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Deciphering Nature's Secret of Seaweed Extract as a Biostimulant on Horticultural Crops: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author AT participated in collection of data, resources and writing of original draft. Author AM carried out sequence alignment, formal analysis, editing of review, revising it critically for important intellectual content and have given final approval of the version to be published.

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Review Article

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ABSTRACT

Seaweed extracts have gained significant attention in horticultural practices due to their diverse range of beneficial effects on plant growth, development, and stress tolerance. The presence of antioxidants and Osm-protectants in seaweed extracts helps mitigate oxidative damage and maintain cellular integrity under adverse conditions. It also holds great promise as a valuable input in horticultural systems, offering a range of benefits including enhanced soil health, and sustainability. This review aims to summarize and analyze the benefits of seaweed extract application on horticultural crops. The extracts derived from seaweed are rich in essential nutrients which are available from through which plants can absorb easily and promote growth. It also contains numerous bioactive compounds

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including cytokinins, auxins, gibberellins, and betaines, which act as plant growth regulators. The application of seaweed extracts can induce systemic acquired resistance (SAR) in plants, triggering defense mechanisms against pathogens and pests, which can reduce the need for synthetic pesticides and fungicides, promoting sustainable and environmentally friendly horticultural practices. In addition to its direct effects on plants, seaweed extract enhances soil health and microbial activity. It serves as a natural biostimulant, promoting beneficial microbial populations in the rhizosphere, which facilitate nutrient uptake and cycling. Moreover, the humic substances present in seaweed extract contribute to soil structure improvement, water retention, and nutrient availability, fostering a conducive environment for plant growth.

Keywords: Antioxidants; biostimulants; environment; growth regulators; microbial; seaweed.

1. INTRODUCTION

Seaweed extract has been shown to improve bacterial germination and increase seedling vigour by increasing root length and density [1]. Seaweeds are rich in bioactive chemicals that enhance plant development, boost yields, and increase the resilience of plants to non-biological and biological challenges. A variety of seaweeds promoted plant development [2]. Because seaweed extract is non-toxic in nature and eco-friendly, it is more convenient to use than synthetic fertilisers. The utilisation of seaweed extracts in plants enhances plant development there by increases yield production, improves the soil quality and water retention capacity, helps in mitigating plant abiotic stress, stimulates nutrient uptake in plants, utilized as an indicator in metal pollution monitoring, acts as elicitors against plant pathogens and used for production of ethanol [1](Fig 1). Biostimulants are said to help plants grow and develop more fully, as well as their physiological processes, biological traits, and food yield [3].

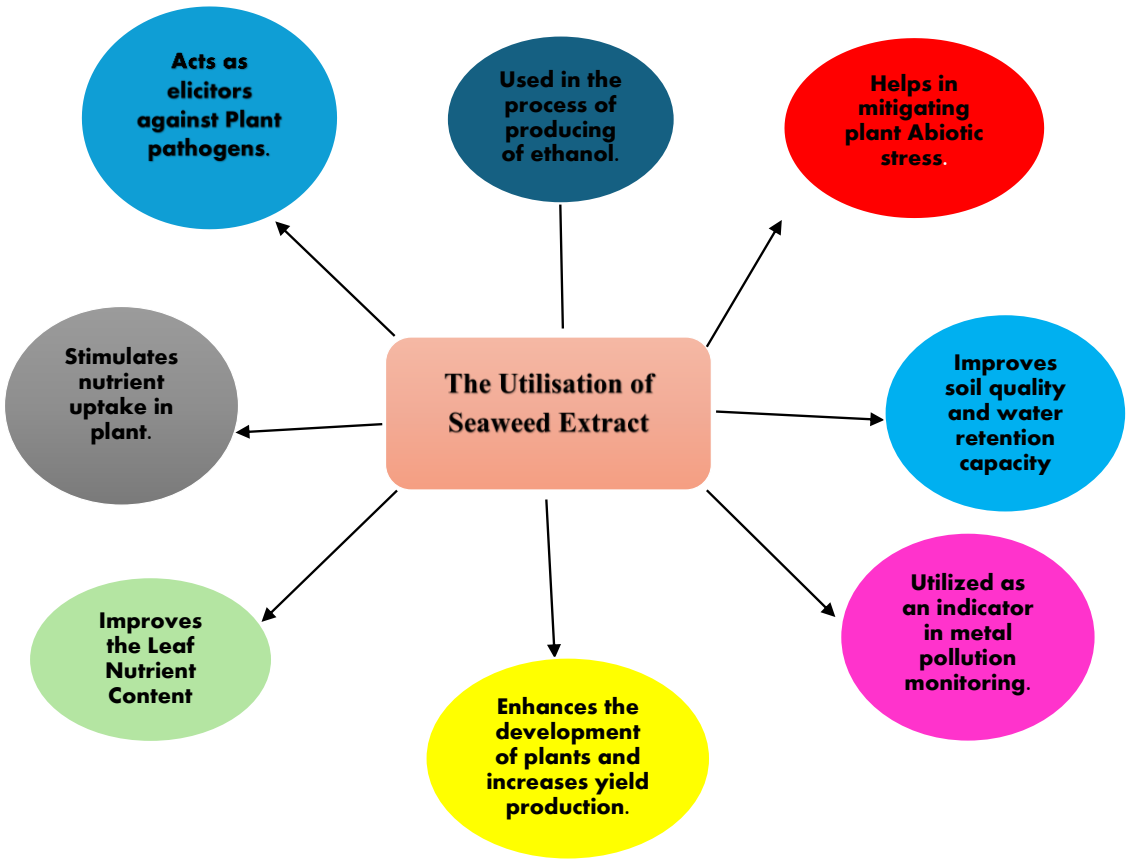

Fig. 1. An illustration highlighting various applications extracts of algae from the sea in plants

Secondary metabolites produced by seaweeds have many biological properties including antibacterial, antiviral, nematocidal, and anticoagulant properties [4]. Aqueous extract of *gymnospora* seaweed, *gracilaria* and *lithospora* and *ulva* were found to be the best seaweed biofertilizer for pepper seed germination [5]. Many sugar alcohols, phenols, mucopolysaccharides, and other organic substances found in seaweed can help plants grow Fig. 1 better and keep the earth moist [6]. Most tests on abiotic stress have been done in controlled gardens, but the good benefits of seaweed extract have also been seen in farming [7]. A lot of seaweed is used as biofertilizers, biostimulants, and nutrition supplements. The extract of ascophyllum nodosum raises the amount of chlorophyll and the efficiency of photosynthesis while also encouraging root growth [8]. In the past few years, growing kelp has grown to produce more than 30 million tonnes of new biomass, which has a market worth of at least us$13.3 billion. 95% of the world's seaweed production comes from kelp/saccharin (35.4%), kappaphycus and eucheuma (33.5%), gracilaria (10.5%), porphyra (8.6%), and undaria pinnatifida (7.4%) [9] say it's more than that. They can also lessen abiotic stress and enhance the biochemical components of plants [10]. Because they contain vital nutrients like chelated microminerals, which are more readily available than both inorganic and organic minerals, as well as several kinds of complex carbohydrates with prebiotic supplement properties and health-promoting colouring agents, seaweeds are excellent substitutes for nutritional supplements for domesticated livestock.

This plant like life produces 70% to 80% of oxygen in air through photosynthesis, and seaweeds is considered the lungs of ocean [11]. Seaweed extracts are excellent sources of essential nutrients such as N, P, K, Ca, and Mg as well as providing various organic components, trace elements and growth regulators for crop growth and production (Table 1) [12]. Seaweed comes in many forms, includes LSF (Liquid Seaweed Fertiliser), granules, and powder. Seaweed droppings have the advantage of not containing seeds or other fungi. High germination rate, shoot and root length, and seedling viability index were detected When seeds were soaked in small amount of seaweed extracts [13]. Seaweed is often used as a source of agar, agarose and carrageenan in laboratories, pharmaceuticals, cosmetics, paper, cellulose, dyes , and refined foods. When potatoes were planted with all the required fertilizer using *K. alvarezii* differentiation, growth, yield, and quality all improved [14]. *Macrocystis pyrifera* extract promotes the growth of bean seeds and various tomato varieties [15].

Table 1. Various components of Seaweed Extract [10]

Biochemical Properties	Percentage
1.Organic Components	
Carbohydrates	35.02%
Total amino acids	6.11%
Alginic acid	8.50%
Mannitol	4.23%
Betanines	0.037%
2.Macro Elements	
NH_4^+	2.83%
P_2O_5	2.60%
K_2O	4047%
Mg	0.65%
S	3.00%
Ca	0.28%
3.Micro Elements	
Ferrous	0.0162%
Manganese	0.0012%
Zinc	0.0057%
Boron	0.0046%
4.Growth Regulators	
Auxin(IAA)	0.024%
Cytokinin	0.018%

2. RESOURCES FOR SEAWEED IN INDIA

More than 7500 km of coastline in India is suitable for cultivation of different seaweed species [16]. Mumbai, Ratnagiri, Goa, Karwar, Varkala, Vizhinjam, and Chilka in Odisha around Pulicat in Andhra Pradesh, Tamil Nadu. Seaweeds grow around the Lakshadweep, Andaman and Nicobar Islands as well as along the coasts of Tamil Nadu and Gujarat. India has 46 industries 25dependent on seaweed for Alginate production and 21industries for agar and a total of 37industries do not have enough basic materials to operate at maximum level. The Gujarat coast is in the northwest of India, and it is about 1596 miles long. The writers found 198 different kinds of seaweed along the Gujarat coast between the high and low tides. There were 109 species from 62 Rhodophyta genera, 54 species from 23 Chrolophyta genera, and 35 species from 16 Phaeophyta genera at the start. Seaweeds has divided into three types depending on their colours, which have been successfully used in a variety of applications, including horticulture [2] (Fig. 2). Some seaweeds are plentiful and widely distributed, regardless of geographical location, whereas others are restricted to specific places. There has been a lot of sargassum in many spots in the US and the Caribbean over the last few years.

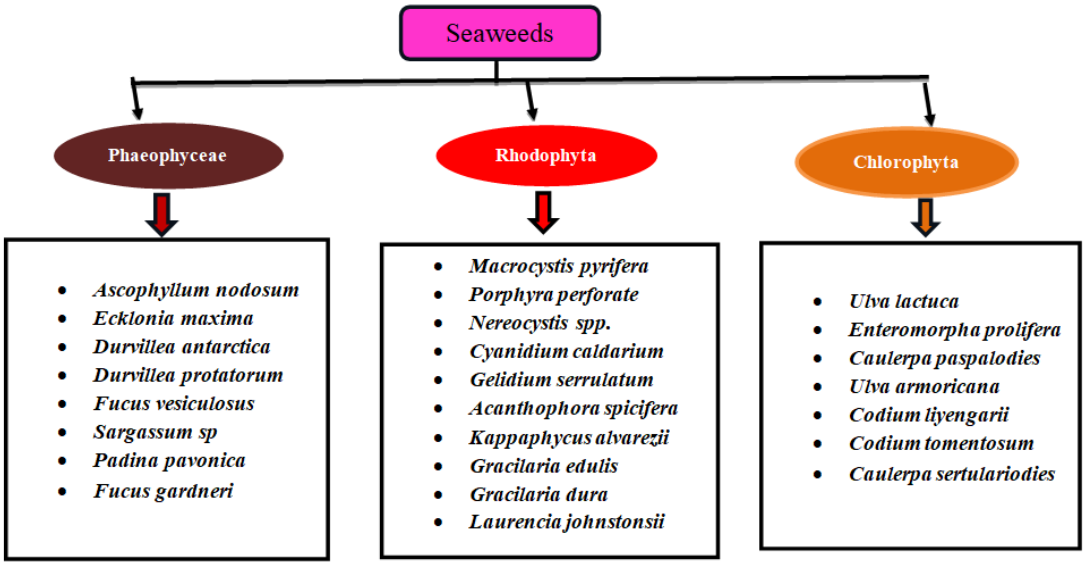

Fig. 2. Seaweed classification according to their colour (Phaeophyceae(brown), Rhodophyta (red), Chlorophyta (Green))

3. DISCUSSION

3.1 Effect of Seaweed as a Elicitors in Plants

Some of the substances found in seaweed products are carbohydrates, proteins, lipids, fats, and different micro and macronutrients that help plants grow [16]. The plant's defence system knows what they are and helps the plant fight off diseases. One example is that algal carbohydrates help plants grow and keep them safe from pathogens [17,18]. Many useful substances in seaweed products help plants grow and protect themselves. It was shown that fucoidans can protect plants [19]. Plants that are handled with the extract make new proteins, and the bioactive material is what makes the extract work [20]. For phenylalanine ammonia-lyase (PAL) to work in the jujube palm, fucoidans from *F. spiralis* and *B. bifurcate* can begin the phenolic metabolism process [19]. Carotenoids are a group of powerful antioxidants that are found in seaweed products. Also in the extract are phenolic substances like quercetin, cinnamic acid, flavonoids, isoflavones, benzoic acid, and flavonoids [2]. Also, it is known that elicitors make more secondary metabolites. There are many types of Algae, Seaweeds polysaccharides, their nature, quantity, and chemical composition vary depending on species and the environment. Seaweeds generally contain up to 78% dry weight polysaccharides, but the levels varies seasonally. Adding *U. fasciata* and *S. lacerifolium* to the soil helps radish plants grow, sprouting rate, and physiological and biochemical traits [21].

Table 2. Biostimulants produced from seaweed extract have an impact on main crops

Crop	Seaweed Extract	Effects observed	Reference
"Onion (*Allium cepa*)"	*"A. nodosum*	It Accelerates germination and seedling viability. Increase lightness and weight. Increase the mineral content of ascorbic acid. The incidence of downy mildew decreases. Help prevent water stress and increase nitrogen, phosphorus and potassium absorption.	Abbas, M et al., [28] Hidangmatum, A. and Sharma, R. [29]
"Potato (*Solanum tuberosum*)"	*"A. nodosum K. alvarezii Gracilaria edulis E. maxima"*	Helps things grow. Boost the production and quality of tubers. Make it easier to handle drought.	Dziugiel, T and Wadas, W. [30] Prajapati, A et al., [31].
"Lettuce (*Lactuca sativa*)"	*"A. Nodosum Durvillaea Antarctica potatorum Ecklonia maxima Durvillaea"*	Make the roots and shoots grow faster. The amount of chlorophyll rose. Photosystem II and the production of photochemicals.	Yusuf, R et al., [32] DiMola, I et al., [33]
"Cucumber (*Cucumis sativus*)"	*"A. nodosum Macrocystis pyrifera Ulva armoricana"*	Fruit production increased. Fruit with a higher nutritional value Infections caused by leafspot, blight, wilt, grey mould were suppressed	Hidangmayum, A and Sharma, R [29]
"Sweet pepper (*Capsicum annuum*)"	*"A. nodosum Sargassum spp. A. spicifera"*	Rapid development of shoots and roots Chlorophyll content has increased (SPAD index). Flowering has increased. Fruit output has increased. Fruit quality enhancement. Resistance to *Alternaria capsica, Phytophthora capsica, and Xanthomonas campestris pv. vesicatoria* It is more resistance to drought and salinity	Dalal, A et al., [34] Sadasivam, V et al., [35] DiMola,I et al., [33]
"Tomato (*Solanum lycopersicon*)"	*"Ascophyllum Sargassum spp. Cystoseira Laminaria digitata pyrophyllite's*	Increase seedling viability and germination rate. The growth of shoot and root is significantly increased. Chlorophyll content increased. (SPAD index—Soil Plant Analysis Development) Flowering increased.	AI-Ghamdi,A.A and Elansary, H.O [36] Digruber,T et al., [37] Ali et al., [38] Sadasivam, V et al., [35]

Crop	Seaweed Extract	Effects observed	Reference
	Gelidium serrulatum *Ulva lactuca* *Fucus spiralis* *A. spicifera* *Nodosum"*	Fruit yield increased. Improving Fruit quality. Diseases such as powdery mildew and Verticillium wilt are better protected. Its tolerant to cold stress, salinity and drought is better.	Murtic,S et al., [39] Esserti,S et al., [40]
"Strawberry *(Fragaria x ananassa)"*	*"A. nodosum* *Sargassum sp.* *Laminaria sp.* *Duvillaea potatorum"*	Crops grow rapidly. The content of canopy carbohydrates, leaf phosphorus and potassium is increased. Yield increase. Good fruit and nice scent. Fortitude against powdery mildew grey mould, leak anthracnose, leather rot, stem end rot, and stem end rot	Mattner,S.W et al., [41] Kapur,B et al ., [42]
"Spinach (*S. oleracea*)"	"*A. nodosum* *E. maxima* *Codium liyengarii"*	The amount of fresh food, dry biomass, and overall leaf area all went up. The SPAD score went up. The micro- and protein levels got better. Improvement against Drought.	Dookie,M et al., [43] Poberezny, J et al., [44] Rouphael, Y et al., [45]
"Carrot (*Daucus carota*)"	"*A. nodosum* *E. maxima"*	The crop index (HI)increased, and food price increased. Reduce the intensity of fungal diseases caused by black rot and gray mould	Kiraci, S [46]
"Apple (Malus domestica)"	"*A. nodosum* *Codium tomentosum*"	Lowering the other bearing The amount of chlorophyll goes up. The rate of transpiration and respiration goes up. Anthocyanin content increased. As the intensity increases, the intensity of red also increase. Post-harvest Fruit browning is reduced.	Valencia, R.T et al., [47]

3.2 Seaweed Extracts' Effect on Protein Biosynthesis in Plants

Worldwide seaweed production has increased in recent years, reaching 30 million tonnes per year. Seaweed biostimulants can improve horticultural productivity by increasing crop quality and protein content per hectare. Studies have also shown that stress from the outside can change the roots and make more food [22-24]. It has also been found that seaweed products can help crops deal with abiotic stress and keep their nutrients [24]. A lot of research has shown that kelp products can make plants like Leguminosae and Gramineae have more protein. There may be a relationship between increased protein content and better assimilation by plant of essential elements required for protein synthesis. This improvement in decay process may be a result of algae.

3.3 Improving Plants Resilience to Biotic Stresses by Seaweed Extracts

Changes in the climate and frequent application of pesticides have accelerated the spread of contagious and durable pathogens and diseases in critical crops, resulting in severe decreases in horticultural production. Extracts from seaweed were used to treat the infections caused by bacteria and fungi. Increased vigour of seaweed extract-treated plants, preexisting resistance. As a result of changes in the behavior of microbes, the ground becomes more protective, which lowers the number of infections. These are [2,25] say that it is managed by the *Citrus psyllid, Caulerpa sertularioides, Laurencia johnstonsii and Sargassum derivatives*. Additionally, seaweed extracts can prevent major economic losses by reducing aphids, borers, and thrips in sugarcane [26,27]. Extracts of various red, brown, and green algae macroalgae (Table 2) have been shown to have potent antibacterial and antifungal properties. In addition to boosting immunity against bacterial and fungal infections, research has shown that seaweed extracts reduce the intensity of symptoms associated with viroids and viruses. Pretreatment of the *Solanum lycopersicum* chlorotic dwarf viroid with β - carrageenan polysaccharide derived from seaweed extract reduced symptoms.

3.4 Overcoming Stress-Induced Limits in Plants

Temperature, rainfall, soil nutrient content, soil texture, pH, and ability to retain water are all geographical factors to consider when conducting agricultural activities in each area. Certain compounds can either be too abundant or too scarce, which might stress plants [16]. The seaweed-derived polysaccharides and oligosaccharides function as chelating agents, binding other components and generating a gel that can efficiently contain water [48]. Fulvic acid, a biostimulant derived from *Ascophyllum nodosum* (L), helps soya beans that aren't getting enough water [8]. The products not only help plants produce and grow, but they also stop plant pathogens from spreading. Biostimulants found in different types of kelp also help plants deal with stress better, including drought, ion balance, oxidative stress, salt stress, osmotic stress, cold stress, temperature tolerance, high-temperature tolerance, cold tolerance, and heavy metal tolerance [49]. Biostimulants produced from seaweed have recently been commercialized as plant productivity enhancers. The use of seaweed extracts in the environment can lead to better agricultural practices [50]. When tomatoes were stressed by salt, those that were fed two commercial extracts had better fruits with more vitamin C [51,52].

4. CONCLUSION

Seaweeds are diverse in an assortment of ways, including their natural occurrence, composition, harvesting and cultivation methods, and usage. The diverse array of benefits associated with seaweed extract underlines its potential to revolutionize horticultural practices, particularly in the context of increasing global demands for food production, environmental sustainability, and climate resilience. Their fast growth rates and composition make it ideal for hastening the transition to a biobased, circular, sustainable, and equitable society. Also, new research shows that kelp products change gene expression and make molecular changes in plants that are treated with them. The results of a previous study that used different kinds of seaweeds could be looked at again to see if they offer natural opportunities for making new biological goods. Seaweed extract contains many chemicals that help many different types of crops grow better. The present assessment raises awareness regarding the efficacy of seaweed as a biostimulant in contrast to readily available synthetic fertilizers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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