Use of Sea Weed Extracts as Plant Growth Regulators for Sustainable Agriculture

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Abstract

Sea weed extracts are the inexpensive source of naturally occurring plant growth regulators which have greater potential as biostimulants in agriculture. The endogenous plant growth regulators present in the sea weed extracts and concentrates is thought to be involved in the promoting plant growth and yield. Different plant phytohormones and growth regulators present in sea weed extracts are known to enhance the yield and yield attributes of crops, when applied exogenously. Seaweed liquid fertilizers are useful for achieving higher agricultural production, because the extract contains growth promoting hormones like Auxins, Gibberellins, Cytokinins, Gibberellins, Abscisic acid, Ethylene, Betaine and Polyamines other than the trace elements, vitamins, amino acids, antibiotics and micronutrients. This paper reviews the literature supporting evidence for the occurrence of plant growth regulators in sea weed extracts and seaweed concetrates and their use for sustainable agriculture and horticulture.

1. Introduction

Seaweeds and various seaweed extracts have been utilized in agricultural practices since long. The extracts of marine macroalgae viz. brown, red and green algae are known to have positive effect on growth and yield of crops. The brown algae are the most commonly used sea weeds in agriculture. Sea weed extracts contain different phytohormones like Auxins, Gibberellins, Cytokinins, Abscisic acid, Ethylene, Betaine and Polyamines and other growth promoters along with trace elements, vitamins, amino acids, antibiotics and micronutrients which enhance the yield and yield attributes of crops, when applied exogenously. Sustainable agriculture is the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources (CGIAR, 1978). Sea weeds and sea weed extracts which are important components of organic farming are a promising avenue for yield maximization through their biostimulatory role on crop plants. Sea weeds and their extracts are integral to sustainable farming because of their multifarious utility in various fields of agriculture including nutrient and crop management, growth promotion and plant protection etc.

2. Chemical composition of Sea weeds

Seaweeds contain a diverse range of organic compounds which includes several common amino acids *inter alia* aspartic acid, glutamic acid and alanine in commercially important species. Alginic acid, laminarin and mannitol represent nearly half of the total carbohydrate content of commercial seaweed preparations. Seaweeds also contain a wide range of vitamins which might be utilized by crops. Vitamins C, B, (thiamine), B_2 (riboflavin), B_{12}, D_3, E, K, niacin, pantothenic, folic and folinic acids occur in algae. Although vitamin A is not present, the presence of its precursor carotene and another possible precursor, fucoxanthin has been found (Stephenson, 1968). Apart from the above organic and inorganic constituents, there is evidence of presence of substances of a more stimulatory and antibiotic nature. The organic constituents of sea weed extract include plant hormones which elicit strong physiological responses in low doses (Crouch and van Staden, 1993).

3. Plant hormones found in Sea weed extracts

Various phytohormones and plant growth regulator are found in different sea weed concentrates and marine macroalgal extracts viz. Auxins, Gibberellins, Cytokinins , Abscisic acid, Ethylene, Betaine and Polyamines and simulate plant growth when applied exogenously.

3.1. Auxins

Auxins or auxin-like compounds are known to occur endogenously in many marine algae. The presence of indole-3-acetic acid (IAA) has been recorded in a range of marine algae, like *Nereocystis* spp., *Ecklonia maxima*, *Macrocystis pyrifera*, *Ascophyllum nodosum*, *Porphyra perforata*, *Fucus vesiculosus, Caulerpa paspaloides* and *Sargassum heterophyllum* etc. Indole-3-acetic acid (IAA) has also been found in *Caulerpa paspaloides*, *S. heterophyllum* and other algae. Auxin-like substances like phenyl-3-aceticacid (PAA), hydroxyphenyl aceticacid (OH-PAA) from *Undaria pinnatifida* extracts (Abe ., 1972 and 1974) and 3(hydroxyacetyl) indole in *Prionitis lanceolate* extracts (Bernart and Gerwick, 1990) have been reported. IAA has been found in hydrolyzed, liquified *A. nodosum* commercial preparation. The seaweed concentrate of the brown alga *Ecklonia maxima*, exhibits a remarkable root promoting ability when applied to cuttings, which is attributed to endogenous indoles like Indole-3-carboxylic acid (ICA); N,N-dimethyltryptamine; indole-3-aldehyde (IAId); and in addition, iso-indole, 1, 3-dione (N-hydroxyethylphthalimide) in the extracts (Crouch and Van Staden,1991). In higher plants IAA occurs as an inactive conjugate with carboxyl groups, glycans, amino acids, and peptides, which, upon hydrolysis, are converted to free active IAA (Bartel 1997), where as in marine algae, it occurs as conjugates of indole and amino acids (Stirk et al., 2004).

Table 1: Extracts of some Sea weeds with growth stimulant role in Agriculture and Horticulture

Sl. No	Species	Algal type	Application
1	*Ascophyllum nodosum*	Brown algae	PGS
2	*Macrocycstis pyrifera*	Red algae	PGS
3	*Ecklonia maxima*	Brown algae	PGS
4	*Durvillea antarctica*	Brown algae	PB
5	*Durvillea protatorum*	Brown algae	PGS
6	*Porphyra perforata*	Red algae	PGS
7	*Fucus vesiculosus*	Brown algae	PGS
8	*Caulerpa paspaloides*	Green algae	PGS
9	*Sargassum heterophyllum*	Brown algae	PGS
10	*Nereocystis spp.*	Red algae	PGS
11	*Chara globularis*	Brown algae	PGS
12	*Sargassum muticum*	Brown algae	PGS
13	*Enteromorpha prolifera*	Green algae	PGS
14	*Cyanidium caldarium*	Red algae	PGS
15	*Laminaria digitata*	Brown algae	PGS
16	*Ulva lactuca*	Green algae	GR

PGS: Plant growth stimulant; PB: Plant biostimulant; GR: Growth retardant

3.2. Cytokinins

Cytokinin is the most common phytohormone recorded from sea weed extracts. Cytokinins have been detected in fresh seaweeds (Hussein and Boney 1969) a well as seaweed extracts (Brain and others 1973). The cytokinins present in seaweed extracts include trans-zeatin, trans-zeatin riboside, and dihydro derivatives of these two forms (Stirk and van Staden 1997). Seawater taken from the *Fucus-Ascophyllum* zone is found to contain cytokinin as 6-(3-methyl-2-butenylamino) purine. Different cytokinins like Iso-pentenyl adenosine, zeatin, zeatin riboside, dihydrozeatin, iso-pentenyladenine, 2-hydroxy-6-methylaminopurine and 2-hydroxy-1-methylzeatin have been reported from *Sargassum muticum*, *Porphyra perforata* and *Chara globularis.* Most crop responses to seaweed are thought to be primarily due to the cytokinin group of plant hormones. Seaweed extracts with cytokinin activity are capable of producing physiological change, even when applied at low concentrations used under field conditions. Several cytokinins like trans-zeatin, trans-zeatin riboside and their dihydro derivatives; iso-pentenyladenine; iso-pentenyl adenosine and several cytokinin glucosides have been identified and quantified in a several seaweed extracts.

3.3. Gibberellins

The presence of gibberellin-like substances in seaweeds is well known. The presence of gibberellic acid in *Enteromorpha prolifera* and *Ecklonia radiata* has been confirmed (Jennings, 1968). At least two compounds have been recorded that behave like the gibberellins GA_3 and GA_7, although these may be vitamins A_1, and A_4 (Stephenson, 1968). A terpenoid, α-tocopherol a major component of the E group of vitamins present in sea weeds, may mimic gibberellin activity(Gopala, 1984; Jensen,1969). Gibberellin-like compounds are also readily found in a diversity of seaweeds. It is thought that these compounds may break down during the manufacturing process. Gibberellin activity has been found in some freshly made-up seaweed preparations.

3.4. Abscisic Acid

The presence of water soluble growth inhibitors like Abscisic acid has been confirmed in *Laminaria digitata*, *Ascophyllum nodosum* (Hussian and Boney,1973) and *Ulva lactuca* (Hartmann and Kester,1983). There is presence of higher level of abscisic acid in some commercial extracts of *A. nodosum*. ABA is also present in the green algae *Enteromorpha compressa* (Niemann and Dorfiiing, 1980). The water-soluble growth inhibitors extracted from *Laminaria digitata* and *A. nodosum* resulted in marked inhibition of lettuce hypocotyl growth (Hussain and Boney 1973).

3.5. Ethylene

There are few studies on ethylene, but the precursor of ethylene,1-Aminocyclopropane-1-carboxylic acid (ACC) was found in the sea weed concentrate prepared from the brown kelp *E. maxima*. The level of the ethylene-releasing compound was estimated as 9.29 nmol ml^{-1}(Nelson and Van Staden,1985). The presence of ethylene in SWC, however, still remains to be demonstrated.

3.6. Betaines

Betaines are the compounds found in the extracts of sea weeds which behave like cytokinins. Betaines have been isolated from many of the species of brown algae used for the production of seaweed extracts. *Ascophyllum nodosum* extracts contain c-aminobutyric acid betaine, d-aminovaleric acid betaine and laminine whilst *Laminaria* species have a range of betaines including glycine betaine (Blunden et al., 1986). In plants, betaines serve as a compatible solute that alleviates osmotic stress induced by salinity and drought stress;however, other roles have also been suggested (Blunden and Gordon,1986), such as enhancing leaf chlorophyllcontent of plants following their treatment with sea weed extracts (Blunden et al., 1997). This increase in chlorophyll content may be due to a decrease in chlorophyll degradation (Whapham et al., 1993). Yield enhancement effects due to improved chlorophyll content in leaves of various crop plants have been attributed to the betaines present in the seaweed (Genard et al., 1991; Blunden et al. 1997). It has been indicated that betaine may work as a nitrogen source when provided in low concentration and serve as an osmolyte at higher concentrations (Naidu et al., 1987). Betaines have been shown to play a part in successful formation of somatic embryos from cotyledonary tissues and mature seeds of tea (Wachira and Ogada 1995; Akula et al. 2000).

3.7. Polyamines

The polyamines are a group of compounds that act as plant growth regulators but are not classified as plant hormones. These are a class of compounds, which have several amino groups replacing hydrogen usually in alkyl chain e.g. *putrescine, spermidine and spermine*. Polyamines are known to have significant effect on the stability of various conformational states of RNA and DNA and are often associated with important phases in cell division cycle. They also impart membrane stability to different cellular membranes. Several polyamines have been determined in the unicellular thermoacidophilic red alga, *Cyanidium caldarium* (Hamana et al., 1990). As polyamines affect a wide range of physiological growth processes, the occurrence of these compounds in seaweed products could influence plant growth. At present they have not been recorded in commercial seaweed products.

4. Effect of Sea weed extracts on Plant Growth and Yield

Sea weed extracts affects various aspects of growth and development including overall health of the plants. The effect of sea weed extracts on crop plants can be discussed on the aspects like root development and mineral absorption, effect on shoot growth and photosynthesis, effect on crop yield and vegetative propagation.

4.1. Root development and mineral absorption

Seaweed products promote root growth and development (Metting et al., 1990; Jeannin et al., 1991). The root-growth stimulatory effect is more pronounced when extracts were applied at an early growth stage in maize, and the response was similar to that of auxin, an important root growth-promoting hormone (Jeannin et al., 1991). SWC application is found to reduce transplant shock in seedlings of marigold, cabbage and tomato by increasing root size and vigor. SWC treatment enhanced both root: shoot ratios and biomass accumulation in tomato seedlings and wheat by stimulating root growth, indicating that the components in the seaweed had a considerable effect on root development. The root-growth-promoting activity is observed when the seaweed extracts are applied either to the roots or as a foliar spray (Biddington and Dearman 1983; Finnie and van Staden 1985). The concentration of SWC is a critical factor in its effectiveness as in tomato plants high concentrations(1:100 seaweed extract: water) inhibits root growth but stimulatory effects are found at a lower concentration (1:600). Biostimulants in general are capable of affecting root development by both improving lateral root formation and increasing total volume of the root system (Atzmon and van Staden, 1994; Vernieri et al., 2005). An improved root system could be influenced by endogenous auxins as well as other compounds in the extracts. Seaweed extracts improve nutrient uptake by roots, resulting in root systems with improved water and nutrient efficiency, thereby causing enhanced general plant growth and vigor.

4.2. Effect on Shoot Growth and Photosynthesis

Seaweeds and seaweed products enhance plant chlorophyll content (Blunden et al., 1997). Application of a low concentration of *Ascophyllum nodosum* extract to soil or on foliage of tomatoes produced leaves with higher chlorophyll content than those of untreated controls. This increase in chlorophyll content is due to reduction in chlorophyll degradation, which might be caused in part by betaines in the seaweed extract. Glycine betaine delays the loss of photosynthetic activity by inhibiting chlorophyll degradation during storage conditions in isolated chloroplasts. The extracts of *Ascophyllum nodosum* have been shown to affect the root growth of Arabidopsis at

Table 2: Different physiological roles of Sea weed extracts similar to plant growth regulators

Sl No.	Plant growth regulators in Seaweed extract	Implied physiological roles similar to plant growth regulators	References
1	Auxin as IAA and conjugates of indole and amino acids	a. Extract of Ecklonia maxima exhibited remarkable root-promoting activity on mung bean b. Increased rooting in marigold (Tagetus patula) by treatment with Ecklonia maxima extracts (10% SWC Kelpak) for about 18 hours c. Seaweed extracts improve water and nutrient uptake by roots with improved water and nutrient efficiency, thereby causing enhanced general plant growth and vigor.	Crouch et al., 1992; Crouch and van Staden,1991; Crouch et al., 1990 Crouch and van Staden,1991;
2	Cytokinins as trans-zeatin, trans-zeatin riboside, and dihydro derivatives of these two forms	a.Photosynthates partitioning and nutrient mobilization in treated plants b. Seaweed extracts contain substantial amounts of cytokinins which is known to mitigate abiotic stress-induced free radicals (i) by antioxidative enzyme activities which scavenges several reactive oxygen species (ROS) (ii) direct scavenging by preventing ROS formation by inhibiting xanthine oxidation c. Yield increases in seaweed-treated plants are thought to be associated with cytokinin present in the extracts	Stirk and van Staden,1997; Hahn et al, 1974; McKersie and Leshem 1994; Fike et al. 2001 Ayad,1998 ; Fike et al., 2001 Featonby-Smith and van Staden 1983a, b, 1984
3.	Gibberellins	a. Using the lettuce hypocotyl bioassay, the presence of Gibberellins in the extracts of Ascophyllum nodosum has been detected b. A nodosum extract induce amylase activity independent of GA_3 and might act in concert with GA-dependent amylase production leading to enhanced germination and seedling vigor in barley	William et al.,1976 Rayorath et al.,2008
4.	Ethylene	Not known	
5.	Abscisic acid	The water-soluble growth inhibitors extracted from Laminaria digitata and A. nodosum resulted in marked inhibition of lettuce hypocotyl growth	Hussain and Boney,1973; Tietz et al., 1989; Kingman and Moore,1982
6.	Betaines	Increase in chlorophyll content in treated plants by reducing chlorophyll degradation	Whapham et al., 1993
7.	Polyamines	Not known	

very low concentrations (0.1 g L^{-1}), whereas plant height and number of leaves were affected at concentrations of 1 g L^{1-} (Rayorath et al., 2008).

Plants treated with extracts shows growth enhancement effects over control plants; for example, plants treated with *A. nodosum* extract were at a more advanced developmental stage when compared with untreated plants and the effect is concentration dependent. Application of Sea weed extracts improves plant mineral uptake by the roots and in the leaves.

4.3. Effect on crop yield

Seaweed extracts probably encourage flowering by initiating robust plant growth (Abetz and Young 1983). Yield increases in seaweed-treated plants are thought to be associated with the hormonal substances present in the extracts, especially cytokinins (Featonby-Smith and van Staden 1983a, b, 1984). Cytokinins in vegetative plant organs are associated with nutrient partitioning, whereas in reproductive organs, high levels of cytokinins may be linked with nutrient mobilization. Cytokinin in sea weed concentrate shifts distribution of photosynthate from vegetative parts (roots, stem, and young leaves) to the developing fruit and promotes fruit development. Seaweed extract induces early flowering and increases fruit yield when sprayed on tomato plants during the vegetative stage, producing large sized fruits with superior quality (Crouch and van Staden,1992). Seaweed concentrates trigger early flowering

Table 3: Physiological effects elicited by seaweed extracts and possible mechanism(s) of bioactivity

Mode of application	Effects	Possible Mechanisms
Aerial application		
1. Seed treatment 2. Seedling dip 3. Foliar spray	• Growth responses 1. Improved shoot and root growth 2. Higher flowering and fruit set 3. Better yield	• Modulation of phytohormones • Increased photosynthetic efficiency and carbon assimilation • Delayed senescence
	• Biotic stress resistance 1. Resistance to fungal, bacterial and viral pathogens 2. Resistance to insect pests	• Antimicrobial • Antifeedant and insect repellant • Up regulation of disease resistance genes e.g. PR genes
	• Abiotic stress resistance 1. Salt and drought resistance 2. Freezing and chilling resistance 3. Enhanced photosynthesis	• Reduced transpiration • Enhanced stomatal conductance • Upregulation of subset of stress resistance metabolome
	• Enhanced nutritional quality	• Altered metabolism • Upregulation of biosynthetic enzyme
Soil application		
1.Incorporation of marine bioproducts 2.Soil drenching 3. Addition of extracts to hydroponics	• Suppression of soil borne • diseases and nematodes • Abiotic stress resistance	• Antimicrobial • Enhanced growth of friendly microbes • Anti-infective
	• Improved modulation • Promote plant growth promoting • rhizobacteria	• Altered metabolism • Modulation of root exudates • Differential expression of signal molecules • and biosynthetic enzymes
	• Water and low temperature stress resistance	• Altered root architecture • Efficient water and nutrient uptake

and fruit set in a number of crop plants. Sea weed extract of *Ecklonia maxima* is found to increase the number of flowers and seeds flower^{-1} head in marigold when applied immediately after transplanting (Aldworth and van Staden,1987).

Application of Ascophyllum nodosum extract has been shown to increase the yield of cauliflower, lettuce, and maize (Abetz and Young 1983; Jeannin et al., 1991). Foliar application of *Ecklonia maxima* extracts is known to enhance yield in bean, wheat, barley and peppers (Nelson and van Staden,1984; Beckett and van Staden, 1989; Featonby-Smith and van Staden, 1987; Arthur et al., 2003). *Ascophyllum nodosum* extract has also been shown to have positive effects on the yield of Thompson seedless grape (Norrie and Keathley,2006).

4.4. Role in vegetative propagation

Seaweed products are exploited in conventional vegetative propagation (Crouch and van Staden 1991; Atzmon and van Staden 1994; Kowalski et al., 1999) in many crop species. It is a common practice to apply auxins exogenously to enhance rooting in cuttings in certain species that are difficult to root. Increased rooting has been observed in marigold (*Tagetus patula*) treated with 10% the sea weed concentrate Kelpak (*Ecklonia maxima*) for about 18 hours (Crouch and van Staden 1991). Similarly, Kelpak, when applied at a 1:100 dilution, is found to increase the number of rooted cuttings and improve the vigor of the roots in difficult-to-root cuttings of *Pinus pinea* (Atzmon and van Staden 1994). Foliar application of commercial liquid seaweed extract from *Ascophyllum nodosum*, supplemented with BA and IBA, enhances the number of propagules (crown divisions) plant^{-1} in the ornamental herbaceous perennial *Hemerocallis* sp (Leclerc et al., 2006).

4.5. Role in alleviation of different abiotic stresses in crop plants

Abiotic stresses such as drought, salinity, and temperature extremes can reduce the yield of major crops and limit agricultural production worldwide. Salinity and drought are becoming wide spread in many regions of the world, with an estimated 50%

of all arable lands possibly being salinized by 2050 (Flowers and Yeo 1995). Many abiotic factors such as drought, salinity, and temperature are manifested as osmotic stress and cause secondary effects like oxidative stress, leading to an accumulation of reactive oxygen species (ROS) such as the superoxide anion and hydrogen peroxide. These are known to damage DNA, lipids, carbohydrates, and proteins and also cause aberrant cell signaling. Seaweed extracts from *Ascophyllum nodosum* have been shown to contain betaines, including gamma-amino butyric acid betaine, 6-aminovaleric acid betaine, and glycine-betaine. Plants sprayed with seaweed extracts also exhibit enhanced salt and freezing tolerance (Mancuso et al., 2006). Commercial formulations of *Ascophyllum* extracts are known to improve freezing tolerance in grapes. Seaweed extracts which contain substantial amounts of cytokinins are known to mitigate stress-induced free radicals by direct scavenging and by preventing reactive oxygen species (ROS) formation by inhibiting xanthine oxidation (McKersie and Leshem, 1994; Fike et al. 2001). It is hypothesized that seaweed extract-induced heat tolerance in plants might be attributed largely to the cytokinin components in the seaweed extracts (Ervin et al. 2004; Zhang and Ervin 2008). It has also been reported that commercial seaweed extracts like Kelpak mediate stress tolerance by enhancing K^+ uptake in plants. The extracts of sea weeds like *Ascophyllum nodosum* and *Ecklonia maxima* are known to alleviate several abiotic stresses in crop plants when applied exogenously. After Khan et al.(2009)

5. Conclusion

The utilization of sea weeds and sea weed extracts in agriculture are becoming increasingly popular worldwide. Their utility can only be fully exploited for crop production through further research into their biochemical nature and mechanism of action. Seaweed extracts are also known to protect plants against a number of biotic and abiotic stresses and offers potential for field application. Therefore, research into developing sustainable methods to alleviate these stresses should be a priority. The use of sea weed extracts in agriculture not only reduces the application of harmful agrochemicals but also helps in protecting the environment. Their integration into popular farming practices worldwide can augment yield of crops in a sustainable manner.

6. References

Abe, H., Uchiyama, M., Sato, R., 1972. Isolation and identification of native auxins in marine algae. Agricultural and Biological Chemistry 36, 2259-2260.

Abe, H., Uchiyama, M., Sato, R., 1974. Isolation of phenylacetic acid and its p-hydroxy derivative as auxin-like substances from *Undaria pinnatfda*. Agricultural and Biological Chemistry 38, 897-898.

Abetz, P., Young, C.L., 1983. The effect of seaweed extract sprays derived from Ascophyllum nodosum on lettuce and cauliflower crops. Botanica Marina XXVI, 487-492.

Akula, A., Akula, C., Bateson, M., 2000. Betaine: a novel candidate for rapid induction of somatic embryogenesis in tea (*Camellia sinensis* [L.] O. Kuntze). Plant Growth Regulation 30, 241-246.

Aldworth, S.J., van Staden, J., 1987. The effect of seaweed concentrate on seedling transplants. South African Journal of Botany 53,187-189.

Arthur, G.D., Stirk, W.A., van Staden, J., 2003. Effect of a seaweed concentrate on the growth and yield of three varieties of *Capsicum annuum*. South African Journal of Botany, 207-211.

Atzmon, N., van Staden, J., 1994. The effect of seaweed concentrate on the growth of Pinus pinea seedlings. New Forests 8, 279-288.

Ayad, J.Y., 1998. The effect of seaweed extract (*Ascophyllum nodosum*) extract on antioxidant activities and drought tolerance of tall fescue (*Festuca arundinacea* Schreb.). Ph.D. dissertation, Texas Tech University, Lubbock.

Bartel, B., 1997. Auxin biosynthesis. Annual Review of Plant Physiology and Plant Molecular Biology 48, 51-66.

Beckett, R.P., van Staden, J., 1989. The effect of seaweed concentrate on the growth and yield of potassium stressed wheat. Plant and Soil 116, 29-36.

Bernart, M., Gerwick, W.H., 1990. 3(hydroxyacetyl) indole, a plant growth regulator from the Oregon red alga *Prionitis lanceolata*. Phytochemistry 29, 3697-3698.

Biddington, N.L., Dearman, A.S., 1983. The involvement of the root apex and cytokinins in the control of lateral root emergence in lettuce seedlings. Plant Growth Regulation 1, 183-193.

Blunden, G., Cripps, A.L., Gordon, S.M., Mason, T.G., Turner, C. H., 1986. The characterisation and quantitative estimation of betaines in commercial seaweed extracts. Botanica Marina 29, 155-160.

Blunden, G., Gordon, S.M., 1986. Betaines and their sulphono analogues in marine algae. In: Round, F.E., Chapman, D.J. (Eds), Progress in phycological research, vol 4. Biopress Ltd, Bristol, 39-80.

Blunden, G., Jenkins, T., Liu, Y., 1997. Enhanced leaf chlorophyll levels in plants treated with seaweed extract. Journal of Applied Phycology 8, 535-543.

Blunden, G., Jones, E.M., Passam, H.C., 1978. Effects of post-harvest treatment of fruit and vegetables with cytokinin- active seaweed extracts and kinetin solutions. Botanica Marina 21, 237-240.

Brain, K.R., Chalopin, M.C., Turner, T.D., Blunden, G., Wildgoose, P.B., 1973. Cytokinin activity of commercial aqueous seaweed extract. Plant Science Letters 1, 241-245.

CGIAR, 1978. Farming Systems Research at International Agricultural Research Centre Roam Secretariat Agric Dept. FAO.

Crouch, I.J., Beckett, R.P., van Staden, J., 1990. Effect of seaweed concentrate on the growth and mineral nutrition of nutrient stressed lettuce. Journal Applied Phycology 2, 269-272.

Crouch, I.J., Smith, M.T., van Staden, J., Lewis, M.J., Hoad, G.V., 1992. Identification of auxins in a commercial seaweed concentrates. Journal of Plant Physiology 139, 590-594.

Crouch, I.J., van Staden, J., 1992. Effect of seaweed concentrate on the establishment and yield of greenhouse tomato plants. Journal Applied Phycology 4, 291-296.

Crouch, I.J., van Staden, J., 1991. Evidence for rooting factors in a seaweed concentrate prepared from *Ecklonia maxima*. Journal of Plant Physiology 137, 319-322.

Crouch, I.J., van Staden, J., 1993. Evidence for the presence of plant growth regulators in commercial seaweed products. Plant Growth Regulation 13, 21-29.

Ervin, E.H., Zhang, X., Fike, J., 2004. Alleviating ultraviolet radiation damage on Poa pratensis: II. Hormone and hormone containing substance treatments. Horticultural Science 39,1471-1474.

Featonby-Smith, B.C., 1984. Cytokinins in *Ecklonia maxima* and the effect of seaweed concentrate on plant growth. Ph.D. thesis, University of Natal, Pietermaritzburg

Featonby-Smith, B.C., van Staden, J., 1983a. The effect of seaweed concentrate on the growth of tomato plants in nematode-infested soil. Scientia Horticulture 20, 137-146.

Featonby-Smith, B.C., van Staden, J., 1987. Effects of seaweed concentrate on grain yield in barley. South African Journal of Botany 53, 125-128.

Featonby-Smith, B.C., van Staden, J., 1983b. The effect of seaweed concentrate and fertilizer on the growth of Beta vulgaris. Zeitschrift für Pflanzenphysiologie 112,155-162.

Featonby-Smith, B.C., van Staden, J., 1984. The effect of seaweed concentrate and fertilizer on growth and the endogenous cytokinin content of Phaseolus vulgaris. South African Journal of Botany 3, 375-379.

Fike, J.H., Allen, V.G., Schmidt, R.E., Zhang, X., Fontenot, J.P., Bagley, C.P., Ivy, R.L., Evans, R.R., Coelho, R.W., Wester, D.B. 2001. Tasco-Forage: I. Influence of a seaweed extract on antioxidant activity in tall fescue and in ruminants. Journal of Animal Science 79, 1011-1021.

Finnie, J.F., van Staden, J., 1985. Effect of seaweed concentrate and applied hormones on in vitro cultured tomato roots. Journal of Plant Physiology 120, 215-222.

Flowers, T.J., Yeo, A.R., 1995. Breeding for salinity resistance in crop plants-where next? Australian Journal of Plant Physiology 22, 875-884

Genard, H., Le Saos, J., Billard, J.P., Tremolieres, A., Boucaud, J., 1991. Effect of salinity on lipid composition, glycine betaine content and photosynthetic activity in chloroplasts of *Suaeda maritima*. Plant Physiology and Biochemistry 29, 421-427

Gopala, R.P., 1984. Gibberellin-like behaviour of α-tocopherol in green gram *Vigna radiata*. Geobios 11, 21-25

Hahn, H., de Zacks, R., Kende, H., 1974. Cytokinin formation in pea seeds. Die Naturwissenschaften 61, 170-171

Hamana, K., Matsuzaki, S., Niitsu, M., Samejima, K., Nagashima, H., 1990. Polyamines of inicellular thermoacidophillic red alga, *Cyanidium caldarium*. Phytochemistry 29, 377-380

Hartmann, H.T., Kester, D.E., 1983. Plant Propagation: Principles and Practices (4th Edn.), Englewood Cliffs, USA: Prentice Hall, 234-297.

Hussain, A., Boney, A.D., 1969. Isolation of kinin-like substances from *Laminaria digitata*. Nature 223, 504-505.

Hussain, A., Boney, A.D., 1973. Hydrophilic growth inhibitors from *Laminaria* and *Ascophyllum*. New Phytology 72, 403-410.

IPCC, 2007. Summary for policymakers. In: Parry, M.L., Canziani, O.F., Palutikot, J.P., vander Linden, P.J., Hanson, C.E., (Eds), Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Jeannin, I., Lescure, J.C., Morot-Gaudry, J.F., 1991. The effects of aqueous seaweed sprays on the growth of maize. Botanica Marina 34, 469-473.

Jennings, R.C., 1968. Gibberellins as endogenous growth regulators in green and brown algae. Planta 80, 34-42.

Jensen, A., 1969. Tocopherol content of seaweed and seaweed meal. I. Analytical methods and distribution of tocopherols in benthic algae. Journal of the Science of Food and Agriculture 20, 449-453.

Khan, W., Rayirath, U.P., Subramanian, S., Jithesh, M.N., Rayorath, P., Mark Hodges, D., Critchley, A.T., Craigie, J.S., Norrie, J., Prithiviraj, P., 2009. Seaweed Extracts as Biostimulants of Plant Growth and Development. Journal of Plant Growth Regulation 28, 386-399.

Kingman, A.R., Moore, J., 1982. Isolation, purification and quantification of several growth regulating substances in *Ascophyllum nodosum* (Phaeophyta). Botanica Marina 25, 149-153.

Kowalski, B., Jager, A.K., van Staden, J., 1999. The effect of a seaweed concentrate on the in vitro growth and acclimatization of potato plantlets. Potato Research 42, 131-139

Leclerc, M., Caldwell, C.D., Lada, R.R., Norrie, J., 2006. Effect of plant growth regulators on propagule formation in *Hemerocallis* spp. and *Hosta* spp. Horticultural Science 41, 651-653.

Mancuso, S., Azzarello, E., Mugnai, S., Briand, X., 2006. Marine bioactive substances (IPA extract) improve ion fluxes and water stress tolerance in potted Vitis vinifera plants. Advances in Horticultural Science 20, 156-161.

McKersie, B.D., Leshem, Y.Y., 1994. Stress and stress coping in cultivated plants. Kluwer Academic Publishers, Dordrecht.

Metting, B., Zimmerman, W.J., Crouch, I.J., van Staden, J., 1990. Agronomic uses of seaweed and microalgae. In: Akatsuka, I. (Ed), Introduction to applied phycology. SPB Academic Publishing, The Hague, Netherlands, 269-627.

Naidu, B.P., Jones, G.P., Paleg, L.G., Poljakoff-Mayber, A., 1987. Proline analogues in Melaleuca species: response of *Melaleuca lanceolata* and *M. uncinata* to water stress and salinity. Australian Journal of Plant Physiology 14, 669-677.

Nelson, W.R., van Staden, J., 1984. The effect of seaweed concentrate on wheat culms. Journal of Plant Physiology 115, 433-437.

Nelson, W.R., Van Staden, J., 1985. 1-Aminocyclopropane-l-carboxylic acid in seaweed concentrate. Botanica Marina 28, 415-417.

Niemann, D.I., Dorfing, K., 1980. Growth inhibitors and growth promotors in *Enteromorpha compressa* (Chlorophyta). Journal of Phycology 16, 383.

Norrie, J., Keathley, J.P., 2006. Benefits of *Ascophyllum nodosum* marine-plant extract applications to 'Thompson seedless' grape production. (Proceedings of the Xth International Symposium on Plant Bioregulators in Fruit Production, 2005). Acta Horticulture 727, 243-247.

Rayorath, P., Narayanan, J.M., Farid, A., Khan, W., Palanisamy, R., Hankins, S., Critchley, A.T., Prithiviraj, B., 2008. Rapid bioassays to evaluate the plant growth promoting activity of *Ascophyllum nodosum* (L.) Le Jol. using a model plant, *Arabidopsis thaliana* (L.) Heynh. Journal of Applied Phycology 20, 423-429.

Rayorath, P., Khan, W., Palanisamy, R., MacKinnon, S.L., Stefanova, R., Hankins, S.D., Critchley, A.T., Prithiviraj, B., 2008. Extracts of the Brown Seaweed Ascophyllum nodosum Induce Gibberellic Acid (GA_3)-independent Amylase Activity in Barley. Journal of Plant Growth Regulation 27(4), 370-379.

Stephenson, W.A., 1968. Seaweed in agriculture and horticulture. Faber and Faber, London.

Stirk, W.A., Arthur, G.D., Lourens, A.F., Novak, O., Strnad, M., van Staden, J., 2004. Changes in cytokinin and auxin concentrations in seaweed concentrateswhen stored at an elevated temperature. Journal of Applied Phycology 16, 31-39.

Stirk, W.A., 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, 327-330.

Tietz, A., Ruttkowski, U., Kohler, R., Kasprik, W., 1989. Further investigations on the occurrence and the effects of abscisic acid in algae. Biochemie und Physiologie der Pflanzen 184, 259-266.

Vernieri, P., Borghesi, E., Ferrante, A., Magnani, G., 2005. Application of biostimulants in floating system for improving rocket quality. Journal of Food Agriculture and Environment 3, 86-88.

Wachira, F., Ogada, J., 1995. In vitro regeneration of *Camellia sinensis* (L.) O. Kuntze by somatic embryogenesis. Plant Cell Report 14, 463-466.

Whapham, C.A., Blunden, G., Jenkins, T., Hankins, S.D., 1993. Significance of betaines in the increased chlorophyll content of plants treated with seaweed extract. Journal of Applied Phycology 5, 231-234.

Williams, D.C., Brain, K.R., Blunden, G., Wildgoose, P.B., Jewers, K., 1976. Plant growth regulatory substances in commercial seaweed extracts. Proceedings of International Seaweed Symposium 8, 59-63.

Zhang, X., Ervin, E.H., 2008. Impact of seaweed extract-based cytokinins and zeatin riboside on creeping bentgrass heat tolerance. Crop Science 48, 364-370.