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Sustainable Agriculture: Modern Applications of Algae Biostimulants (Seaweed) and their Impact on Plant Physiology

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A plant biostimulant is basically an organic material which improves plant growth, when applied in small volumes. This study is aimed to highlight recent developments in processing microalgae for "agricultural biostimulants (AB), summarizing the biologically active parts of brown macroalgae and determining the factors helping the use of AB to manage biotic and abiotic stresses in crops. The policy drivers promoting the use of algae biostimulants or seaweed in farming are also the focus of the study. This study discusses the use of algae biostimulants in crop growth and production as well as benefits of foliar application, seed priming, hydroponic treatments, and soil drenches. Using algae biostimulants on crops can result in various benefits with reported impacts like higher fruit and crop yields, improved rooting, salt and drought tolerance, freezing, improved resistance to bacteria, fungi, and virus, and photosynthetic activity. ABs are applicable as an alternative and it is used along with synthetic products for crop protection as well as plant growth controllers. It may play a vital role in retaining crop production, quality and health with a lot of active ingredients. Microalgae is widely unexplored across the world. This study highlights some of the future scope for future research and studies.

Keywords: biostimulants, algae biostimulants, seaweed, plant physiology, agricultural biostimulants.

1. Introduction

Seaweeds (microalgae) and macroalgae are the part of "algae" and it contains a vast group of organisms which are found especially in aquatic conditions. With over 156,000 species, both micro- and macro-algae "eukaryotic algae" are rich blend of biological diversity (Hughes et al., 2021). The seaweed or macroalgae are multicellular organisms, which are prevalent in both salt- and freshwater, classified as red, brown, and green algae (Øverland et al., 2018). They are environmentally vital as they are helpful to supply oxygen to the sea and they are the major producers for food chain (Chan et al., 2006).

In this day and age, seaweeds are widely gaining attention as they are known to be eco-friendly and rich in nutrients because they contain micronutrients, vitamins and minerals like boron, calcium, potassium, zinc, magnesium, phosphorous, and various other elements. They are the only plant sources of omega-3 fatty acids (Patel et al., 2021). In addition, seaweeds can be used in cosmetics, feed additives, dietary additives and substitutes, as well as other species which are processed well to gather thickening agents like agar and alginate (Chandía et al. 2004) or bioactive compounds like minerals, lipids, proteins, amino acids, carbohydrates, osmo-protectors, antimicrobial compounds, and phytohormones (Patel et al., 2021).

Seaweeds or microalgae are collected in the wild form and cultivated and used majorly as food product in Asian cuisine. In addition, whether cultivated or present on beaches in coastal regions of the Americas and Europe, seaweed is widely introduced and consumed in simple dishes and in molecular gastronomy and modern kitchen (Mouritsen et al., 2021). Microalgae are photoautotrophic elements with potential to adapt to various environmental conditions and rapid growth (Ortiz-Moreno et al, 2019). Microalgae, which includes prokaryotic cyanobacteria and eukaryotic organisms have attracted a lot of interest due to their unicellular structure, ability to have heterotrophic growth, high photosynthetic efficiency, and adaptability to industrial and domestic wastewater, potential to yield important co-products, and willingness to metabolic engineering (Chiaiese et al., 2018).

Seaweeds include a lot of compounds which protect marine environment at biomolecular level. Only a few microalgal species can have commercial value. This knowledge gap of microalgae has garnered a lot of interest in biotechnology industry since microalgae has been applied in cosmetics, biofuels, pharmaceuticals, and nutraceuticals (Porcelli et al. 2020; Fernández et al. 2021). Along with it, they are used in bioremediation of pollutants by getting rid of heavy metals and purifying water under mixed and pure strains (Chatzissavvidis and Therios, 2014). Algae play a vital role in agriculture where thy can be biofertilizers (Haroun & Hussein, 2003; Grzesik et al., 2017).

Special metabolites have been reported widely for seaweeds with promising biological components and they are used most widely for microalgae extracts as they regenerate or maintain soil fertility of agricultural land and improves high crop yield (Hughes et al., 2013). These compounds are very vital as they regenerate or maintain soil fertility and improve high yield in crops. There is a paradigm shift in agriculture from merely on direct nutrition to other functions which help in plant growth in indirect manner, while protecting soil quality. This way, algae have high potential. This study highlights existing knowledge on R&D as this is a novel field. Because of rising use of algae- based biofertilizers and bio-stimulants, this study discusses the role of micro and macro algae in retaining soil stability and fertility, along with mechanisms of action as well as potential relation between cultivated plants and organisms. Along with it, this study provides a complete insight to production of algae along with cost of transformation of biomass of algae into biofuels.

2. Literature Review

Modern farming widely needs alternative to synthetic pesticides and fertilizers to respond to changes in global regulations and laws along with responding to increasing food demand without toxic chemicals. Microbial and non-microbial biostimulants like silicon, humic substances, micro- and macro-algal extracts are effective and sustainable alternatives of synthetic chemicals that can provide benefits to the environment, human health, biodiversity, and economy. Rouphael & Colla (2020) discussed the implications of non-microbial and microbial bio-stimulants to improve the growth of seedlings and crop yield, quality of produce, nutrient use, and resistance/tolerance to different abiotic stresses in a specific salinity, nutrient deficiency, drought, and high temperature condition. This study will foster transfer of knowledge among stakeholders, researchers, biostimulant and fertilizer industries, farmers, specialists, etc. and improve knowledge of molecular and physiological mechanisms and applications of biostimulants in various cropping systems.

Algal extracts, biomass, or derivatives have always been known to be a valuable material to benefit mankind and cultivated plants. It has been evident in the last decades that formations of algae can induce different effects on crops like improving yield, quality, and biomass, and algae has a lot of bioactive compounds as well as signaling molecules, along with organic and mineral nutrients. The demand to reduce non-renewable input of chemical in agriculture has required the use of algae as biostimulant, along with their ability to promote plant yield in sub-optimal environments like saline environments. Carillo et al. (2020) discussed some of the research areas important to implement in micro- and macro-algae extracts. They provided existing knowledge of compositions, extraction approaches, and action mechanisms of algae, with special emphasis on salt stress management. They also discussed potential research areas and limitations. It is concluded that integration and comparison of information on physiological and molecular response of plants to algal and salt extracts must also help in extraction application approaches. The impact of algal biostimulants have been investigated widely from the applied point of view as well as use of various scientific disciplines is much required to develop new strategies to improve tolerance to salt pressure.

Plant biostimulants were once known as “snake oil” and there was skepticism related to agricultural benefits. These days, a lot of scientific evidence is available related to benefits of algae biostimulants. These days, seaweed is widely known as full- fledged category of agricultural inputs and a great business opportunity for agroindustry stakeholders. Seaweed extracts are the major category of biostimulants. They are well-regarded as substances that can improve crop productivity and reduce abiotic stress. Seaweed extracts come from extracting various macroalgae species which, as per the extraction approach, helps in producing complex blend of compounds which are biologically active. On the other hand, plant responses are usually inconsistent and decipher the mechanism of action which is highly complex. Scientists worldwide have recently explored hidden system of action of those resources by employing high-throughput and multidisciplinary approaches, molecular biology, plant physiology, multi-omics, and agronomy techniques. El Boukhari et al (2020) provided fresh and new insights to seaweed extract while managing new-fangled stands as per existing scientific knowledge and considering both industrial and academic claims to meet market needs. The impact of those products as well as extraction process on nutrient consumption as well as their role in biotic and abiotic stress control are discussed while focusing on mechanisms at genetic and metabolic level. In addition, the study has discussed some of the effects which are indirect and overlooked of seaweed extracts like their impact on microbiome of plant.

Seaweeds are very important marine resources with different uses in modern farming. Seaweed extracts have been used over the centuries in agriculture to improve crop yield and plant growth. In modern farming, synthetic fertilizers and chemicals are widely used which have posed global health concern and polluted agricultural lands. Hence, encouraging the use of natural fertilizers and plant growth controllers like seaweeds are suggested with promising benefits. In addition, biostimulants derived from seaweed extract have plant growth-promoting properties and they help to improve overall resilience of plant. Additionally, seaweed extracts can improve soil fertility and soil health. Nanda et al. (2022) discussed various approaches to obtain seaweed-based biostimulants. In addition, they illustrated the role of those biostimulants in promoting plant growth, controlling biotic and abiotic stresses in plants, and improving soil quality as well as common mechanism. Additionally, some of the vital applications of seaweed extracts in various areas have been discussed.

Biotic and abiotic stresses control the productivity and growth of plants. In this existing international scenario, to meet the growing demand of global population, synthetic and chemical fertilizers are widely exploited for agricultural growth. These toxins pose a serious threat to public health, environment, plants, and animal health. To reduce chemical footprint in agriculture, Shukla et al. (2019) discussed the ability of "Ascophyllum nodosum (ANE)" to improve agricultural productivity and plant growth. The scientific study attempts to explain how specific compounds in extracts help in improving plant tolerances to biotic and/or abiotic stresses, promoting plant growth, and their impact on microbe/root interactions. These reports have focused on using different seaweed extracts to improve the efficiency of nutrient use in treated plants. These studies have investigated biochemical, physiochemical, and molecular mechanisms as discussed with model plants. There is a vast research gap in how "A. nodosum extracts" act. This study discusses several benefits of biostimulants based on "A. nodosum" on plant growth as well as their defense mechanisms.

2.1. Research Gap

Because of intensive practices in modern agriculture, farmlands are subject to constant degradation. Agricultural yield depends entirely on soil fertility, which acts as a substrate and important resource for plants which should replenish nutrients. Existing research is mainly focused on development of modern natural products from aquatic plants with same efficiency as that of synthetic products, without affecting human health and environment (Dineshkumar et al, 2018)." Using algae or algal extracts as fertilizers can meet global problem of biodegradable and non-toxic products on a large scale (Prakash & Nikhil, 2014). Hence, this study focuses on sustainable agricultural methods of using seaweed extracts as well as their effects on plant physiology.

2.2. Research Objectives

- To explore elicitor and bioactive components of seaweed extracts that help in plant yield growth
- To discuss the effects of algae biostimulants (seaweed extracts) on plant growth and physiology
- To explore the effects of seaweed extracts to environmental and abiotic stresses

3. Methodology

To fulfil the above objectives, this study is based on secondary data collected from various sources related to modern agricultural practices and sustainable agriculture. This study adopts qualitative research approach which includes recent developments related to the field of agriculture. This study uses keyword research with terms like “algae biostimulants”, “seaweed extracts”, “agricultural practices”, “plant physiology”, etc. Data has been collected from various studies published in peer-reviewed journals and stored in databases like Google Scholar, MDPI, Science Direct, IEEE Xplore, Elsevier, etc.

4. Data Analysis

4.1. Elicitor and Bioactive Components of Seaweed Extracts Seaweed extracts consist of different bioactive substances which promote and elicit plant defense and growth reactions (Khan et al., 2009). In different metabolic paths, some of these elements are “plant growth hormones, polysaccharides, sterols, fatty acids, minerals, oxylipins, amino acids and proteins, peptides, lipids, etc. which are biologically active (Khan et al., 2009, Crouch & van Staden, 1993). These elements in extracts vary widely as per the species and class of seaweed along with extraction method used. Seaweeds have a lot of polysaccharides whose quantity, type, and chemical structure varies on the environmental conditions and seaweed species. Seaweeds usually have polysaccharides of around 76% of dry weight but it also shows seasonable changes.

Some of the most important algal polysaccharides are fucoidan, galactans, alginates, and laminarin, and most of them are represented proportionally in seaweed extracts. Extraction methods have a lot of impact on SWE composition. Usually during the process of extraction, polysaccharides are complex molecules transformed into oligomers which are significantly bioactive. Small molecules are highly degraded in the same way like hormones (Jayaraman and Ali, 2015). Seaweed extracts have various types of carotenoids that are highly strong antioxidants. These extracts also have phenolic compounds like flavonoids, phenolic acids, cinnamic acid, isoflavones, quercetin, lignans, and benzoic acid.

Algal extracts have different minerals as seaweeds are mostly found in seawater and they bioaccumulate minerals. Seaweed extracts contain phyto-hormonic elements like gibberellins, cyto-kinins, auxins, betaines, and abscisic acid (Delaunois et al., 2014). The impact of these substances rely on the type of plant, type of application, and its receptor mechanism (Ali et al., 2016). Figure 1 and Table 1 highlighted vital compounds of seaweed extracts which work in balance to induce defense systems and promote plant growth.

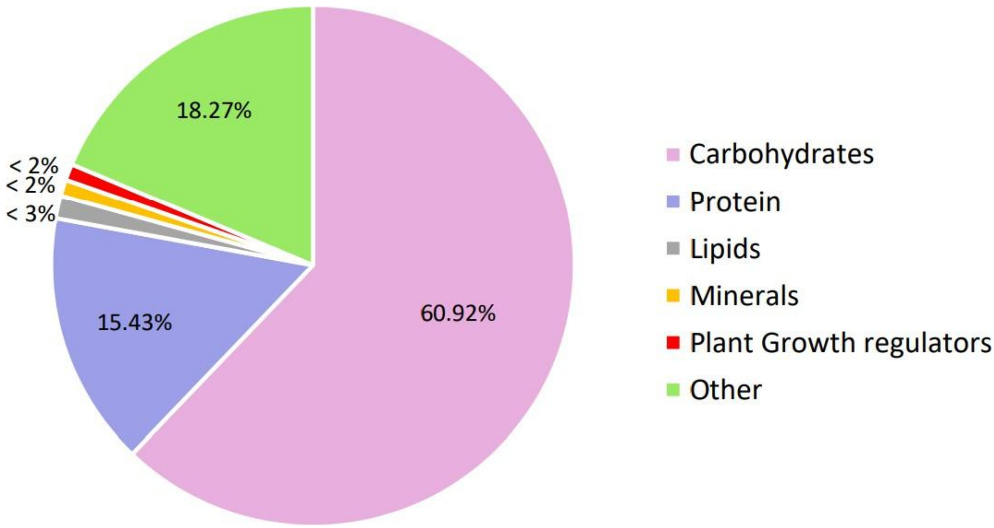

Figure 1 – Composition of Seaweed Extracts in red, green, and brown categories

Source – Ali et al. (2021)

Table 1 – Key bioactive elements of seaweed extracts

Bioactive elements	Chlorophyceae (Brown)	Rhodophyceae (Red)	Phaeophyceae (Green)	References
Polysaccharides	Cellulose	Cellulose	Alginates	Vera et al., 2011; Mercier et al., 2001
Inulin		Carrageenans Cellulose	Heteroglucans Glucomannans Mannans	
Laminaran		Complex mucilages	Fucose	
Sulfated mucilages	Glycogen		Glucuronoxylofucans	
Plant growth controllers	Auxins	Auxins	Auxins	Crouch & Van Staden, 1993; Yalçın et al., 2019; Stirk & Van Staden, 1996

	Cytokinins Gibberellins	Cytokinins Gibberellins Gibberellins	Cytokinins	
Indole-3-acetic acid (IAA)		Indole-3-acetic acid (IAA)	Indole-3-acetic acid (IAA)	
Abscisic (ABA)		acid Abscisic (ABA)	acid Abscisic acid (ABA)	
	Brassinosteroids	Brassinosteroids	Brassinosteroids	
	Strigolactones	Strigolactones	Strigolactones	
	Salicylic Acid	Salicylic Acid	Salicylic Acid	
	Kinetin	Kinetin	Kinetin	
	Zeatin	Zeatin	Zeatin	
6-benzyl purine (BAP)		amino 6-benzyl purine (BAP)	amino 6-benzyl amino purine (BAP)	
Sterols	Isofucosterol	Cholesterol	Fucosterol	Nabil & Cosson, 1996; Hamdy & Dawes, 1988; Govindan et al., 1993
Ergosterol		Cholester ol derivatives	Fucosterol derivatives	
Clionasterol		β-sitosterol Campesterol	Cholesterol Clerosterol	Fucosterol

Betaines	γ-Aminobutyric acid	γ-Aminobutyric acid	γ-Aminobutyric acid	MacKinnon et al., 2010; McNeil et al., 1999
Glycine		Glycine	Glycine	
δ-Aminovaleric acid		δ-Aminovaleric acid	δ-Aminovaleric acid	
Laminine		Laminine	Laminine	

Seaweed extracts have a lot of growth benefits for plants. However, those are mostly because of their stimulatory feature which leads to different reactions in the plant, while leading to overall improvement and growth to resist both abiotic and biotic stress (Figure 2). However, it must be noted that seaweed extracts include different bioactive components and no specific component can be assigned to positive benefits (Figure 1). Actually, trails with parts of seaweed extracts have observed that there is no fraction that can show all the effects where the entire extract is used. Hence, this trend shows that parts of whole extract works together to evoke overall effective response in plant where each component works on different metabolic networks either interactively or independently (Rombolà et al., 2001; Grundy et al., 2015) (Figures 2 and 3).

Plants cured with seaweed extracts have usually improved absorption of nutrients and improved vigor and growth. Rapeseed plants treated with A. nodosum extract observed a rise in sulfur and nitrogen absorption (Billard et al., 2014). It was justified due to upregulation of genes coding iron, sulphate, and nitrate transporters. There is also a rise in activity or transcription of nutrient transporters which is seen in acquisition of plant nutrition in seaweed extract in plant membrane (El Boukhari et al., 2020). Using A. nodosum in spinach increased protein, biomass, carotenoid, and chlorophyll content, antioxidant activity, phenolics and flavonoids. There is a correlation between rise in biomass and rise in expression of GSI gene in nitrogen integration. There is a relation between rise in chlorophyll and expression of choline monooxygenase and betaine aldehyde dehydrogenase".

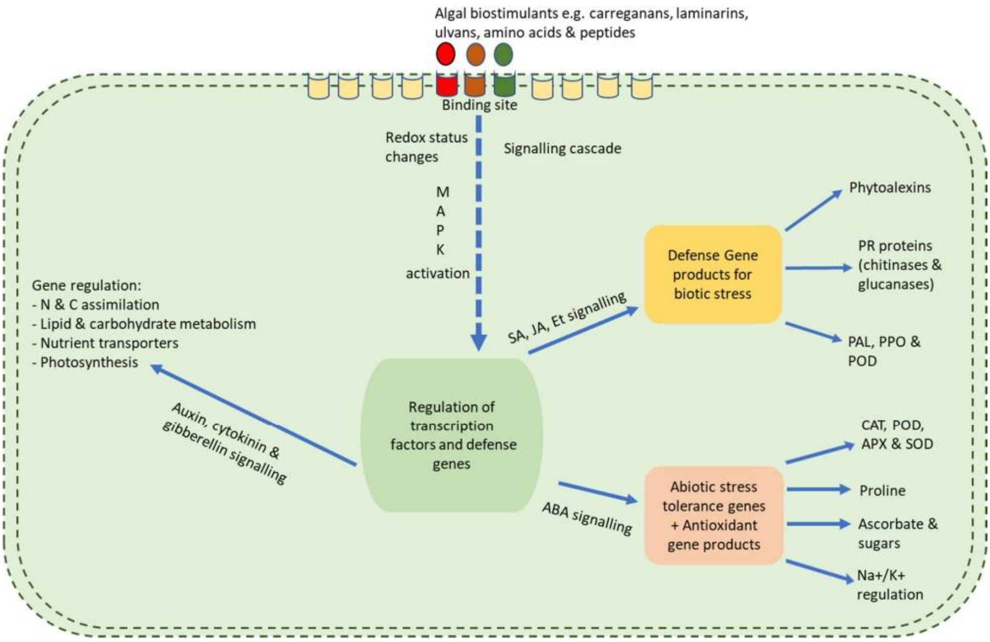

Figure 2 – A schematic illustration of mechanism of seaweed extract

Source – Ali et al. (2021)

In Figure 2, the binding of elicitor and algal receptor sites activates secondary messengers which leads to several downstream processes (Jayaraj et al., 2008). After insight of elicitor, "dephosphorylation" and "reversible phosphorylation" of cytosolic proteins and plasma membrane proteins take place, it follows the improvement of "cytosolic (Ca2+)" efflux of K+/influx of H+, and C1-, acidification of cytoplasm while activating "mitogen-activated protein kinase (MAPK)" and acidification of cytoplasm. When it comes to follow MAPK activation, "reactive nitrogen species (RNS)" and "reactive oxygen species (ROS)" are produced along with initiation of NADPH oxidase (Mercier et al., 2001; Dubiella et al, 2013; Delaunois et al., 2014). A flow of chemical reactions enables improved growth regulation and resistance in the plant.

4.2. Effects of Algae Biostimulants (Seaweed Extracts) on Plant Growth and Physiology

A biostimulant is defined as a material which works when applied to soil or plant and stimulates natural processes to improve consumption of nutrients or deficiency of nutrients and improve tolerance to abiotic stress and crop quality, irrespective of its nutrient value, according to the "European Biostimulant Industry Council (EBIC) (Ricci et al, 2019). Using seaweeds as fertilizer has been very prevalent, but their role as a biostimulant has been recently discovered to understand applications in agriculture (Mukherjee & Patel, 2020). With the rising environmental concern in farming, it means that high production should reduce environmental impact and should be sustainable.

Hence, studying algal extracts as biostimulants is among the main directions of biotechnology of algae (Shekhar et al., 2012).

Microalgae and seaweeds have been known as the rich source of biostimulants in plants and microalgae have been widely exploited. For microalgae, despite having positive effects on crop growth, yield, and development, their commercial use is limited by production cost and lack of research (Kapoore et al., 2021). Although algal extracts have increased interest in production of crop lately due to their stimulatory benefits, mechanisms are still not clear to underline those benefits (Tan et al., 2021). Concentrations of seaweed are widely applied in low doses and they have growth-promoting impact because of their plant growth controllers like cytokinins, brassinosteroids, auxins, abscisic acid, and gibberellins (Nguyen et al. 2020). Commercial algae products contain some other purified compounds like alginates, laminarin, polyanionic substances, and carrageenan (Du Jardin, 2015), gibberellins, abscisic acid, betaines, and amino acids (Michalak and Chojnacka, 2015). They can be applied to plants directly as foliar application or soil solution. The promotion of plant growth could be due to its synergistic impact (Santner et al., 2009). Table 2 lists important compounds and their effects of application.

Various mechanisms have been discovered to justify the improvement in plant growth, nutrient content, higher yield, and plat growth by applying algal extracts. These can be split between mechanisms affecting plant physiology or soil. Applications to target biochemistry and plant physiology will be applied as foliar spray. They may also cover inoculation of seeds, roots, or soil, while soil is drenched to improve soil properties.

Table 2 – Compounds in algal extracts and their actions

Compounds in algal extracts	Actions	References
Gibberellins	They start germination of seeds and play a vital role in elongation of seed and development of flower and seeds	Bose et al. (2013)
Cytokinins	They play a vital role in shoot and root growth and mobilization of nutrients while preventing heat stress	Zhang et al (2010)
Auxins	They play their part in formation and development of roots	Ronga et al (2019)
Laminarin	They promote defense responses in plants by expressing gene proteins related to pathogenesis and improve nutrient absorption	Michalak et al. (2015)
Carrageenan	They also boost nutrient uptake as natural elicitor and play a vital role in plant protection	Khan et al. (2009)
Alginates	The promote response of plants to pathogens and maintain soil moisture	Michalak et al. (2015)
Betaines	They help plants to resist drought and osmotic stress	Panda et al.

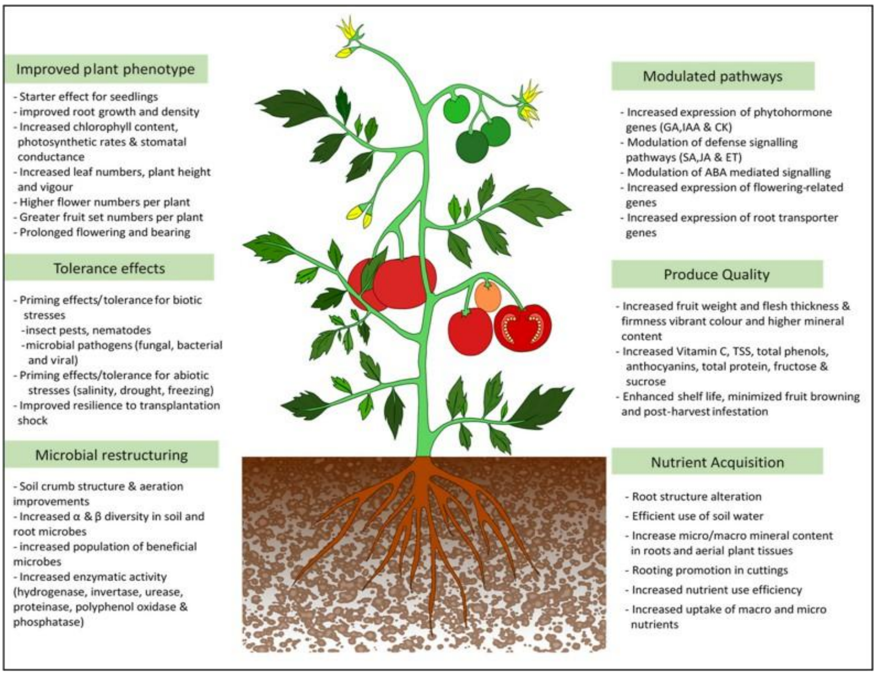

Figure 3 – Effects of Algae Biostimulants on Soil and Plant systems

Source – Ali et al. (2021)

There are different studies conducted both in greenhouse and in the field showing biostimulant properties of plants in algal extracts. Seaweed extract is known as organic and natural growth of plant because it improves abiotic stress tolerance and nutrition efficiency, and/or crop quality (Du Jardin, 2015). When it comes to study plant growth and nutrient uptake, Almaroai and Eissa (2020) conducted field study for 2 years on the impact of various doses of foliar application of Amphora ovalis or marine algae extracts on onion. It is found that highest algal extract dose improved nitrogen, phosphorous, and potassium absorption by onions in comparison to unsprayed plants.

In relation to studies based on plant growth and nutrient uptake, Turan & Köse (2004) tested the effect of foliar application of three commercial algal extracts on nutrient uptake in grape plants. They showed drastic improvement in Cu uptake when there was less nutrient available. There was a rise in uptake of Calcium, N, P, K, Fe, Cu, Mn, Mg, and Zn nutrients in ideal condition. Rathore et al (2009) reported improvement on S, N, P, and K in soybean with foliar application of “Kappaphycus alvarezii extracts”. There was a positive correlation of this improvement with the dose and largest concentration of nutrient in treatment achieved highest dose.

An Ascophyllum extract has been applied by Merwad (2020) on wheat in order to withstand salinity stress and fond higher grain and straw yield, protein content, and plant height than control. Crouch et al. (1990) tested the impact of algal extract on Ca, Mg, and K absorption and lettuce growth. They reported improved nutrient uptake and plant growth when plants were also getting the right nutrient solution. With similar commercial product, Nelson & Van Staden (1984) observed a drastic improvement in root growth as well as higher P and N content in comparison to control treatment. Various studies have found that plants cured with seaweed extracts were found to have higher amount of mineral than control plants (Mahmoud et al. 2019; Di Filippo-Herrera et al. 2019).

According to El-Aziz Kasim et al. (2016), priming seeds with seaweed extracts can improve the photosynthetic pigment in radish plant leaves. Meanwhile, applying seaweed extracts improved lead pigment of chlorophyll a, b, a+b, and carotenoids (Mahmoud et al., 2019). Applying “Pterocladia capillacea” seaweed extract improved the amount of carotene, chlorophyll a and b in Jew’s mallow during two seasons in a row” (Ashour et al, 2020).

4.3. Effects of Seaweed Extracts to Environmental and Abiotic Stresses

Various studies have been conducted on the effects of seaweed extracts to improve stress tolerance and to evaluate the impact on various crops as seaweed extracts protect plants against abiotic and environmental stress (Van Oosten et al. 2017; Michalak et al. 2017). Higher phenolic content in seaweed extract is related to protection against stress (Mansori et al., 2015). Seaweed extract also plays a regulatory role in gene expression and it is rich in antioxidant activity (Shukla et al., 2018). Most of the studies have focused on seaweed extracts to resist salinity, drought, or heat stress. There is a lack of information of those effects against nutrient unbalance as well as underlying mechanisms (Carrasco-Gil et al. 2018).

Rayirath et al. (2009) investigated the potential of various organic sub-fractions to increase freezing tolerance with “A. nodosum extract on Arabidopsis thaliana. This tolerance was increased by lipophilic sub-fractions. Mansori et al (2015) investigated the impact of “Ulva rigida” red algae and “Fucus spiralis” brown algae in green bean plants against draught stress tolerance. It is found that seaweed extract enhanced growth in both drought stress and without drought conditions in bean plants. Bradáčová et al. (2016) tested extracts with Mn and Zn to improve cold stress tolerance and seaweed extract was found to be effective by increasing those micro components.

Carrasco-Gil et al. (2021) conducted a study on the tolerance to lack of Fe in tomato when various compounds were applied from algal extracts in various doses. Lowest dosage of laminarin, phenolics, and fucose compounds were helpful to alleviate this problem. A. nodosum extracts were found to be effective for plant growth against saline stress in avocado plants at nascent stage (Bonomelli et al., 2018). Finally, a lot of studies have found that algal extracts are useful to reduce drought stress on crops. Martynenko et al. (2016) evaluated whether soybean could survive during five days in drought. From plants, leaves didn’t wilt with commercial seaweed extract and had improved survival after rewatering on day 5”. A. nodosum extract was also applied to Arabidopsis plants as pre-treatment for plants to deal with stress and improve efficiency of water use by Santaniello et al. (2017).

Some of the benefits of agricultural biostimulants are formation of seedlings, improved germination of seeds, nutrient distribution and mobilization, rooting of flowering, cuttings, crop and fruit yield, improved chlorophyll, and senescence retardation and leaf area, improved resistance to pests and disease, and shelf life. There is a huge body of research which showed the use and benefits of macroalgal extracts, even though the reasons are still not explored for positive results. Studies are still going on to determine the mode of action of macroalgal extracts. Crop-based studies are yet to identify when, how, and where marine algal extracts can be applied to improve crop productivity under abiotic and biotic stress.

The factors affecting the use of microalgal extracts for agricultural purposes define the final price of the product. These days, the use of macroalgal extracts has been reduced by the cost of production, especially for high-value crops like protected crops and fruits. However, there is also a rise in cost of fertilizers and this situation may be changed by crop protection products as macroalgal extract shows improved productivity and effectivity to improve plant growth. There will be different factors to determine the future growth in agriculture sector, such as, availability of microalgae. Developing eco-friendly protocols for biofuel was other area to impinge on the future growth (Sharma et al., 2014).

Plants treated with some agricultural biostimulants could better managed abiotic and biotic stresses in studies conducted in North America. For instance, impact of low soil moisture and high temperature, salinity, fungal disease, cold, herbicides, nematodes, and highly intense UV light was reduced by macroalgal extracts (Zhang and Schmidt 2000; Nabati et al. 1994; Jayaraj et al. 2008; Schmidt, 1993; Schmidt and Zhang, 2001; Sun et al. 1997). Plants are conditioned well to deal with abiotic and biotic stresses by applying macroalgal extracts on crops. This condition may be partly related to activity like an elicitor of polysaccharides in macroalgal extracts. Applying metabolic materials also improve anti-senescence response by modifying gene expression in plants (Jayaraj et al., 2008).

Even though plants are naturally capable to deal with abiotic and biotic stresses, most of the crops are lost by various stresses across the world, reducing up to 50% of yields (Pociecha et al. 2008; Bray et al. 2000). Non-pathogenic fungi or bacteria can bring inherent resistance against several pathogenic bacteria, viruses, and fungi in plants (Wolski et al. 2006). To make the most of induced resistance, a detailed study is needed to know the activated biotic and abiotic signals and pathways for signal transduction. The outcome of interaction between host and pathogen seems to rely on cascades of recognition, defense reactions, and attacks at the microbe/plant interface (Pieterse and van Loon, 2006) and recent studies have shown certain parts of macroalgal extracts to induce those defense mechanisms (Lapshina et al. 2006).

Some of the effects are known on the impact of environmental stresses on arable crops and their quality as well as the outcome which seem to rely on complex environmental and physiological factors. During the early growth stage, microspore stage of development of pollen is subject to have abiotic stress in rice, wheat, sorghum, and barley (Dolferus et al., 2011). On the other hand, knowing the molecular and physiological processes which causes absorption of stress-induced pollen may control and maintain productivity in case of abiotic stress. Factors like drought, heat, and cold may lead to extreme changes in yield of grains and significant loss of yield in cereal crops. Researchers have observed some of the common trends like stimulation of antioxidants and protein or control lipid and starch, and worsening of feed palatability and value. These results can improve crop quality in stressful conditions by controlling limiting effects or positive stress effects (Wang & Frei, 2011).

Any benefit of macroalgal extract could help ensure global food security with healthy "monocotyledonous crops as maize, rice, and wheat crops are leading the global food crop production (Anon, 2011). Seaweed extracts have components that have large effects on Arabidopsis and same effects on the growth and metabolism of monocotyledons can be observed (Jannin et al., 2013). The major benefit of macroalgal extracts are root and shoot development and germination.

When it comes to produce grass and cereals, some studies have observed that there is a neutral impact of macroalgal extracts for growth inhibition (De Waele et al., 1988) and there is also solid evidence on the efficacy of those applications and a lot of studies have observed positive effects. Foliar applications of brown algae improved shoot weight of maize by up to 42% and root weight by up to 45%. In the same way, brown Sargassum spp. extract improved root weight by 57 percent and root weight by 50% (Matysiak et al., 2011).

Seeds soaked in macroalgal extracts also improved germination with drastic improvements and benefits in crop growth. This study highlighted the role of frequency and concentration of application of macroalgal extract as lower doses often showed best growth. On maize roots, the stimulatory effects seem to be more pronounced when applied at early growth stage and effects seem to be similar to the ones induced by auxins (Jeannin et al., 1991). E. maxima extracts also showed positive effects on both root and shoot dry weights of wheat (Nelson and van Staden, 1986).

The complex nature of macroalgal extracts has been observed on cereal growth. Beckett and van Staden (1990) showed the complex effects of macroalgal extracts on the growth of cereals. They tested the effect of those extracts on wheat with potassium deficiency. It is observed that there was no effect of E. maxima extracts on wheat getting proper supply of potassium. But K- stressed wheat has shown improvement in both grain weight and grain number. There was no positive impact on wheat with high potassium deficiency. The increased yield in wheat crops with moderate K-stress was above and over the growth with similar application of ashed macroalgal extract. The most common cause of effects of macroalgal biostimulants was most likely the cytokinin activity.

Abiotic stresses like high salinity, drought, and extreme temperatures are huge threats to cereal production in the world as well as potential role of macroalgal biostimulants in reducing those effects have been observed in the past (Semenov and Shewry, 2011). There have been improvements in the frost tolerance and winder hardiness by applying A. nodosum extracts (Burchett et al., 1998). Some of the most ideal evidence showing the efficiency of macroalgal extracts has been observed from studies conducted on turfgrass with a lot of physiological effects.

In the 1960s, a lot of studies have observed the effects of organic materials on the growth of turfgrass. It is found that cytokinins, auxins, ethylene, gibberellins, and abscisic acid are possibly important to impact plant growth and they have effects which could not be related to typical plant nutrients (Goatley & Schmidt, 1990). It is concluded that stimulation of plant growth couldn’t be duplicated by similar application of nutrients and found that vitamins were the potential substances (Frankenerger and Arshad, 1995). The abiotic stresses consists of low heat, soil moisture, and drought were weakened by macroalgal treatments (Zhang et al., 2002).

In creeping, drought-stressed bent-grass, macroalgal extracts (applied with humic acid) improved root mass by around 68% (Zhang & Ervin, 2004).” In Turf studies, it is also observed that macroalgal extracts have played a vital role in controlling the impact of fungal pathogens and nematode in cereals and grasses (Fleming et al., 2006). Dollar spot disease was reduced significantly when bent-grass was cured with macroalgal extract as well as humic acid (Zhang et al., 2003). This way, increased levels of superoxide dismutase seemed to be the part of disease protection.

5. Discussion

Micro- and macro-algae have a lot of bioactive elements and some of them are available already in commercial products and are playing a vital role in eco-friendly fertilizers. There are several important topics and points are covered in this study related to applying algae for sustainable agriculture. Where possible, algae can be the source of nutrients to sustain traditional or indigenous agricultural practices, to testify the actual nutritional value of algae. Though both macro- and micro- algae have direct potential for fertilizing nutrients, indirect potential of biostimulant, and use of psychological responses through different pathways.

This study has explored adoption of microalgae and macroalgae as part of fertilization in order to improve fertility and health of soils in agriculture. The key here is to promote internal metabolism to protect crops from agents and stress leading to damage to the field, improve productivity, boost cultivated plants, and optimize yields. Another remarkable fact is the way microalgae is leveraged to improve soil protection and quality, along with maintaining organic matter of the soil.

Macroalgae has already been used for seaweed applications in farming because it is easy to prepare and harvest fertilizers. On the other hand, there are different benefits of microalgae for large-scale application and production as biofertilizers, partly due to their production from marine waters and it is also associated with several industrial applications. Nevertheless, producing microalgae for industrial applications or agriculture is affected by technical barriers and ample market value.

6. Conclusion

One thing that has been focused is position of microalgae to produce biostimulants, use of microalgae as biofertilizers, and its potential to reduce environmental stress. They contain inactive compounds or active biochemical compounds which affect plant growth. They also have other compounds like micronutrients, antioxidants, or nutrition supplements which are highly valuable to fertilize crops. Biostimulants are already in high demand in agriculture worldwide, providing alternative solutions or products to chemical fertilizers to maintain soil fertility and agricultural yield while controlling environmental degradation and soil degradation. The benefits of microalgae and algae have already been defined, even though the feasibility to produce affordable formulations and large-scale production need a lot of attention. New initiatives should have applications to improve the cost-benefit ratios and address production approaches.

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