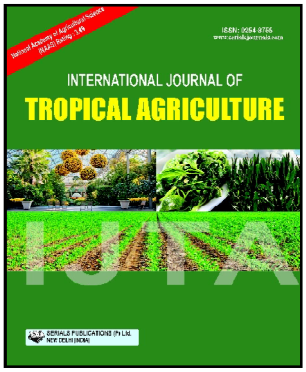

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Seaweed Extract as A Biostimulant and a Pathogen Controlling Agent in Plants

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Abstract: Seaweeds are green, brown and red marine macroalgae. These marine macroalgae are considered to be an excellent natural bio source in different aspects of agriculture fields. The extracts of brown seaweed are widely used in the horticulture and agricultural crops for their plant growth promoting effects and for their ameliorating effect on crop tolerance to abiotic stress. The chemical constituent of seaweed extracts includes the complex polysaccharide, fatty acids, vitamins, phytohormones and mineral nutrients. They have great profiency in improving soil physical and chemical properties. Macroalgae are characterized by producing large array of biologically active biocidal substances against plant infecting pathogens. Bioactive compound like fatty acids in particular polyunsaturated fatty acid (PUFAs), proteins (amino acid), biflavonoids, sulfated polysaccharides, carotenoid polyphenols and carbohydrate are considered to have the bactericidal, antiviral and fungicidal effects against some plant-infecting pathogens. These macroalgae can be generally considered as promising multifunctional bio inoculants and ecofriendly environmental tools in recent trends of organic farming.

Key words: Seaweed, Bio stimulant, Plant disease management, Antifungal activity

1. INTRODUCTION

Seaweeds are members of the algal group, which range in size from microscopic single cells to some of the largest plants known to man, such as giant seaweeds, forming dense forest in coastal water and referred to as ‘marine algae’ (Lee, 1986; Thomas, 2002). Macroalge comprises nearly 10,000 species and contribute to approximately 10% of the total world marine productivity. The marine seaweed belongs to the families Chlorophycaeae (green), Rodophyceae (Red), and Phaeophyceae (brown). The characteristics of green colour of green algae is due to the presence of chlorophyll as in higher plants. The brown pigments of Phaeophytes is due to dominance of xanthophylls and fucoxanthin pigments and the reason for red colour in Rodophytes is due to phycoerythrin pigment (Abad *et al.,* 2011). The mostly used species is brown seaweed species which have been identified and studied for their economic value in agriculture and pharmaceutical industries. The brown seaweed *Ascophyllum nodosum* is the most researched and commercially explored species (Vgarte *et al.* 2006) and other species like *Fucus, Laminaria, Sargassum* etc., are used as biofertlizers in agriculture. The brown algae have a source of potash & iodine, while bromine is sourced from red seaweed (Prescott, 1984).

The seaweed extracts have now gained much wider acceptance as 'plant biostimulants'. In general, seaweed extracts, even at low concentrations, are capable of inducing an array of plant responses, such as promotion of plant growth, improvement of flowering & yield and also enhanced quality of products, improved nutritional content of the edible product. The application of different extracts of seaweed have been reported to enhance plant tolerance to wide range of abiotic stresses *i.e.*, salinity, drought and temperature extremes. There are several reports to demonstrate the beneficial effect of seaweed products on plant seed germination, enhanced resistance to pathogens and abiotic stress and improved postharvest quality (Hankin and Hockey, 1990; Norrie and Keathley, 2006; Jayaraj e*t al*., 2011).

Marine macroalage are considered as an excellent source of bioactive compounds that has a broad range of biological activities like antibacterial (Bouhlal *et al.,* 2010; Singh and Chaudhary, 2010) and antifungal activities (De felicio *et al*., 2010, 2011). These extracts also have been used in agriculture as soil conditioners to enhance the crop productivity (Newton, 1951; Booth, 1969; Abdel-Raouf *et al*., 2012). In this review, we report the use of various seaweed extracts as plant biostimulants and also bring together a comprehensive update of the efforts carried out on seaweed products as bioactive compound for enhancing and conditioning plant growth and plant resistance to pathogens.

2. ORIGIN, PRODUCTION PROCESS AND CHEMICAL COMPOSITION OF SEAWEED EXTRACTS

Seaweeds are a diverse assemblage with close to 10,000 species of red, brown and green seaweed (Khan *et al*., 2009). Based on the abundance and distribution, brown seaweed (Phaeophyta) are most commonly used for the commercial manufacture of extracts for application in Agriculture and Horticulture. Amongst the brown seaweed, *Ascophyllum nodosum*, *Ecklonia maxima*, *Macrocystis pyrifera* and *Durvillea potatorum* are the most frequently and commercially used extract by the industries (Khan *et al.,* 2009). In general, cellular matrices are bound by alginic acid residues. The commercial seaweed extract industry employs a wide range of proprietary, extraction processes in order to disrupt the cells and release beneficial components into the extract; some of the process include alkali extraction, acid extraction and cell bust technology. The chemical composition of extracts largely depends on the method of extraction and on the chemical products used during the production process. Therefore, the biological activity of extracts of the same seaweed raw material obtained by different extraction processes may be considerably different (Kim *et al*, 2012; Khairy and EL-shafay, 2013).

The various commercial extracts made from brown seaweed as a raw material contain a diverse range of inorganic and organic components. The inorganic components of *A.nodosum* extracts include nitrogen, phosphorous, potassium, calcium, iron, magnesium, zinc, sodium and sulphur (Rayorath *et al.,* 2009). Besides the mineral components brown seaweed extracts also contain varying amount of organic compounds that include osmolites (eg: betaines). A number of betaines and betaine analogues have been identified in seaweed extracts (Blunden *at al.*, 2009; Mackinnon *et al.,* 2010). Blunden *et al.,* (2009) reported that the dominant betaine in *A.nodosum* was ã-aminobutyric acid betaine (ABAB) which was present at levels of 0.02-0.07% dry weight. Recently, 4 betaines viz., glycine betaine. è-aminovaleric acid betaine, ã-aminobutyric acid betaines and laminine were reported in *A.nodosum* and its commercial extracts (Mackinnon *et al.*, 2010). In addition to betaines extracts of brown algae are also reported to contain amino acids. However, protein fractions of brown algae posses only 3-15% of dry weight of the brown seaweed, which is not as much as green and red algae that contain 10-47% protein in dry weight (Fleurence, 1999; Fike *et al.,* 2001; Nagahama *et al.*,2009). Brown algae also contain bioactive secondary metabolites, vitamins and vitamin precursors (Berlyn and Russo, 1990; Blunden *et al.,* 1985). Various authors reported that these compounds interact synergistically to enhance the growth of land plants by hitherto unknown mechanism (Norrie and Keathley, 2006; Craigie *et al.,* 2008; Craigie, 2011).

One of the major components of commercial extracts of all seaweeds are the polysaccharides. These may account for upto 30-40% of the extract on a dry weight basis (Rayorath *et al.,* 2009). The common polysaccharides found in brown seaweed extracts include alginates, fucoidans, laminarans, lichenan like glucans and fucose containing glucans (Khan *et al.,* 2009). Fucoidans possess different structures due to their varying degree of methylation, sulphation and branching. Depending on the chemical and physical methods employed during extraction of raw material, the season of harvest and the algal species, the structure of the fucose containing polymers vary (Craigie, 2011). Alginates are polymers of mannuronic and guluronic acid, the viscosity of which varies depending on the seaweed species. Alginates are shown to promote plant growth (Yabur *et al.,* 2007). Laminarins on the other hand are known and registered elicitors of plant defense responses against fungal and bacterial pathogens (Mercier *et al.*, 2011).

Seaweeds, particularly brown seaweed are rich in phenolic compounds. Phenolics are secondary metabolites that are synthetized under stress which protect cells and celluar components (Nakamura *et al.,* 1996; Wang *et al.*, 2009). Important roles of phenolic compounds include antioxidant activity, scavenging radicals such as single oxygen, superoxide, hydroxyl, alkoxyl and peroxy radicals (Andjelkovic *et al.,* 2006). Brown seaweeds such as *Fucus vesiculosus , F.serratus* and *A.nodosum* have high concentrations of total phenolics (Laetitia *et al.*, 2010; Keyrouz *et al.*, 2011; Balboa *et al.,* 2013). Phenolic compounds also chelate metal ions. It has been shown that phenolic compounds with catechol (dihydroxy benzene) or galloyl (trihydroxy benzene) group had strong chelating activities. Phlorotannin complex polymers of phloroglucinol, eckol and dieckol are phenolic compounds found in brown seaweeds, and in comparison with other members of phenolic family, have more phenolic rings in their structure, enabling them to scavenge the radical species. Shibata *et al.,* (2003) showed that phlorotannins, of marine algae were more efficient antioxidants when compared to catechin, ascorbic acid, phlorofucofuroeckol A.dieckol, 8,8-bieckol, epigallocatechin gallate (EGCG), resveratrol and á-tocopherol.

Seaweed extracts also contain a number of phytohormones including auxin, cytokinin, gibberellins, abscisic acid and brassino steroids (strik *et al.,* 2014). Phytohormones like activity of seaweed extract is discussed that the authors suggested that the phytohormone like activity of a commercial *A.nodosum* extract was due to elicitor molecules present in the extract that perturb endogenous phytohormone metabolism in the treated plants by a selective regulation of phytohormone metabolic genes.

Brown seaweed such as *Alaria esculenta, A. nodosum, Ectocarpus siliculosus, Fucus serratus, F. spiralis, F. vesiculosus, Halidrys siliquosa, Laminaria digitata, L. hyperborea. L. saccharina, Pilayella littoralis* contain osmolytes such as mannitol as an important protective compound in response to abiotic stressors. Mannitol is also known as a chelating agent and explains the reason that seaweed is able to release unavailable elements of the soil (Reed *et al.,* 1985).

3. AGRICULTURAL USES

Marine bioactive substances extracted from seaweed are currently used in organic farming. In order to avoid excessive application of fertilizers and improving the uptake through the roots or leaves (Hankins *et al.,* 1990). Seaweed & seaweed products obtained directly through

- Physical treatment including dehydration, freezing and grinding.
- Extraction with water or aqueous solution, acid and/or alkaline.
- Fermentation.

Craigie (2011) describes the first mention of the use of seaweed in agriculture. Its about the first half of the 1st century, when it was recommended to use seaweed for transplanting cabbage plantlets. The first dried seaweed extracts were exported in 1959. At that time, the use of seaweed fertilizer was supposed to face the traditional way of fertilizing the soil (Booth, 1969). The foliar mineral nutrition has become a common practice in agriculture in the 1960's, it was a moment that helped sales of seaweed extracts. Marine bioactive substances extracted from seaweed are currently used in food, animal feed, as raw material in the industry and have therapeutic applications.

Seaweed are also used as biological scrubber to clean effluent water from intensive fish farms of substances like heavy metals, nitrates and phosphates before the water is returned to open sea, the concentration of metals in seaweed could be easily disposed of upon harvest. The polyanionic properties of seaweed and unicellular algae have proved to be valuable in remediation of soils contaminated with heavy metals (Blunden, 1991; Metting *et al.,* 1990).

4. METHOD OF APPLICATION

4.1. Seed Treatment

Presoaking of crop seeds in an aqueous suspension of chemicals for 12-24 h is practiced all over the world. The same technique, also known as priming, could be used for application of seaweed products to seeds, usually at regular concentrations as administered for other methods. Seed treatment allows adsorption and absorption of seaweed products on or into seeds. The immediate effect should be noticeable upon germination and seedling emergence. The positive effects also follow subsequently in the form of enhanced seedling vigour, increased levels of resistance to pathogens, increased chlorophyll content and reduced levels of pathogenic inoculum on seeds (Farooq *et al.*, 2008).

4.2. Foliar Application

Foliar application of seaweed products is the most common method used universally. This method of application yields measurable responses in growth and yield in a range of crops including cereals, vegetables, legumes, fruits crops, ornamentals and turfgrass. The positive responses include improved flowering and fruiting capacity, enhanced product quality and yield, improved resistance to diseases, pest and abiotic stress (Zhang and Erwin, 2008; Jayaraj *et al.,* 2008, 2011; Zodope *et al.,* 2011; Ali *et al.,* 2013). The concentration of foliar applications ranges from 0.2% to 1% and rarely exceeds the limit. Grower normally apply weekly to fortnightly sprays through a high or low volume sprayer till runoff, preferably in early morning depending upon optimization specific to the crop, variety, location and environment. On many occasions phytotoxicity is not noticed except at very higher doses. (Jayaraj *et al.,* 2011; Ali *et al.,* 2013).

5. DISEASE MANAGEMENT

5.1. Antifungal Activity

Natural algal extracts are nowadays more applicable, instead of synthetic fungicides, in controlling of plant- infecting fungi due to their higher safety and relatively negligible impacts on environment (Haroun *et al.,* 1995: Brimmer and Boland, 2003; Gatal *et al.,* 2011). A considerable number of recent studies showed that crude and purified algal preparation are able to protect the plants against several pathogenic fungi (Cluzet *et al.,* 2004; Paulert *et al.,* 2009, 2010). *Laminaria digitata* (brown algae) has been found to induce the plant defense mechanism against several pathogens such as *Botrytis cinerea* and *Plasmapara viticola* in grapevine (Aziz *et al.*, 2003). The root rot infection can be controlled by applying the marine macro algal powder and also improve the crop growth like vines length, shoot length and fresh shoot weight which have been found to be higher in macro algae treated plants when compared to control (or) chemical fungicide Topsin-M . Marine macroalgae-treated plants exhibit earlier fruiting process than control or chemical fungicide-treated plants. These findings have also been noticed using different extract from the brown algae *Stoechospormum marginatum* and green algae *Codium iyengari* to control the root infected fungi *F. solani* (Ara *et al.*, 1998). Tuney *et al.,* (2006) also observed positive antifungal activities using varied methanolic, acetone, diethyl ether and ethanolic extracts of *Cystoseira mediterranea* and *Ulva rigida.*

Sultana *et al.,* (2011) reported that application of dry powders of three marine macro algal products like *Spatoglossum variabile, Melanothamnus afaqhusainii* and *Halimeda tuna* have more or similar suppressive effects on crops as compared to fungicide Topsin-M in greenhouse and in field conditions. Ibraheem *et al.,* (2017) revealed that the application of *Padina gymnospora, Sargassum latifolium and Hydroclathrus clathratus* powders as soil amendments decreased the % of root rotting diseases. Then *P. gymnospora* and *S. latifolium* powders increased the root length and fruits fresh weight as compared to control. A significant disease resistance was also assessed in greenhouse experiment of plants against wilt disease promoting fungus *Verticillium dahlia* using aqueous brown algae extracts like *Cystoseira myriophylloides, Laminaria digitata, Fucus spiralis* either by spraying the whole plant or using seed imbibition techniques (Esserti *et al* 2017).

Raj *et al.,* (2016) found some fungicidal effects induced by *Sargassum wightii* which controls the rice sheath blight disease and attributed this defense mechanism to high levels of phenolics and early accumulation of phytoalexin compounds in rice plant. The marine macroalgal extracts of *Gelidium serrulatum, S. filipendula* and *Ulva lactuca* extracts showed induced jasmonate signaling defense system (Ramkisson *et al* 2017). Then *G. serrulatum* sequentially induced salicylic acid signaling pathway. In conclusion, the marine macroalgae are important natural resources that could be used on large scale to control plant infecting fungi.

5.2. Antibacterial Activity

Marine macro algae produces wide spectrum of chemically active metabolites including alkaloids, polyketides, cyclic peptides, polysaccharides, phlorotannin, diterpenols, sterols, quinones, lipid, glycerols which have broad range of biological activities against other organism in their environment (Al-saif *et al.*, 2014; Abdel-raouf *et al.*, 2015). Marine macroalgae have received much attention for their possibility as natural antioxidants, antibacterial and cytotoxic properties (Mayalen *et al.*, 2007; Kayalvizhi *et al.*, 2012; Kosanic *et al.,*2015; Moubayed *et al.*, 2017). The algal extracts are tested for different organic solvents which could be a potential tool to explore bioactive compounds which is responsible for positive effect on plant pathogen and mechanism of their action (Michalak and Chojnacka, 2015). For ex. the methanolic extract of *S. wightii*, exhibit highest activity against *P. syringae* which cause leaf spot diseases on valuable medicinal plant *Gymnema sylvestre* (Kumar *et al*., 2008). Ethyl acetate extract showed less effect. Some other taxa such as *Chaetomorpha antennina*, *Gracilaria corticata* etc., shows less effective bactericidal activity on *P. syringae*. Then the acetonic extracts of brown macroalgae, *S.polyceratium* shows activity against different bacterias such as *E. carotovora* and *E.coli* using disc diffusion method (Kumar *et al*., 2008). Meanwhile, ethanolic extracts of *S. polyceratium*, *C. racemosa* and *G. cerviornis* have active effect against *S.aureus (*Borbon *et al.,* 2012). The methanolic extract of *Sargassum wightii* has been identified to inhibit the growth of *X. oryzae pv. oryzae* (Arunkumar *et al.,* 2005). Moreover, ethanolic extracts of *Cystoseira stricta* have been reported to minimize the growth of various bacteria (Pesando and Caram, 1984). In greenhouse experiment, application of *C. myrio phylloides* and *F. spiralis* extract reduced crown gall diseases caused by *Agrobacterium tumefaciens* (Esserti *et al.,*2017).

It has been shown that antibacterial properties of macro algae are attributed to different groups of bioactive fatty acids. Contributions of Rosell and Srivastava (1987), Barbosa *et al.,* (2007), Oh *et al*., (2008), Gerasimenko *et al.,(*2014) and Ibraheem *et al*.,(2017) point out fats and fatty acids extracted from marine algae had antibacterial activities. Active antibacterial extracts from different brown algae is found to be made up of saturated and unsaturated fatty acids with a predominance of myristic, palmitic, oleic and eicosapentaenoic acids (Bazes *et al.,* 2009; Ibraheem *et al.,* 2017). Marine macroalgae extracted polysaccharides in particular ulvans from green algae (Chlorophyta), alginates, fucans and laminarin from brown algae (Phaeophyta) and carrageenans and porphyran from red algae (Rodophyta) and their derived oligosaccharides, have been found to stimulate the plant defense responses and protections against a wide spectrum of plant infecting pathogens (Vera *et al*., 2011; Kraan,2012). In greenhouse experiment, the extracts of *C. myriophylloides, L. digitata* and *F. spiralis* shows significant levels of defense enzymes which includes polyphenol oxidases and peroxidases when compared to control.

5.3. Anti-Viral Activity

Plant virus disease/plant cancer are the second largest group of plant diseases and are mainly responsible for a great loss to the agriculture industry. The Chemotherapeutic management is a direct and effective method for controlling viruses but it causes a series of side effects includes improvement of pathogen-resistance to these drugs with time and accumulation of excessive pesticide residues in soil. Much great progress has been made for discovery of new biogenic antiviral substances. The structures of these active components largely include protein, polyaccharies, alkaloids, flavonoids, polyphenols and oils from plants, protein and polysaccharides from microorganisms and micro and macroalgae (Zhao *et al.,* 2017). Investigations of Pulz and Gross (2004); Mohammed *et al.,* (2012); Zaid *et al.,* (2016) on macroalage highlighted the wide spectrum of their antiviral effects. A few studies focused on their application in agriculture field (Manzo *et al.,* 2009). Alginates at conc. of 10mg/ml have been found to inhibit 95% of potato virus x (PVX) disease (Pardee *et al.,* 2004). The mechanism of these antiviral algal interactions were explained based on the inhibition of virus adsorption on host cells through competing with virus binding (Durate *et al.,* 2004), or through the synergistic combination between polysacchardies with target host cell to block viral entry (Feldman *et al.,* 1999). Betaines; dictyodial; dictyol C; dicytol H have been isolated from marine brown algae, *Dictyota ciliolate* in general reported to posses cytotoxic and antiviral activities against some plant viruses (Manzo *et al.,* 2009). Wang *et al.,* (2004) and Liu *et al.,* (2005) also succeeded in isolating the carbohydrate-binding proteins from the marine green alga *Ulva pertusa* with anti-TMV activity. Pardee *et al.,* (2004) investigated the anti-PVX effect using methanol extracts from 30 different species of marine algae but out of that 30, only 6 species (*Fucus gardneri silva, Alaria marginta Postels & Ruprecht, Ralfsia sp.* (Berkely*), Codium fragile (*surinagar) Hariot, *Fragilaria oceanic cleva and Egregia menziesii* (Turnu) J.E.Areshoug) shows the inhibition rates by more than 80% at a concentration of 10mg/ml.

6. PLANT BIOSTIMULANT ACTIVITY

6.1. Seaweed as Biofertilizers

Seaweed have been used for centuries as fertilizers in coastal Asia and Europe; they are rich in potassium and other minerals, break down slowly and are eventually good soil builders (Lee Thomas, 1986). Seaweed contain all major and minor plant nutrients, trace elements, alginic acid, vitamin, auxin, gibberellin and antibiotic compounds (Stephenson, 1966). For centuries, farmers have collected driftwood and seaweed from the shore to use as soil conditioning and mulches, but more recently there has been an expansion of this industry to produce the liquid fertilizer from seaweed extracts (mostly dried brown seaweed). The benefits of seaweed derived fertilizer and soil conditioners have been well documented since they contain valuable stores of trace elements (Thomas, 2002, Dhargalkar and pereira, 2005). Fresh seaweed and dried seaweed meal and liquid seaweed extract contain alginic acid and polyuronides, which combine with metallic radicals in soil to form cross-linked polymers. These swell when wet and retain moisture. This improves the water holding capacity of soil and the formation of crumb structures, which improves aeration and capillary action.

Seaweed affects the physical, chemical and biological properties of soil upon application, which in turn positively affects plant growth. Alginates positively affect soil properties and encourage the growth of beneficial fungi. Alginates are present in seaweeds as salts of calcium, magnesium, potassium and sodium accumulated in the cell walls (Rioux *et al.,* 2007). They are natural biodegradable polymer and form high molecular weight complexes that can absorb soil moisture, imbibe and retain moisture and help retain soil structure.

Seaweed products have excellent polyanionic properties, which enables them to be used for bioremediation of heavy metal contaminated soils (Blunden, 1991). Brown seaweed are rich in polyuronides like alginates and fucoidans; these have chelating abilities that stimulated the growth of plant roots as well as boosting microbial activity (Eyras *et al.,* 1998; Moore, 2004). A study by kantachote *et al.,* (2004) proved that soils supplemented with seaweed improve the biodegradation rate of dichoro diphenyl trichloroethane (DDT). This was attributed to an increase in bacterial population and also optimum bioavailability of DDT and its residues in the soil solution and also to favourable change in soil structures to an effect of sodium derived from the seaweed.

6.2. Seaweed Extracts on Plant Growth and Copy Yield

Plant growth under seaweed product treatment (soil treated with seaweed products, or extracts applied to foliage) exhibited a wide range of growth responses including effects on seed germination, seedling growth, plant growth parameters including the leaf number, leaf area, flower number, fruit number, fruit weight, plant height, root length, increase in plant biomass and fruit yield and improved tolerance to disease, pest and abiotic stresses (Metting *et al.*, 1990; Blunden, 1991; Zhang and Schmidt, 1997; Stirk and Van staden,1997; Hong et al., 2007; Jayaraj *et al.,* 2008; craigie, 2011; Ali *et al.,* 2013, 2015). For this reason, seaweed products could be deemed as biostimulants. Biostimulants or metabolic enhancers by definition are material other than fertilizer that promote plant growth when applied in small quantities, which include the macro and micro elements, amino acid, vitamin cytokinins, auxin and abscisic acid. They affect the cellular metabolism in plant, which lead to enhanced crop growth and yield. Seaweed contain these components and is bioactive at low concentrations (Crouch and van staden, 1993; Reitz and Trumble, 1996; Durand *et al.,* 2003; Stirk *et al.,* 2003; Ordog *et al.,* 2004). The benefits of seaweed products to seed germination and early seedling growth have been observed in several plants (Farooq *et al.*, 2008), though there were instances of inhibitory effects on seed germination (Zodape *et al.,* 2008). Though the chemical components of seaweed extracts have been characterized, it is hard to establish which of them are involved in a particular type of plant growth stimulation. There is also variation in the activity of commercial seaweed extract. For ex, use of different seaweed extracts in apples showed varying levels of positive effect on vegetative growth, flowering and fruit yield, with some negative effects on fruits quality during storage (Ordog *et al.,* 2004).

Shah (2013) reported yield improvement in tomato plants following seaweed based nutrient sprays applied 1 week after transplanting and three more times at 2 week intervals. This treatment achieved fruit yield increase by 62% for the 2 plant varieties used. Seaweed extract also increased tomato fruit yield through the production of larger-sized fruits with superior quality, the number of flowers and seeds per flower head also increased (Crouch and van staden, 1992; Ali *et al,* 2013). The seaweed product Maxicrop R enhanced yield in lettuce and increased heart size of the florets and curd diameter in cauliflower (Abetz and young, 1983). Use of the seaweed products Kelpak substantially increased the yield in barley (Featonby-smith and van staden, 1987) and peppers (Arthur *et al.,* 2003). Increased yields were also reported in beans (Nelson and van standen, 1984), and seedless grape (Norrie and keathley, 2006). Zodape *et al.,* (2009) reports that foliar application of seaweed extract of *K.alvarezii* at 10% conc. on green gram resulted in significantly increased yield when compared with the control by 30.11% due to increased number of pods, pod weight per plant and number of seeds / pods. Seaweed extract also improved the nutritional quality of seeds through increased carbohydrate, protein and mineral content in seeds in comparison to control plants of green gram. Okra palnt when treated with 2.5% liquid seaweed fertilizer had yield increased significantly by 20.47% and the nutritional quality was also improved.

Thirumaran *et al.,* 2009) recorded higher fruit yield in *Abelmoschus esculentus* treated with 20% seaweed liquid fertilizer of brown seaweed *R.intricata*. A significant improvement in size of olives and the quality of olive oil was recorded in trees sprayed with an *A.nodosum* extract fortified with nitrogen and boron (Chouliaras *et al.,* 2009). Foliar application of different concentrations of seaweed extract of *K. alvarezii* on soybean crop under rainfed conditions significantly enhanced the yield parameter. When celeriac plants were sprayed with seaweed extract at higher rates it significantly increased the green leaf yield, while root yield was comparable with those of untreated controls and other treatments. Zodape *et al.,* (2011) observed that seaweed sprays on tomato plants with *K.alvarezii* (5.0%) resulted in increased fruit yield (60.89%), increased fruit size and number of fruits/ plant which in turn, increased by 75.11%

The effect of *K.alvarezii* sap on growth and yield of tomato was studied under field conditions. *K.alvarezii* extract, applied as foliar spray (5%) increased the yield of tomato fruit (60.89%) when compared to control plants, which was attributed to an increase in number of fruits/plant and increased size of fruit.

In a recent study by Ali *et al.,* (2013) & (2015) in field tomatoes , plants treated with *A.nodosum* seaweed extract formulation produced increased number of flowers and had a high flower to fruit ratio, larger fruit size, increased fruit firmness and overall fruit yield. Applicaton of seaweed extracts from *K.alvarezii* and *Gracilaria edulis* was found to increase the grain yield significantly by 19.74% and 13.16% for plants receiving 7.5% and 5.0% concentrations of *K.alvarezii* and *G.edulis* extracts respectively against control. There have been occasions where under certian conditions an extract may even be inhibitory (Reitz and Trumble, 1996). The least or nil response to seaweed products is generally observed with plants raised under near-optimal conditions.

6.3. Growth Hormones

The concentration of material nutrient elements presents in commercial seaweed concentrates (SWC) alone cannot account for the growth responses elicited by seaweed extract (Blunden, 1972, 1991). Beneficial effects observed in various plant growth bioassays have led to speculation that SWC's contain plant growth regulatory substance (Williams *et al.,* 1981; Tay *et al.,* 1985; Mooney and Van staden, 1986). Furthermore the wide range of growth responses induced by seaweed extracts implies the presence of more than one group of plant growth-promoting substances/hormones (Tay *et al.,* 1985; Crouch and Van staden 1993a).

Cytokinins: Cytokinin have been detected in fresh seaweed (Hussein & Boney, 1969) and seaweed extracts (Brain *et al.,* 1973). The Cytokinin present in seaweed formulation include trans-zeatin, trans-zeatin riboside, dihydro derivatives of these two forms (Stirk and Van staden 1997). Liquid chromatography/mass spectroscopy (LC/MS) analysis of 31 seaweed species representing various groups revealed that zeatin (z) and isopentenyl (IP) conjugates of cytokinins are predominant cytokinin (Strik *et al.,* 2004). Seaweed concentrate also contained aromatic cytokinin BAP (Benzyl amino purine) and topolin (6-(3-hydrorybenzyl-amino) purine) derivatives (Stirk *et al.,* 2004).

Auxins: Marine algae are also reportedly rich in auxin and auxin like compounds (Crouch and van staden 1993). An *A. nodosum* extract has as high as 50mg IAA/gm of dry extract. *Ecklonia maxima* exhibited a remarkable root –promoting activity on mung bean, an effect reminiscent of auxins (crouch and van staden, 1991). GC/MS analysis of the extract revealed the presence of indole compounds, including IAA in SWC (Crouch *et al.,* 1992).

Auxin have been detected in other algal species like *Porphyra perforata*, but the levels found were low (Zhang *et al.,* 1993). In higher plants IAA occur as an inactive conjugate with carboxyl group, glucans, aminoacids and peptides which upon hydrolysis are converted to free active IAA (Bartel, 1997). Strik *et al., (*2004) found 4 aminoacid and 3indole conjugates of IAA in extracts of 2 seaweeds *E.Maxima* and *Macrocystis pyrifera*. Biologically active auxin-like compound other than IAA were reported in alkaline hydrolytes of *A.nodosum, Fucus vesiculosus* and other seaweeds (Buggler and Craigie, 1971).

Sterols: As with many other eukaryotic cells, sterols are an essential group of lipids. Generally, a plant cell contains a mixture of sterols such as â-sitosterol, Stigmasterol, 24-methylenecholestrol and cholesterol (Nabil and Cosson, 1996). Brown seaweed chiefly contains fucosterol and fucosterol derivatives whereas red seaweeds primarily contain cholesterol and cholesterol derivatives. Green seaweed accumulates mainly ergosterol and 24-methylene cholesterol (Ragan and Chapman 1978; Handy and Dawes, 1988; Govindan *et al.,* 1993; Nabil and Cosson, 1996).

7. ABIOTIC STRESS

Abiotic stresses such as drought, water logging, salinity and extreme temperatures are major factors that affect productivity and quality of the crops (Kobayashi *et al.,* 2008). There has been an increase in the incidence of abiotic stresses in the recent years, largely due to climate change and that has caused an unprecedented increase in extreme weather patterns and incidents. Furthermore, the impact of intensive

Table 1
Common sterol constituents of green, red and brown seaweed

Seaweed	*Type of Sterol*
Chlorophyceae (Green)	22 – Dehydrocholestrol
	Brassicasterol
	Cholesterol
	Codisterol
	Decortinol
	Fucosterol
	Zymosterol
Rhadophyceae (Red)	24 – Methylenophenol
	Campesteol
	Desmosterol
	Fucosterol
	Stigmasterol
	Obusifol
Phaeophyceae (Brown)	22 – Dehydrocholesderol
	Campesterol
	Clionasterol
	Porifasterol
	Cholesterol

agricultural practices also contributes to widespread occurrence of unfavourable conditions for growth and development of crop plants. Abiotic stresses account for considerable losses in crop production around the world (Zhu, 2000; Wang *et at,* 2003). For instance, it has been estimated that abiotic stresses lower the production yield to less than 50%. Among the abiotic stresses, salinity affects approximately half of all irrigated land (Flowers and Yeo, 1995; Moghadam *et al.,* 2013). Salinity alone could significantly limit the yield of major agricultural crops for production of food (Zhu, 2000). Strategies that are available to mitigate abiotic stresses that adversely affect plant productivity are limited, one of the major limitations being genetic complexity of abiotic stress resistance in plants. Most of abiotic stress resistance mechanism are oligogenic, a large number of genes mediate plant response to abiotic stresses. This limits the development of plant genotypes that are resistant to abiotic stresses both via conventional breeding and by using biotechnological approach. Seaweed extracts have been shown to reduce the impact of abiotic stress in large number of plants and offer a tantalizing opportunity. Bioactive compounds present in the seaweed extracts enhance the performance of plants under abiotic stresses. The average osmotic potential of treated plants was -1.57 MPa compared to -1.51 MPa in the untreated control after 9 days of seaweed extract treatment (Wilson, 2001).

Considerable research has been conducted on the effect of seaweed extract on turf grass. Seaweed extract significantly improved the survival of Kentucky bluegrass under salinity conditions. Seaweed extract treatment enhanced both above and below the ground growth of grass at soil salinity of 0.15 S/m (Nabati *et al.,* 1994). One of the mechanism activated from seaweed extract was significant reduction in the accumulation of sodium ions in the plant, grass treated with seaweed extract had less sodium in tissue, as compared to grass that did not receive seaweed extract treatment (Yan, 1993). This seaweed extract have been reported to improve the thermal tolerance of plants. Application of seaweed extracts imparted heat tolerance in creeping bent grass (Zhang *et al.,* 2008) and the authors suggested that this effect could be due to the presence of "cytokinin – like" substances in the extract along with an increase in k^+ uptake.

8. FUTURE STRATEGIES OF SEAWEED EXTRACTS AND THEIR USE AS PLANT PATHOGENS

1. Seaweeds which occur naturally shall be used to prepare extracts and their formulations by mass culturing them under laboratory conditions.
2. Novel compounds shall be prepared which may enhance plant growth and may induce their resistance.

3. Products which are very effective shall prepared by combining various seaweed species.
4. Then efficacy of seaweed products shall be examined by employing both field and laboratory experiments.
5. The delivery system of those compounds into fields shall be done simply and easily.
6. Strengthening of researcher in the field of seaweed and its products shall be made.
7. For alleviation of abiotic stress-induced damages and to augment resistance capacity of plants to such abiotic stresses, a vast research on the usage of seaweed as well as its products shall be carried out.

9. CONCLUSION

The use of seaweed extracts has been widely reported to enhance the plant growth vigour and productivity and improve resistance to pest and diseases. In particular, the seaweed extracts made from different raw materials, and by different procedures are attributed with number of beneficial effects such as increased nutrient uptake, biotic and abitotic stress tolerance and improvement in the quality of products. This seaweed extracts are suggested to apply when there is stressful condition that affect crop performance. According to Bazes *et al.,* (2009), not all the seaweed extracts are the same and even the same raw material processed by different extraction method leads to extract with different characteristics. Various methods of application have been tried, of which the effective ones were foliar and soil treatment. In terms of cost and simplicity, foliar application of lower concentrations of seaweed extracts is more effective than other application methods and the increased growth and yield effects are attributed to the components including growth hormone-like substances like betaines, chelated nutrients and materials. Most of the seaweed extract products currently in the market are extracts of the whole seaweeds and the extracts are an attractive agricultural input endowed with multiple beneficial effects on plant growth and productivity. It would be interesting to study the physiological effects of specific chemical components in order to develop a second generation of seaweed products with specific plant bio stimulant activities. Further, research and development would help maximize the utility of seaweeds to the agriculture and sustainable crop growth.

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