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Protein hydrolysates as potent biostimulants: Reprogramming plant metabolism for enhanced growth and secondary metabolite production

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Abstract

Protein hydrolysates (PHs) have emerged as potent plant biostimulants capable of reprogramming plant metabolism to enhance growth, productivity, and stress resilience. Derived from animal, plant, and microbial protein sources through chemical, enzymatic, thermal, or microbial hydrolysis, PHs contain bioactive peptides and free amino acids that regulate nitrogen and carbon metabolism, hormone-like signaling pathways, reactive oxygen species (ROS) detoxification and epigenetic processes. Their ability to stimulate root development, shoot biomass accumulation, photosynthetic efficiency and the biosynthesis of secondary metabolites, including phenolics, flavonoids, carotenoids, glucosinolates and essential oils, highlights their potential to improve both crop yield and nutritional quality. Furthermore, PHs enhance plant tolerance to abiotic stresses such as salinity, drought and heavy metal toxicity by modulating physiological, biochemical and molecular responses. In line with the goals of sustainable agriculture, PHs reduce dependence on chemical fertilizers, improve nutrient use efficiency and are compatible with organic farming systems. Despite significant progress, challenges related to production standardization, molecular characterization and a comprehensive understanding of their mechanisms of action remain. Addressing these knowledge gaps will be essential for maximizing the agronomic potential and commercial adoption of PH-based biostimulants.

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