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"Towards multi-functional agro-ecosystems
promoting climate resilient futures"

Harnessing molecular breeding to develop climate-smart crops for future agro-ecosystems

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Abstract

Global food security is severely threatened by climate change and unpredictability, which destabilise agro-ecosystems through increased abiotic and biotic pressures, altered rainfall patterns, and rising temperatures. These modifications disturb the ecological balance and functional diversity of agricultural systems in addition to lowering crop output. The shift from single output farming methods to multi-functional agro-ecosystems that incorporate productivity, resilience, sustainability, and ecosystem services is becoming increasingly necessary in this setting.

The use of molecular breeding to create climate smart crops that support resilient and adaptable agro-ecosystems is examined in this paper. It examines current developments in genome editing, quantitative trait locus (QTL) mapping, genomic selection, and marker-assisted selection, emphasising their contributions to hastening the creation of crop varieties suited to intricate the changing climate circumstances. These methods make it possible to find and use genes linked to pest and disease resistance, drought and heat tolerance, salinity resilience, yield stability, and improved reactivity to increased carbon dioxide (CO_2).

To improve breeding efficiency and ecological flexibility, a special focus is on combining high-throughput phenotyping, climate informed breeding targets, and multi-environment genetic data. Case studies show how molecular technologies can assist crops that perform consistently across varied and stress-prone conditions, such as the production of rice varieties combining submergence tolerance (SUB1) with yield stability and genomic selection for drought and heat tolerant maize. In order to improve photosynthetic efficiency under future climate scenarios, emerging targets for CO_2 responsiveness, such as allelic variation in Rubisco activase and sedoheptulose^{-1},7-bisphosphatase, are also highlighted. Beyond technological advancements, this paper examines socioeconomic, legal, and ethical factors that affect adoption, especially in poor nations, in order to place molecular breeding into the larger agro-ecosystem framework. It highlights how crucial it is to match breeding practices with regional farming systems, preserve biodiversity, and use resources sustainably. This review has forward looking roadmap for developing crop varieties that not only withstand climate stress but also improve the functionality and resilience of agro-ecosystems by connecting molecular breeding with climate foresight, ecosystem based approaches, and enabling policy environments.

Keywords: Climate resilient crops, food security, genome editing, genomic selection, molecular breeding, sustainable agriculture

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