

CRISPR meets tissue culture: The future of precision plant breeding.

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Introduction

As global agriculture faces mounting pressure to produce more food with fewer resources, the convergence of two transformative technologies CRISPR/Cas genome editing and plant tissue culture is revolutionizing precision plant breeding. CRISPR enables targeted genetic modifications with unprecedented accuracy, while tissue culture provides a controlled environment for regenerating plants from edited cells. Together, they offer a powerful toolkit for developing resilient, high-yielding, and climate-smart crops faster than ever before. CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) is a genome editing system derived from bacterial immune mechanisms. Paired with the Cas9 enzyme, it allows scientists to make precise cuts in DNA, enabling gene knockouts, insertions, or replacements. Unlike traditional genetic modification, CRISPR does not necessarily introduce foreign DNA, making it more acceptable in regulatory and public spheres [1, 2].

Synthetic promoters and transcription factors can be used to reprogram plant cells during tissue culture, enhancing regeneration and transformation efficiency. Machine learning models are being developed to predict optimal tissue culture conditions and CRISPR targets, streamlining the breeding pipeline. Plant tissue culture involves growing plant cells, tissues, or organs in a sterile, nutrient-rich medium under controlled conditions. It enables the regeneration of whole plants from single cells, which is essential for applying CRISPR edits. Techniques like callus induction, somatic embryogenesis, and micropropagation are

used to propagate edited cells into viable plants [3, 4].

The integration of CRISPR with tissue culture solves a major bottleneck in plant breeding: delivering edits to the right cells and regenerating them into fertile plants. This synergy allows: Efficient transformation of recalcitrant species, Rapid trait fixation through clonal propagation, Multiplex editing of multiple genes simultaneously, Scalable production of elite cultivars [5, 6].

For example, in cotton, CRISPR edits are delivered via *Agrobacterium*-mediated transformation or biolistics, followed by tissue culture-based regeneration. CRISPR-tissue culture systems have been used to enhance traits like drought tolerance, disease resistance, and nutritional quality. In rice, editing the *GW2* gene improved grain width and nutritional content. In tomatoes, CRISPR has been used to develop varieties resistant to Tomato Yellow Leaf Curl Virus (TYLCV). CRISPR enables reverse genetics knocking out genes to study their function. Tissue culture allows researchers to regenerate edited plants and observe phenotypic changes, accelerating gene discovery and trait mapping [7, 8].

Wild species can be rapidly domesticated by editing key traits like seed shattering, flowering time, and fruit size. Tissue culture facilitates the regeneration of these edited wild plants into cultivars suitable for agriculture. Despite its promise, CRISPR-tissue culture systems face hurdles: Some species or cultivars are difficult to regenerate *in vitro*. These advanced CRISPR variants allow precise nucleotide changes without double-strand breaks. When combined with tissue

culture, they offer safer and more accurate trait modifications [9, 10].

Conclusion

The fusion of CRISPR and tissue culture marks a new era in precision plant breeding. By enabling targeted genetic edits and efficient plant regeneration, this approach offers a fast, flexible, and sustainable pathway to crop improvement. As technologies evolve and barriers fall, CRISPR-tissue culture systems will become central to feeding the world, preserving biodiversity, and building climate-resilient agriculture.

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