AATCC Review

24 February 2025: Received
19 April 2025: Revised
26 April 2025: Accepted
29 May 2025: Available Online

https://aatcc.peerjournals.net/

Review Article

Open Access

From sea to soil: How seaweed extracts benefit vegetable production?

Amninder Kaur[1], Puja Rattan*[2], Sanjeev Kumar[2], Aaqib Ayub[2] and Ashutosh Sharma[1*]

[1]*Faculty of Agricultural Sciences, DAV University, Jalandhar, Punjab, India*
[2]*Division of Vegetable Science, FOH&F, SKUAST-Jammu, J&K, India*

ABSTRACT

The increasing reliance on inorganic, chemical fertilizers to meet the global food demands has posed a significant threat to human health and the environment. However, there has been a continuous search for eco-friendly alternatives. Recently, a sustainable alternative in the form of seaweed-based bio-fertilizers has garnered considerable attention for their nutrient-rich nature and ease of application. Generally, the seaweeds are classified into red, green, and brown algae, and all of them can be used to prepare seaweed extracts. They are rich in proteins, carbohydrates, vitamins, minerals, and plant growth regulators like auxins and cytokinins etc. Their application in agriculture has been linked to significant improvements in growth, yield, and quality parameters of various crop plants by different researchers. They are particularly useful in vegetable crops and hence can be used to enhance vegetable production worldwide. They have been found quite useful across a variety of vegetable crops. Seaweed extracts are commercially available in their liquid, powder, or granular forms, which are shown to have a variety of benefits, like improvement in nutrient uptake, stimulation of soil microbiota, and boosting of antioxidant properties. Further, the seaweed extracts are also effective in mitigating both biotic and abiotic stress in vegetable crops, including drought, salinity, temperature extremes, insect pests, and plant pathogens, by improving plant defence responses and improving their physiology to enhance stress resilience. Commercially important seaweeds are harvested from coastal regions, where the setting up of such industries is more economical. Various studies consistently demonstrate that integrating the use of seaweed extracts as bio-stimulants with conventional fertilizers can enhance crop performance with reduced environmental concerns. However, there have been some challenges in their application and dosage optimizations, on a plant-to-plant bases. The present review proposes seaweed extracts as non-toxic, bio-degradable bio-stimulants as a promising solution for achieving sustainably in agriculture and improving global vegetable production for ensuring the nutritional security of the increasing human population.

Keywords: *Biostimulants, Sustainable agriculture, Organic fertilizers, Plant growth regulators, Stress tolerance, Crop productivity, Chemical fertilizers, Soil microbiota, Vegetable crops.*

Introduction

With the aim of producing larger yields from a limited amount of land, inorganic fertilizers are swelling in demand as the population grows, leading to enhanced need for food and fiber. Only by adopting new agricultural technological practices, such as switching from chemical intensive agriculture and using organic inputs like manure, seaweed biofertilizers, biopesticides, slow-release fertilizer, and nano-fertilizers, etc., will improve the application and use efficiency of the fertilizers and the detrimental effects of these synthetic chemicals on human wellness and the ecosystem can be reduced or eliminated. With the aim of producing larger yields from a limited amount of land, inorganic fertilizers are swelling in demand as the population grows, leading to enhanced need for food and fiber. A healthy environment and ecology for the present and the future will result from choosing organic farming [1] over inorganic fertilizers.

Corresponding Author: **Puja Rattan and Ashutosh Sharma*

DOI: https://doi.org/10.21276/AATCCReview.2025.13.03.97

The agricultural sector will gain from seaweeds since they are often compostable, harmless, noncorrosive, and unthreatening to living beings [2].

Seaweeds are macroscopic marine algae that are categorized into three types based on their colour [3] *viz*., green, brown, and red (Figure 1). The nutritional value of seaweeds and their advantageous non-nutritive components are well established. Carbohydrates, minerals, proteins, and vitamins are all abundant in seaweeds. Red seaweeds are rich in proteins, while green seaweeds are densely packed with lipids and carbohydrates. Up to 36% of its dry weight is made up of minerals [4]. Natural seaweeds are being used in place of synthetic fertilizers. Because seaweed extracts contain a variety of growth regulators, including cytokinins [5], auxins [6], gibberellins [7], and other macro and micronutrients essential for plant growth, they are highly effective liquid fertilizers and bio-stimulants. Seaweed extracts improve nitrogen uptake from soil [8], develop tolerance to ecological stress [9], aid in the creation of expedient soil bacteria [10], and support antioxidant qualities [11].

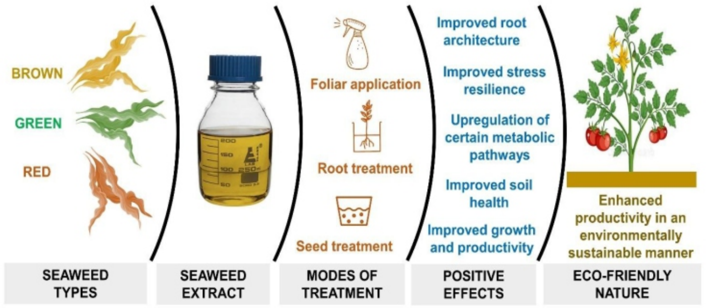

Figure 1: A schematic diagram showing how the extracts obtained from different types of seaweeds are applied in vegetable crops and improve their overall growth productivity and stress resilience in an eco-friendly manner.

About 60 of the roughly 700 marine algae species that have been described in the deep-water and offshore areas of the Indian coast are significant from a commercial standpoint. In India, Tamil Nadu, Gujarat, Maharashtra, Goa, Lakshadweep, Andhra Pradesh, and Karnataka are the top seaweed-producing states. The Andaman and Nicobar Islands, West Bengal, and Orissa are also home to a few species [12,13]. The three main classifications of seaweeds are based on their ability to absorb a specific wavelength of light and the primary colour that they contain. The kingdom Protista comprises three kinds of algae: the Rhodophyta (red algae), the Chlorophyta (green algae), and the Phaeophyta (brown algae) [14]. Of these, only 10% of the total documented green algae are found in marine environments, whereas the members of red and brown algae are typically found in aquatic environments. Seaweeds are known to produce a variety of polysaccharides that either act as a reserve food source or are an essential part of their cell walls. Anti-cancer, anticoagulant, antidiabetic, anti-inflammatory, and antibacterial properties have been found in these polysaccharides [15]. They are commonly considered 'wonder plants of the sea' because of their growing demand in the food, cosmetic, and pharmaceutical industries [16].

Seaweed extracts have already been commercialized and are now used in agricultural activities. There are many varieties of seaweed, such as powder, granular, and LSF (Liquid Seaweed Fertilizer). Cereals, legumes, and countless floral plants have all been demonstrated to thrive well on whole or finely chopped algae-based composts or the extracts thereof. Because such products are devoid of viable weed seeds and other harmful moulds, seaweed manure is highly beneficial. Liquid seaweed extracts are also used as a topical agent to improve the growth and yield of horticultural crops, vegetables, fruit plants, and grains [17,12].

Seaweed Use in Agriculture

Seaweeds have been used since ancient times to enhance soil and boost agricultural yields (Figure 2). However, it was originally mentioned in the first half of the first century that transplanting cabbage was a good idea [18]. The general belief that plants only absorb nutrients through their roots and not their leaves prevented seaweed extract from becoming widely employed in agriculture for about ten years, despite the fact that it was first produced in liquid form in 1950. The use of seaweed extract is steadily increasing to boost output and productivity without endangering the environment. As our knowledge of plant physiology advances, bio-stimulants are becoming more and more well-liked globally in sustainable agriculture these days [19].

There are several commercially available formulations that incorporate seaweed extracts in an odd ratio. Agriculture is the most prevalent application for brown algae, particularly *Ascophyllum nodosum* [20].

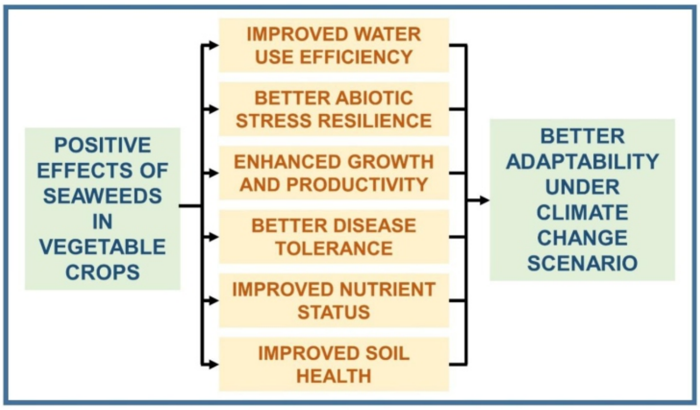

Figure 2: Various ways by which the seaweed extracts improved productivity and enhanced the adaptability of vegetable crops in a sustainable manner.

Numerous studies demonstrate that applying seaweed extracts to various vegetable crops, including tomatoes [21,22] and brinjal [23,24], improves growth indices, yield potential, and quality. Among them are bottle gourd [25], broccoli [26], onion [27], cucumber [28,29], cluster-bean [30], lettuce [31], okra [32], radish [33], sweet pepper [34], and numerous others.

Effects of seaweed extracts on growth, yield, and quality parameters of vegetable crops

Numerous researchers have noted that applying seaweeds has a good impact on a variety of vegetable crop metrics. The growth parameters of potatoes (cv. Kufri Jyoti) have been significantly impacted by the foliar application of seaweed extracts, specifically *Kappaphycus alvarezii* sap (K-sap) and *Gracilaria edulis* sap (G-sap). The most growth was observed with an economically feasible treatment of the foliar spray of 10% K-sap extract [35]. Additionally, it was noted that the highest increase in the vegetative development of potato, cv. Spunta was obtained when seaweed extract was applied at a rate of 5 mL/L. [36]. It has also been observed that seaweed extracts improve potato germination or shoot emergence. When seaweed extract (200 mg/L) was applied, the number of tubers that germinated increased, as did the number of leaves, leaf area, and tubers, as well as the plant's productivity [37]. Several studies have also assessed the use of seaweed extract in conjunction with the recommended dosage of fertilizers. When combined with the recommended amount of fertilizer, seaweed extracts (10% K-sap or 10% G-sap) significantly increased the growth characteristics of potatoes, such as plant height and stem number, compared to the control [38]. When compared to control plants, the seaweed extracts 'Alga 600' and 'Sea Force 2' demonstrated the best vegetative characteristics in potatoes [39]. The application of SWE resulted in improved tomato plant growth (flower clusters, flower number, fruit number, root length, root and shoot dry weight, SPAD) and plant productivity (yield and quality) when *Durvillaea potatorum* and *Ascophyllum nodosum* (brown algae) were added to the soil growing tomato plants [21]. In contrast to the control, [40] found that using seaweed extract (*Sargassum horneri*) considerably boosted tomato yield by 4.6–6.9%. In tomatoes cultivated in greenhouses and fields, the application of seaweed extracts from *A. nodosum* improved the values of flower clusters, fruit production, number of fruits, shoot dry weight, and root dry weight [41, 42] (Figure 3).

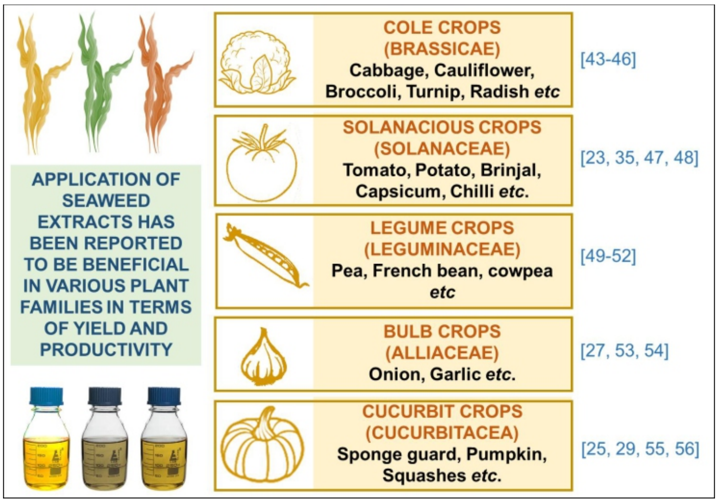

Figure 3: Examples of the beneficial effect of seaweeds in the vegetable crops of some important plant families, as evident from recent studies with supporting references in in square brackets.

It has been observed that using the SWE combination of *Durvillaea potatorum* and *A. nodosum* can increase broccoli's growth and yield metrics [45]. In contrast to the control, smearing the tomato plants with seaweed extracts (*Ascophyllum nodosum*) at 1 or 2 g/l reflected the highest values of setting percentage, number of fruits/plant, yield/plant, and total soluble solids [57]. Spraying tomato hybrids with seaweed extracts at 1 g/l recorded the highest values for plant growth characters, leaves, and total dry weight. Further, it was also recorded that when *Sargassum tenerrimum* extract is used on tomato plants, a gradual improvement in yield and growth is observed [58].

Moreover, the application of *A. nodosum* extracts to tomato plants had a gradual impact on the quantity and productivity of flower clusters [41]. Whereas, the seaweed extract from *Padina gymnospora* considerably improved the somatic and generative parameters in tomato [59]. This is because the roots grew and proliferated better, which allowed them to effectively draw nutrients from the deeper soil layers [60]. In a study on the effects of seaweed fertilizer that was made using three seaweeds: *Turbinaria ornata* (TSF), *Ulva intestinalis* (USF), and *Portieria hornemannii* (PSF) on *Vigna radiata* growth and yield, [61] found that the seaweed fertilizer (SF) in particular, PSF, was a low-cost and environmentally safe fertilizer for increasing yield.

Auxins and cytokinins found in seaweed extract (from *Turbinaria ornata*) may play an important role in root and shoot growth in *Vigna radiate* [62]. The increase in shoot, root, and biomass production in *Vigna radiata* was attributed to the micro and macro elements found in the seaweed extract (*Ulva lactuca*) [63]. When soluble extract from *A. nodosum* was sprayed over spinach leaves, higher levels of phenolics, flavonoids, and antioxidants were noted [64]. When a concentration of 15% of the seaweed extract was applied to soybean plants, they grew taller than the control [65]. Similar results were observed when 500 ml ha^{-1} of seaweed extract was applied to soybean plants during the flowering stage [66].

An improvement in pea growth indices and yield was observed when seaweed extracts were applied [49]. They found that the number of pods per plant, pod fresh weight, pod length, number of seeds per pod, and 100-seed weight improved when 4 mL L^{-1} seaweed extract was applied to the leaves and soil as opposed to 0, 1, 2, and 3 mL/L. Further, the application of seaweed extracts to pea plants produced improved the parameters like number of pods, seeds per pod, plant length, number of primary branches, length of pods, number of root nodules in roots [67], which were essential for fixing nitrogen in the atmosphere, number of flowers, and green mass production. In cauliflower, improvements were noted in characteristics such as plant height, leaf count, plant spread, curd diameter, curd weight, and yield [68]. Additionally, The use of seaweed extract (Alga mix) was recommended to improve growth indices and yield potential of cauliflower [69].

Studies have also been conducted on the effects of seaweed extracts and a few other bio-stimulants on potatoes. Bio-stimulants are one of the agrotechnological components used in contemporary plant cultivation that, when combined with fertilization and plant protection, can positively impact both the amount and quality of yields [70, 71]. In the potato cv. Spunta, the seaweed extract (5 mL/L) enhanced tuber yield and yield-contributing characteristics [36]. The optimal dosage for increasing potato crop production was found to be 5 milliliters per litre (mL/L) of the seaweed True Algae Max [61]. Seaweed extracts have grown in popularity recently as bio-stimulants for improving plant growth, yield, quality, and productivity [72]. Seaweed extracts affect the quality parameters in addition to amplifying the growth parameters and yield-related features in potatoes. The quality of potatoes (cv. Kufri Jyoti) was greatly impacted by the foliar application of several seaweed extracts, such as *Kappaphycus alvarezii* sap (K-sap) and *Gracilaria edulis* sap (G-sap). In addition to indicating its economic feasibility, a 10% K-sap spray produced the highest nutrient (N, P, and K) uptake, values for quality attributes like ascorbic acid, and a decrease in sugar content [35]. Nitrogen, total soluble solids, and protein contents of the potato tubers were accelerated by the foliar application of 'Primo' an organic bio-stimulant, to the potato cultivar 'Sante' [73]. Table 1 below shows how various seaweed extract affected vegetable crop growth, yield, and quality.

Table 1: Effect of seaweed on growth, yield, and quality of vegetable crops.

Crop	Seaweed	Effect	Concentration	Reference
Potato	TAM® True-Algae-Max	Higher potato yield production, quality, besides biochemical and physiological traits.	5 mL/L	[47]
Cucumber	Seaforce and Seamino	Increased cucumber yield, fruit number per plant, fruit weight.ml	1.5 mL/L	[28]
Potato	Bio algeen S90 and Kelpak SL	Enhanced tuber weight per plant, average tuber weight and tuber yield.	Bio-algeen S90: 2 L/ha and Kelpak SL: 2 L/ha	[74]
Potato	Algae extract	Increased the plants growth attributes as leaves number, the leaf area, tubers number, and the plant production.	200 mg/L	[37]
Potato	Primo	Amplified plant growth and yield.	250 ml/ha	[73]
Sweet Potato	*Ulva lactuca*	Boost sweet potato growth, yield and tuber root chemical compositions.	15%	[75]

Sweet pepper	Mar Marine and Basfoliar Aktiv	Enhanced Vegetative growth.	2 mL/L and 3 mL/L	[34]
Lettuce	Basfoliar Kelp	Extending the shelf-life of fresh-cut leaf lettuce.	4 mL/L	[76]
Okra	*Rosenvigea intricate*	Enhanced growth, yield, chlorophyll pigment and soil profile.	20%	[32]
Capsicum	*Codium Decorticatum*	Maximum germination of seed, fresh and dry weight, root and shoot length, number of branches, leaf area, number of pods and content of total chlorophyll, chl a, and chl b, protein, carbohydrate and lipids were observed.	50%	[77]
Onion	*Ascophyllum nodosum* extract	Increased total soluble solids, ascorbic acid and minerals (N, P, and K), bulb weight and yield.	3%	[27]
Cucumber	True Algae Max	Enhanced cucumber yield.	100%	[29]
Okra	*Sargassum spp.* Gel formulation	Increased carbohydrate, Protein, dietary fibre and vitamin-C content of fruits.	2%	[22]
Capsicum	Kelpak extract	Boost the number and size of the marketable fruit.	0.4%	[78]
Potato	Alga 600 and sea force 2	Enhanced plant height (cm), aerial stem number, total chlorophyll, fresh weight of vegetative part (gm) and tuber yield.	3mL/L	[39]
Potato	*Kappaphycus alvarezii* (K sap) and *Gracilaria edulis* (G sap)	Increment in marketable and total tuber yield of potato.	10% K sap +10% G sap + suggested dose of chemical fertilizer	[38]
Carrot	Actiwave®	Improved growth and quality parameters	10 g/L	[79]
Potato	*Kappaphycusalvarezii* (K sap) and *Gracilariaedulis* (G sap)	Increased plant height, tuber yield.	10% K sap +10% G sap + RDF	[35]
Hot pepper	True- Algae-Max	Enhanced yield and prominent amounts of biological molecules like chlorophyll, ascorbic, phenolic compounds, flavonoids, and total nutrients.	1%	[48]
Tomato	*Sargassum* sp.	Promoting hypocotyl and root growth of tomato plant.	5 mg/L	[2]
Red radish	Seaweed extract	Enhanced growth, quality and yield in red radish.	3 mL/L	[44]
Soyabean	*Sargassum wightii and Ulva lactuca*	Increased shoot length, leaf length leaf width, number of leaves, root length chlorophyll-a (mg/g FW), chlorophyll-b (mg/g FW), total Chlorophyll (mg/g FW), and carotenoids (mg/g FW).	2% and 2%	[50]
Lettuce	*A. nodosum, Durvillaea potatorum, Durvillaea Antarctica*, and *Ecklonia maxima*	Increased root and shoot, chlorophyll content, photo-chemical efficiency, activity of photosystem II, and marketable yield increase.	4%, N 30 kg	[80, 81]
Onion	*A. nodosum*	Increased bulb diameter, eight, minerals and ascorbic acid content.	0.55%	[53]
Broccoli	*Durvillaea potatorum*, and *A. nodosum*	Increased the leaf area, stem diameter and biomass of broccoli.	145%	[45]
Bottle gourd	Seaweed extract	Enhanced crop performance, young shoot yield and quality of *L. siceraria*.	3mL/L	[25]
Brinjal	*Sargassum wightii*	Improved the plant height, flowers/plant and chlorophyll content.	5 ml	[82]
Brinjal	*Laurencia obtuse*	Significantly affected seed germination and growth of *Solanum melongena*, and also improved soil profile.	2%	[23]
Capsicum	*Ulva lactuca*	Improved growth, yield and quality parameters such as protein content, soluble sugar and chlorophyll content of thethird young leaves.	1%	[83]
Guar (*Cyamopsis tetrogonolaba*)	*Rosenvigea intricate*	Increased growth, yield, chlorophyll and soil profile.	20%	[30]
Pea	*Ascophyllum nodosum*	Enhanced pea growth, photosynthetic pigments, and yield-related traits.	4 mL/L	[49]
Cauliflower	Seaweed extract	Increased the concentration of phosphorous, potassium, and boron.	6.6 mL/L	[43]

Effects of seaweed extracts in mitigating the harmful effects of plant stress

Seaweed extracts are not only useful bio-stimulants in improving the growth and productivity of vegetable crops but also safeguard them from several harmful effects of both abiotic and biotic stresses. Further, their nonhazardous nature to the environment is one of their key characteristics [80]. Thus, bio-stimulants (such as seaweed extracts) have a positive impact on plant growth and development that extends beyond increasing yield and includes helping plants cope with biotic and abiotic stress [58, 81, 86]. Moreover, it was recorded that using seaweed extracts under salt stress improved the amount of chlorophyll in tomato plants [87]. The tomato's ability to withstand salt may be due to bioactive substances found in seaweed extracts, such as polyphenols, flavonoids, soluble sugars, and amino acids. Seaweed extracts are a new class of bio-stimulants that help plants become more resilient to a variety of abiotic stresses [88]. This could be attributed to the presence of bioactive substances such as vitamins, amino acids, phytohormones, and trace minerals [89].

A similar conclusion were made another group [90], who proposed that seaweed extracts boost the synthesis/activities of both enzymatic and non-enzymatic antioxidants. Further, it was found that applying seaweed extracts to tomato leaves under salt stress boosted the accretion of Cl^- ions, which in turn reduced the water potential and the concentration of Na^+ ions [91].

Seaweed extracts also protect plants from biotic stress. It was found that applying seaweed extracts to the plants reduced the amount of nematode infestation [92]. Root-knot nematode incidence in tomatoes is reduced when soil is amended with a commercial liquid formulation of *E. maxima* (sea-bamboo) extract. When administered topically, *A. nodosum* extracts decreased the incidence of *Phytophthora capsici* infection in chili [93]. Seaweed extracts also increased the number and activity of *Pythium ultimum* antagonistic bacteria in cabbage [94]. Further, the application of chitosan and extract from *Ascophyllum nodosum* works in concert to activate peas' host defense against powdery mildew, primarily through the modulation of the signaling pathway mediated by salicylic acid

(SA) and jasmonic acid (JA) [95]. When *Ascophyllum nodosum* (SW) extract was sprayed at a rate of 0.2% on carrots and exposed to *Alternaria radicina* and *Botrytis cinerea* inocula six hours later, it was recorded that there is a substantial decrease in disease severity at 10- and 25-days following inoculation, as compared to control plants [96]. The treated plants showed increased activity of defense-related enzymes such as β-1,3-glucanase, phenylalanine ammonia lyase, polyphenol oxidase, chitinase, and peroxidase (PO), indicating the function of seaweed extracts in carrot disease resistance.

When the effects of Marmarine, a formulation of marine plant extract from *Ascophyllum nodosum*, on cucumbers infected by *Phytophthora* sp. were investigated; it was recorded that it may improve resistance by increasing the activity of several defense-related enzymes and changing the transcript levels of several defense related genes [97]. When *Ascophyllum nodosum* (brown seaweed) extract was applied at a 0.5% concentration and used in conjunction with fungicides, it significantly decreased the incidence of disease in tomatoes caused by foliar pathogens such as *Alternaria solani* and *Xanthomonas campestris* pv. *vesicatoria* [41]. Further, the *verticillium* wilt can also be effectively controlled by using a seaweed extract made from *Ecklonia maxima*, when used at a concentration of 1% [98]. The use of seaweed extracts for reducing the adverse effects of various biotic and abiotic stresses have been compiled in Table 2.

Table 2: Influence of seaweed extract on growth, yield and quality of vegetable crops under abiotic stress

Crop	Abiotic stress	Seaweed	Concentration	Effect	Reference
Brinjal	Salt stress	*Ascophyllum nodosum*	5 mL/L	Enhanced growth, yield and quality of brinjal.	[99]
Bean (*Phaseolus vulgaris* L.)	Drought stress	*Ulva rigida* and *Fucus spiralis*	25%	Improved plant height, Enhanced chlorophyll a (Chl a), chlorophyll b (Chl b) pigments and contents of glycine betaine (GB) were also detected with all SWE treatments under water deficit.	[100]
Tomato	Salt stress	*Padina gymnospora*	0.2%	Enhanced root and shoot length, root and shoot area and shoot and root fresh weight.	[59]
Tomato	Heat stress	*Ascophyllum nodosum*	0.106%	Increased flower development, pollen viability, and fruit production.	[101]
Tomato	Salt stress	*Sargassum vulgare*	2% and 5%	Improved seedling growth of tomato.	[102]
Tomato	Salt stress	*Ulva lactuca*	1 mg/ml	Increased fresh weight.	[103]
Tomato	Salt stress	*Rygex* and *Super fifty (SU)*	2.50 mL/L and 2.00 mL/L	Improved water use efficiency and increased tomato yield by 49% (R) and 70% (SU) regardless of the salinity level.	[91]
Zucchini squash	Salt stress	*Ecklonia maxima*	3 mL/L	Increased yield and shoot biomass, as well as fruittotal soluble solid contents in comparison to untreated plants.	[104]
Spinach	Drought stress	*Ascophyllum nodosum*	0.5%	Enhanced spinach growth, high photosynthetic rate.	[105]
Okra	Reduced NPK	*Ecklonia maxima*	0.40%	Increased leaf number, root and stem thickness, shoot and root weight and leaf area.	[106]
Cucumber	Low temperature stress	Seaforce and Seamino	1.5mL/L	Improved flowering characters, and increased cucumber yield (fruit number per plant, fruit weight per plant and yield per plant).	[28]
Okra	Drought stress	*Ascophyllum nodosum*	0-0.3%	Increased the chlorophyll abundance and activity of anthocyanin, proline.	[85]
Pepper	Salt stress	*Ascophyllum nodosum*	1-3 g/L	Increase leaf biomass	[107]
Radish	Heavy metal stress	*Ulva fasciata* and *Sargassum lacerifolium*	1.1 mg/kg	Improved growth	[108]
Soyabean	Salt stress	*Sargassum wightii* and *Ulva lactuca*	1% seaweed liquid fertilizer	Improved growth, yield, chlorophyll pigment and soil profile.	[50]
Sweet potato	Nutrient stress	*Ascophyllum nodosum*	0.75%	Enhanced quality of tuber roots.	[109]
Chicory	Drought stress	*Ecklonia maxima*	7.7%	Increased growth, yield and total chlorophyll, proline and ascorbic acid content	[110]
Soyabean	Drought stress	Red seaweed	10%	Improved yield.	[111]
Bean	Salt stress	*Sargassum vulgare*	0.5%	Increased germination of bean.	[112]
Tomato	Drought stress	*Chondrus crispus*	0.1%	Enhanced tomato growth and drought resistance.	[113]
Tomato	Drought stress	*Ascophyllum nodosum*	0.33%	Boost plant growth, foliar density, chlorophyll, lipid peroxidation, proline, soluble sugars.	[114]
Lettuce	Salt stress	*Ascophyllum nodosum*	10 mL/L	Increased root, stem, total plant weight.	[115]
Cucumber	Salt stress	*Ascophyllum nodosum*	2 g/kg	Enhanced fruit yield.	[116]
Tomato	Salt stress	*Dunaliella salina* exo-polysaccharides	0.1 g/L	Increased chlorophyll, protein, and proline content.	[117]
Cowpea	Salt stress	Seaweed extracts	2-4%	Higher photosynthetic pigments, proline and Phenylalanine ammonia lyase activity.	[118]

Conclusion and future prospects

In the last few decades, there has been a sharp growth in demand for chemical fertilizers to meet the demands of the growing human population. Their use not only increases the cost of cultivation but also raises some serious environmental and human health concerns. On the other hand, the use of seaweed extract tends to improve the ability of plants to absorb nutrients, leading to better productivity, particularly in vegetable crops. The seaweed extracts are gaining popularity as eco-friendly alternatives to improve the growth, quality, and productivity of vegetable crops.

Therefore, the use of seaweed extracts holds immense promise in sustainable vegetable production. As global concerns grow over the adverse effects of synthetic fertilizers and pesticides on human health and the environment, the demand for natural bio-stimulants like seaweed-based products is expected to rise sharply. Seaweed extracts, derived from diverse species such as *Ascophyllum nodosum*, *Sargassum spp.*, and *Ulva lactuca, etc.*, are also rich in bioactive compounds, including phytohormones, and boost stress resistance in plants. Their multifaceted benefits in improving the yield, quality, and resilience of vegetable crops have been well-documented by various researchers.

As the research in this field advances, the development of more refined formulations tailored to specific crop types, growth stages, and environmental conditions is likely, which will further enhance their efficacy. Integration with precision agriculture technologies, such as targeted foliar applications via drones and data-driven irrigation systems, can also further optimize their usage efficiency and reduce their wastage. Moreover, the use of seaweed extracts in combination with other bio-stimulants is yet to be studied in different combinations in detail, which is likely to reduce doses of synthetic fertilizers. The large-scale popularisation and commercialisation, supported by robust policy frameworks and farmer education, will be crucial for widespread adoption. Additionally, expanding the cultivation of economically important seaweed species along the coastline may provide rural livelihood opportunities while supporting circular bio-economy goals. Recently, efforts have been initiated to study the molecular mechanisms by which seaweed extracts affect plant physiology, enabling the breeding of varieties more responsive to these natural stimulants. Overall, seaweed-based bio-stimulants represent a sustainable solution for enhancing vegetable production in light of the increasing global human population, resource scarcity, climate change, and the need for healthier food systems.

Supplementary Data

There is no supplementary data pertaining to the review

Author contribution statement

Author AK collected the data and wrote the first draft of the manuscript, AS and PR conceptualized the review, drafted the framework (headings and subheadings) of the review, edited the manuscript, and improved the figures. SK compiled the information in the form of and helped in the editing of the manuscript, whereas AA prepared the figures and also helped in the editing of the manuscript. All authors read and approved the final manuscript.

Acknowledgements

The authors duly acknowledge the facilities provided by DAV University, Jalandhar, and SKUAST-Jammu for the collection and compilation of the review.

Conflict of interest

There is no conflict of competing interests, financial or otherwise.

Funding

There is no funding for the publication of this review

Ethical Statement

NA

Data availability

NA

References

1. Kumar, R., Kumar, R., and Prakash, O. 2019. The impact of chemical fertilizers on our environment and ecosystem. In *Research Trends in Environmental Sciences* (Second Edition), pp.71-85.

2. Fatimah, S., Alimon, H. and Daud, N. 2018. The effect of seaweed extract (*Sargassum* Sp) used as fertilizer on plant growth of *Capsicum annum* (Chilli) and *Lycopersicon esculentum* (Tomato). *Indonesian Journal of Science and Technology*, 3(2): 115-123.

3. Orberg, S. B., Duarte, C. M., Geraldi, N. R., Sejr, M. K., Wegeberg, S., Hansen, J. L. and Krause-Jensen, D. 2023. Prevalent fingerprint of marine macroalgae in arctic surface sediments. *Science of the Total Environment*, 898, pp. 165507.

4. Subbiah, V., Xie, C., Dunshea, F. R., Barrow, C. J. and Suleria, H. A. 2022. The quest for phenolic compounds from seaweed: Nutrition, biological activities and applications. *Food Reviews International*,*39*(8), pp.5786-5813.

5. Durand, N., Briand, X. and Meyer, C. 2003. The effect of marine bioactive substances (N PRO) and exogenous cytokinins on nitrate reductase activity in *Arabidopsis thaliana*. *Physiologia Plantarum*, *119*(4):489-493.

6. Sahoo, D. 2000. *Farming the ocean: seaweeds cultivation and utilization*. Aravali Books International, New Delhi.

7. Stirk, W. A. and Van Staden, J. 1997. Isolation and identification of cytokinins in a new commercial seaweed product made from *Fucus serratus* L. *Journal of applied phycology*, 9, pp.327-330.

8. Turan, M. and Kose, C. 2004. Seaweed extracts improve copper uptake of grapevine. *Acta Agriculturae Scandinavica, Section B- Soil and Plant Science*, 54 (4): 213-220.

9. Zhang X., Ervin, E. H. and Schmidt, E.R. 2003. Plant growth regulators can enhance the recovery of Kentucky bluegrass sod from heat injury. *Crop Science*, 43(3):952-956.

10. Khan, W., Rayirath, U. P., Subramanian, S., Jithesh, M. N., Rayorath, P., Hodges, D. M., Critchley, A. T., Craigie, J. S., Norrie, J. and Prithiviraj, B. 2009. Seaweed extracts as biostimulants of plant growth and development. *Journal of plant growth regulation*, 28, pp. 386-399.

11. Verkleij, F.N. 1992. Seaweed extracts in agriculture and horticulture: a review. *Biological Agriculture and Horticulture*, 8 (4):309-324.

12. Fazli, R., Dwivedi, M. C., Puniya, R., Sharma, V. and Anil Kumar, M. K. S. 2023. Effect of seaweed extract under different doses of NPK on growth parameters of wheat. *The Pharma Innovation Journal*,12(1):3019- 3023

13. Tandel, K. V., Joshi, N.H., Tandel, G.M, Patel, M.R. and Tandel, J.T.2016.Seaweed cultivation in India, a new opportunity of Revenue Generation. *Advances in Life Sciences*, 5(7): 2487-2491.

14. Sangeetha, J., Thangadurai, D., Islam, S. and Hospet, R. (Eds.).2023. *Algal Metabolites: Biotechnological, Commercial, and Industrial Applications*. CRC Press.

15. Stoica, R. M., Moscovici, M.,Lakatos, E. S. and Cioca, L. I. 2023. Exopolysaccharides of Fungal Origin: Properties and Pharmaceutical Applications. *Processes*, *11*(2): 335.

16. Umashree, V. R., Anjana, K., Vidya, D., Vinod, B., Nayana, K., Sreelakshmi, M., Raja, R. and Arunkumar, K. 2023. An introduction to algae materials. In *Algae Materials* (pp. 1-28). Academic Press, Elsevier.

17. Elansary, H.O., Skalicka-Wozniak, K. and King, I.W. 2016.Enhancing stress growth traits as well as phytochemical and antioxidant contents of Spiraea and Pittosporum under seaweed extract treatments. *Plant Physiology and Biochemistry*, 105:310–320.

18. Craigie, J. S. 2011. Seaweed extract stimuli in plant science and agriculture. *Journal of applied phycology*, 23, pp. 371-393.

19. Nardi, S., Pizzeghello, D., Schiavon, M. and Ertani, A. 2016.Plant bio-stimulants: physiological responses induced by protein hydrolyzed-based products and humic substances in plant metabolism. *Scientia Agricola*, 73 (1): 18-23.

20. De Saeger, J., Van Praet, S., Vereecke, D., Park, J., Jacques, S., Han, T. and Depuydt, S. 2020. Toward the molecular understanding of the action mechanism of *Ascophyllum nodosum* extracts on plants. *Journal of Applied Phycology*, 32(1): 573-597.

21. Hussain, H. I., Kasinadhuni, N. and Arioli, T. 2021. The effect of seaweed extract on tomato plant growth, productivity and soil. *Journal of Applied Phycology*, 33(2): 1305-1314.

22. Swarnam, T. P., Velmurugan, A., Lakshmi, N. V. and Kavitha, G. 2020. Foliar application of seaweed extract on yield and quality of okra (*Abelmoschus esculentus* L.) grown in a tropical acid soil. *Trends in Biosciences*, *13*(6): 0974-8431.

23. Pandya, M. P. and Mehta, S. K. 2022. Effect of Presoaking of *Solanum melongena* L. (Brinjal) Seed in *Laurencia obtusata* seaweed extract on germination and growth Parameter. *Journal of Emerging Technologies and Innovative Research*, 9(2): 849-855.

24. Yusuf, R., Syakur, A., Masud, H., Latarang, B., Kartika, D. and Kristiansen, P. 2021. Application of local seaweed extracts to increase the growth and yield eggplant (*Solanum melongena* L.). In IOP Conference Series: *Earth and Environmental Science*,681(1), pp. 012019.

25. Consentino, B. B., Sabatino, L., Mauro, R. P., Nicoletto, C., De Pasquale, C., Iapichino, G. and La Bella, S. 2021. Seaweed extract improves *Lagenaria siceraria* young shoot production, mineral profile and functional quality. *Horticulturae*, 7(12), pp. 549.

26. Hammood, N.M. 2021. Effect of Organic Nutrients on Growth and Yield of Broccoli *Brassica oleracea* L. var. *italica* Plenck. I*ndian Journal of Ecology*, 48(5): 1414-1418.

27. Abbas, M., Anwar, J., Zafar-ul-Hye, M., Iqbal Khan, R., Saleem, M., Rahi, A. A., Danish, S. and Datta, R. 2020. Effect of seaweed extract on productivity and quality attributes of four onion cultivars. *Horticulturae*, 6(2), pp. 28.

28. Sarhan, T. Z., and Ismael, S. F. 2014. Effect of low temperature and seaweed extracts on flowering and yield of two cucumber cultivars (*Cucumis sativus* L.). *International Journal of Agricultural and Food Research*, 3(1): 41-54.

29. Hassan, S. M., Ashour, M., Sakai, N., Zhang, L., Hassanien, H. A., Gaber, A. and Ammar, G. 2021. Impact of seaweed liquid extract bio stimulant on growth, yield, and chemical composition of cucumber (*Cucumis sativus*). *Agriculture*, 11(4), pp. 320.

30. Thirumaran, G., Arumugam, M., Arumugam, R. and Anantharaman, P. 2009. Effect of seaweed liquid fertilizer on growth and pigment concentration of *Cyamopsiste trogonolaba. American-Eurasian Journal of Agronomy*, 2 (2): 50-56.

31. Kusumawati, R., Munifah, I. and Basmal, J. 2019. The effect of seaweed fertilizer and compost combination on the growth of lettuce head. *IOP Conference Series:Earth and Environmental Science*, 383 (1), pp. 012042.IOP Publishing.

32. Thirumaran, Arumugam, M., Arumugam, R. and Anantharaman, P. 2009. Effect of seaweed liquid fertilizer on growth and pigment concentration of *Abelmoschus esculentus* (L.) medikus. *American-Eurasian Journal of Agronomy*, 2, pp. 57-66.

33. Sakr, M. T., Ibrahim, H. M., Elawady, A. E. and Abo Elmakarem, A. A. 2019. Effect of humic acid, seaweed extract and essential oils as antioxidants on pre-and post-harvest quality of red radish plants. *Horticulture International Journal*, 3(3): 129-138.

34. Hussein, H. A., Jawad, D. H., and Abboud, A. K. 2019. Effect of foliar nutrition by seaweed extract marmarine and Basfoliaraktiv in growth and yield of pepper sweet (Along type) Sierra Nevada variety under in plastic houses conditions. *International Journal of Botany Studies*, 4(4): 112-116.

35. Garai, S., Brahmachari, K., Sarkar, S., Mondal, M., Banerjee, H., Nanda, M. K. and Chakravarty, K. 2021. Impact of seaweed sap foliar application on growth, yield, and tuber quality of potato (*Solanum tuberosum* L.). *Journal of Applied Phycology*, 33, pp.1893-1904.

36. Binnoubah, A. H. A., Saed, Z. H. A. and Hadia, A. A. A. 2022. Response of growth and potato tubers yield to potassium fertilization and some bio-extracts. *Middle East Journal of Agriculture Research,* 11(03): 781-789.

37. Issa, R., Boras, M. and Zidan, R. 2019. Effect of seaweed extract on the growth and productivity of potato plants. *SSRG International Journal of Agriculture and Environment Sciences*, 6, pp. 83-89.

38. Prajapati, A., Patel, C. K., Singh, N., Jain, S. K., Chongtham, S. K., Maheshwari, M. N., Patel, C. R. and Patel, R. N. 2016. Evaluation of seaweed extract on growth and yield of potato. *Environment and Ecology*, 34(2): 605-608.

39. Sarhan, T. Z. 2011. Effect of humic acid and seaweed extracts on growth and yield of potato plant (*Solanum tubersum* L.) Désirée' cv. *Mesopotamia Journal of Agriculture*, 39(2): 19- 25.

40. Yao, Y., Wang, X., Chen,B.,Zhang, M. and Ma, J. 2020. Seaweed extracts improved yields, leaf photosynthesis, ripening time, and net returns of tomato (*Solanum lycopersicum* Mill.). *ACS omega,* 5(8), 4242-4249.

41. Ali N., Farrell A., Ramsubhag A. and Jayaraman J.2016. The effect of *Ascophyllum nodosum* extract on the growth, yield and fruit quality of tomato grown under tropical conditions. *Journal of Applied Phycology*, 28, pp.1353-1362.

42. Renaut, S., Masse, J., Norrie, J., Blal, B. and Hijri, M. 2019. A commercial seaweed extracts structured microbial communities associated with tomato and pepper roots and significantly increased crop yield. *Microbial Biotechnology*, 12 (6):1346–1358.

43. Youssif, H. E. and Tawfeeq, A. M. 2021. Effect of foliar application of seaweed extract and cytokinin on growth and yield of cauliflower plant (*Brassica oleracea* var. *botrytis*). *Tikrit Journal for Agricultural Sciences*, 21 (4):17-24.

44. Sahu, J., Sharma, S. P., Singh, J., Deshmukh, U.B., Nishad, D. and Mishra, R. 2022. Effect of seaweed extract and humic acid on yield parameters of red radish. *The Pharma Innovation Journal*, 11(6): 01-05.

45. Mattner, S., Wite, D., Riches, D., Porter, I. and Arioli, T. 2013. The effect of kelp extract on seedling establishment of broccoli on contrasting soil types in southern Victoria, Australia. *Biological Agriculture & Horticulture*, 29 (4):258–270.

46. Yusuf. R., Bahrudin, Masud, H., Abdul Syakur, A., Afriana, D.S., YuliantiKalaba, Y. and Kristiansen, P. 2020. Application of local seaweed extracts on growth and yield of mustard greens (*Brassica juncea* L.).In *IOP Conference Series: Earth and Environmental Science,* 484(1), pp.012066. IOP Publishing.

47. Ammar, G. M., Ashour, M. M. and Hassan M.S. 2022. Enhancing potato production by applying commercial seaweed extract (TAM®) bio stimulant under field conditions. *Journal of the Advances in Agricultural Researches*, 27(3): 492-504.

48. Ashour, M., Hassan, S. M., Elshobary, M. E., Ammar, G. A. G., Gaber, A., Alsanie, W. F., Mansour, A. T. and El-Shenody, R. 2021. Impact of commercial seaweed liquid extract (TAM®) bio stimulant and its bioactive molecules on growth and antioxidant activities of hot pepper (*Capsicum annuum*). *Plants*, 10(6), pp. 1045.

49. Naz, S., Muhammad, H. M. D., Ramzan, M., Sadiq, B., Ahmad, R., Ali, S. and Altaf, M. A. 2023. Seaweed Application Enhanced the Growth and Yield of Pea (*Pisum sativum* L.) by Altering Physiological Indices. *Journal of Soil Science and Plant Nutrition*, 23(4), 6183-6195.

50. Ramarajan, S. Henry L. and Saravana, G. 2013. Effect of seaweed extracts mediated changes in leaf area and pigment concentration in soybean under salt stress condition. *Research and Reviews: A Journal of Life Sciences*, 3, pp.17-21.

51. Al-majdi, M.H.K., Al-abojaml, N.H.N. and Mehdi, D.H. 2024. Effect of seaweed extract and nitrogen fertilizer on the growth and yield traits of pea (*Pisum sativum* L.). *Sabrao Journal of Breeding and Genetics*, 56 (5): 2119-2126.

52. Mohammed, A. and Hamdoon, M., 2014. Effect of Seaweed Extract and Phosphorous Application on Growth and Yield of Pea Plant. *Building Organic Bridges*, 3, pp.695-696.

53. Hidangmayum, A. and Sharma, R. 2017. Effect of different concentration of commercial seaweed liquid extract of *Ascophylum nodosum* on germination of onion (*Allium cepa* L.). *International Journal of Science and Research* (IJSR), 6(7), 1488-1491.

54. Samanta, S., Biswas, N., Chattopadhyay, N., Bandyopadhyay, A. and Ghosh, D. K. (LKN) 2024. Influence of seaweed extract on growth, yield and quality of onion cv. Sukhsagar. *Journal of Crop and Weed*, 20(1): 102-107.

55. Trejo Valencia, R., Sanchez Acosta, L., Fortis Hernandez, M., Preciado Rangel, P., Gallegos Robles, M.A., Antonio Cruz, R.D.C. and Vazquez Vazquez, C. 2018. Effect of seaweed aqueous extracts and compost on vegetative growth, yield, and nutraceutical quality of cucumber (*Cucumis sativus* L.) fruit. *Agronomy*, 8(11), pp.264.

56. Suriya, R. and Madhanakumari, P. 2023.Effect of Organic manures and Bio-stimulants on the Yield of Snake gourd (*Trichosanthes cucumerina L.*). *Annals of Plant and Soil Research,* 25(1): 177-181.

57. Nour, K. A. M., Mansour, N. T. S. and Abd El-Hakim W.M. 2010. Influence of foliar spray with seaweed extracts on growth, setting and yield of tomato during summer season. *Journal of Plant Production*, Mansoura University, 1(7): 961-976.

58. Sasikala, M., Indumathi, E., Radhika. and S., Rajendran, S. 2016. Effect of seaweed extract (*Sargassum tenerrimum*) on seed germination and growth of tomato plant (*Solanum lycopersicum*). *International Journal of ChemTech Research*, 9(9): 285-293.

59. Hernandez-Herrera, R. M., Sanchez-Hernandez, C. V., Palmeros-Suarez, P. A., Ocampo-Alvarez, H., Santacruz-Ruvalcaba, F., Meza-Canales, I. D. and Becerril-Espinosa, A. 2022. Seaweed Extract Improves Growth and Productivity of Tomato Plants under Salinity Stress. *Agronomy*, 12(10), pp. 2495.

60. Hernandez-Herrera, R.M., Santacruz-Ruvalcaba, F., Ruiz-Lopez, M.A.,Norrie, J. and Hernandez-Carmona, G. 2013. Effect of liquid seaweed extracts on growth of tomato seedlings (*Solanum lycopersicum* L.). J*ournal of Applied Phycology,* 26, pp. 619–628.

61. Karthik, T. and Jayasri, M. A. 2023.Systematic study on the effect of seaweed fertilizer on the growth and yield of *Vigna radiata* (L.) R. Wilczek (Mung bean).*Journal of Agriculture and Food Research*, 14, pp.100748.

62. Punitha, P., Priyadharshini, K.N., Devi, S.D., Kumar, J.R. and Santhanam, A.B.P. 2022. Effect of seaweed liquid extract as an organic bio stimulant on the growth, fatty acids and high - value pigment production of *Vigna radiata*. *Biomass Conversion and Biorefinery,* 14, pp. 7345–7357.

63. Castellanos-Barriga, L., Santacruz-Ruvalcaba, F., Hernandez-Carmona, G., Ramirez-Briones, E. and Hernandez-Herrera, R. 2017. Effect of seaweed liquid extracts from *Ulva lactuca* on seedling growth of mung bean (*Vigna radiata*). *Journal of Applied Phycology*, 29, pp.2479-2488.

64. Fan, D., Hodges, M., Zhang, J., Kirby, C.W., Ji, X., Locke, S.J., Critchley, A.T. and Prithiviraj, B.2011**.** Commercial extract of the brown seaweed *Ascophyllum nodosum* enhances phenolic antioxidant content of spinach (*Spinacia oleracea* L.) which protects *Caenorhabditis elegans* against oxidative and thermal stress. *Food Chemistry*, 124(1):195–202.

65. Rathore, S., Chaudhary, D., Boricha, G., Ghosh, A., Bhatt, B., Zodape, S.T. and Patolia, J.S. 2009. Effect of seaweed extract on the growth, yield and nutrient uptake of soybean (*Glycine max*) under rainfed conditions. *South African Journal of Botany*, 75(2): 351-355.

66. Guerreiro, J., Blainski, E., Silva, D., Caramelo, J., Pascutti, T., Oliveira, N. and Filho, P.J. 2017. Effect of the seaweed extract applied on seeds and/or foliar sprays on soybean development and productivity. *Journal of Food Agriculture and Environment*,15(1): 18-21.

67. Yashvardhan, V. 2023. Effect of Vermicompost and Seaweed Extract on Growth and Yield on Local Small Pod Garden Pea (*Pisum sativum* L.) Variety. *Journal of Experimental Agriculture International*, 45(7):182-189.

68. Kharbyngar, B. and Singh, D. 2019. Influence of seaweed extract, organic and inorganic fertilizers on growth and yield of cauliflower (*Brassica oleracea var.botrytis*) cv. Pant Sugra. *Journal of Pharmacognosy and Phytochemistry*,8(4):2088-2090.

69. Mahmood, A. K., Omar, S. J. and Halshoy, H. S. 2021. The Impact of (Alga Mix) Seaweed and Garlic Extraction on Growth and Yield of Cauliflower. *Euphrates Journal of Agricultural Science,*13(3):9-15.

70. Rutkowska, A. 2016. Bio-stimulants in modern plant cultivation. *Soil Science Plant Cultivation Pulawy*, 48, pp.65–80.

71. Mystkowska, I. T. 2018. Biostimulators as a factor affecting the yield of edible potato. *Acta Agrophysica*, 25(3): 307-315.

72. Paradikovic, N., Teklic, T., Zeljkovic, S., Lisjak, M. and Spoljarevic, M. 2019. Biostimulants research in some horticultural plant species-A review.*Food and Energy Security*,*8*(2): 1-17.

73. Haider, M. W., Ayyub, C. M., Pervez, M. A., Asad, H. U., Manan, A., Raza, S. A. and Ashraf, I. 2012. Impact of foliar application of seaweed extract on growth, yield and quality of potato (*Solanum tuberosum* L.).*Soil and Environment*,31(2): 157-162.

74. Wadas, W. and Dziugiel, T. 2020. Changes in assimilation area and chlorophyll content of very early potato (*Solanum tuberosum* L.) cultivars as influenced by biostimulants. *Agronomy*, 10(3), pp.387.

75. Helaly A. A. E. 2021. Green seaweed extract: a complementary bio-fertilizer and bio-stimulator for growth and yield of sweet potato plants. *Scientific Journal of Agricultural Sciences*, 3(1): 1-14.

76. Miceli, A., Vetrano, F. and Moncada, A. 2021. Influence of *Ecklonia maxima* extracts on growth, yield, and postharvest quality of hydroponic leaf lettuce. *Horticulturae*, 7(11), pp.440.

77. Vijayakumar, S., Durgadevi, S., Rajalakshmi, S., Gopalakrishnan, T. and Parameswari, N. 2019. Effect of seaweed liquid fertilizer on yield and quality of *Capsicum annum* L. *Acta Ecologica Sinica*, 39(5): 406-410.

78. Arthur, G., Stirk, W. and Van, J. 2003. Effect of seaweed concentrate on the growth and yield of three varieties of *Capsicum annuum*. *South African Journal of Botany*, 69(2): 207-211.

79. Taha S. S. and Abdelaziz, M.E. 2015.Effect of different concentrations of seaweed extract on growth, yield and quality of two carrot (*Daucus carota* L.) cultivars. *Current Science International*,4(4): 750-759.

80. Yusuf, R., Kristiansen, P. and Warwick, N. 2019. Effect of two seaweed products and equivalent mineral treatments on lettuce (*Lactuca sativa* L.) growth. *Journal of Agronomy*, 18, pp.100-106.

81. Di Mola, I., Cozzolino, E., Ottaiano, L., Giordano, M., Rouphael, Y., Colla, G. and Mori, M. 2019. Effect of vegetal- and seaweed extract-based biostimulants on agronomical and leaf quality traits of plastic tunnel-grown baby lettuce under four regimes of nitrogen fertilization. *Agronomy*, 9(10): 571.

82. Sreelatha, K., Mathew, L. and Kaladharan, P. 2018. Drenching aqueous extracts of seaweeds for enhancing growth, biochemical constituents and yield of *Solanum melongena*. *Journal of the Diabetic Association of India,*60(2):18-23.

83. Sridhar, S. and Rengasamy, R. 2010. Effect of seaweed liquid fertilizer on the growth, biochemical constituents and yield of *Tagetes erecta,* under field trial. *Journal of Phytology*, 2(6): 61-68.

84. Ali, O., Ramsubhag, A. and Jayaraman, J. 2021. Biostimulant properties of seaweed extracts in plants: Implications towards sustainable crop production. *Plants*, 10(3), pp. 531.

85. Ali, J., Jan, I., Ullah, H., Ahmed, N., Alam, M., Ullah, R., El-Sharnouby, M., Kesba, H., Shukry, M., Sayed, S. and Nawaz, T. 2022. Influence of *Ascophyllum nodosum* extract foliar spray on the physiological and biochemical attributes of okra under drought stress. *Plants*, 11(6), pp.790.

86. Cook, J., Zhang, J., Norrie, J., Blal, B. and Cheng, Z. (2018). Seaweed extract (*Stella Maris*®) activates innate immune responses in *Arabidopsis thaliana* and protects host against bacterial pathogens. *Marine drugs*, 16(7), pp.221.

87. Krid, A., El Hallabi, M., Ennoury, A., Kamal Aberkani, N. N., Nhiri, M. and Hassani Zerrouk, M. 2023. The potential of seaweed extracts as a biostimulant for improving salt stress tolerance of *Solanum lycopersicum* L. *South African Journal of Botany*, 161, pp. 305-316.

88. Kocira, A., Lamorska, J., Kornas, R., Nowosad, N., Tomaszewska, M., Leszczynska, D., Leszczynska, L., Kozowicz, K. and Tabor, S. 2020. Changes in biochemistry and yield in response to biostimulants applied in Bean (*Phaseolus vulgaris* L.). *Agronomy*, 10(2), pp.189.

89. Kocira, S., Szparaga, A., Kubo, M., CzerwiNska, E. andPiskier, T.2019. Morphological and biochemical responses of *glycine max* (L.) Merr. to the use of seaweed extract. *Agronomy*, 9(2), pp.93.

90. Latique, S., Ben Mrid, R., Kabach, I., Kchikich, A., Sammama, H., Yasri, A., Nhiri, M., El Kaoua, M., Douira, A. and Selmaoui, K. 2021. Foliar application of *Ulva rigida* water extracts improve salinity tolerance in wheat (*Triticum durum* L.). *Agronomy,* 11(2), pp.265.

91. Di Stasio, E., Oosten, M. J. V., Silletti, S., Raimondi, D., Dell'Aversana, E., Carillo, P. and Maggio, A. 2018. *Ascophyllum nodosum*-based algal extracts act as enhancers of growth, fruit quality, and adaptation to stress in salinized tomato plants. *Journal of Applied Phycology,* 30, pp. 2675-2686.

92. Wu Y., Jenkins T., Blunden G., Whapham C. and Hankins S.D. 1997. The role of betaines in alkaline extracts of *Ascophyllum nodosum* in the reduction of *Meloidogyne javanica* and *M. incognita* infestations of tomato plants. *Fundamental and Applied Nematology*, 20(2), pp. 99-102.

93. Lizzi, Y., Coulomb, C., Polian, C., Coulomb, P. J., and Coulomb, P. O. 1998. Seaweed and mildew: what does the future hold? *Phytoma La Defense Des. Vegetaux.* 508, pp.29–30.

94. Dixon, G. and Walsh, U.F. 2004. Suppressing *Pythium ultimum* induced damping-off in cabbage seedlings by biostimulation with proprietary liquid seaweed extracts. *Acta Horticulturae*,635, pp.103-106.

95. Patel, J., Vinodkumar S., Rao, G. L., Rathor, P. and Balakrishnan, P. 2020. Combined application of *Ascophyllum nodosum* extract and chitosan synergistically activates host-defense of peas against powdery mildew. *BMC Plant Biology*, 20, pp. 1-10.

96. Jayaraj, J., Wan, A., Rahman, M. and Punja, Z. 2008. Seaweed extract reduces foliar fungal diseases on carrot. *Crop Protection*, 27(10):1360-1366.

97. Abkhoo, J. and Sabbagh, S.K., 2016. Control of *Phytophthora melonis* damping-off, induction of defense responses, and gene expression of cucumber treated with commercial extract from *Ascophyllum nodosum*. *Journal of Applied Phycology,* 28, pp.1333–1342.

98. Rekanovic, E., Potocnik, I., Milijasevic-Marcic, M., Stepanovic, M., Todorovic, B. and Mihajlovic, M.2010. Efficacy of seaweed concentrate from *Ecklonia maxima* (Osbeck) and conventional fungicides in the control of verticillium wilt of pepper. *Pesticides & phytomedicine*, 25(4): 319-324.

99. Hegazi, A., Nafeh, A., ElSayed, G. and Abdalla. 2014. Alleviation of salt stress adverse effect and enhancing phenolic anti-oxidant content of eggplant by seaweed extract. *Gesunde Pflanzen*, 67(1): 21-31.

100. Mansori, M., Chernane, H., Latique, S., Benaliat, A., Hsissou, D. and Kaoua, M. 2015. Seaweed extract effect on water deficit and antioxidative mechanisms in bean plants (*Phaseolus vulgaris* L.). *Journal of Applied Phycology*, 27, pp.1689-1698.

101. Carmody N., Goni O., Langowski L. and O'Connell Shane. 2020. *Ascophyllum nodosum* extract biostimulant processing and its impact on enhancing heat stress tolerance during tomato fruit set. *Frontiers in Plant Science*.11, pp.807.

102. Aymen, E. M., Latique, S., Halima, C., Cherif, H. and Mimoun, E.2014. Effect of seaweed extract of sargassum vulgare on germination behavior of two tomatoes cultivars (*Solanum lycopersicum*L.) under salt stress. *Octa Journal of Environmental Research*, 2(3): 203-210.

103. El Boukhari, M.E., Barakate M., Choumani, N., Bouhia, Y. and Lyamlouli, K. 2021.*Ulva lactuca* Extract and Fractions as Seed Priming Agents Mitigate Salinity Stress in Tomato Seedlings. *Plants*, 10(6):1104.

104. Rouphael, Y., Veronica, M., Carmen, A., Giampaolo, R., Giuseppe, C.and De Pascale, S. 2017. Effect of *Ecklonia maxima* seaweed extract on yield, mineral composition, gas exchange, and leaf anatomy of zucchini squash grown under saline conditions. *Journal of Applied Phycology*, 29, pp.459-470.

105. Xu, C. and Leskovar, D. I. 2015. Effects of *A. nodosum* seaweed extracts on spinach growth, physiology and nutrition value under drought stress. *ScientiaHorticulturae*, 183, pp.39-47.

106. Papenfus, H., Kulkarni, M., Wendy, S., Jeffrey, F. and Staden, J. 2013. Effect of a commercial seaweed extract (Kelpak®) and polyamines on nutrient-deprived (N, P and K) okra seedlings. *Scientia Horticulturae*, 151,pp.142–146.

107. Yildiztekin, M., Tuna, A. and Kaya, C. 2018. Physiological effects of the brown seaweed (*Ascophyllum nodosum*) and humic substances on plant growth, enzyme activities of certain pepper plants grown under salt stress. *Acta Biologica Hungarica*, 69(3):325-335.

108. Ahmed, D., Gheda, S. and Ismail, G. 2021. Efficacy of two seaweeds dry mass in bioremediation of heavy metal polluted soil and growth of radish (*Raphanus sativus* L.) plant. *Environmental Science and Pollution Research*, 28(10):12831-12846.

109. Doss, M.M., El-Araby, S.M., Abd El-Fattah, M.A. and Helaly, A.A. 2015. The impact of spraying with different concentrations of seaweed extract under different levels of mineral NPK fertilizers on sweet potato plants. *Alexandria Journal of Agriculture Research,*2(5), pp.3415.

110. Sabatino, L., Consentino, B. B., Rouphael, Y., Baldassano, S., Pasquale, C. and Ntatsi, G. 2023. *Ecklonia maxima*-derivate seaweed extract supply as mitigation strategy to alleviate drought stress in chicory plants. *Scientia Horticulturae*, 312, pp.111856.

111. Mannan, M. A., Yasmin, A., Sarker, U., Bari, N., Dola, D. B., Higuchi, H. and Alarifi, S. 2023. Biostimulant red seaweed (*Gracilaria tenuistipitata* var. *liui*) extracts spray improves yield and drought tolerance in soybean. *Peer Journal*, 11,pp. e15588.

112. Salma, L., Mohamed, E., Maher, S., Aloui, H., Hannachi, C., Chernane, H., Mansori, M.and Elkaoua, M. 2014. Effect of seaweed extract of *Sargassum vulgare* on germination behavior of two bean cultivars (*Phaseolus vulgaris* L) under salt stress. *IOSR Journal of Agriculture and Veterinary Science*, 7(2):116 - 120.

113. Domingo, G., Alvarez-Vinas, M., Torres, M., Dominguez, H. and Vannini, C. 2023. The Role of protein-rich extracts from *Chondrus crispus* as biostimulant and in enhancing tolerance to drought stress in tomato plants. *Plants*, 12(4), pp.845.

114. Goni, O., Quille, P. and O'Connell, S. 2018. *Ascophyllum nodosum* extract biostimulants and their role in enhancing tolerance to drought stress in tomato plants. *Plant Physiology and Biochemistry*, 126, pp.63–73.

115. Guinan, K.J., Sujeeth, N., Copeland, R.B., Jones, P.W., O'Brien, N.M., Sharma, S. Prouteau, P.F.J. and O'Sullivan, J.T.2013. Discrete roles for Extracts of *Ascophyllum nodosum* in enhancing plant growth and tolerance to abiotic and biotic stresses. *Acta Horticulturae*, 1009, pp.127-135.

116. Demir, K., Gunes, A., Inal, A. and Alpaslan, M. 1999. Effects of humic acids on the yield and mineral nutrition of cucumber (*Cucumis sativus* l.) grown with different salinity levels. *Acta Horticulturae*, 492, pp.95-104.

117. El Arroussi, H., Benhima, R., Elbaouchi, A., Sijilmassi, B., El Mernissi, N., Aafsar, A. and Smouni, A. 2018. *Dunaliella salina* exopolysaccharides: a promising biostimulant for salt stress tolerance in tomato (*Solanum lycopersicum* L.). *Journal of Applied Phycology*, *30*, pp.2929-2941.

118. Manaf, H.H. (2016) Beneficial effects of exogenous selenium, glycine betaine and seaweed extract on salt stressed cowpea plant. *Annals of Agricultural Science*, 61(1):41–48.