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Seaweed-derived biostimulants for sustainable crop production: A review

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ABSTRACT

The increasing concerns over climate changes and environmental impacts of synthetic agrochemicals have led to a growing interest in natural alternatives such as seaweed-based biostimulants. These extracts contain diverse bioactive compounds, including phytohormones, polysaccharides, proteins, polyphenols, and vitamins, which contribute to enhanced plant growth, stress tolerance, and soil health. Seaweed biostimulants have demonstrated their ability to improve germination, growth, and yield under both optimal and stressful conditions. Additionally, seaweed-derived compounds influence microbial communities, promoting beneficial interactions that enhance soil structure and fertility. Their different mode of applications further expands their utility in modern agriculture. Despite their numerous advantages, challenges remain regarding cultivation, large-scale production, and regulatory frameworks. Further research is needed to optimize extraction methods, elucidate mechanisms of action, and explore economic feasibility. This systematic review brings focus to the potential of seaweed-based biostimulants as sustainable agricultural inputs, discussing their chemical composition, mechanisms of action, techniques of extraction, application strategies, challenges and future perspectives for improving crop productivity and resilience.

1. Introduction

The increasing demand for sustainable agricultural practices to address global food security and environmental degradation has intensified interest in natural, eco-friendly alternatives to synthetic agrochemicals (Nanda et al., 2021). Among these alternatives, seaweed-based biostimulants have emerged as promising tools for enhancing crop productivity, improving stress resilience, and reducing reliance on chemical fertilizers (Deolu-Ajayi et al., 2022; Yong et al., 2024). Derived from marine macroalgae, these biostimulants contain a diverse array of bioactive compounds, including polysaccharides, phenolics, proteins, phytohormones, and minerals (Leandro et al., 2019; Ali et al., 2021; Matos et al., 2021; El-Beltagi et al., 2022). Their application has been shown to enhance germination, growth, biomass, crop yield, and resilience across a wide range of plant species, making them valuable tools in environmentally friendly farming systems (Ahmed et al., 2022; Ali et al., 2022a; Munisamy et al., 2023; Radwan et al., 2023; Sabatino et al., 2023). These benefits are primarily due to specific mechanisms through which seaweed extracts influence plant physiology and metabolism (Sujeeth et al., 2022). Among these mechanisms are growth regulation, boosting nutrient uptake, increasing resistance to biotic and abiotic stress, promoting the activity of beneficial soil microbes, and enhancing soil structure (Nanda et al., 2021; Asif et al., 2023; Trivedi et al., 2023).

The efficacy of seaweed biostimulants is intrinsically linked to their biochemical composition, which varies significantly depending on species, geographical origin, and extraction methods (Ertani et al., 2018; Ali et al., 2021). To better utilize these resources, numerous extraction methods are employed and continually optimized, including traditional and modern techniques (Quitério et al., 2022; Bitwell et al., 2023). Moreover, the modes of application, such as soil incorporation or foliar spraying, constitute a critical factor in optimizing the effectiveness of seaweed-based biostimulants, as they enable the targeted activation of specific physiological and biochemical mechanisms within the plant

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