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Biotechnological Interventions for Enhancing Herbicide Resistance in Wheat

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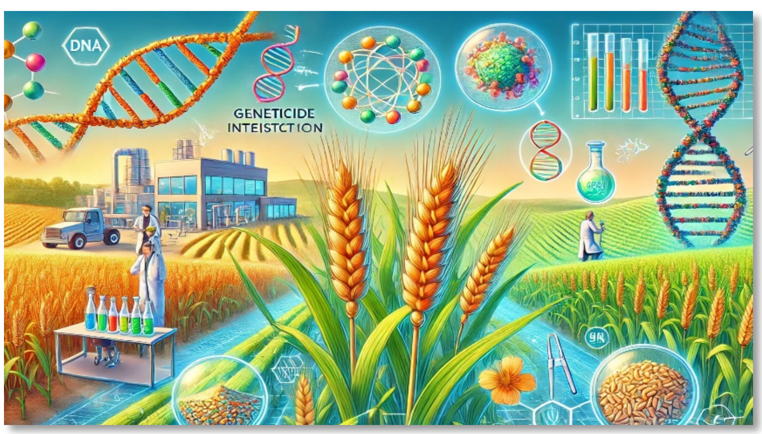
Wheat (*Triticum aestivum*) is one of the most important staple crops globally, providing a significant portion of calories and nutrients to the human population. However, weed infestation poses a major threat to wheat production, leading to substantial yield losses. Traditional methods of weed management, primarily relying on chemical herbicides, have raised concerns about environmental pollution, herbicide resistance, and food safety. In this context, biotechnological interventions offer promising solutions to enhance herbicide resistance in wheat. By leveraging techniques like genetic engineering, CRISPR-Cas9, and marker-assisted selection (MAS), researchers are developing herbicide-resistant wheat varieties that can withstand selective herbicides without compromising yield or environmental safety.



This article explores the latest biotechnological approaches to herbicide resistance in wheat, their effectiveness, and future prospects.

Biotechnological Approaches for Herbicide Resistance

The application of biotechnology in enhancing herbicide resistance in wheat involves several advanced techniques, each offering unique advantages. These approaches not only improve weed management efficiency but also aim to minimize the environmental footprint of wheat production.

1. Genetic Engineering and Transgenic Wheat

Genetic engineering has emerged as a powerful tool for developing herbicide-resistant crops. By incorporating herbicide-tolerant genes into the wheat genome, scientists can create transgenic varieties capable of surviving herbicide applications that kill surrounding weeds. For instance, the introduction of the EPSPS (5-enolpyruvylshikimate-3-phosphate synthase) gene confers resistance to glyphosate, a widely used herbicide. Similarly, the integration of the bar gene, which encodes phosphinothricin acetyltransferase, provides resistance to glufosinate herbicides. These transgenic wheat varieties enable broad-spectrum weed control with reduced herbicide application rates, thereby lowering chemical input costs for farmers.

2. CRISPR-Cas9: A Revolutionary Tool

CRISPR-Cas9 has revolutionized plant biotechnology by offering a precise and efficient method for genome editing. Unlike traditional transgenic methods, CRISPR enables the modification of native genes responsible for herbicide sensitivity without introducing foreign DNA, making the resulting wheat varieties more acceptable to regulatory bodies and consumers.For example, researchers have successfully utilized CRISPR to knock out the ALS (Acetolactate Synthase) gene, which is targeted by ALS-inhibiting herbicides. This modification prevents the herbicide from binding to the ALS enzyme, thereby conferring resistance. Such gene edits are inheritable and can be integrated into conventional breeding programs to rapidly disseminate herbicide-resistant traits. The potential of CRISPR extends beyond herbicide resistance, offering possibilities for enhancing abiotic stress tolerance and disease resistance in wheat, thereby contributing to sustainable agriculture.

3. Marker-Assisted Selection (MAS)

Marker-assisted selection (MAS) is a non-GMO approach that accelerates the development of herbicide-resistant wheat varieties by using molecular markers linked to resistance genes. MAS allows breeders to select plants carrying desirable traits without the need for transgenic modifications. For instance, markers linked to the cytochrome P450 gene family have been used to identify wheat varieties with natural resistance to ACCase-inhibiting herbicides. By combining multiple resistance genes, MAS facilitates the creation of wheat lines with broad-spectrum resistance to various herbicides. This approach not only reduces the risk of resistant weed populations but also complements transgenic methods in integrated weed management strategies.

Challenges and Limitations

The adoption of biotechnological approaches to enhance herbicide resistance in wheat faces several challenges:

1. **Regulatory Hurdles**: Strict regulations and lengthy approval processes for GM crops can delay the commercialization of herbicide-resistant wheat varieties.
2. **Public Perception**: Concerns about the safety and environmental impact of GM crops can limit their acceptance among consumers.
3. **Gene Flow Risks**: There is a potential risk of gene flow from herbicide-resistant wheat to wild relatives, leading to the emergence of superweeds.
4. **Economic Barriers**: High development costs and intellectual property issues can restrict the adoption of biotechnological interventions, especially among small-scale farmers.

Addressing these challenges requires transparent regulatory policies, public awareness campaigns, and affordable access to biotechnological innovations.

Conclusion

Biotechnological interventions hold significant promise for enhancing herbicide resistance in wheat, providing effective and sustainable alternatives to traditional weed management practices. Techniques such as genetic engineering, CRISPR-Cas9, and MAS have demonstrated their potential to reduce herbicide usage, improve crop productivity, and minimize environmental impact. However, overcoming challenges related to regulation, public perception, and cost is essential for the widespread adoption of these technologies. A holistic approach that integrates biotechnology with traditional agronomic practices can pave the way for a sustainable future in wheat production.

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