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Role of Seaweed extracts for plant disease management

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ABSTRACT

Now a days, agrochemicals have become the keystone of principal methods of plant health management. However, reduction of agrochemical usage has become a major goal shared by many countries and a key issue in public policy making since negative influences of agrochemicals on the environmental conditions such as development of fungicide resistance, decline status of biodiversity, soil, water contamination and residue in food, air have been established unambiguously. So, there is a need for to develop a more efficient, an innovative and sustainable plant health management practices which do not affect the biodiversity status at the same time improves the production, productivity and crop quality parameters. Seaweeds are essential plant growth bio-stimulants due to their high composition of phenols, flavonoids, polysaccharides and antioxidant compounds. Seaweed extracts stimulated the seed yield, seed germination, plant growth parameters, biometric attributes, thousand-grain weight, plant height, protein and fat composition in Agricultural and Horticultural crops which were increased. Foliar application, soil application or seed treatment of seaweeds against various phytopathogens including biotic such as fungi, bacterial, nematode, and mesobiotic pathogens like viral diseases as well as insects has been confirmed by many scientific reports. They are mostly used as a powder and sometimes available also as a liquid form. They are having the mode of action of inducing systemic resistance, and bio-protectant activity by induced or combined activity of microbial biota and enhancing crop yield. This review explains about the role of seaweed extracts for plant diseases management strategies.

Keywords: *Seaweeds, Sargassum, Antimycotic, Plant growth promotion, plant disease management, bioprotectant*

Introduction

The increasing global population demands improving crop production, whereas resources such as soil and irrigation are becoming the restrictive factors and eco-friendly concerns which thereby dictate a minimum quantity of Agrochemicals usage. To ensure crop security and sustainable cultivation practices, the development of new varieties, hybrids, and transgenic plants are necessary. These include addressing many factors, positively yield and grain quality characteristics whereas negatively increases biotic and abiotic constraints in Agriculture [1].

Now a days, agrochemicals (Contact, Systemic and New generation fungicide groups) have become the keystone of principal methods of plant health management [2]. However, the reduction of agrochemical usage has become a major goal shared by many countries and a key issue in public policy making since negative influences of agrochemicals on the environmental conditions such as the development of fungicide resistance, decline status of biodiversity, soil, water contamination and residue in food, air have been established unambiguously [3]. So, there is a need for to develop a more efficient, innovative and sustainable plant health management practices which do not affect biodiversity status at the same time improves production, productivity and crop quality parameters [4].

Seaweeds are the natural resources of biologically inducing components with broad spectrum of biological protection such as antimycotic, antibacterial, antiviral, antioxidant and cytotoxic activities. They act as Phytostimulator, Phytohormones and Phytoelicitor results positively in increased crop production and significantly improving the natural innate immunity in crops [5]. They are also highly compatible with other disease management components, paving the way for an Integrated Cropping/Disease Management (ICM/IDM) approach geared towards crop sustainability. Among the seaweeds, *Sargassum wightii* is a brown macro alga exhibited the highest antifungal and antibacterial activity against plant pathogens [6].

The UN proposed seventeen SDGs (Sustainable Development Goals) after critically analysing the threats of climatic change (https://sdgs.un.org/). These SDGs aim at interrelationship efforts towards the improvement of economic, and social status without disturbing the environmental conditions[7]. Simultaneously, Govt. of India proposed the scheme of double the farmer's income by 2022-23 [8] through all the eco-friendly possible means that can be adopted individually or in a

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combination mode [9]. Achieving the SDGs and farmers' income are very tough situation for developing countries like India while improving the economic health. Environmental based inputs that have the potential improve the plant health management and adaptability of the environment against pollution hazards [10]. Implementation of these environmental based inputs through innovative approaches of crop health management has a high potential to create employment opportunities (Mass production of bioprotectants and seaweed collection, extract preparation), improve the bio-diversity, reduce the loss of NRM (Natural Resource Management) and climatic change impacts, ensure crop production, productivity, protection, and nutritional security. This review explains about the role of seaweed extracts for plant disease management.

Role of Seaweeds in disease management and plant growth promotion

Because of the growing consciousness of harmful effects of pesticides, there has been a new model alteration towards 'green farming' as an alternative and more sustainable approach. In various aspects of green farming, the use of naturally derived plant biostimulants (the new name is Bioeffector) is one of the major concepts for sustainable crop cultivation. These are stimulants that when applied in crop at low conc., an elicit diverse physiological responses that trigger growth and development and provide protection against biotic and abiotic stresses. There are many plant biostimulants such as seaweed extracts, humic and fulvic acid, and chitosan used in crop cultivation [11].

The advantages of seaweeds use in crop cultivation have been mentioned, including improved germination percentage, deeper root formation, frost resistance, changes in plant tissue composition, increased resistance to fungal, bacterial, viral, and nematode diseases, reduced pest incidence, higher biometric and yield attributes, longer shelf-life and increased animal health when livestock grazes on treated crops [12,13]. Seaweeds are benthic marine macroalgae mainly used for the manufacturing of agar, alginate, organic liquid fertilizers and manures [14] Peres *et al.* [15]was the first to observe antifungal substances in seaweeds against plant diseases. Jolivet *et al.* [16] observed that seaweed extracts induce resistance in plants against diseases, plant growth, yield and quality.

Induction of an innate immunity in crops using polysaccharide or oligosaccharide extracted from seaweeds offers promising crop protection strategies [17]. Seaweed metabolites are observed to protect the crops against abiotic and biotic stresses. The seaweed metabolites contain bioactive compounds with various bio-pesticidal properties such as antimycotic, antiviral, antibacterial and antiprotozoal activities. Among the seaweed extracts, brown, red, and green seaweed metabolites are the potent antimicrobial compounds [18]. These antimicrobial compounds belong to phlorotannins, fatty acids, polysaccharides, halogenated compounds, alkaloids, terpenoids and lectins groups [19].

A significant number of recent reports mentioned that crude and purified macroalgal preparations are able to develop the resistance in crop plants against several plant pathogens [20,21,22]. Seaweed extracts activated the antioxidant enzymes such as Peroxidase, Polyphenol oxidase that catalyse the lignin and phenolic synthesis against biotic stress. Jasmonic Acid (JA)/SA signaling has well-known role in an induction of ISR activity in response to various pathogens infection. These seaweed extracts also activate the JA/SA signaling which ultimately induces the ISR activity against various biotic agents causing plant diseases [23]. Seaweeds are important sources of plant nutrition, which helps to improve the nutrient status of the crop including some micro- and macronutrients such as N, P, K, Ca, S, Mg, Zn, Mn and Fe [24].

Seaweeds are the main source of effectors / elicitors due to the occurrence of polysaccharide compounds. Involvement of these sugars in early signalling processes through the secondary metabolic pathways activates in plants and activation of plant defense action [22,25]. Seaweed polysaccharides have been mentioned to convey the resistance in plants against various diseases, which includes carrageenan [26], laminarin [27], ulvan [28] and alginate [29]. Seaweed extracts low molecular weight bioactive molecules have been shown to improve crop growth [30]. All commercial seaweed extract products are mostly from the seaweeds like *Ascophyllum nodosum*, *Fucus*, *Laminaria*, *Sargassum* and *Turbinaria* spp. [31]. Ethanol extracts of *S. myricocystum* at ten percent concentration effectively inhibited the fungal growth of *Colletotrichum falcatum* causing red rot disease in sugarcane under *in vitro* experiments [32]. Seaweed extracts improve the nutrient uptake, plant growth promotion, and resistance development against biotic and abiotic stresses in a variety of agricultural crops, including rice [33], maize [34], tomato [35], arabidopsis [36], grape [37], okra [38] and olive [39].

Sargassum wightii is a brown algae observed with antagonistic activity under *in vitro* conditions against bacterial plant pathogen such as *P. syringae* and *Xanthomonas oryzae* pv. *oryzae* causes leaf spots in the *Gymnema sylvestre* [40] and rice bacterial blight [41]. Similarly, *Halimeda tuna* is a green-algae works under *in vitro* conditions against various plant pathogens such as *Aspergillus niger*, *A. flavus*, *A. alternata*, *Penicillium* sp. and *Rhizopus* sp. [42,43]. Likewise, Ara *et al.* [44] mentioned that the brown algae *Spatoglossum asperum* fatty acid ester completely inhibited the sclerotial plant pathogens such as *Macrophomina phaseolina, R. solani* and the tropical wilt pathogen *F. solani* under *in vitro* conditions. The phenolic derivatives from green, brown, and red algae are directly arrested the growth of *A. solani* [45] *A. cucumerinium, A. radicina, Didymella applanata* and *Botrytis cinerea* under both *in vitro* and *in vivo* conditions [46,47]. Raj *et al.* (2016a & b) observed that some antimycotic impacts initiated by *S. wightii* which managed the sheath blight disease and associated this innate immunity action due to high levels of phenolics in rice plants. Seaweed extracts also enhanced the tomato yield through the production of fruits with high quality, the number of flowers and seeds per flower head also improved [48] . Use of the commercial seaweed product namely Kelpak considerably increased the biometric and yield attributes in barley [49] and peppers [50]. Improved biometric characters were also reported in beans [51] and seedless grapes [52] due to the application of seaweed extracts.

Foliar spray with seaweed extracts from *Gelidium serrulatum* and *Sargassum* spp., the affectation by bacterial disease in tomato and cotton is reduced by nearly 80 percent, due to the accumulation of host defense compounds [53,54,55]. Seaweed extract *A. nodosum* activates the SA-mediated defensive action in tomato and soybean against root-knot nematodes through an increased antioxidant enzymes in treated plants [56].

Seaweeds collection (Graff, [6])

One Kg of vigorously, live seaweed macroalgae samples were collected from Pamban island, Rameswaram (9.2876° N, 79.3129° E), Tamil Nadu, India and the seaweeds were collected

by random method of sampling. The samples were washed, firstly in seawater and then secondly by tap water to remove the unnecessary dusts and epiphytic plants. Seaweeds collection from the middle part was completed during the low tide. Seaweed samples were placed in a polythene bag and labelled for further wet and dry preservation[57]. After, it was air-dried under shade conditions for nearly 72 hrs. Seaweed samples were identified with the expert from the Faculty of Marine sciences people.

Sl.No.	Seaweed
1.	*Sargassum wightii*
2.	*S. siliquastrum*
3.	*S. muticum*
4.	*S. polycystrum*
5.	*S. fusiforme*

Crude seaweed extracts preparation (Vallianayagam *et al.,* [58])

Shade-dried seaweeds were cut into pieces and powdered with the help of blender. After that, pulverized seaweed sample (50 g each seaweed) was separately extracted for a week, three times in a half lit. of chloroform and methanol (1:1(v/v)) using a titration flask in dark conditions. Seaweed extractants were collected and concentrated by using an evaporation flask under low pressure (@ 45°C). Finally, seaweeds were weighed and kept in – 20^0 C for subsequent *in vitro* and *in vivo* experiments [59].

Aqueous seaweed extract preparation

Fifty grams of seaweed extract in a dried form was mixed with a lit. of distilled water. After the mixed solution was autoclaved it was followed by centrifuged conditions (nearly 600 seconds for 10000 rpm level). The seaweed supernatant solution was filtered and kept under refrigerator conditions for further studies and also compatibility studies with biocontrol agent and plant activator.

Biochemical and Enzymatic changes in Crops due to Seaweed application

A positive impact of seaweeds treatment on the crops, and antioxidant potential was mentioned, expressed by the increased synthesis of phenolics, flavonoid, anthocyanins and antioxidant activities [60]. The seaweed extract application as a foliar spray on bean plant enhanced the vegetative growth at lower concentrations and enhanced the biochemical parameters when compared to control bean plants [61]. Foliar spray of *Sargassum* extract, at higher conc. markedly enhanced the defense enzymatic activities in shoots of salt-stressed Barley plants. Also, treatment with *Sargassum* extracts significantly improved the effect of lipid peroxidation, total antioxidant activity, proline and phenols in the barley plant. *S. latifolium* caused great variations in the biometric attributes of barley plant as well as in the biochemical contents of soluble carbohydrates, sugars and soluble proteins [62]. Wheat seeds primed with the Seaweed extracts of *Ulva linza* possessed higher levels of ash, soluble proteins and sugars as well as essential macronutrients and amino acids in wheat plants. In the treated wheat seedlings, new proteins were expressed, which could be owing to the activity of bioactive components in the Seaweed extracts [63].

Seaweed extract application and their role on this research work highlighted through various innate immunity enzymes that could result in the induction of host defense against diseases in rice [64,65], carrot [47], tomato and sweet pepper [66]and cucumber [67].

Catalase, PO, and PPO enzymatic activity were significantly improved in Sugarcane treated with Seaweed extracts against drought stress [68].

The non-microbial organic plant bio-stimulant Seaweed extract, *Ulva lactuca* biopriming with tomato seedlings enhances the PAL enzymatic activity and salicylic acid in leaves thereby suppressing of Fusarium wilt disease [69]. In general, an increased enzymatic PAL activity and salicylic acid in plants is often correlated with SAR (Systemic Acquired Resistance) against Biotic and abiotic stresses [70]. Seaweed *Chlorella vulgaris* extract applied as a foliar spray and root drenching in lettuce seedlings enhanced the PAL activity and improved the morpho-biometric attributes [71]. Furthermore, a dramatically improved defense enzymatic activities of chitinase, β-1,3 glucanase, PO, PPO, PAL and phenolic content were found in sweet pepper plants treated with *Ascophyllum* seaweed extract when compared to control treatment [72].

A possible role of these PR proteins in defense action in potato plants are highlighted by the scientific analysis of Bokshi *et al.,* [73], displaying resistance activity against *A. solani, Erysiphe cichoracearum,* and *F. semitectum* pathogen by application of immunity activator Bion WG50 (Benzothiadiazole (BTH)). PO, PPO, PAL, Chitinase, and β-1,3-glucanase enzymes were significantly increased in Tomato and Sweet pepper plants treated with *S. vulgare* and *Acanthophora spicifera* (Seaweed extracts) against foliar pathogens [74].

Bio-efficacy of seaweed extracts against Plant Pathogens

Generally, *S. wightii* @ 30 % showed the maximum level of plant pathogenic fungal inhibition under laboratory conditions. This bio-efficacy of the seaweeds hypothesis was confirmed by previous reports [75,75].

Seaweeds are the bioactive molecules due to the production of various antioxidant compounds such as flavonoids, peptides, sterols, terpenes, fatty acids and other phenolic compounds [77]. Seaweeds have an exposed stimulating molecule with antimicrobial activity against plant pathogenic prokaryotic and eukaryotic organisms. Various plant growth promoting substances, amino acids, phenols, and defense enzymes are the main ingredients of seaweeds that are supported with the antimycotic properties of seaweeds [78].

In addition to that, some seaweed constituents are the potential of an induce the crops natural innate immunity and help their resistance against biotic stress, showing a priming potential [79]. The main mode of action for this antimycotic effect is the distraction of fungal membrane caused by bioprotectant molecule of seaweeds, which leads to fungal cell lysis [80]. Considering the biotic issues referred to above-mentioned reports and constant decline of the available sustainable plant health management practices given the promising outputs of *in vitro* experiments, seaweeds constitute a variety of bioactive compounds with antimycotic effect against plant pathogens. Given this frame work, seaweeds are added one of the integrated components of crop disease management in future level of research.

Evaluation of plant growth promotion activity of seaweed extract

In general, seed treatments with *Sargassum* species @ 10 g/ kg of rice seeds significantly increased the seed growth characteristics and reduction of disease incidence when compared to control treatment [81]. These results are in promise with Graff [6,82], which improved crop growth parameters and reduction of disease incidence in rice by seed

treatment with various seaweed extracts. Different bio protectants like fungal, bacterial bio-pesticides, seaweed extracts, humic acid, fulvic acid, chitosan are considered as crop bio-stimulating compounds in seeds bio-priming to improve their yield attributes, defense against biotic and abiotic stresses [83]. *S. plagiophyllum* treated with green gram seeds revealed that the organic bio-stimulant improve the PGPC (plant growth promoting compounds) which might be helpful for the maximum level of germination percentage, fresh and dry weight [84]. Similar outputs have described an increased germination percentage of seeds treated with *Sargassum* species [85,86,87].

Many scientific reports have confirmed that the biotic stresses of various crops can be minimized through spraying with seaweed extracts [88,89,90]. *Ascophyllum* seaweed extract applied as a foliar spray @ 0.5 % to minimize the early blight and bacterial leaf spot disease in tomato [53]. Foliar application of red seaweed *Kappaphycus alvarezii* reduces the disease incidence of blast in rice caused by *Magnaporthe grisea* [91,92]. Seaweed components affect the plant metabolism, increased chlorophyll pigment, producing the plant growth promoting substances which leads to improve the crop biometrics [90]. Raghavendra *et al.* [54] reported that commercial formulation of *S. wightii* namely Dravya develops the resistance in cotton plants against bacterial blight disease when compared to antibiotics application and increased the yield attributes.

Seaweed contains oligosaccharides, polysaccharides such as laminarin, carrageenans, and ulvans were mentioned to be critical to the events involved in plant innate immunity pathways [93]. Also, the field trial results revealed that *S. wightii* application in maturity stages of the crop minimize the brown spot and improved the yield attributes. Therefore, the abovementioned explanations could be accredited for the bio efficiency of seaweed extract *S. wightii* as a foliar spray, in managing the rice brown spot disease.

Compatibility studies between *B. subtilis*, ASA and Seaweeds under *in vitro*

In the integrated plant health management package, *S. wightii* can be incorporated along with bacterial antagonistic organism *B. subtilis* and plant activator Acetylsalicylic Acid (ASA) for effective and highly compatibility under *in vitro* conditions to find out the compatibility studies. These compatibility results are in line with the results of Graff [6]. He was mentioned that different seaweed extracts such as red, green, brown seaweed and compost tea were highly compatible with the *B. subtilis* under *in vitro* conditions. Likewise, Ambika and Sujatha, [32] mentioned that fungal and bacterial bio control agents are highly compatible with both the aqueous and ethanol extracts of *Sargassum, Gracilaria* and *Caulerpa* seaweed extracts. Therefore, forming a new and an innovative Integrated Disease Management (IDM) component, highly compatibility and synergistic action of Seaweeds, Resistance inducing chemical or plant activators or/and combined with biocontrol agents for future level of competent crop protection strategies.

Role of seaweed extracts for nutrient composition and crop growth promotion

Seaweeds were the main source of antifungal, antibacterial, antiviral, antinematodal, antifoulant, antioxidant properties, osmoprotectant, phycoremediant, plant growth regulators, bioactive compounds, phytochemicals, polysaccharides, fatty acids, crude proteins, amino acids, phenols carbohydrates, vitamins, and minerals lead to improve sustainable crop production and crop protection strategies. They were considered as bioactive elicitor/effector molecule to elicit plant immunity against diseases thereby protecting the plants [94].

Numerous reports confirmed the beneficial effect of seaweed extracts on the growth of Poaceae family. Foliar application of seaweed extracts was proven to increase the biometrics of rice plants [95], wheat [96], Sugarcane [97], Sorghum [98] and Maize [34]. Seaweed extracts promotes the uptake of water and nutrients from the soil, which results in increased crop biometric and yield parameters. Foliar treatment of soybean with Seaweed extracts stimulated the seed yield, thousand grain weight, number of pods, number of nodes, height, protein and fat contents in seeds which were increased [99].

Brown seaweed *S wightii* on rice applied as mulch during transplantation trail increased the plant height, number of tillers, number of seeds per panicle when compared to control treatment [100]. Brown seaweed *S. wightii* contains the bioactive compound sulphoglycerolipid 1-0-palmitoyl-3-0(6'-sulpho-α-quinovopyranosyl)-glycerol inhibits the growth of Bacterial blight pathogen in rice [41]. It has more polysaccharide compounds when compared to other seaweed extracts. These polysaccharides have the potential to invade the plant pathogens cell and successfully inhibit the nucleus growth that leads to the cell damage [101].

A considerable number of scientific reports available for *Sargassum* seaweed extracts has excellent fungicidal activity against various phytopathogenic fungi [102]. Very recently, seaweeds are involved microbial associated molecular patterns (MAMP) dependent signaling pathways which leads the induction of natural host defense enzymes [103]. Methanol extracts of *Sargassum* treated plants increased not only antioxidant activity, free radical scavenging enzymes but also Reactive Oxygen Species (ROS) [104]. The foliar application of Brown seaweed *Sargassum* increases the plant height, thousand grain weight, grain, straw yields and healthy grain formation were also reported by previous workers[105,106,107].

Conclusion

Seaweeds are the biological source of active compounds, such as phenolic compounds, laminarins, carotenoids, and provides to develop the defense action in crops. Among the various bio-stimulant compounds produced by brown algae, Phenolic compounds are mainly responsible for antifungal and antibacterial activities. Seaweed protects the plants from various foliar and soil borne pathogens by inducing the innate plant immunity activity and a higher accumulation of antioxidant compounds. So, there is need to highly commercialize and popularize the seaweeds sources application in Agriculture which will be helpful for plant growth promotion and crop protection management strategies.

Future scope of the study

Commercialization of seaweeds in Agriculture to improve the environmental sustainability. In future level, there is possibility of development of combined effect of seaweeds and phytochemicals will be act as elicitor for pest and disease management.

Conflict of interest

There is no conflict of interest related to this review article.

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