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UNVEILING THE OCEAN'S SECRET: HARNESSING SEAWEED AS A POWERFUL BIOSTIMULANT IN AGRICULTURE

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The shift towards using seaweed-based biostimulants in modern agriculture is driven by the need for more sustainable and efficient farming practices. As conventional agricultural methods face challenges such as soil degradation, environmental impact, and regulatory constraints, biostimulants offer a promising alternative. Seaweeds, abundant in oceans, contain a rich blend of natural growth hormones, amino acids, and minerals that enhance plant growth, nutrient absorption, and stress tolerance. While their agricultural potential has been recognized since ancient times, the modern push for organic food production has sparked a renewed interest in using seaweed-based biostimulants in agriculture.

Over the past five decades, the agroindustry has achieved significant milestones by capitalizing on the chemical revolution, which gave rise to mineral fertilizers. This fruitful collaboration between agronomical and chemical sciences played a pivotal role in the remarkable increase in crop yields, effectively addressing the growing nutritional demands brought on by the post-World War II population surge. Today, in the context where environmental issues due to climate change are pervasive, modern agriculture is facing an array of formidable challenges with profound implications for global food production, sustainability and food security. In this quest for sustainable agriculture, we often find ourselves looking to the earth's fertile soils and the myriad of techniques to enhance crop production to meet nutritional demand of burgeoning world’s population. However, an often-overlooked treasure lies beneath the surface of our oceans i.e., seaweed.

Marine algal seaweed species are often seen as an overlooked natural resource. For centuries, they have been used as a source of food, raw materials for industry, and in medicinal applications. Today, as modern agriculture grapples with the need to reduce synthetic chemical inputs and minimize its environmental footprint, seaweed is emerging as a

powerful biostimulant with the potential to revolutionize how we grow our crops. Biostimulants belong to the category of natural preparations that have the capacity to enhance overall plant health, vitality, and growth, while simultaneously provide them protection against environmental stress. Recently, biostimulants are recognized as a new category of products in "Fertilizer Amendment Order 2021", on February 23, 2021. These products are distinct from fertilizers and pesticides. These refers to the substances or microorganism or a combination of both whose primary is to stimulate physiological processes, to enhance nutrient uptake, growth, yield, nutritional efficiency, crop quality and provide stress tolerance when applied to plants, seeds or rhizosphere, regardless of its nutrient content. Harnessing seaweed as a biostimulant in agriculture is not only a story of innovation but also firmly grounded to the principles of sustainable agriculture. Seaweed extract based biostimulants contain many bioactive substances viz. polysaccharides, minerals, vitamins, amino acids, antioxidants, pigments and hormones (Craigie, 2011). Bioactive substances found in seaweeds work together to enhance plant growth by optimizing both physiological and biochemical processes within the plants. Numerous research investigations have unveiled the multifaceted advantages of seaweed-based biostimulants on plants. These natural extracts have been shown to facilitate early seed germination and robust seedling establishment, improved crop performance and thereby yields, increased resistance to environmental stress, and extended post-harvest shelf life of perishable agricultural products (Norrie and Keathley, 2006). Besides eliciting a growth promoting effect on plants, seaweed biostimulants also improve soil health thereby offers a sustainable alternative to synthetic fertilizers (Blunden, 1991).

Nurturing Plant and Soil Health: Positive Impact on Crops

Derived from various species of marine algae, seaweed based biostimulants offer a myriad of benefits for plants and the surrounding environment.

1. Enhanced nutrient uptake and crop yields

Seaweed-based biostimulants enhance plant nutrient uptake, and this improvement depends on how they are applied. These biostimulants can be administered either directly to the soil or sprayed onto the plants as a foliar application. When introduced into the soil, biostimulants encourage root growth and development through the presence of root growth-promoting hormones, ultimately enhancing the plant's ability to absorb nutrients more efficiently. Conversely, when applied as a foliar spray, certain compounds within the

seaweed extract are directly absorbed through the plant's leaves, contributing to nutrient uptake and overall plant health. Seaweed extract @ 5% applied via a combination of corm dipping and foliar spray produced outstanding results in the development of saffron. This strategy resulted in a significant rise in corm production as well as noticeable improvement in growth parameters (Chaudhary *et al*., 2023). Deepana *et al*., (2021) found that applying seaweed extract @ 12.5 $kgha^{-1}$ to the soil, along with a 0.5% foliar spray during tillering and panicle initiation, significantly improved yield attributesvis-a-visrice productivity.

2. Imparted resistance to environmental stresses

Seaweed biostimulants contain natural growth regulators like cytokinins and auxins that help plants to cope with adverse environmental stress. Whether it's abiotic or biotic stress, plants treated with seaweed biostimulants tend to exhibit greater resilience and adaptability. Biostimulants obtained from the biomass of red seaweeds like *Kappaphycus* and *Eucheuma* species were found to provide protection against fungicide induced stress when applied to rice plants (Banakar *et al*., 2022).In a study conducted by Radwan *et al*., in 2023, seed priming of promising fodder and oil crop, *Citrullus lanatus*, in Egypt using extracts derived from the seaweed *Ulva lactuca* was observed to induce salt stress. This stress triggered the production of bioactive compounds, including betaines and phenolic compounds, which, in turn, facilitated successful seed germination, enhanced plant growth, and increased salt resistance.

3. Improved soil health

Biostimulants have a pioneering role in improving soil health by supporting a healthy environment beneath our feet. Through the stimulation of beneficial microorganisms, seaweed and their extracts actively participate in the processes of nutrient cycling and the decomposition of organic matter in the soil. In turn, the proliferation of microbial activity enhances the porosity and structure of the soil thereby improving water retention and aeration. Seaweed biostimulants also plays a crucial role in mitigating soil degradation and environmental pollution by reducing the need of synthetic fertilizers. Furthermore, the gelling and chelating abilities of polysaccharides found in seaweed extracts, alongside other active organic compounds, contribute to the enhancement of soil structure vis-à-vis soil health. Consequently, they contribute significantly to cultivating a more sustainable and ecologically balanced soil ecosystem. The application of seaweed as an organic amendment, coupled with the incorporation of pruning waste in grapevine fields, has proven to be a valuable strategy

for enhancing soil fertility. This approach has demonstrated its superiority over inorganic fertilization by significantly increasing soil organic matter content, thereby improving the overall soil fertility status (L. de Sosa *et al*., 2023). Ngoroyemoto *et al*., 2020 found that the synergistic application of PGPR (Plant Growth-Promoting Rhizobacteria) and seaweed extracts enhanced the yield and mineral content of leafy vegetables like *Amaranthus hybridus* by encouraging the growth of beneficial microorganisms and increasing the bioavailability of essential nutrients.

Conclusions and Future Perspectives

In conclusion, seaweed's role as a biostimulant in modern agriculture is a crucial advancement in addressing global challenges related to food production, sustainability, and food security. Seaweed-based biostimulants have the potential to revolutionize agriculture by improving crop growth, yield, and resilience while also reducing reliance on synthetic inputs. As we confront environmental issues and the need for sustainable practices, harnessing the bioactive properties of seaweed offers a promising pathway towards a resilient food production system. This natural resource beneath the oceans represents an innovative and eco-friendly solution to meet the growing demands of a burgeoning global population. However, the mechanisms underlying the physiological responses triggered by seaweed extracts in plants are largely unknown. With the completion or near-completion of the genomes of many plant species, there is a possibility to look into the impact of seaweed extracts on the entire plant genome. This genomic approach holds the potential to unveil the precise mechanisms by which seaweed induces growth responses and alleviates stress in plants, offering valuable insights for optimizing their application in agriculture. Moreover, research and innovation in this field will continue to expand, unlocking new applications and formulations that maximize the benefits of seaweed based biostimulants for improved crop performance and overall agricultural sustainability.

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