about the products	0.72
	Product form, shape convenience	0.81
Consumer beliefs	Value for money	0.69
	Family acceptance	0.63
	Ease of availability	0.64
Consumer knowledge	Nutrient rich	0.74
	Contains Dietary fibre	0.77
	Safe for consumption	0.62
Peer influence	First to buy new product	0.76
	Buy newer product	0.79
	First to know about the product	0.61

beliefs', 'peer influence' and 'consumer knowledge' (about the product) which influence the consumers for accepting new seaweed products were chosen for the study. Pre-tested schedules prompting responses on a 5-level Likert scale were distributed to consumers frequenting a popular shopping mall in Ernakulam. Out of the 150 questionnaires distributed only 112 responses were usable. Respondents belong to Low :<Rs.5 lakh (38%), Medium : Rs. 5 lakh – Rs.10 lakh (49%)) and High: >Rs.10 lakh (13%) income groups. Assuming the Null hypothesis as existence of relationship between the four variables and consumer acceptance of the new products, factor analysis was performed. Factor analysis of the four variables showed factor scores above 0.6 for each of dimensions tested and is shown in Table 1.

Cronbach's α for reliability was 0.413 for innovativeness, 0.711 for beliefs, 0.753 for knowledge and 0.687 for peer influence. The marketing strategy should concentrate on consumer beliefs and knowledge. Popularization efforts through exhibitions and news coverage will widen the consumer base for the seaweed products. Further target groups for the products will be the consumers who spend at least Rs.500 for this category of food.

Future Research Aspects and Challenges

The global production and processing of seaweeds has increased drastically from 14.7 million tonnes in 2005 to 30.4 million tonnes in 2015, contributed by both culture and capture sectors. Within the present scenario of the seaweed production blooming in recent years, concern has arisen for implementing stringent policies mainly to ensure the sustainability of the seaweed industry. The augmented use of seaweeds in medicines, cosmetics and various other fields has urged the policy makers to enact laws and regulations to safeguard the industry. The challenges confronted include efficient resource management in coastal regions, ensuring disease free seed banks in order to reduce the complete dependence on limited genetic stocks and to establish resilient biosecurity guidelines to lessen the infestation of non-indigenous pests and pathogens into the culture areas. Development of seaweed-based nutraceuticals and functional foods are the need of the hour, but currently it is at a stage of infancy. The development of these products will advance the health status of people in India, especially the younger children and pregnant women deprived of daily nutrition. The export of the products will also contribute in boosting the economy of the country through foreign exchange.

he coastline of India is about 8000 km in length and about 40% of the population lives along the coastline. Still, most of the coastline remains untapped for seaweed cultivation. Mohammed (2016) listed the major problems in the seaweed industry as (i) overexploitation leading to scarcity of raw material, (ii) poor quality raw material, (iii) labour shortages during the paddy harvesting and transplanting

season, (iv) lack of technology to improve processed product quality, and (v) lack of information on new and alternative sources of raw materials. Efforts are required to disseminate suitable harvesting techniques which will aid in increased production. Extensive surveys need to be conducted to identify suitable sites for large-scale seaweed culture. The stakeholders in the sector are demanding more virulent seed to increase the production through farming. The wild seaweed stock seems depleting over the years which threatens the very livelihood of thousands of women who depend on harvesting seaweed from sea. An increase in the surface temperature of the sea because of climate change and overexploitation of seaweed are the likely reasons for the diminishing harvest. The women involved in this sector demand that their livelihood be recognised by the government so that their rights are protected. The shortage of raw material has caused leading seaweed processors utilising only 25% capacity. There were 37 agar industries in Madurai in which 7 are functioning and are not processing even 40% of their capacity

Policy Recommendations

- There exists a requisite to map biodiversity and quantitative estimates of economically important seaweeds along the Indian coast.
- The possibility of employing remote sensing techniques shall be explored to monitor the seaweed beds along the Indian coast on a timely basis.
- Require establishing a national facility for Marine macro algal herbarium collection (844 seaweeds have been reported from Indian coast) and the seaweed collection shall be explored for R&D activities.
- Seaweed gains significance as a prospective bioactive compound in the area of pollution control and waste water management systems despite its functional usage in the field of food and biomedicine.
- Require certification by marine stewardship council, since large scale exploitation of seaweed for its industrial exploitation of our nation based on the south-east coast.
- Despite its wide usage in the food industry, presently they promise a wide range of exploitation in the field of pharmaceutics, biomedicine and cosmetics. Hence there is an immediate requirement to expand the seaweed cultivation in our nation.
- To optimise the yield to avoid crashing of crops, carrying capacity has to be carried out in seaweed farming sites.
- To promote the seaweed cultivation in India, seeds of commercially important seaweeds like *Kappaphycus*, Gracilaria, *Gelidiella*, *Eucheuma* have to be imported from countries where they are cultivated after obtaining necessary clearance.
- Top priority shall be given to *Kappaphycus alverazii* due to its harvesting ease and persistence of intrinsic bioactive compounds like carrageenan especially in the region of Gulf of Mannar coast, Andaman and Nicobar and Lakshadweep islands.
- Special insights have to be given in the area of extractive aquaculture since seaweeds have their pronounced usage in cleaning the excess nutrients in the polluted water bodies due to their ability to clean excess nutrients in polluted waters.
- Environment friendly disposal of waste should be practised frequently.

CONCLUSION

Though Indian subcontinent is blessed with abundant seaweed resources of commercial and nutritional significance, the number of well-established seaweed industries are relatively scanty as compared to countries such as China, Japan, Indonesia, Philippines, Korea, Malaysia etc. In the global scenario, the seaweed industry has witnessed substantial socio-economic benefits to marginalized coastal communities especially in some developing countries, which have limited access to alternative resources to boost their economic activities. It is interesting to note that it has emerged as one of the most relevant opportunities in some communities to improve their livelihood strategies. Since the rising global

demand for seaweed-derived products, seaweed cultivation has greater potential to deliver added socio-economic benefits to Indian coastal communities, which are looking for alternate resources for their income as seafood catches depletion day by day. In India, seaweed industries are based primarily on the culture of *Kappaphycus* species, which has grown significantly in the Philippines and Indonesia over the last two decades. Strengthening strategies should be adapted. It has to go a long way for utilising it to the fullest, keeping in mind the opportunities which are open and challenges that should be handled.

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