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Biostimulants and Their Role in Alleviating Abiotic Stress in Crops

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Climate change has been linked to a warming trend and increased climatic variability, which increases extreme weather events (Lavell et al., 2012; Pradeep et al., 2022). Agricultural productivity is heavily influenced by weather conditions and extreme weather events can have detrimental effects on crop yields. Abiotic stresses such as drought, cold, salinity and high temperature significantly reduced food crop production globally. Traditional plant breeding methods aimed at enhancing tolerance to these stresses have had limited success, largely due to the polygenic nature of stress tolerance (Mantri et al., 2012). An important consideration is the combined effect of different stresses on crops. In the field, crops are often exposed to multiple abiotic stresses simultaneously (Bulgari et al., 2019). To enhance the resilience of agricultural systems and safeguard both crop yield and quality, adaptation and mitigation strategies are crucial. A multi-level approach is necessary to manage abiotic stresses, including agronomic practices and the development of more stress-tolerant crop varieties through breeding. Breeding new cultivars with higher tolerance to abiotic stresses, whether through traditional methods, genetic engineering, or genome editing, seems to be a key solution for addressing the challenges posed by climate change and ensuring global food security. Additionally, other strategies, such as use of biostimulants, can helps in improving stress tolerance of existing crop varieties and mitigate the effects of climate change (Zuzunaga-Rosas et al., 2022).

Biostimulants have been proposed as agronomic tools to counteract abiotic stresses. Plant biostimulants refer to materials that contain substances or microorganisms whose function is to enhance natural processes which benefit nutrient uptake, improving nutrient efficiency, increasing tolerance to abiotic stresses, and enhancing crop quality, regardless of their nutrient content (Ricci et al., 2019). Biostimulants contain bioactive molecules that have a beneficial effect on plants and improve their ability to tolerate adverse environmental conditions, acting on primary or secondary metabolism (Bulgari et al., 2019).

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The main categories of biostimulants are:

- Humic substances
- Seaweed extracts
- Protein hydrolysates and other nitrogen containing compounds
- Microorganisms
- Chitosan
- Botanicals
- Nanoparticles
- Biostimulants derived from extracts of food waste or industrial waste streams, composts and compost extracts, manures, vermicompost, aquaculture residues and waste streams, and sewage treatments

Currently, there is a wide variety of biostimulant products, such as those based on mixtures of amino acids, seaweed and microalgae extracts, enzymes, humic substances, polysaccharides, phytohormones, and/or vitamins, sometimes supplemented with micro and/or macronutrients and microorganisms (e.g., fungi and bacteria) (Gil-Ortiz et al., 2023). These products are also used to help the crop during periods of high metabolic demand, such as rooting, sprouting, flowering, fruit set, and/or fruit formation (Escaich et al., 1991). Biostimulants have been used for several decades to strengthen crop plants against stress by promoting improved yield and crop quality under adverse environmental conditions (Paradikovic et al., 2011; Yakhin et al., 2017).

Antistress effects are reported in seaweed extracts and it is hypothesised that protective compounds like antioxidants and regulators of endogenous stress responsive genes are involved in inducing stress tolerance (Calvo et al., 2014). The interactions between plants and their beneficial fungi, especially endosphere and rhizosphere microbes, are regarded as promising strategies to stimulate plant development in adverse environments such as saline lands and heavy metal-contaminated lands (Ou et al., 2023). Plant growth promoting fungi (PGPF) could promote iron and phosphorus absorption in plants. Ou et al., 2023, reported that mixed suspensions of PGPF induced the production of catalase, soluble sugar and chlorophyll, which in turn enhanced the drought tolerance of mulberry and accelerated their growth

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recovery after drought. Protein hydrolysates and other nitrogen containing compounds also reported to enhance stress tolerance in plants. Chelating and complexing activities of specific amino acids and peptides are deemed to contribute nutrient availability and acquisition by roots. They also increase the iron and nitrogen metabolism, improves the water and nutrient use efficiency and thereby improve stress tolerance against various environmental conditions (Du Jardin, 2012; Halpern et al., 2015). Nanoparticles are another category of biostimulants which play a significant role in enhancing plant tolerance to abiotic stresses such as drought, salinity and heavy metals. They improve the physiological and biochemical processes in plants, facilitating better growth and resilience under adverse environmental conditions. Recent studies indicate that nanoparticles can enhance antioxidant activity and reduce oxidative stress in plants, ultimately leading to improved crop yield and quality (Khan et al., 2024).

The major challenges associated with biostimulants include production capacity, raw material sourcing, toxicity levels, optimal dosing and mode of action (Dragovoz et al., 2009). Furthermore, the potential toxicity of biostimulants on plants has received limited attention in research. These issues may be resolved through advancements in integrated approaches such as agronomics, metabolomics and phenomics, which can facilitate the discovery of mode of action of biostimulants and optimization of their dosing strategies (El-Sese et al., 2020).

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