ARTICLE IN PRESS

Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Seaweed utilization and its economy in Indian agriculture

Prashant M. Singh [a], Dipak Maity [b,*], Sumit Saha [c], Nabin Kumar Dhal [d]

[a] Department of Biotechnology, Institute of Chemical Technology Mumbai-Indian Oil Campus, Bhubaneswar, Odisha 751013, India
[b] Department of Chemical Engineering, University of Petroleum and Energy Studies, Dehradun, Uttarakhand 248007, India
[c] Materials Chemistry Department, CSIR-Institute of Minerals & Materials Technology, Bhubaneswar, Odisha 751013, India
[d] Environment and Sustainability Department, CSIR-Institute of Minerals and Materials Technology, Bhubaneswar, Odisha 751013, India

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Seaweeds
Agriculture
Bioactive components
Fertilizer
Crop nutrient

ABSTRACT

The marine ecosystem has a great potential for agricultural applications. Seaweeds are the most researched marine algae for various agrochemicals, pharmaceuticals, cosmetics, and biotechnological applications due to the bio-actives which safe for their usage. This article describes the use of seaweeds in agricultural applications as elicitors, their effects on plants in increasing the nutritional value of crops, and escalating the plant stress tolerance. The article ends with a note on the various research gaps that need to be studied for their complete application in agriculture and Indian Government Schemes to develop seaweed farming and product development.

Selection and peer-review under responsibility of scientific committee of the International Conference on Advanced Materials and Mechanical Characterization (ICAMMC 2021).

1. Introduction

The majority of the population is engaged in agriculture. Different factors affect the crop yield, including abiotic and biotics which influence the quality and quantity of the crops. The salinity of the soil, temperature, humidity, wind, rain, drought, and ultraviolet radiations are abiotic factors that can significantly reduce crop yield. Biotic factors such as bacteria, fungi, viruses, and various pests, affect the crop and reduce the output of harvesting. To overcome these issues, multiple chemicals, as well as chemical fertilizers, are used. These chemicals can affect animals, humans, and other organisms. As human beings are at the higher level of consumers, these chemicals accumulate and can disrupt many processes like protein production or absorption of vital nutrients in the human body [1]. This can be avoided by using various bio-organic compounds/species in agriculture and increasing awareness of organic farming [2].

The marine ecosystem is a rich source of numerous plants and algae, such as seaweeds, seagrasses, and mangroves which need to be studied for several applications. Recently, seaweeds have been attracted a great deal of attention in agricultural applications. There are many seaweed species, and these are divided into three types based on the pigments they produce: Phaeophyta (Brown), Rhodophyta (Red), and Chlorophyta (Green) [3]. Seaweeds, being macroalgae, have all the essential nutrients required for plant growth and protection. Due to the presence of all vital nutrients and their positive effects on plants, biochemicals extracted from these seaweeds called biostimulants have a surge [4]. These biostimulants help in the overall development of plants and environmental conditions. Some commercially available seaweed biostimulants and their formulators are listed in Table 1.

The application of seaweeds in Indian agriculture is limited due to certain reasons. Agricultural practices carried out near the coastal regions apply the dried form (powdered or flakes) of seaweed to the soil or spray filtrate obtained after grinding the seaweeds [22]. This is because of the native farmer's awareness regarding the availability of seaweeds. On the other hand, Indian farmers are habitual to and are more confident in using chemical fertilizers and manure. Moreover, the farmers residing away from the coastal belt or living in the interior of Indian counterparts are unaware of the availability and importance of seaweeds. The knowledge gap restricts the farmers from buying seaweed extracts available in the market, which becomes a challenge for the industries to expand the production of seaweed extracts. This is also due to the techno-economic analysis of the seaweed industry, its products, and its applications.

Many seaweeds products are used for the agricultural process in international agriculture, be it biostimulants or as soil conditioners. The coastal population of Ireland uses *Ascophyllum* sp. and

* Corresponding author.
E-mail address: dipakmaity@gmail.com (D. Maity).

https://doi.org/10.1016/j.matpr.2022.04.595
2214-7853/
Selection and peer-review under responsibility of scientific committee of the International Conference on Advanced Materials and Mechanical Characterization (ICAMMC 2021).

Table 1
Commercially available algal bio-stimulant formulators in India.

Sr. No.	Product Name	Seaweed Species	Formulators	Applications	Ref.
1.	Seaweed	Various species*	Shatu Biologicals Ltd., Maharashtra	(i) Enhances seed germination (ii) Balances the crop nutrients (iii) Improves the flower and fruit quality	[5]
2.	Organic Six	Various species* (Brown seaweeds)	ManiDharma Biotech Ltd., Tamil Nadu	(i) Better root systems (ii) Healthier foliage and fruit appearance (iii) Greater resistance to disease and pests (iv) Improves seed germination	[6]
3.	Biovita	*A. nodosum*	PI Industries Ltd, Gujarat	(i) Provides plant growth supplements (ii) Improves plant metabolism (iii) Improves soil health and plant health (iv) Increases antioxidants for improved stress resistance	[7]
4.	Seaweed flakes	*Fucus* sp.	Aquatic Chemicals, Maharashtra	(i) Helps in soil conditioning (ii) Provides resistance to diseases and pests (iii) Enhances seed germination	[8]
5.	Ocean Gold	*A.nodosum/S. laminaria*	VNET, Gujarat	(i) Helps to endure environmental stress (ii) Promotes development of shoots (iii) Balances the fecundity of soil (iv) Enhances the fruit quality and improves their set numbers (v) Stimulates cell division and increases leaf size	[9]

* The name of the seaweed species is not disclosed.

Fucus sp. as soil conditioners frequently to prepare the soil before taking cultivation of potatoes. Many products have been obtained from the brown seaweed consisting of biomolecules like abscisic acid, gibberellins, cytokinins, and auxins which are used as biostimulants in agricultural practices in different countries like Australia, Chile, South Africa, France, and China [22–24].

These bio-stimulants are chemicals that positively help the plants when applied in lower concentrations. The major bioactive components present in the seaweed extracts are polysaccharides, lipids, proteins, terpenes, phenolics, and various halogenated compounds [10]. A schematic diagram of seaweed bioactive extraction is shown in Fig. 1. They play significantly as plant growth regulators [11,12], pesticides, and fungicides [13]. Moreover, plant growth happens due to auxins, gibberellins, cytokinin, phenolic compounds, and various oligosaccharides. The presence of different bioactive compounds from seaweeds has been previously discussed, but the role of these compounds in agriculture has not been mentioned [14]. These bioactive compounds derived from seaweeds are proved to be excellent candidates for their use as nano-fertilizers. The plants readily absorb nano-fertilizers in the nano-range compared to the bulk fertilizers. It is reported that sapling growth can be improved, and the effect of stress can be reduced due to the salinity of the irrigation [15].

2. Seaweeds in India

India has more than 7500 km long coastline, which acts as a dockyard for different types of seaweed growth. The seaweeds float freely or are attached to substrates such as rocks, wooden logs, etc., present at the sea coasts. Kerala, Cochin, Goa, Gujrat, Tamil Nadu, Andaman-Nicobar Island, Odisha, and Maharashtra support the growth of seaweeds. In Odisha, 14 different marine algae from five different places of the Chilika Lake, namely- Balugaon, Kalijai, Barkul, Pathara, and Satpara have been documented [17]. These 14 reported seaweeds are *Grateloupia filicina var. luxurians*, *Gracilaria verrucosa*, *Gracilariopsis megaspore*, *Ceramium diaphanum var. elegans*, *Polysiphonia subtilissima*, *Polysiphonia sertularioides*, *Ulva lactuca*, *Ulva fasciata*, *Enteromorpha compressa*, *Enteromorpha flexuosa* subsp. *flexuosa*, *Enteromorpha intestinalis*, *Cladophora glomerata*, *Pithophora oedogonia*, and *Chaetomorpha linum*. Based on the observations, it is concluded that Chilika Lake doesn't support the growth of brown seaweeds. The acquired seaweed's morphology, locations, and habitat are well documented [17].

Gujarat coast, located in northwest India, has a coastline of around 1596 km. The authors recorded 198 species of marine algae from the intertidal regions of the Gujarat coast. This diversity revealed 109 species of Rhodophyta from 62 genera, 54 species of Chrolophyta from 23 genera, and 35 species of Phaeophyceae from 16 genera. Besides, the Gulf of Kachchh islands shows a rich

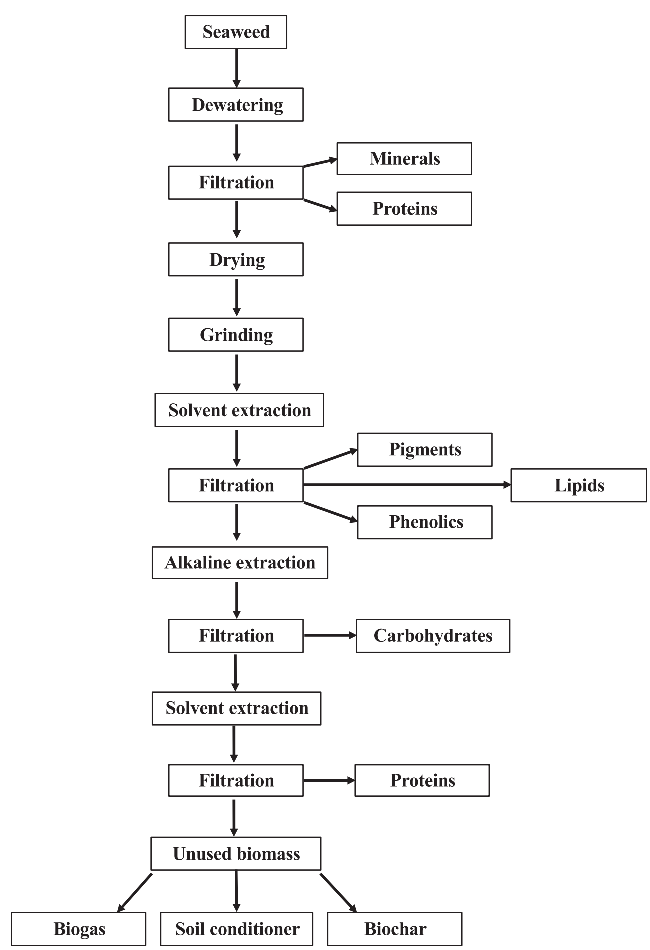

Fig. 1. Schematic diagram for various seaweed bioactive extraction [16].

seaweed diversity accounting for 130 species from Dani, Dhabdhabha, Kulubhar, Manmarodi, and Narara Islands. The maximum range of seaweeds collected from Kulubhar islands is 93 species, whereas the minimum 14 species are collected from Narara islands [18]. The study, which was carried out at the coast of Okha from November 2016 to October 2017, shows 39 species of seaweeds comprised of 16 chlorophytes, 13 rhodophytes, and 10 phaeophytes [19].

Apart from this, the 1076 km long Tamil Nadu coast is filled with abundant seaweeds species belonging to the genera *Ulva*, *Chaetomorpha*, *Bryopsis*, and *Grateloupia* dwell in the rocks and boulders and lower and upper intertidal regions. Among these, *G. edulis*, *G. foliifera*, *G. verrucosa*, and *G. salicornia* species are found in Palk Bay's muddy inter-subtidal areas due to the convergence of many rivers curving to the sea. The Gulf of Mannar shows ample growth of *Sargassum*, *Acanthophora*, *Hypnea*, *Gelidiella*, and *Turbinaria* species along with several *Ulva* species from 20 islands of Gulf of Mannar [20].

Similarly, different marine algae are flourished at 121 km long rocky coastline in the Sindhudurg district of Maharashtra, including 38 recorded species of seaweeds: 16 species of Chlorophyta (6 genera), 10 species of Phaeophyta (6 genera), and 12 species of Rhodophyta (11 genera). Nevertheless, a significant number of seaweeds species (36) are collected from selected sites such as Chivala (Malvan) coast, followed by Devgad (33) and Vengurla (33), Malai (32), Vijaydurg (31), Kunkeshwar (30), Kolamb (29) and Mithbav (27) [21].

3. Effect of seaweeds on plants

As mentioned before, seaweed extracts have various organic constituents which help the plants in different ways for their growth and development. The chemicals present in the extracts are called bio-stimulants which can stimulate the growth and development of the crops when applied in small amounts. The application of chemical nutrients helps plant growth, but this growth is merely due to the nutrients supplied by the chemical fertilizers. However, the bio-stimulants alter and manage the cell division, instigating the flowering of the plants [25] and controlling the root-shoot elongation [26]. Apart from these, seaweed bio-stimulants enhance the rooting, yield, stress tolerance, resistance against various fungi, bacteria, viruses, and photosynthetic activity [12,22,27]. Moreover, seaweed extracts have shown promising results in the growth and yield of multiple crops such as rice [28], cucumber [29], strawberry [30], grapes [31], tomatoes [32,33], and capsicum [34]. Besides, seaweeds from the Tamil Nadu coast showed promising results in the growth and yield of the green gram, black gram, mustard, and paddy [35].

Similarly, tomato seedlings treated with liquid extracts obtained from *Ulva lactuca* (green algae) and *Grateloupia filicina* (red algae) showed an increased level of terpenes in the tomato leaf compared to the untreated saplings [36]. An 18% increase in fatty acid is reported in tomato leaf after the treatment with *Ulva lactuca.* Such an increased level of components in the waste part of plants can be helpful in terms of extracting a good yield of secondary metabolites of high value. The improved fatty acid in the tomato leaf can also be used for biofuel production.

Moreover, seaweed extracts have shown promising results in improving photosynthesis, increased carbohydrate and lipid content [27], and increased nutritional value of foods [38]. Besides their growth-stimulating properties [39], seaweeds are also potential candidates for crop protection due to different existing components in the extracts. These extracts elicit resistance by regulating the gene expression, inducing the salicylic acid pathway, reactive oxygen species-dependent pathways, and various other pathways. The effects of aqueous extracts, alkaline extracts, and dry powder of seaweeds on different crops are well documented [40].

Nevertheless, the phenolic compounds present in the seaweed extracts act as structural polymers, signal compounds, and defense response chemicals. These phenolic compounds provide an antimicrobial effect and stimulate the plant defense systems. They also

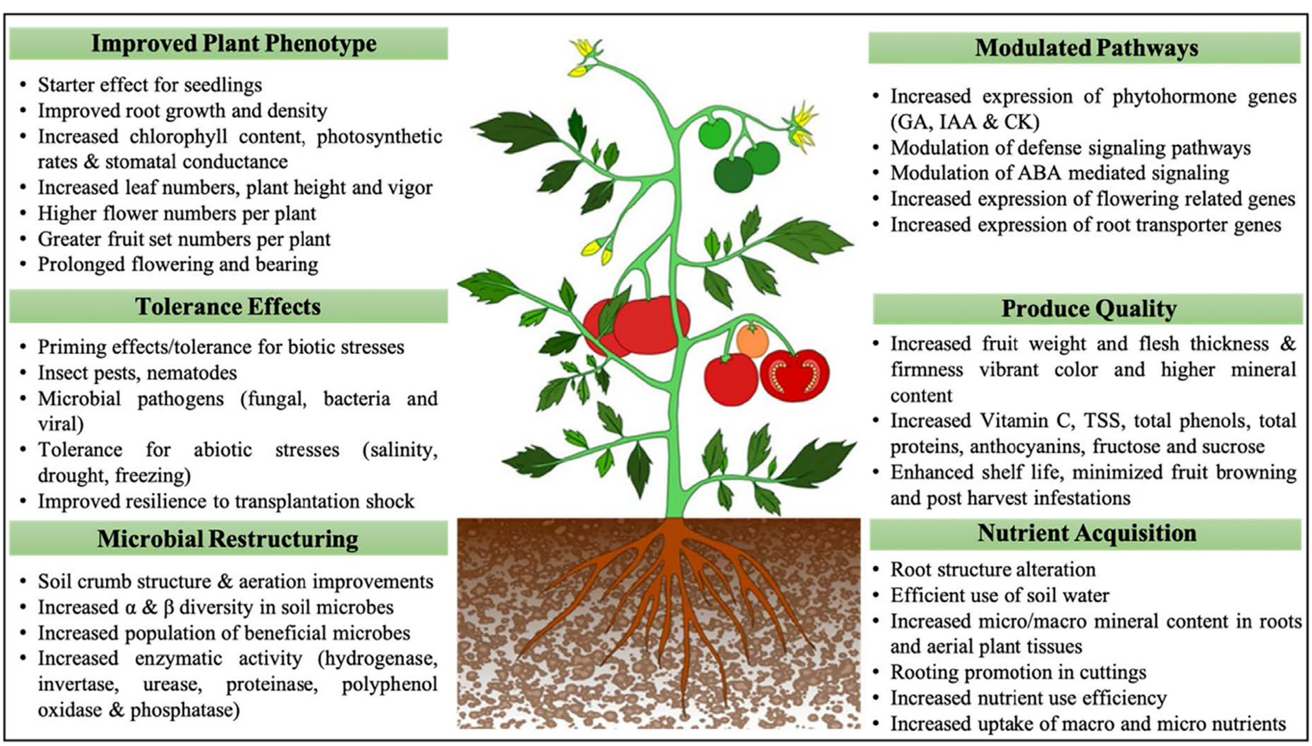

Fig. 2. Effects of seaweeds on plants and soil (Reproduced from [37]).

increase the nutritional value of crops when applied to the plants [41]. Various extraction methods can increase the presence of these phenolic compounds. For example, when the microbial solid-state fermentation extraction method is used, the biological functionalities and bioavailability of the nutrients in seaweeds are improved due to their high amino acid and phenolic content [42]. Seaweeds are also applied to the soil in granules and powder form, enhancing the soil and water holding capacity, thereby acting as soil conditioners when applied to the soil [43,44]. They maintain the nutritional quality of the soil, which is necessary for plant growth. Besides their soil conditioning activity, seaweeds also show anti nematode activity. They prevent the plant's roots from root-knot nematode, which will help in reducing the plant parasite nematode diseases [45].

Moreover, they show positive effects on soil respiration and nitrogen mobilization. The positive impacts of seaweed extracts on plants and soils can be seen in Fig. 2 [37]. Apart from using seaweeds as a whole, a mixture of various bioactive compounds can be used economically by separating or extracting different bioactive molecules from the seaweeds. But these bioactive molecules are prone to decay or lose their activity over time. However, this problem can be solved by immobilizing them with various biomolecules or encapsulating them into different polymers, which can help preserve their activity and release the bioactive compounds slowly and more effectively in a sustainable manner.

4. Seaweed extracts as elicitors in plants

Seaweed extracts contain various biomolecules such as carbohydrates, proteins, lipids, fats, and several micro and macronutrients. These biomolecules also act as elicitors apart from providing nutrients to the crops. They are recognized by the plant's innate immunity system, thereby helping plants cope with pathogen infections. For example, algal polysaccharides promote growth and protect plants from pathogens [39,46]. Different oligosaccharides and polysaccharides such as beta-glucans, alginates, fucans, ulvans, and carrageenans have elicitor activity [22,47–51]. Ulvans are sulfated rhamnose heteropolysaccharides that are present in green seaweed *Ulva* spp. Fucans and carrageenans are sulfated polysaccharides present in brown and red seaweeds [52]. Ulvans tend to induce resistance against rust [53], powdery mildew [54,55], anthracnose [56,57], and wilt development in tomato [58]. A study carried out by Soukaina et al. shows that fucoidans exhibit promising results in plant protection [59]. The fucoidans obtained from *F. spiralis* and *B. bifurcate* show elicitor activity on phenolic metabolism due to phenylalanine ammonia-lyase (PAL) activity in palm dates [59].

Similarly, glucan laminarin shows excellent results in reducing the severity of downy mildew and gray mold on the grapevine under lab conditions [60]. Under greenhouse conditions, the grapevine sprayed with glucan laminarin revealed a reduced downy mildew disease infection rate of 85% and 57% with a dose of 5 g and 1.25 g per liter, respectively, implying the dose-dependent resistance [61]. These elicitors are also known to increase the production of secondary metabolites [52,62–64].

5. Mitigating stress-induced limitations in plants

Every region has different geographical conditions such as temperature, rainfall, nutrient content of the soil, soil texture, pH, water retention capacity, which are extremely important to be considered while performing agricultural activities. The absence or excessive presence of these conditions may lead to stress conditions for the plants. Extreme temperature, nutrient deficiency, salinity, drought, and pH are the different stresses that plants face depending upon the regions, indirectly affecting crop production and yield. Increasing the plant's stress tolerance helps them grow under unfavorable conditions [65]. Besides, the application of seaweed extracts on plants produces various stress-related metabolites, which help alleviate the plant's stress tolerance [41,66]. For example, the fucoidans obtained from brown algae *Macrocystic pyrifera* were shown to act as a stimulator in improving the salt stress tolerance in wheat plants [67], fulvic acid based biostimulant obtained from *Ascophyllum nodosum* (L) extract showed increased water deficiency tolerance in soybean [68]. These extracts help stimulate plant growth and productivity and limit the development of phytopathogens.

Moreover, plants show various physical, biochemical alterations to adapt to different stress conditions. Nevertheless, soil health is a vital part of agriculture and needs to be maintained to produce a better yield. In most arid regions where the water holding capacity of the soil is low, seaweeds can be used to increase their water-holding capacity by providing moisture to the soil. The polysaccharides and oligosaccharides extracted from the seaweeds act as chelating agents to bind other elements and thus forming a gel that can hold water effectively [69]. These natural poly-/oligo-saccharides can be engineered to increase their water-binding ability so that the engineered components can lead to bringing down the losses that occur due to temperature and drought. Furthermore, bio-stimulants prepared from various seaweed extracts alleviate abiotic stress like drought tolerance, ion homeostasis, oxidative stress, salt tolerance, osmotic stress, cold stress tolerance, heat tolerance, temperature stress, chilling tolerance, and heavy metal tolerance [70]. Thus, it is evident that yield can be improved by increasing the stress tolerance of the plants.

6. Seaweed economy in India

According to the Food and Agriculture Organization (FAO), the global market value for seaweed was USD 12 billion in 2019. According to the State of World Fisheries and Aquaculture (SOFIA), the global production of seaweeds, including wild-collected and cultivated algae, was 32.4 million tonnes in 2020, according to the State of World Fisheries and Aquaculture (SOFIA). In 2018, India produced 5300 tonnes of wet seaweed weight, around 0.02% of the world's total share. The total seaweed production in 2020 was 25,000 tonnes which are expected to increase to 1,120,000 tonnes by 2025 with the help of funds provided by the Government of India (GOI). Since 2017, the department of fisheries, GOI, has funded many research institutes that worked together to provide training, assistance for seaweed cultivation and set up seaweed processing units. The total biomass produced between 2017 and 2020 from *Gracilaria* spp. and *Kappaphycus alvarezii* were 255.32 tonnes and 201.72 tonnes wet weight, respectively. Since 2017, the total funds released by National Fisheries Development for projects was INR 53.55 million, which benefitted 1000 beneficiaries.

According to the Pradhan Mantri Matsya Sampada Yojna (PMMSY), the Government of India has planned to invest approx. 640 crore INR Rupees for five years. The objectives of the scheme are listed below:

To increase the production and productivity in the seaweed aquaculture in the country for harnessing the capacity of the coastal waters and reducing reliance on wild harvest.
To improve the seaweed value chain and industrial product diversification to meet domestic demand and reduce dependence on imports.
To promote seaweed cultivation as a viable and sustainable livelihood amongst rural communities, particularly for women.

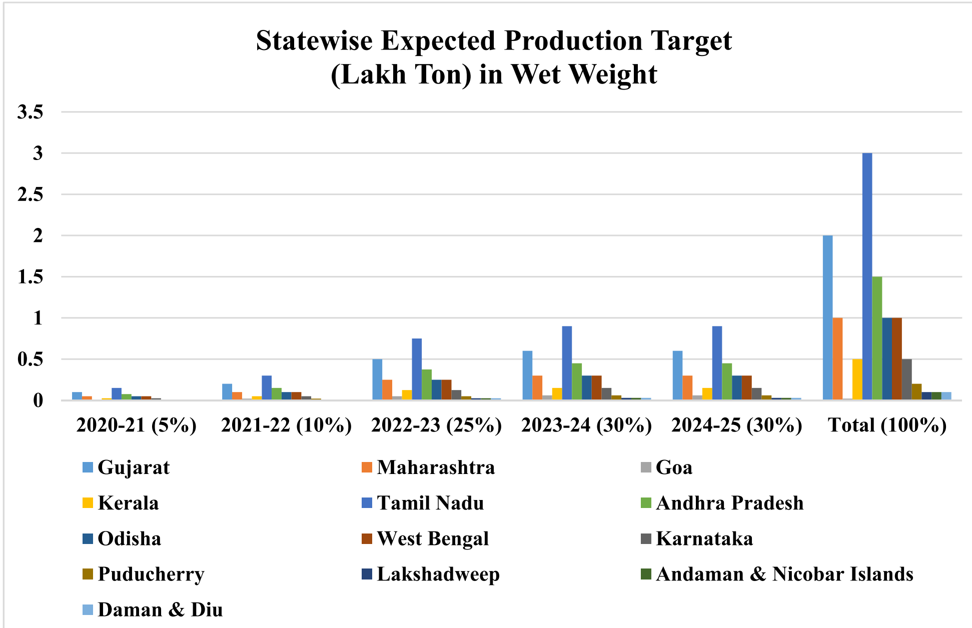

Fig. 3. State-wise expected target of seaweed production [71].

To establish an institutional mechanism in research and development in seaweed farming and value chain and mechanism for effective technology transfer.

Under the PMMSY, the coastal states of India have determined an expected target to achieve by the year 2025 (Fig. 3).

Apart from allocating targets to individual states, the GOI has prepared state-wise funding patterns under PMMSY. This fund will be used for seaweed cultivation and for establishing seed banks, genetic improvement programs for high-yielding cultivars, seaweed parks, etc. These funds will help seaweed cultivation, provide employment to huge populations and bring economic empowerment to coastal women.

7. Challenges and future perspective

Seaweeds grow in water-rich mineral supplements and can sequester carbon. Due to rapid industrialization, contamination of water bodies has taken place. This becomes a challenge for the seaweeds to thrive in such contaminated water, resulting in the low availability of raw materials. The nescience on seaweeds and their application among the farmers of interior India limits the use of seaweeds in agriculture. Also, the rapid tourism development near the sea coast or beaches indirectly affects seaweed growth.

Different methods have been employed for the extraction of bioactive molecules from seaweeds. Research should focus on combining other extraction methods to extract various bioactive stimulants separately from Ascophyllum nodosum seaweeds and investigate their applications. Enzyme-mediated extraction of bioactive molecules from *A. nodosum* needs to be studied due to the lack of available data. As the effects of these extracts depend on the extraction methods, it is essential to develop and optimize a new process that can give optimal results irrespective of the extraction process. The crude seaweed extracts are a mixture of different bioactive molecules, and it is crucial to study the physicochemical effects of other bioactive molecules from the extracts on plants. It is also essential to understand the component's interaction in the extracts to determine the concentration used at different plant growth stages. These bioactive molecules are prone to decay over time; hence its study regarding its preservation is also as vital as studying the bioactive molecules extracted from seaweeds. Nevertheless, an investigation is required to determine the mechanism behind various bioactive molecules in plant growth and development.

8. Conclusion

The present research highlights the importance of fertilizers from seaweed extracts and their applications in growth regulators in plants. To avoid the applications of conventional methods, we think the approach should be an extensive study on the extraction of bioactive molecules, which has been done sporadically. We strongly suggest extraction of the same from different site-specific seaweeds for improving the shelf life of different crops and pest control. An extensive skilled development training program should be conducted for common awareness for the cultivation of seaweeds in different parts of the country and to generate revenue for livelihood. A quick action plan or road map may be prepared and bring the knowledge to the environmentalists and conservationists for immediate germplasm conservation, which will be extinct. Hence, the authors have an opinion on extensive exploration of seaweeds in different parts of the country for sustainable agricultural development.

CRediT authorship contribution statement

Prashant M. Singh: Writing – original draft, Writing – review & editing. **Dipak Maity:** Conceptualization, Writing – review & editing, Supervision. **Sumit Saha:** Conceptualization, Writing – review & editing, Supervision. **Nabin Kumar Dhal:** Conceptualization, Visualization, Writing – original draft, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We want to acknowledge previously reported work by the researchers who have been cited in this review paper. Prashant M. Singh would like to thank The Director of ICT-IOCB, Odisha, for constant support and guidance. Dipak Maity would like to thank The Dean, University of Petroleum and Energy Studies (UPES), Dehradun, for his support and guidance. Sumit Saha wishes to thank Prof. Suddhasatwa Basu, Director, CSIR-Institute of Minerals & Materials Technology, Bhubaneswar, India, for in-house financial support (Grant number: CSIR-IMMT-OLP-112) and requisite permissions.

References

[1] A.P. Møller, K. Laursen, Reversible effects of fertilizer use on population trends of waterbirds in Europe, Biol. Conserv. 184 (2015) 389–395, https://doi.org/10.1016/j.biocon.2015.02.022.
[2] M.C. Kyriacou, Y. Rouphael, Towards a new definition of quality for fresh fruits and vegetables, Sci. Hortic. (Amsterdam). 234 (2018) 463–469, https://doi.org/10.1016/j.scienta.2017.09.046.
[3] W. Khan, U.P. Rayirath, S. Subramanian, M.N. Jithesh, P. Rayorath, D.M. Hodges, A.T. Critchley, J.S. Craigie, J. Norrie, B. Prithiviraj, Seaweed extracts as biostimulants of plant growth and development, J. Plant Growth Regul. 28 (4) (2009) 386–399, https://doi.org/10.1007/s00344-009-9103-x.
[4] P. du Jardin, Plant biostimulants: Definition, concept, main categories and regulation, Sci. Hortic. (Amsterdam). 196 (2015) 3–14, https://doi.org/10.1016/j.scienta.2015.09.021.
[5] Shatu Biologicals Ltd, Seaweed, (n.d.). https://www.exportersindia.com/shatubiological/about-us.htm (accessed November 13, 2021).
[6] ManiDharma Biotech Ltd, Organic Six, (n.d.). https://www.manidharmabiotech.com/agriculture-seaweed-extract.html#agriculture-seaweed-extract (accessed November 13, 2021).
[7] PI Industries Ltd, Biovita, (n.d.). https://www.piindustries.com/search.aspx?Keywords=biovita (accessed November 13, 2021).
[8] Aquatic Chemicals, Seaweed flakes, (n.d.). https://www.agro-chemicals.net/seaweed-extract-flakes.html#organic-seaweed-extract-powder (accessed November 13, 2021).
[9] VNET, Ocean, (n.d.). http://www.vnet.co.in/seaweed-extract.htm (accessed November 13, 2021).
[10] A. Pal, M.C. Kamthania, A. Kumar, Bioactive Compounds and Properties of Seaweeds—A Review, OALib. 01 (04) (2014) 1–17, https://doi.org/10.4236/oalib.1100752.
[11] M. Ashour, S.M. Hassan, M.E. Elshobary, G.A.G. Ammar, A. Gaber, W.F. Alsanie, A.T. Mansour, R. El-Shenody, Impact of commercial seaweed liquid extract (Tam®) biostimulant and its bioactive molecules on growth and antioxidant activities of hot pepper (capsicum annuum), Plants. 10 (6) (2021) 1045, https://doi.org/10.3390/plants10061045.
[12] S.M. Hassan, M. Ashour, N. Sakai, L. Zhang, H.A. Hassanien, A. Gaber, G. Ammar, Impact of seaweed liquid extract biostimulant on growth, yield, and chemical composition of cucumber (Cucumis sativus), Agric. 11 (4) (2021) 320, https://doi.org/10.3390/agriculture11040320.
[13] A.S. Soliman, A.Y. Ahmed, S.E. Abdel-ghafour, M.M. El-sheekh, H.M. Sobhy, Antifungal bio-efficacy of the red algae Gracilaria confervoides extracts against three pathogenic fungi of cucumber plant, Middle East J. Appl. Sci. 08 (2018).
[14] K.RR. Rengasamy, M.F. Mahomoodally, M.Z. Aumeeruddy, G. Zengin, J. Xiao, D. H. Kim, Bioactive compounds in seaweeds: An overview of their biological properties and safety, Food Chem. Toxicol. 135 (2020) 111013, https://doi.org/10.1016/j.fct.2019.111013.
[15] S.N.Y. Al-naqeeb, T.K. Merza, Effect of spraying with nano seaweed extract and quality of irrigation water on growth of volkamer lemon rootstock saplings, Plant Arch. 20 (2020) 3952–3954.
[16] G.S. Matos, S.G. Pereira, Z.A. Genisheva, A.M. Gomes, J.A. Teixeira, C.M.R. Rocha, Advances in extraction methods to recover added-value compounds from seaweeds: Sustainability and functionality, Foods. 10 (3) (2021) 516, https://doi.org/10.3390/foods10030516.
[17] D. Sahoo, N. Sahu, D. Sahoo, A critical survey of seaweed diversity of Chilika Lake, India, ALGAE. 18 (1) (2003) 1–12.
[18] B.N. Jha, C.R.K. Reddy, M.C. Thakur, M. Umamaheswara-Rao, Seaweeds of India. The diversity and distribution of seaweeds of the Gujarat Coast, Dev. Appl. Phycol. 3 (2009).
[19] T.H. Dave, D.T. Vaghela, B.G. Chudasama, Status, distribution and diversity of some macroalgae along the intertidal coast of Okha, Gulf of Kachchh, Gujarat in India, ~ 327 ~, J. Entomol. Zool. Stud. 7 (2019).
[20] M. Ganesan, N. Trivedi, V. Gupta, S.V. Madhav, C. Radhakrishna Reddy, I.A. Levine, Seaweed resources in India - Current status of diversity and cultivation: Prospects and challenges, Bot. Mar. 62 (2019) 463–482, https://doi.org/10.1515/bot-2018-0056.
[21] Nitin Manohar Valanju, Biodiversity of seaweeds along the coastline of Sindhudurg (Maharashtra), in: Dr. Nivas Desai, Dr. Umesh Pawar, Dr. Vishal Aparadh, Dr. Manasi Patil (Ed.), Res. Interv. Adv. Plant Sci., 2020th ed., Bhumi Publishing, Kolhapur, 2020: pp. 175–182.
[22] H.S.S. Sharma, C. Fleming, C. Selby, J.R. Rao, T. Martin, Plant biostimulants: A review on the processing of macroalgae and use of extracts for crop management to reduce abiotic and biotic stresses, J. Appl. Phycol. 26 (1) (2014) 465–490, https://doi.org/10.1007/s10811-013-0101-9.
[23] J.S. Craigie, Seaweed extract stimuli in plant science and agriculture, J. Appl. Phycol. 23 (3) (2011) 371–393, https://doi.org/10.1007/s10811-010-9560-4.
[24] T. Arioli, S.W. Mattner, P.C. Winberg, Applications of seaweed extracts in Australian agriculture: past, present and future, J. Appl. Phycol. 27 (5) (2015) 2007–2015, https://doi.org/10.1007/s10811-015-0574-9.
[25] M. Dookie, O. Ali, A. Ramsubhag, J. Jayaraman, Flowering gene regulation in tomato plants treated with brown seaweed extracts, Sci. Hortic. (Amsterdam). 276 (2021) 109715, https://doi.org/10.1016/j.scienta.2020.109715.
[26] V.G. Allen, K.R. Pond, K.E. Saker, J.P. Fontenot, C.P. Bagley, R.L. Ivy, R.R. Evans, R. E. Schmidt, J.H. Fike, X. Zhang, J.Y. Ayad, C.P. Brown, M.F. Miller, J.L. Montgomery, J. Mahan, D.B. Wester, C. Melton, TASCO: Influence of a brown seaweed on antioxidants in forages and livestock-A review, J. Anim. Sci. 79 (E-Suppl) (2001) E21, https://doi.org/10.2527/jas2001.79E-SupplE21x.
[27] H. Sati, K. Chokshi, R. Soundarya, A. Ghosh, S. Mishra, Seaweed-based biostimulant improves photosynthesis and effectively enhances growth and biofuel potential of a green microalga Chlorella variabilis, Aquac. Int. 29 (3) (2021) 963–975, https://doi.org/10.1007/s10499-021-00667-9.
[28] B. Pramanick, K. Brahmachari, A. Ghosh, S.T. Zodape, Effect of seaweed saps on growth and yield improvement of transplanted rice in old alluvial soil of west bengal, Bangladesh J. Bot. 43 (1) (2014) 53–58, https://doi.org/10.3329/bjb.v43i1.19746.
[29] T.Z. Sarhan, Effect of bread yeast application and seaweed extract on cucumber (Cucumis sativus L.) plant growth, yield and fruit quality, Mesopotamia J. Agric. 39 (2011). https://doi.org/10.33899/magrj.2011.30359.
[30] N. Weber, V. Schmitzer, J. Jakopic, F. Stampar, First fruit in season: seaweed extract and silicon advance organic strawberry (Fragaria×ananassa Duch.) fruit formation and yield, Sci. Hortic. (Amsterdam). 242 (2018) 103–109, https://doi.org/10.1016/j.scienta.2018.07.038.
[31] J. Norrie, J.P. Keathley, Benefits of Ascophyllum nodosum marine-plant extract applications to "Thompson seedless" grape production, in, Acta Hortic. (727) (2006) 243–248, https://doi.org/10.17660/ActaHortic.2006.727.27.
[32] P.S. K. Venkatesan, Seasonal Influence of Seaweed Gel on Growth and Yield of Tomato (Solanum lycopersicum Mill.) Hybrid COTH 2, Int. J. Curr. Microbiol. Appl. Sci. 6 (9) (2017) 55–66.
[33] V. Sidhu, D. Nandwani, Cultivar Evaluation and Yield Performance of Tomato in an Organic Management System, J. Hortic. 04 (2017) 11–15, https://doi.org/10.4172/2376-0354.1000201.
[34] G.D. Arthur, W.A. Stirk, J. van Staden, P. Scott, Effect of a seaweed concentrate on the growth and yield of three varieties of Capsicum annuum, South African J. Bot. 69 (2) (2003) 207–211, https://doi.org/10.1016/S0254-6299(15)30348-3.
[35] R. Muthezhilan, K. Jayaprakash, C. Parthiban, A.A. Jaffar Hussain, Plant growth promoting effect of seaweeds collected from east coast of Tamil Nadu, India, Biosci. Biotechnol. Res. Asia. 11 (SE) (2014) 53–58.
[36] M.A. El-Sheikh, S.N. Sleim, H.S. Abou-Elnasr, The Effect of Seaweed Extracts on Chemical Composition of Tomato Plant (Solanum lycopersicum), Alexandria Sci. Exch. J. 41 (6) (2020) 523–529.
[37] O. Ali, A. Ramsubhag, J. Jayaraman, Biostimulant properties of seaweed extracts in plants: Implications towards sustainable crop production, Plants. 10 (3) (2021) 531, https://doi.org/10.3390/plants10030531.
[38] P. Flores, M.A. Pedreño, L. Almagro, V. Hernández, J. Fenoll, P. Hellín, Increasing nutritional value of broccoli with seaweed extract and trilinolein, J. Food Compos. Anal. 98 (2021) 103834, https://doi.org/10.1016/j.jfca.2021.103834.
[39] D. Pacheco, J. Cotas, C.P. Rocha, G.S. Araújo, A. Figueirinha, A.M.M. Gonçalves, K. Bahcevandziev, L. Pereira, Seaweeds' carbohydrate polymers as plant growth promoters, Carbohydr. Polym. Technol. Appl. 2 (2021) 100097, https://doi.org/10.1016/j.carpta.2021.100097.
[40] P.S. Shukla, T. Borza, A.T. Critchley, B. Prithiviraj, Seaweed-Based Compounds and Products for Sustainable Protection against Plant Pathogens, Mar. Drugs. 19 (2) (2021) 59, https://doi.org/10.3390/md19020059.
[41] M. Drobek, M. Frąc, J. Cybulska, Plant biostimulants: Importance of the quality and yield of horticultural crops and the improvement of plant tolerance to abiotic stress-a review, Agronomy. 9 (6) (2019) 335, https://doi.org/10.3390/agronomy9060335.
[42] M.N. Norakma, A.H. Zaibunnisa, W.A.R.W. Razarinah, The changes of phenolics profiles, amino acids and volatile compounds of fermented seaweed extracts obtained through microbial fermentation, Mater. Today Proc. 48 (2022) 815–821, https://doi.org/10.1016/j.matpr.2021.02.366.
[43] R. Kumari, I. Kaur, A.K. Bhatnagar, Enhancing soil health and productivity of Lycopersicon esculentum Mill. using Sargassum johnstonii Setchell & Gardner as a soil conditioner and fertilizer, J. Appl. Phycol. 25 (2013) 1225–1235, https://doi.org/10.1007/s10811-012-9933-y.
[44] I. Duarte, S. Hernández, A. Ibañez, A. Canto, Macroalgae as Soil Conditioners or Growth Promoters of Pisum sativum (L), Annu. Res. Rev. Biol. 27 (6) (2018) 1–8.
[45] T.I. Williams, S. Edgington, A. Owen, A.C. Gange, Evaluating the use of seaweed extracts against root knot nematodes: A meta-analytic approach, Appl. Soil Ecol. 168 (2021) 104170, https://doi.org/10.1016/j.apsoil.2021.104170.
[46] A. Mzibra, A. Aasfar, H. El Arroussi, M. Khouloud, D. Dhiba, I.M. Kadmiri, A. Bamouh, Polysaccharides extracted from Moroccan seaweed: a promising

source of tomato plant growth promoters, J. Appl. Phycol. 30 (5) (2018) 2953–2962, https://doi.org/10.1007/s10811-018-1421-6.

[47] A. Kobayashi, A. Tai, H. Kanzaki, K. Kawazu, Elicitor-Active oligosaccharides from algal laminaran stimulate the production of antifungal compounds in alfalfa, Zeitschrift Fur Naturforsch. - Sect. C, J. Biosci. 48 (7-8) (1993) 575–579, https://doi.org/10.1515/znc-1993-7-808.

[48] O. Klarzynski, B. Plesse, J.-M. Joubert, J.-C. Yvin, M. Kopp, B. Kloareg, B. Fritig, Linear β-1,3 glucans are elicitors of defense responses in tobacco, Plant Physiol. 124 (3) (2000) 1027–1038, https://doi.org/10.1104/pp.124.3.1027.

[49] O. Klarzynski, V. Descamps, B. Plesse, J.-C. Yvin, B. Kloareg, B. Fritig, Sulfated fucan oligosaccharides elicit defense responses in tobacco and local and systemic resistance against tobacco mosaic virus, Mol. Plant-Microbe Interact. 16 (2) (2003) 115–122, https://doi.org/10.1094/MPMI.2003.16.2.115.

[50] I. Ben Salah, S. Aghrouss, A. Douira, S. Aissam, Z. El Alaoui-Talibi, A. Filali-Maltouf, C. El Modafar, El Modafar, Seaweed polysaccharides as bio-elicitors of natural defenses in olive trees against verticillium wilt of olive, J. Plant Interact. 13 (1) (2018) 248–255, https://doi.org/10.1080/17429145.2018.1471528.

[51] J. Khedia, M. Dangariya, A.K. Nakum, P. Agarwal, A. Panda, A.K. Parida, D.R. Gangapur, R. Meena, P.K. Agarwal, Sargassum seaweed extract enhances Macrophomina phaseolina resistance in tomato by regulating phytohormones and antioxidative activity, J. Appl. Phycol. 32 (6) (2020) 4373–4384, https://doi.org/10.1007/s10811-020-02263-5.

[52] M.J. Stadnik, M.B.d. Freitas, Algal polysaccharides as source of plant resistance inducers, Trop. Plant Pathol. 39 (2) (2014) 111–118, https://doi.org/10.1590/S1982-56762014000200001.

[53] D.Z. Delgado, M.B. de Freitas, M.J. Stadnik, Effectiveness of saccharin and ulvan as resistance inducers against rust and angular leaf spot in bean plants (Phaseolus vulgaris), Crop Prot. 47 (2013) 67–73, https://doi.org/10.1016/j.cropro.2013.01.003.

[54] R. Paulert, D. Ebbinghaus, C. Urlass, B.M. Moerschbacher, Priming of the oxidative burst in rice and wheat cell cultures by ulvan, a polysaccharide from green macroalgae, and enhanced resistance against powdery mildew in wheat and barley plants, Plant Pathol. 59 (4) (2010) 634–642, https://doi.org/10.1111/j.1365-3059.2010.02300.x.

[55] V. Jaulneau, C. Lafitte, M.-F. Corio-Costet, M.J. Stadnik, S. Salamagne, X. Briand, M.-T. Esquerré-Tugayé, B. Dumas, An Ulva armoricana extract protects plants against three powdery mildew pathogens, Eur. J. Plant Pathol. 131 (3) (2011) 393–401, https://doi.org/10.1007/s10658-011-9816-0.

[56] R. Paulert, V. Talamini, J.E.F. Cassolato, M.E.R. Duarte, M.D. Noseda, A. Smania, M.J. Stadnik, Effects of sulfated polysaccharide and alcoholic extracts from green seaweed Ulva fasciata on anthracnose severity and growth of common bean (Phaseolus vulgaris L.)Die Wirkung von sulfonierten Polysacchariden und alkoholischen Extrakten aus der Grünalge Ulva fasciata auf den Anthracnosebefall und das Wachstum von Buschbonenpflanzen (Phaseolus vulgaris L.), J. Plant Dis. Prot. 116 (6) (2009) 263–270.

[57] M.B. de Freitas, M.J. Stadnik, Race-specific and ulvan-induced defense responses in bean (Phaseolus vulgaris) against Colletotrichum lindemuthianum, Physiol. Mol. Plant Pathol. 78 (2012) 8–13, https://doi.org/10.1016/j.pmpp.2011.12.004.

[58] C. El Modafar, M. Elgadda, R. El Boutachfaiti, E. Abouraicha, N. Zehhar, E. Petit, Z. El Alaoui-Talibi, B. Courtois, J. Courtois, Induction of natural defence accompanied by salicylic acid-dependant systemic acquired resistance in tomato seedlings in response to bioelicitors isolated from green algae, Sci. Hortic. (Amsterdam). 138 (2012) 55–63, https://doi.org/10.1016/j.scienta.2012.02.011.

[59] S. Bouissil, Z.E. Alaoui-Talibi, G. Pierre, H. Rchid, P. Michaud, C. Delattre, C. El Modafar, Fucoidans of Moroccan Brown Seaweed as Elicitors of Natural Defenses in Date Palm Roots, Mar. Drugs. 18 (12) (2020) 596, https://doi.org/10.3390/md18120596.

[60] A. Aziz, B. Poinssot, X. Daire, M. Adrian, A. Bézier, B. Lambert, J.-M. Joubert, A. Pugin, Laminarin Elicits Defense Responses in Grapevine and Induces Protection Against Botrytis cinerea and Plasmopara viticola, Mol. Plant-Microbe Interact. 16 (12) (2003) 1118–1128, https://doi.org/10.1094/MPMI.2003.16.12.1118.

[61] S. Trouvelot, A.-L. Varnier, M. Allègre, L. Mercier, F. Baillieul, C. Arnould, V. Gianinazzi-Pearson, O. Klarzynski, J.-M. Joubert, A. Pugin, X. Daire, A β-1,3 glucan sulfate induces resistance in grapevine against Plasmopara viticola through priming of defense responses, including HR-like cell death, Mol. Plant-Microbe Interact. 21 (2) (2008) 232–243, https://doi.org/10.1094/MPMI-21-2-0232.

[62] F. Bi, S. Iqbal, M. Arman, A. Ali, M.-u. Hassan, Carrageenan as an elicitor of induced secondary metabolites and its effects on various growth characters of chickpea and maize plants, J. Saudi Chem. Soc. 15 (3) (2011) 269–273, https://doi.org/10.1016/j.jscs.2010.10.003.

[63] A. González, R. Contreras, A. Moenne, Oligo-carrageenans enhance growth and contents of cellulose, essential oils and polyphenolic compounds in Eucalyptus globulus trees, Molecules. 18 (8) (2013) 8740–8751, https://doi.org/10.3390/molecules18088740.

[64] M. Bayraktar, E. Naziri, I.H. Akgun, F. Karabey, E. Ilhan, B. Akyol, E. Bedir, A. Gurel, Elicitor induced stevioside production, in vitro shoot growth, and biomass accumulation in micropropagated Stevia Rebaudiana, Plant Cell. Tissue Organ Cult. 127 (2) (2016) 289–300, https://doi.org/10.1007/s11240-016-1049-7.

[65] M. Pérez, E. Falqué, H. Domínguez, Antimicrobial action of compounds from marine seaweed, Mar. Drugs. 14 (3) (2016) 52, https://doi.org/10.3390/md14030052.

[66] X. Zhang, E.H. Ervin, R.E. Schmidt, Plant growth regulators can enhance the recovery of Kentucky bluegrass sod from heat injury, Crop Sci. 43 (3) (2003) 952–956, https://doi.org/10.2135/cropsci2003.9520.

[67] P. Zou, X. Yang, Y. Yuan, C. Jing, J. Cao, Y. Wang, L. Zhang, C. Zhang, Y. Li, Purification and characterization of a fucoidan from the brown algae Macrocystis pyrifera and the activity of enhancing salt-stress tolerance of wheat seedlings, Int. J. Biol. Macromol. 180 (2021) 547–558, https://doi.org/10.1016/j.ijbiomac.2021.03.039.

[68] V. do Rosário Rosa, A.L. Farias dos Santos, A. Alves da Silva, M. Peduti Vicentini Sab, G.H. Germino, F. Barcellos Cardoso, M. de Almeida Silva, Increased soybean tolerance to water deficiency through biostimulant based on fulvic acids and Ascophyllum nodosum (L.) seaweed extract, Plant Physiol. Biochem. 158 (2021) 228–243, https://doi.org/10.1016/j.plaphy.2020.11.008.

[69] S.S. Mahusook, F.A.A. Rajathi, H.N.S. Maharifa, R. Sharmila, Comparative Study of Agarophytes - Gracilaria edulis and Gelidiella acerosa as Biostimulant and Application of Agar for Water-holding in Soil and Plant Growth Promotion, Agric. Sci. Dig. - A Res. J. (2021), https://doi.org/10.18805/ag.d-5108.

[70] K. Bisen, Bio stimulants and Bio effect or Mediated Mitigation of A biotic Stress in Crop Plant, IJARAAS. 2 (2020) 21–27.

[71] D.R. Ranjan, International Webinar: Entrepreneurship Development On SEAWEED BUSINESS BY COOPERATIVES, Dep. Fish. Min AHD&F, Govt. India LINAC-NCDC, Dep. Agric. Coop FW, Min Agri FW, Govt. India NEDAC, Bangkok. (2021). https://www.youtube.com/watch?v=IIukHf5fbjY (accessed November 13, 2021).