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Seaweed - An Eco-friendly Alternative of Agrochemicals in Sustainable Agriculture

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AM and SS designed the study, wrote the protocol and wrote the first draft of the manuscript. All Authors managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Sustainable agriculture demands the use of our natural resources to enhance production and productivity without depleting the natural base along with a vision to preserve them for our future generation. The effect of modern agriculture driven by agrochemicals has raised serious concern about the health and wellbeing of our environment and humans as well. The growth of the population and shrinking resources has created the need for searching new technology and resources to balance between feeding and preserving the environment. Researchers are nowadays more focussed towards trying and testing new products to reduce our dependency on agrochemicals. Among the various alternatives, Seaweed has drawn the attention of many researchers due to its unique properties and abundant availability. They are nowadays used to increase the yield by enhancing the nutrient uptake by the plant. This can reduce excessive fertilizer application for yield enhancement. Seaweed extracts are also showing effective response against various pest and diseases. This property can also play a very important role in reducing our dependency on harmful chemicals for pest control.

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1. INTRODUCTION

The use of seaweed extract is increasing due to its potential use in sustainable agriculture [1], especially in rainfed crops to avoid excessive fertilizer. Seaweed extract is currently used in organic farming to reduce excessive application of fertilizers and improve nutrient uptake through roots or leaves of the plant [2]. Use of seaweed extract in many crops has increased various parameters such as yield and tolerance to environmental stress [3], nutrient uptake [4] and antioxidant properties [5]. Seaweed extract increases stomata uptake efficiency in plants [6]. Ethanol extract of *Chaetomorpha aerea* exhibited good antibacterial property against various gram positive and gram negative bacteria in laboratory condition [7]. Foliar spray of seaweed extract has shown its ability against phytopathogenic fungi [8] [9]. Polysaccharides obtained from seaweeds are known for their excellent water holding capacity and hence find extensive application in food industries as gelling and thickening agents. Carrageenan, a hydrocolloid extracted mainly from *Eucheuma* spp. and *Kappaphycus* spp. is widely used in dairy and chocolate industries due to its ability to bind proteins efficiently in the suspension and prevent fractionation of milk protein. Bromophenol extracted from marine algae *Symphyocladia latiuscula* have been reported to exhibit antioxidant property [10]. Agar-agar extracted from red algae is widely used in laboratories for culturing microorganism. There are lots of uses of seaweed, however, in this review we present an overview related to role of seaweed in increasing yield and other parameters of crops so that it can be utilised efficiently in sustainable agriculture.

2. SEAWEED CHARACTERISTICS

Seaweeds or marine macro-algae represent a diverse group of plant-like organism which lack real root system and vascular system as found in flowering plants but are capable of performing photosynthesis due to variety of pigments present in them. Generally they have specialised structures (holdfast) that help them to attach on the rocks or other hard substances in the coastal areas. Most of the seaweeds come from three importance division based on the dominant pigment present in them and their ability to absorb a particular wavelength of light. The Rhodophyta (red algae), the Chlorophyta (green algae) and the Phaeophyta (brown algae) are the three groups of algae classified under the kingdom Protista. Among these, the members of red algae and brown algae are generally found in marine environment while only 10% of the total reported green algae in marine environment. The study of algae is called Phycology.

Seaweeds are known to synthesize a large number of polysaccharides which either form an integral component of their cell wall or a reserve food material in them. These polysaccharides have been reported to containing anti-cancer [14], anticoagulant [15], antidiabetic [16], anti-inflammatory [17] and antimicrobial [18] property. Due to its increasing demand in food industry, cosmetic industry and pharmaceutical industry, they are often regarded as wonder plants of the sea. Till now the major use of seaweed has been in food industry. Of the total reported seaweeds; 221 are economically important seaweed out of which, 145 species are used for food and 110 species for phycocolloid production.

Table 1. Algae classification and characteristics

Classes	Major pigment	Reserve food material	Cell wall composition	Example
Rhodophyta (Red algae)	Chlorophyll a, d, Phycoerythrin	Floridean starch, Floridoside	Cellulose, Pectin and Polysulphate easters such as agar and carraggenan	*Porphyra, Gracilaria and Gelidium*
Phaeophyta (Brown algae)	Chlorophyll a, c and fucoxanthin	Mannintol, Laminarin	Cellulose and algin	*Dictyota, Laminaria* and *Sargassum*
Chlorophyta (Green algae)	Chlorophyll a and b	Starch	Cellulose	*Chlamydomonas*, *Spirogyra* and *Chara*

- [11] [12] [13]

3. USE OF SEAWEED IN AGRICULTURE

The use of seaweeds in agriculture as soil amendment to increase crop productivity dates back to antiquity [19]. However, the first mention of its recommendation on transplanting cabbage dates back to 1st half of 1stcentury [20]. The liquid formulation of seaweed extract was introduced in 1950 but it took almost ten years to become a practice in agriculture due to the conventional belief that plants take nutrients only through roots and not through leaves. With the advancement in our understanding of plant physiology, the use of seaweed extract is increasing day by day on plants to improve the production and productivity without harming the environment. In recent time, biostimulants are gaining wordwide popularity in sustainable agriculture [21]. Different commercial products are available in the market containing seaweeds extracts in a particular proportion. Brown algae, especially *Ascophyllum nodosum*, are most commonly used in agriculture [22].

According to 'European Biostimulant Industry Council' (EBIC) [23], "Plant biostimulants contain substance(s) and microorganism whose function when applied to plants or the rhizosphere is to stimulate natural processes to enhance nutrient uptake, nutrient efficiency, tolerance to abiotic stress, and crop quality". These include - Humic acid, Fulvic acid, Chitosan, Protein hydrolysates, beneficial microorganisms and seaweed extracts.

Seaweed extract have been reported to increased yield and quality in different crops such as Rice [24], *Phaseolus aureus* [25], *Capsicum annuum* [26], Black gram [27], *Brassica napus* [28], Grapes [29], Cucumber [30], Strawberry [31] and Tomato [32]. Application of seaweed gel on tomato plants promote vegetative growth along with flowers and fruits growth [33]. Extract of *A. nodosum* caused 10% increase in vegetative growth of Strawberry [34]. Foliar spray and drenching of seaweed extract on tomatos caused increase in root and shoot length [35]. Drenching of seaweed extract caused increase in leaf area, stem diameter, root biomass and shoot biomass of broccoli [36]. Concentrate application of seaweed on lettuce caused increased uptake of K, Ca and Mg from the soil [37].

Stimplex^R, a commercial product obtained from *Ascophyllum nodosum*, when sprayed to ornamental pepper (*Capsicum annum* L.) in low concentration of 0.75 ml/L, enhanced plant growth parameters [38]. Application of ROOT PLUS, a patented product obtained from seaweed, produced more flowers and fruits as compared to fertilizer treatment [39]. Application of KELPAK 60, a seaweed extract concentration caused increase in dry mass of cucumber [40]. Seaweed extract obtained from *Ascophyllum nodosum* when applied on tomato leaves showed increase in chlorophyll content [41]. Low concentration of *Ascophyllum nodosum* (0.1 g L^{-1}) was found to determine root growth in *Arabidopsis* plant [42]. Application of seaweed (15%) along with recommended dose of fertilizer in green gram significantly increases N, P and K uptake by grains [43]. Seaweed extracts have shown ability to protect the plants against various pest and diseases [44] [45].

The use of inorganic fertilizers is increasing day by day. Total consumption of $N+P_2O_5 + K_2O$ in India had reached to 27.29 million MT during 2018-19 which was 16.79 million MT during 1998-1999 (increase of 62 %). There was wide NPK use ratio of 7.1:2.7:1 during 2018-2019 [46]. It is another tremendous challenge for maintaining the health of the soil. Use of excess inorganic fertilizer is associated with accumulation of heavy metals such as Cd, Hg, Pb. in the ground. Nitrogenous fertilizers pollute the underground water system through leaching. Such type of pollution is responsible for serious health problems when contaminated water reaches our body. The Blue baby syndrome is a classical example of nitrate contamination in groundwater system. Excessive and imbalance dose of fertilizers cause loss in fertility of soil by disturbing various physical, chemical and biological properties of soil such as pH, electrical conductivity, soil structure and beneficial microorganism population.

The products obtained from seaweed are natural, biodegradable, organic, non-toxic and non-hazardous in nature [47]. They can be a probable solution for fertility management in organic agriculture which is at present one of the biggest challenge in our endeavour towards organic agriculture. About 59 species of marine algae have reported to exhibiting stimulating effect on various agriculturally important plants.

The supply of seaweed for industrial purpose is associated with its commercial cultivation. This in turn will create livelihood opportunity for many communities living along the coastal areas. Since the planting of seaweed requires very less input and locally available materials, it may become a boon for poor farmers as well.

Table 2. Commercial Seaweed products used in agriculture [22]

Product name	Seaweed species	Use
Acadian	*Ascophllum nodosum*	Plant growth stimulant
Agri-Grow Ultra	*Nodosum macrocystis*	Plant growth stimulant
AgroKelp	*Ascophllum nodosum*	Plant growth stimulant
Kelpak	*Durvillea antarctica*	Plant growth stimulant
Profert	Unspecified	Plant biostimulant
Fartum	*Eclonia nodosum*	Biofertilizer

Based on the current trend, the use of seaweed is expecting to increase in agriculture as biostimulant and biofertilizer. However, one should also be careful regarding its excessive use. They contain high salt (Na^+, Cl^- and K^+.) which may cause soil salinization finally, hence it is advised to use it with intermittent gap.

4. ROLE OF SEAWEED ON PLANT GROWTH

Seaweed extracts have shown promising results in stimulating seed germination, root development, increased nutrient uptake, optimum performance under stressed environment and enhancement of frost resistance. Few researchers have also reported antifungal [48] and antibacterial [49] effects. However, the exact mechanism of such action is still not very clear [50] [51]. Increased photosynthetic efficiency, higher carbon assimilation, enhanced stomata conductance, efficient water and nutrient uptake delayed senescence, antimicrobial, anti-feedent and insect repellent properties may be the possible mechanism of action by the seaweed extract [22]. It has been observed that the seaweed extract contain a large number of micronutrients (Zn, Ni, Cu, Cd, F, Na and Fe) which is supposed to be playing some supplementary role in the plant growing in micronutrient deficient condition. The thallus of seaweed contains high amount of organic matter in them. The organic matter content present in the seaweed extract was found to be responsible for stimulating growth of the plant [52]. Brown seaweeds containing high amount of alginate is shown to increase the organic matter content of soil due to microbial decomposition which in turn improves the water holding capacity of soil, soil structure and soil aeration. These parameters are essential for better root growth and development. This believe led to wide use of seaweed as bio fertilizer in late 1960s. It has also been found that the application of seaweed extract have improved the level of N, P, K and other minerals in the soil which in turn play an important role in plant growth and development. Apart from the above mentioned elements, seaweed also contains a large number of organic compounds such as protein, fibre, cellulose, hemicelluloses, fat, lignin and vitamins which have capacity to affect the physiology of plants. Seaweed also contains important plant hormones such as auxin, cytokinin and gibberellins. It is believed that the presence of these phytohormones may modulate innate pathways for phytochrome biosynthesis in plants [53]. The growth promoting effect of seaweed extract on fruits and vegetable is thought to be due to high auxin, cytokinin and gibberellins content in them. Auxin is a well-known plant growth regulator playing important role in stem elongation and fruit development in plants. Gibberellins are known for its active role in seed germination while cytokinin play important role in cell division and root development. Hence many researcher claimed that the stimulating property is due to presence of plant growth regulators specially gibberelin [54] and cytokinin [55]. Presence of betaines in seaweed extract might be responsible for increase in chlorophyll content of many plants [56]. Betaines are found in seaweed extracts, though they are traditionally not considered as plant hormones [57]. Plants treated with seaweed extract showed greater transcription of betaine aldehyde dehydrogenase as compared to control [58].

Plant pathogenic microorganism such as fungi, bacteria and nematodes play a major role in yield reduction of crops. Many researchers have tested seaweed extract against these plant pathogenic microorganisms. Seaweed extract have been found to be effective against these harmful microorganism. The antimicrobial activity of seaweed is thought to be due to presence of terpenes in them [59]. Seaweed extracts are effective against phyto-pathogenic fungi [60] [61] [62]. Green seaweed, *Ulva lactuca* and *Ulva fasciata* were effective against *Dysdercus cingulatus* [63]. Extract of *Sargassum tenerrimum* and *Padina tetrastromatica* were found to be effective against *Meloidogyne javanica* [64].

5. SEAWEED CULTIVATION

With the shrinking fertile land and increasing population, humanity is looking for various alternatives to cope up with these problems. Ocean and sea could be an answer to such upcoming challenges. Growing seaweeds does not require weighted investment. The vast extension of coastal areas create ideal environment for its cultivation. Till now the algae cultivation is limiting–at China, Japan and South Korea where they are mainly consumed as food but with the discovery of its industrial uses, its farming is extending up to European countries. In India too, seaweed cultivation is gaining momentum. However it is still in nascent stage as compared to other countries besides having a vast coastline of 7516.6 km. Lack of information, lack of advance technology for product extraction, poor training facilities and underdeveloped marketing facilities have hindered the growth of this sector in India. It was mainly concerned with harvesting of natural seaweeds for supply to the agar and alginate industry. This created ecological imbalance within a very short period of time and hence the need of its proper cultivation was felt. With a motive to explore seaweed cultivation in India, the first experiment was conducted with *Sargassum cinctum* at Porbandar, Gujrat in 1963. The result motivated to explore the possibilities of growing *Gracilaria edulis* at Krusadai Island. The modern era of seaweed farming in India started in 2000 when PepsiCo signed an agreement with CSIR- Cental Salt and Marine Chemicals Research Institute (CSMCRI) for production of plant growth nutrients from it. CSMCRI has played major role in development of seaweed farming in India specially in developing cultivation technologies for *Kappaphycus alvarezii*. With its efforts only, the cultivation of *Kappaphycus alvarezii* has reached to 1490 dry metric tons in 2013 from mere 21 dry metric tons in 2001. In 2015, commercial production of seaweed reached to □ 140 million farm gate values.

Till now approx 844 species of seaweed have been reported from India. Nearly 60 species are commercially important. Large scale cultivation of seaweed is practiced in Tamil Nadu coast and efforts are going on to establish it in Gujrat, Maharastra, Andhra Pradesh, Kerela, Karnataka and Odisha. CSMCRI have developed new technologies for cultivation of seaweeds specially *Kappaphycus alvarezzi*. Some of the methods employed to cultivate seaweeds are - Long line method, Net culture, Single Rope Floating raft method, Fixed Bottom Long Line method, Integrated Multi Trophic Aquaculture (IMTA) method. Cultivation of *Kappaphycus alvarezii* is mainly done by bamboo raft method which is economical as well as feasible. A square shaped raft (3x3) m is made using bamboo. To give strength to this structure, bamboo braces are used diagonally at four corners of the raft. The lower portion is covered with fishing net to avoid drifting of biomass. The two ends of bamboo raft are connected using 3 mm thick Polypropylene ropes at regular interval of 15 cm. These raft ropes are used to attach planting material at regular interval. Finally the raft is anchored in the sea for biomass production. The seaweed cuttings begin to grow under favorable condition and are harvested at an interval of 45 days. Approx 200 kg of wet seaweed can be harvested from each raft per cycle. This has created livelihood opportunity to more than 1500 coastal households of Tamil Nadu earning approximately US $300 per month per households. Various SHGs are playing important role in promoting seaweed farming in coastal areas for livelihood generation. Several Industries have been established such as –

- M/S Marine chemical, Cochin.
- M/S SNAP natural and alginate products Ltd. Ranipet.
- M/S Aqua agri processing Pvt. Ltd.
- M/S Agri life Pvt. Ltd. Hydrabad.
- M/S AK Seaweeds company, Tamil Nadu.

It will further boost seaweed farming in India. These industries utilize seaweed to produce commercial products such as alginate and agar.

6. CONCLUSION

The demand of chemical fertilizers, especially urea has increased tremendously in the past few decades. Farmers are using excessive chemicals to increase their yield. Excessive use of chemical fertilizer is not only increasing the cost of cultivation but also causing harm to environment, human health and soil health. A large portion of applied fertilizer is either lost or remain unutilized in the soil. Use of seaweed extract tends to increase the absorption of nutrients by the plants, which may in turn reduce the excess application of inorganic fertilizers. Previous studies have shown the ability of seaweed extracts to enhance the yield in many crops. The demand of seaweed as bio-stimulant and bio-fertilizer is increasing day by day. Many commercial products are available in the market nowadays. The increasing demand of seaweed is responsible for its commercial cultivation which is creating job opportunities for coastal inhabitants.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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