

CRISPR in Genetic Engineering: Enhancing Crop Resilience and Food Security Through Genome Editing

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Abstract:
Genetic engineering has ushered in a paradigm shift in biological sciences, enabling transformative innovations across medicine, agriculture, and synthetic biology. Among the array of genome-editing technologies, Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)-associated protein 9 (Cas9) has emerged as an unparalleled tool due to its remarkable precision, cost-effectiveness, and efficiency in targeted genomic modifications. This paper delves into the fundamental mechanisms underlying CRISPR-Cas9 technology, elucidating its molecular architecture, mechanisms of action, and functional versatility. Furthermore, we explore its transformative applications, ranging from the correction of hereditary disorders and enhancement of crop resilience (e.g., drought and pest resistance) to advancements in gene therapy, regenerative medicine, and xenotransplantation. Despite its immense potential, the deployment of CRISPR-based genome editing is fraught with ethical dilemmas, biosafety concerns, and regulatory intricacies. This study critically examines the moral and philosophical implications of germline modifications, the potential for unintended genomic alterations, and the broader societal ramifications of human genetic enhancement. Recent scientific advancements have sought to enhance CRISPR precision by mitigating off-target effects and expanding its applicability beyond Cas9 through alternative nucleases such as Cas12 and Cas13. This paper also highlights ongoing innovations—including prime editing, base editing, and epigenome editing (modulating gene expression without DNA cuts), along with CRISPR interference (CRISPRi) and activation (CRISPRa), which regulate gene expression—to further refine genetic interventions while minimizing unintended mutagenic consequences.

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