THE ROLE OF MOLECULAR BIOLOGY METHODS IN INCREASING PLANT YIELD AND STRESS TOLERANCE

Zubayddilayeva Adiba
Navoiy Innovatsiyalar Unversititi 1-kurs
Biologiya yónalish
usarovashsbbona@gmail.com

Abstract:*This article extensively explores the scientific foundations, technological advantages, and practical applications of molecular biology methods aimed at increasing plant yield and stress tolerance. In the context of climate change and global food security challenges, genetic engineering, genome editing, marker-assisted selection, and omics technologies are recognized as key tools for enhancing plant adaptability and productivity.*

Keywords: *Plant biotechnology, stress tolerance, genetic engineering, CRISPR/Cas, omics technologies, yield improvement*

INTRODUCTION

In recent decades, the rapid growth of the world population and climate change have negatively impacted agricultural productivity due to drought, soil salinization, extreme temperatures, diseases, and pests. Although traditional breeding methods are effective, they are time-consuming and have limited precision. Therefore, modern molecular biology-based technologies play a critical role in deeply analyzing plant genetic potential and targeted improvement. Molecular approaches allow the identification of stress-responsive genes, metabolic pathways, and signaling regulators, enabling rapid and precise modification of plant phenotypic traits.

MAIN DIRECTIONS OF MOLECULAR BIOLOGY METHODS

GENETIC ENGINEERING

Genetic engineering enables the introduction of external or modified genes into the plant genome to create desired traits. This method enhances disease resistance, drought tolerance, cold tolerance, and nutrient content. Key advantages include rapid results, precise targeted gene modifications, and reduction of multi-generational breeding processes. For example, Bt gene-introduced cotton varieties are resistant to many pests, reducing pesticide use, while HKT1 gene modifications improve salt tolerance in crops grown on saline soils.

GENOME EDITING (CRISPR/CAS)

CRISPR/Cas is a revolutionary technology in molecular biology that allows precise, rapid, and cost-effective genome modifications. It enables the deletion or activation of stress-responsive genes, optimization of transcription factor regulatory mechanisms, and modification of R-genes involved in plant immunity. New varieties developed using CRISPR/Cas include drought-tolerant wheat, salt-tolerant rice, and disease-resistant tomatoes.

MARKER-ASSISTED SELECTION

Marker-assisted selection (MAS) uses DNA markers to identify genetic traits associated with phenotypes. MAS allows breeders to identify desired genotypes early, accelerate the selection process, and improve varieties with high precision. MAS has led to disease-resistant wheat varieties and drought-tolerant maize lines.

OMICS TECHNOLOGIES

Omics technologies – genomics, transcriptomics, proteomics, and metabolomics – analyze processes occurring in plant cells. Genomics identifies stress-related genes, transcriptomics measures expression levels of stress-responsive genes, proteomics tracks protein changes, and metabolomics identifies metabolites and their pathways. These technologies help fully understand the molecular mechanisms of stress tolerance.

MOLECULAR APPROACHES TO ENHANCE STRESS TOLERANCE

ABIOTIC STRESSES

Abiotic stresses, such as drought, salinity, extreme temperatures, and insufficient light, are among the most critical factors for plants. Molecular approaches enhance osmotic balance genes during drought, improve sodium-ion pump activity under salinity, and stimulate antifreeze protein production for cold tolerance. Editing transcription factors like DREB, NAC, and WRKY enhances plant adaptability.

BIOTIC STRESSES

Biotic stresses include viruses, bacteria, fungi, and pests. Molecular biology strengthens R-genes involved in plant immunity, activates phytoalexin synthesis, and increases pathogen-resistant proteins. For example, CRISPR-mediated PMR6 gene knockout in tomatoes enhances resistance to fungal diseases.

RESULTS AND DISCUSSION

Molecular biology methods play a crucial role in making agriculture more efficient, environmentally sustainable, and competitive. These technologies increase yield, enable efficient resource use, and improve plant survival under stress conditions. However, challenges related to ethics, biosafety, the release of transgenic organisms, and consumer acceptance also require attention.

CONCLUSION

Molecular biology methods are among the most modern and effective approaches for improving plant stress tolerance and yield. Genome editing, marker-assisted selection, and omics technologies provide new opportunities for science. In the future, varieties developed using these methods will contribute to global food security.

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