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# Seaweed Extract for Sustainable Rice Production- A Review

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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***Review Article***

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## ABSTRACT

Seaweed extract is a bio-simulant that obtain from seaweeds like Agar, and Alginate and many more species of seaweed. By application of seaweed extract in rice crop (*Oryza sativa* L.) can increase the growth, grain yield, biological yield and improves the nutrient content in grain. Seaweed extract application also reduces the biotic and abiotic stress on crops. This seaweed extract can be applied in many ways to crop plants like foliar spray, soil incorporation, etc., based on crop type. It can impact the cellular respiration of plants and incorporates many enzymes like NAA, auxins, vitamins, cytokinin's and many other growths promoting hormones in plants. This extract also has growth stimulating properties. It can increase nutrient absorption capacity by increasing root growth. Most of the marine algae are rich in auxins that increase root growth. The application of seaweed extract in soil can improve the physical, chemical, and biological properties of the soil. It can improve Arbuscular mycorrhiza by providing potassium to plant. Application of seaweed extract to soil can improve the availability of nutrients like calcium, nitrogen, phosphorus, potassium, and magnesium. Moreover, foliar spray of seaweed extract in rice crop increases crop

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growth, yield, nutrient uptake, water uptake, increases photosynthesis, and stomatal conductance. So, seaweed extract incorporation in rice cultivation could be a better approach to gain long-term sustainable production.

*Keywords: Rice; seaweed extract; mineral content; physical properties; chemical properties; biological properties.*

## 1. INTRODUCTION

Worldwide, rice is an important crop for both social and economic purposes. Over half of the people in India and about one-third of the world's population eats rice (*Oryza sativa* L.*).*is the most significant staple food crop [1]. The common rice species, *Oryza sativa* L.*,* belongs to the Poaceae family can be grown almost anywhere, except for Antarctica, in a variety of agroclimatic conditions [2]. As, emerging nations are largely concentrated in the Asian region, accounting for almost 95% of both rice production and consumption. In terms of agricultural commodity production, rice crop ranked next to sugarcane and maize, in the order. India comes in second place in terms of both area and production among the major rice-producing countries in the world [3]. India produced 116.42 million tonnes in 44.5 m $ha^{-1}$ of the 782 million tonnes of rice produced worldwide from 167.1 million per hectares [1]. For poor people, especially those in low-income situations, rice provides a less expensive source of calories, fiber, and protein. Rice is praised for its high caloric and nutritional content. The wonderful food rice is a good source of carbohydrate and energy [4]. Nowadays, a greater application of chemical fertilizers is having a negative impact on agriculture, such increasing emissions of greenhouse gases, polluted groundwater, compaction, and degradation of the soil, all of these affect growth of plants and yield production. [5]. Thus, it is needful to develop long-term sustainable practices for optimum production of rice. Seaweed extract is one of the best alternative to reduce synthetic inputs and maintain yield and quality of outputs. Seaweed extract is well known for their ability to reduce abiotic stress and increase plant yield. Several macroalgae species can be extracted to produce complicated combinations of physiologically active substances, depending on the extraction technique used. Natural seaweed extract is typically applied to soil, sprayed on foliage, and soaked seeds. One popular way of fertilisation used in plant production is foliar spraying. One method to reduce pesticide use could be to use organic molecules like those found in seaweed. These organic substances are not poisonous or polluting like pesticides. By modulating molecular, physiological, and biochemical processes, seaweed extracts have been proven to support plant growth and reduce abiotic stressors. Besides of the necessary dietary components, seaweed also contains nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and chlorine, as well as macro- and micronutrients (iron, zinc, copper, molybdenum, manganese, and boron) [6]. It has been shown that seaweed sap improves nutrient absorption, which can support rice's growth, development, and increased yield. As an alternative, seaweed can be a good choice as it contains micro- and macronutrients, vitamins, amino acids, and growth regulators such as cytokinin, auxins, gibberellins, and abscisic acid that promote growth and yield [7]. In addition to other plant bio stimulants, seaweed extract is a new generation of natural organic fertilizer that enhances growth and production, contains highly effective nutrients, and increases many crops' resistance to biotic and abiotic stress [8].

## 2. BENEFITS OF SEAWEED EXTRACT

The fresh seaweed can be mix with soil. Farmers in coastal regions have empirically demonstrated the benefits of seaweed on agriculture since ancient times. Furthermore, a great deal of research has determined and measured the benefits of applying seaweed to crops and soil. One of the things that makes seaweed so remarkable in agriculture is its composition [9]. Agar, ulvans, alginates, and carrageenan are examples of phycocolloids, which are matrix polysaccharides that give seaweed its mechanical strength. Seaweed differs greatly from terrestrial plants in this regard because it has less cellulose. In addition, it contains reserve polysaccharides that are very stable and helpful as chelating agents, such as mannitol and laminarin. [10]. Additionally, seaweed has additional essential nutritional components, including macro- and micronutrients (iron, zinc, copper, molybdenum, manganese, and boron) as well as nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, and chlorine [6]

**Table 1. Mineral content of different seaweed**

| Seaweed species | Nitrogen (%) | Phosphorus (%) | Potassium (%) | Calcium (%) | References |
|---|---|---|---|---|---|
| *Ascophyllum nodosum* | 1.2 | 0.2 | 4.1 | 42.5 | [14] |
| *Corallina elongata* | 0.3 | 0.4 | 0.2 | | [15] |
| *Dasmeresita aculeata* | 1.5 | 0.3 | 3.4 | 27.7 | [16] |
| *Enteromorpha* spp. | 1.9 | 0.1 | 1.5 | 21.5 | [16] |
| *Fucus serratus* | 2.7 | 0.2 | 3.0 | 35.5 | [17] |
| *Gelidium* spp. | 2.2 | 0.2 | 2.4 | 28.5 | [16] |
| *Halidrys siliquosa* | 1.4 | 0.8 | 4.7 | 29.1 | [16] |
| *Laminaria hyperborea* | 2.3 | 0.2 | 8.1 | 26.8 | [17] |
| *Mastocarpus stellatus* | 3.8 | 0.2 | 2.1 | 33.2 | [16] |
| *Pelvetia canaliculata* | 1.2 | 0.1 | 2.5 | 32.2 | [16] |
| *Ulva* spp. | 0.7 | 0.1 | 0.4 | 5.8 | [18] |

The nutrient content of different seaweed extracts are shown in Table 1. Seaweed can provide nutrients for long time in the soil. Seaweed contain nitrogen like organic manure, potassium is high in concentration (particularly in brown algae) and phosphorous in low concentration [11]. Seaweed contains organic nutrients that need to be mineralized in order to be made available to plants. It has been found that bioactive chemicals from SWE function as elicitor agents, promoting plant growth and inducing stress reactions by activating metabolic and molecular processes. Under unfavourable environmental circumstances, seaweed extracts (SWEs) have been used as natural regulators to enhance crop development and productivity [60]. In addition to causing heat stress factor genes (HSFs) and other transcription factors (TFs), abiotic stress responses generally involve the generation of Reactive Oxygen Species (ROS), ionic imbalance, altered $Ca^{2+}$, $K^{+}$ signalling, stomatal behaviour, and increased leaf temperature. All of these factors limit plant growth and productivity. In commercial products, seaweed extracts are increasingly being used to improve tolerance by focusing on different stress pathways [12]**.** Seaweed extract can also benefit soil health by promoting microbial activity and improving soil structure. It acts as a natural bio stimulant, enhancing beneficial microbial populations in the rhizosphere which encourage the decomposition of organic matter, the cycling of nutrients, and the general fertility of the soil. Rice plants can easily absorb nutrients from healthy soil ecosystems, which increases the production of crops[13]. The response and benefits of seaweed extract are shown in Fig. 1 and Fig. 2.

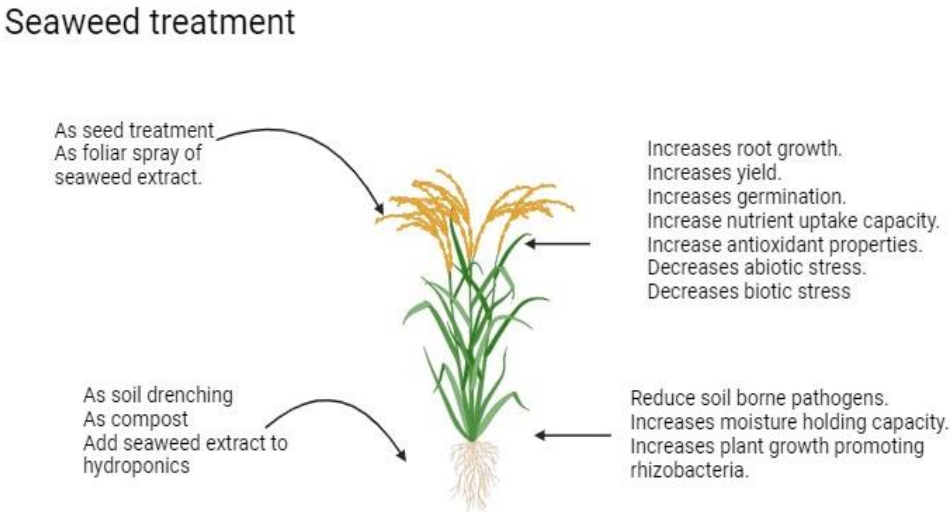


**Fig. 1. Diagrammatic representation of the physiological reactions in plants induced by treatments with seaweed extract [27]**

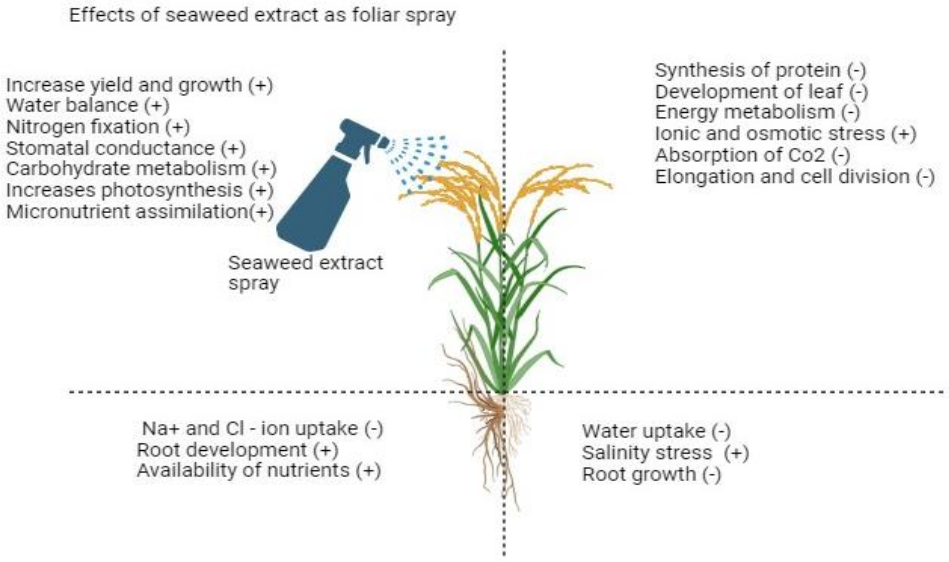


**Fig. 2. Diagrammatic representation of the effect of seaweed extract on crops [62]**

## 3. PREPARATION OF SEAWEED EXTRACT

For the production of liquid extracts, seaweed has to be broken up and dried. The active ingredients in many products are released by hydrolyzing the seaweed under pressure when potassium hydroxide or sodium carbonate is present. The brown alga Ecklonia maxima is used to make Kelpak, a product made in Cape Town, South Africa, by Kelp Products Ltd. Using a cell-burst method that minimizes the need for heat, chemicals, or dehydration. The seaweed is carefully crushed into smaller particles, and the smaller particle are pass under extreme pressure into a low-pressure chamber where they dissolved to produce the liquid extract [19]. Given that the extraction process (temperature, pressure, and solvents) influences the biological activity of constituents like cytokinins, it is obvious that these factors will alter the quality of the seaweed extract. To ensure a high-quality seaweed product, quality control measures (such as bioassays on plant hormones) must be implemented during the extraction process. Finally, preservatives like formaldehyde are added to the liquid extract to stop microbiological contamination. Occasionally, the concentrate is enhanced with additional substances including growth hormones, chelated trace elements (such Fe-EDTA), N, P, and K, as well as substances meant to enhance the active ingredients' solubility (wetting agents) and adherence to the leaf (sticking agents). However, using such enriched seaweed extracts in biological agriculture is prohibited by organic production regulations [20].

## 4. SEAWEED EXTRACT IN RICE GROWTH AND DEVELOPMENT

The cellular metabolism in treated plants is influenced by the chemical components of seaweed, including micro- and macro nutrients, vitamins, amino acids, auxins, cytokinin, and compounds that resemble abscisic acid (ABA). This leads to an increase in crop growth and production [21, 22]. Since each species of seaweed has growth-stimulating properties based on the bioactive chemicals found in the various seaweed extracts, different forms of seaweed exhibit varied physiological responses in encouraging plant development. Seaweed extract's active ingredient works even at very low concentrations [23]. Although many of the chemical components of seaweed extract and their mechanisms of action are still unknown, the evidence from earlier studies has demonstrated that the chemical components exhibit synergistic effect in increasing plants growth performance [24]. There are several methods for applying seaweed extract to plants, such as foliar spraying, treating seeds, adding the extract to the soil in liquid or solid form, soaking the soil, and adding the extract to a hydroponic solution [25]. Table 2. shows that the foliar application and soil application of seaweed extract that significantly increased the various growth

attributes such as plant height, numbers of tillers and dry weight. However, Pramanik *et al*,( 2020) [26] reported that @ 75% RDF + amaze- X granule (soil application) + biozyme granule (soil application) + biozyme liquid (foliar) increases the plant growth attributes compared to 100% RDF + biozyme granule (soil application) + biozyme liquid (foliar). It may be due to the presence of plant hormones and growth regulators in seaweed extract, such as auxin, gibberellins, cytokinin, and macro and micro elements.

**Table 2. Effect of seaweed extract on various growth attributes of rice**

| Sl. No. | Treatments | Plant height(cm) | Number of tillers/$m^2$ | Dry weight ($g/m^2$) | Reference |
|---|---|---|---|---|---|
| 1 | 100%RDF(Control) i.e. 60:30:30 kg/ha N: $P_2O_5$: $K_2O$ | 80.33 | - | 734.63 | [34] |
| | 75% RDF +Amaze-x granule @ 10 kg/ha + Proventus DS legacy spray @ 625 ml/ha | 93.33 | | 934.15 | |
| 2 | Water spray | 35.7 | 467.3 | 1122.0 | [35] |
| | 5% K-sap with 3 spray | 38.1 | 485.0 | 1869.0 | |
| | 7.5% K-sap with 3 spray | 43.2 | 535.0 | 1802.0 | |
| | 10% K-sap with 3 spray | 35.2 | 446.0 | 1301.3 | |
| 3 | Bio-stimulant (Sea grow powder) @1.5 g $l^{-1}$ | 77.02 | 10.58 | 51.68 | [36] |
| | Bio- stimulant (Triacontanol) @ 1 ml $l^{-1}$ | 72.79 | 9.21 | 47.30 | |
| | Bio- stimulant (Chitosan) @ 2.5 ml $l^{-1}$ | 76.94 | 10.47 | 51.57 | |
| | Bio- stimulant (Chitosan Irradiated) @ 2.5 ml $l^{-1}$ | 74.80 | 9.86 | 49.41 | |
| | Control (water spray) | 67.73 | 8.13 | 41.01 | |
| 4 | SEW gel soil application 12.5 kg/ha | 82.6 | - | 760.5 | [37] |
| | SWE gel soil application 25 kg/ha | 80.7 | - | 755.9 | |
| | Foliar spraying of SWE gel 0.5 per cent (v/v) at tillering + Panicle initiation stage. | 72.4 | - | 729.5 | |
| | Foliar spraying of SWE liquid 0.5per cent (v/v) at tillering + Panicle initiation stage | 75.2 | - | 736.3 | |
| | Control (fertilizer alone) | 71.3 | - | 712.3 | |
| 5 | 100% RDF + biozyme granule (soil application) + biozyme liquid (foliar) | 91.65 | - | 1012.3 | [38] |
| | 75% RDF + amaze- X granule (soil application) + biozyme granule (soil application) + biozyme liquid (foliar). | 93.71 | - | 1024.2 | |
| | 100% RDF + biozyme liquid (seed treatment) | 87.13 | - | 953.8 | |
| | 100% RDF + biozyme liquid (root dipping) | 85.00 | - | 908.7 | |
| 6 | LBS6@ 1ml/lts (1 spray at seedling transplantation + 2 spray (30 and 60 DAS) + RDF | 63.1 | 289 | | [7] |
| | LBS6 – S ml/lts (1spray at seedling transplantation + 2 spray (30 and 60 DAT) | 63.9 | 324 | | |
| | LBS10 ml/lts (1 spray at seedling transplantation +2 spray (30 and 60 DAT) | 63.5 | 293 | | |
| | Recommended Dose of Fertilizer (100 %) no seaweed extract. | 57.5 | 230 | | |

The root length of rice crops is significantly impacted by soil applications of seaweed extracts @ 12.5 and 25 kg $ha^{-1}$ and foliar spraying of liquid seaweed extracts at a rate of 0.5% (v/v) during the tillering and panicle initiation stage [28]. The effects of seaweed extracts on various onion cultivars were observed, and it was found that the application of seaweed extracts increased the length of the roots. This increase in root length can be attributed to the expression of an auxin-related gene induced by alginate oligosaccharides, which raises auxin concentrations and encourages the formation and elongation of roots [29]. Auxin concentration in Ecklonia maxima species extract was also observed to have changed noticeably in mung bean root. IAA and indole chemicals were also found in the seaweed extract using the gas chromatography/mass spectroscopy approach [30]. Products made from seaweed are stimulating root formation and growth. When extracts were administered to maize at an early growth stage, the energising effect on root growth was more pronounced, and the response resembled that of auxin [31]. Extracts from seaweed with the ability to promote the growth of lateral roots and increase the overall bulk of the root system [32,33]. The seaweed extracts, which include endogenous auxins and other compounds encouraging root growth [30].

## 5. EFFECT OF SEAWEED EXTRACT ON THE YIELD OF RICE CROP

It was recently found that seaweed extract is more beneficial to chemical fertilizer. Higher organic matter level influences the availability of minerals and moisture for roots in the top soil. [39]. Foliar spraying of sea weed extracts has significantly increased crop yields [40,41]. It contains a plethora of bioactive compounds, including phytohormones as well as nutrients, vitamins, and minerals [42]. These compounds act as natural bio stimulants, promoting plant growth and development. For rice crops, seaweed extract has been shown to stimulate root growth, increase shoot elongation, and enhance overall vegetative Vigor. By providing essential nutrients and growth-promoting substances, seaweed extract facilitates the optimal physiological functioning of rice plants, ultimately leading to increased biomass accumulation and higher grain yield [43].The notable impact of liquid and granular extracts from Sagarika seaweed on Vertisol rice crops. The treatments with 100% RDF + seaweed granules at 25 kg $ha^{-1}$ at 21 DAT and seaweed liquid at 0.25% at 42 DAT produced the maximum yield of rice (62.9 q $ha^{-1}$). In comparison to applying 75% RDF alone (52.58 q $ha^{-1}$), the combination of seaweed extracts with 75% RDF enhanced grain yield by 4.6, 7.9, 11.0, and 12.1% (highest) [44]. The rice yield increases when seaweed absorbs fertiliser, saving 20% of the input. The yield was raised by 58.42%, 62.51%, and 62.06%, respectively, over the control treatment with chemical fertiliser, chemical fertiliser with 5% seaweed extract, and lower dose of chemical fertiliser with 5% seaweed extract when applied [45]. Due to improvements in their chemical and physical characteristics pertaining to immunity, productivity, and stress resistance, the true algae max (*Ulva lactuca, Jania rubens*, and *Pterocladia capillace*) boost cucumber production [46]. The cane yield increased by 9.23, 9.01, and 3.33%, respectively, when seaweed extract was sprayed once at the seedling, early elongation, and early mature phases [47].The yield was greatly boosted by 18–20% by applying seaweed extract at a rate of 12.5 kg $ha^{-1}$ to the soil and by spraying seaweed extract liquid at a rate of 0.5% twice during the stages of panicle initiation and tillering [37]. Treatment @15% *Kappaphyccus* spp. or *Gracilaria* spp. extracts resulted in 18.0% increase in rice grain production compared to the control [37]. In the Northeastern region of India, applying foliar spray with either 10% concentration of *Kappaphyccus* spp. or *Gracilaria* spp. extracts in addition to 100% RDF proved to be a useful alternative for achieving excellent rice yield and grain quality [48]. Table 3. shows that the application of seaweed extract both in soil or foliar application significantly increased the yield attributing characteristics such as grain yield and straw yield etc. However, Ghodake *et al*., 2022.[36] Bio-stimulant (Sea grow powder) @1.5 g $l^{-1}$ increases the crop yield attributes as compared to Bio- stimulant (Triacontanol) @ 1 ml $l^{-1}$. It may be due to seaweed extract contains beneficial phytohormones such as betaines, cytokinins, and other minerals, vitamins, amino acids, and enzymes that maximize rice crop yields in terms of grain, straw, and biological yields of rice crop.

## 6. EFFECT OF SEAWEED EXTRACT IN NUTRIENT UPTAKE IN RICE

Seaweed extract contains natural chelating agents, such as alginates and mannitol, which can chelate essential micronutrients like iron, zinc, and manganese, making them more available for uptake by rice plants This leads to

improved nutrient absorption and utilization, resulting in healthier and more productive rice crops .It acts as a natural biostimulant, enhancing beneficial microbial populations in the rhizosphere, which contribute to nutrient cycling, organic matter decomposition, and overall soil fertility. Healthy soil ecosystems support better nutrient availability and uptake by rice plants, leading to improved crop productivity [49]. According to research done by Leena Banjare *et al*, 2022 [45]. Data on the uptake of nitrogen, phosphorus, and potassium by rice grains showed the treatments involving the application of 100% RDF (120:60:40 N, $P_2O_5$, and K2O) and alone applications of chemical fertiliser significantly increased the uptake of N (57.71 kg ha$^{-1}$), P (10.83 kg ha$^{-1}$), and K (116.23 kg ha$^{-1}$) compared to the 75% RDF [45]. Overall, the effect of seaweed extracts (liquid and granules) on rice (var.-Rajeshwari) nutrient uptake revealed that treatment-wise differences in the nutrient contents of rice grains and straws were found to be non-significant, while the fertility levels and the application of seaweed extracts had a significant impact on the nutrients that rice grains and straws absorbed. The similar results of this experiment were reported by Krishna Kumar *et al*, in 2005 [50] and Senthivelu *et al*, 2007 [51]. Table 4. shows that the application of seaweed extract both in soil or foliar application significantly increase nutrient uptake in rice. However, Mote *et al*, 2022. [52] stated that Biostimulant (silife) foliar application @0.4% significantly increases the nutrient uptake in rice. This might be due to the presence of several bioactive substances that are important for plants growth and vigour, and they also can improve nutrient uptake from soil.

**Table 3. Effect of seaweed extract on various yield attributes of rice**

| Sl. No. | Treatments | 1000 grain weight (g) | Grain yield (t/ha) | Straw yield (t/ha) | Reference |
|---|---|---|---|---|---|
| **1** | 100% RDF + biozyme granule (soil application) + biozyme liquid (foliar) | 22.35 | 4.641 | 5.969 | [38] |
| | 75% RDF + amaze- X granule (soil application) + biozyme granule (soil application) + biozyme liquid (foliar). | 22.77 | 4.885 | 6.068 | |
| | 100% RDF + biozyme liquid (seed treatment) | 22.54 | 4.354 | 5.703 | |
| | 100% RDF + biozyme liquid (root dipping) | 22.47 | 4.188 | 5.542 | |
| **2** | 100%RDF(Control) i.e. 60:30:30 kg/ha N: $P_2O_5$: $K_2O$ | 20.53 | 3.39 | 5.17 | [34] |
| | 75% RDF +Amaze-x granule @ 10 kg/ha + Proventus DS legacy spray @ 625 ml/ha | 21.86 | 3.90 | 5.94 | |
| **3** | Water spray | 21.7 | 3.4 | 7.9 | [35] |
| | 5% K-sap (Kappaphycus alvarezii) with 3 sprays | 22.3 | 3.8 | 8.4 | |
| | 7.5% K-sap (Kappaphycus alvarezii) with 3 sprays | 27.7 | 4.3 | 10.2 | |
| | 10% K-sap (Kappaphycus alvarezii) with 3 sprays | 21.1 | 3.5 | 7.8 | |
| **4** | SEW gel soil application 12.5 kg/ha | | - | - | [37] |
| | SWE gel soil application 25 kg/ha | 14.6 | - | - | |
| | Foliar spraying of SWE gel 0.5 per cent (v/v) at tillering + Panicle initiation stage. | 14.6 | - | - | |
| | Foliar spraying of SWE liquid 0.5per cent (v/v) at tillering + Panicle initiation stage | 14.6 | - | - | |
| | Control (fertilizer alone) | 14.5 | - | - | |
| **5** | Bio-stimulant (Sea grow powder) @1.5 g l$^{-1}$ | 29.30 | 5.070 | 6.213 | [36] |
| | Bio- stimulant (Triacontanol) @ 1 ml l$^{-1}$ | 29.52 | 4.321 | 5.491 | |
| | Bio- stimulant (Chitosan) @ 2.5 ml l$^{-1}$ | 29.73 | 5.035 | 6.183 | |
| | Bio- stimulant (Chitosan Irradiated) @ 2.5 ml l$^{-1}$ | 29.57 | 4.682 | 5.830 | |
| | Control (water spray) | 29.34 | 3.810 | 4.974 | |

**Table 4. Effect of seaweed extract in nutrient uptake in rice**

| Sl. No. | Treatments | Total N uptake | Total P uptake | Total K uptake | References |
|---|---|---|---|---|---|
| 1 | Control | 29.95 | 5.59 | 54.32 | [45] |
| | 75% RDF+Spray of seaweed liquid (0.25%) at 21 DAT. | 55.68 | 10.50 | 101.92 | |
| | 100% RDF+Spray of seaweed liquid (0.25%) at 21 DAT. | 58.97 | 10.88 | 112.29 | |
| | 75% RDF+ soil application of seaweed granule (25kg/ha) at 21 DAT+Spray of seaweed liquid (0.25%) at 42 DAT. | 59.93 | 10.98 | 114.5 | |
| | 100 % RDF+ soil application of seaweed granule (25kg/ha) at 21 DAT+ Spray of seaweed liquid (0.25%) at 42 DAT | 61.29 | 11.59 | 116.23 | |
| 2 | 100% RDF (Control) | 65.86 | 6.572 | 153.6 | [38] |
| | 100% RDF + biozyme granule (soil appli.)+ biozyme liquid (foliar) | 84.74 | 10.493 | 178.2 | |
| | 75% RDF + biozyme granule (soil appli.)+ biozyme liquid (foliar | 80.15 | 12.062 | 174.8 | |
| | 75% RDF+ amaze-x granule(soil appl.)+ biozyme granule (soil appl)+biozyme liquid (foliar) | 89.00 | 11.769 | 185.4 | |
| 3 | 100%RDF(Control) i.e. 60:30:30 kg/ha N: P2O5: K2O. | 70.82 | 7.06 | 163.12 | [34] |
| | 100% RDF +Amaze-x granule @ 10 kg/ha | 85.76 | 10.55 | 176.65 | |
| | 75% RDF +Amaze-x granule @ 10 kg/ha | 78.27 | 8.43 | 172.12 | |
| | 75% RDF + Biozyme granule @ 15 kg/ha + Proventus DS legacy spray @ 625 ml/ha | 88.23 | 12.52 | 185.13 | |
| | T7 -75% RDF +Amaze-x granule @ 10 kg/ha + Proventus DS legacy spray @ 625 ml/ha | 91.45 | 11.49 | 190.74 | |
| 4 | Biostimulant (vermiwash) foliar appl. @ 10% | 94.96 | 26.477 | 80.53 | [52] |
| | Biostimulant (silife) foliar appli. @0.2% | 81.16 | 21.949 | 70.62 | |
| | Biostimulant (silife) foliar appli. @0.4% | 98.45 | 28.006 | 82.92 | |
| | Biostimulant (humic acid) foliar appli. @ 1% | 95.52 | 26.477 | 80.53 | |
| | Control (no foliar application) | 62.69 | 16.663 | 52.42 | |

## 7. EFFECT OF SEAWEED EXTRACT ON SOIL MICROBIAL ACTIVITY

After the treatment of seaweed extract to the soil the bacterial increases in the soil [53]. Applying seaweed extracts and organic matter together has been demonstrated to enhance the number of fungal families in soils [54]. By applying seaweeds and seaweed extracts, soil aggregating agents and beneficial soil bacteria were stimulated to proliferate and modify the quality of the soil, allowing crops to flourish sustainably. The hyphal growth of arbuscular mycorrhiza (AM) fungi was shown to be significantly increased in vitro by the organic fractions (25% MeOH eluates) of red and green algae. Arbuscular mycorrhiza boosting compounds are found in red and green algae, and they aid in the mycorrhizal growth of higher plants. Extracts from marine brown seaweed, specifically *Laminaria japonica Areschoug* and *Undaria pinnatifida* (Harvey) Suringar, have the

potential to boost the growth of AM fungus [55]. Alginate oligosaccharides derived from brown algae may be the cause of the increased arbuscular mycorrhizal (AM) fungal activity, as seen by the elongation and stimulation of hyphal growth [55].

## 8. SEAWEED EXTRACTS' IMPACT ON THE PROPERTIES OF SOIL

Before planting or while a crop is standing, applying seaweed extract enhances the chemical characteristics of the soil. As a manure, seaweed extract offers vital nutrients that promote crop growth. The foliar application of seaweed extract and the addition of coastal sediment improved the peat soil's chemical properties, such as pH and K, Ca, Mg, and Na availability. When *Sargassum horneri* seaweed extract breaks down, phosphorus, ammonium, nitrate, and total nitrogen are released. Additionally, build an aggregate with richer nutrients, enhance the soil's structure, and finally increase the activity of soil microorganisms by chelating with the key cations of $Na^{+}$, $Ca^{2+}$, $Mg^{2+}$ and $K^{+}$. As a result, adding seaweed extract to soil could be a useful tactic to raise its nitrogen, phosphorous and potassium levels [56]. The application of seaweed extract to the soil at a rate of 25 kg $ha^{-1}$ was found to significantly enhance the availability of micronutrients and nutrients such as nitrogen, phosphorous, potassium, calcium, magnesium, and sulphur. [37]. Brown algae *Durvillaea potatorum* and *Ascophyllum nodosum* raise the amount of nitrogen that is accessible in soil [57]. When seaweed was added in comparison to organic fertiliser, soil electrical conductivity, potassium ($K^{+}$), sulphate ($SO_4^{-2}$) and active carbon (C) increased, while possibly mineralizable N and pH declined, with the effects changing with time [58].

The soil reaction, such as pH, and the salt content , electrical conductivity, were not significantly affected by the amounts of fertilizer and seaweed extracts applied. The amount of available nitrogen remaining in the soil after rice was harvested was not greatly impacted by the amount of fertilizer used or the seaweed extracts . Residual available phosphorus in the soil after harvesting of rice was significantly influenced by fertilizer levels and seaweed extracts. The application of 100% RDF+ seaweed granule at 21 DAT + seaweed liquid at 42 DAT resulted in the largest residual accessible phosphorus (27.90 kg/ha), whereas the control group had the lowest available phosphorus (21.82 kg/ha P). Pramanik *et al*, 2020 [26] stated that the application of 100% RDF+ seaweed granule at 21 DAT + seaweed liquid at 42 DAT resulted in the largest residual accessible phosphorus (27.90 kg/ha), whereas the control group had the lowest available phosphorus (21.82 kg/ha P).

Using seaweeds and their extracts improved the soil's composition by promoting the growth of beneficial soil microorganisms and the production of soil aggregating agents, which in return promoted the sustainable development of crops. The organic fractions (25% MeOH eluates) of red and green algae were found to considerably enhance the hyphal development of arbuscular mycorrhiza (AM) fungi in vitro. The findings also demonstrated that, when compared to the control treatment, the roots of passion fruit (Passiflora edulis Sims.)*ITALIC* and papaya (Carica papaya Linn.) *ITALIC* showed an increase in mycorrhizal count when 25% MeOH eluates of red and green algal extracts were applied. [58]. Arbuscular mycorrhiza boosting compounds are found in red and green algae, and they aid in the mycorrhizal growth of higher plants. Extracts from marine brown seaweed, specifically *Laminaria japonica Areschoug* and *Undaria pinnatifida* (Harvey) Suringar, have the potential to boost the growth of AM fungus [59]. Alginate oligosaccharides derived from brown algae may be the cause of the increased arbuscular mycorrhizal (AM) fungal activity, as seen by the elongation and stimulation of hyphal growth. The growth of arbuscular mycorrhiza fungi on trifoliate orange seedlings, *Poncirus trifoliate* (Linn.) Raf., was enhanced by methanol extracts derived from brown algae [60]. When liquid fertiliser containing tangle (*L. japonica*) extracts was applied to a citrus orchard sprinkling system, indigenous AM fungi intended a 27% expansion in root colony and spore number was increased 21% above the control [61].

## 9. IMPACT OF APPLICATION OF SEAWEED EXTRACT ON BIOTIC AND ABIOTIC STRESS OF CROP

Seaweed extracts help plants withstand unfavourable environmental factors like salt, drought, and cold. By increasing chlorophyll content, application of A. nodosum extracts protected Arabidopsis plants against cold stress, may be as a result of reducing the genes responsible for breaking down chlorophyll (AtCLH1 and AtCLH2). Furthermore, important regulators of cold stress tolerance were found to be the transcription factor DREB1A and the

COR78/RD29A genes, which encode chloroplast stromal protein cryoprotection. [63]. Proline, soluble sugar, and unsaturated fatty acid content increases were also linked to improved tolerance to cold stress. Plants treated with seaweed extract during a drought maintained a higher relative water content, enhanced stomatal conductance, reduced transpiration rate, and better water use efficiency [64]. Administering Ascophyllum nodosum seaweed extract sprays (5 and 7 $mL \cdot L^{-1}$ at 6-day intervals) to *Paspalum vaginatum Salam* under extended irrigation intervals (2 and 6 days) and salty growth conditions (1 and 49.7 $dS\ m^{-1}$) for a period of six weeks. According to the findings, during lengthy watering intervals and saline shock circumstances, treated plants' turf quality, leaf photochemical efficiency, root length and dry weight, total non-structural carbohydrates, potassium, calcium, and proline all rose with the use of seaweed extracts [65]. By lowering stomatal closure and raising gas exchange, the seaweed extract may boost photosynthetic rates and promote better development in drought-prone areas [66]. The bioactive elements in the seaweed extract improve plant performance when exposed to abiotic stressors. The increased freezing tolerance of grapes treated with a formulation of *Ascophyllum nodosum* extract may have resulted from a reduction in the osmotic potential of the leaves. Plant defence mechanisms against pests and pathogens were induced by seaweed extracts. The seaweed products improve the rhizosphere microbial community in soi and the plant defence mechanisms for long-term plant health [67-70].

## 10. CONCLUSION

Seaweed extract is the finest bio-stimulant which serve as a good source of essential plant nutrients and promote crop development and production under adverse environmental conditions. Seaweed and its derivatives can be used as a substitute of inorganic fertilizers which can effectively improve rice plant growth, yield, and quality in a viable choice. It improves soil physical and chemical properties and improves biological properties of soil and increases nutrient uptake to the plants. However, it can be concluded that seaweed extracts could be a greater alternative source of nutrients which can leads better rice production in long-term sustainable manner.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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