



Ribonucleoprotein (RNP)-Based Genome Editing in Plants: A DNA-Free Approach to Precision Crop Improvement

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In the race to feed a growing global population under the pressures of climate change, agriculture needs smarter, faster, and more precise tools. Droughts are intensifying, new pests are emerging, and soils are degrading. Traditional breeding, while powerful, often takes years or even decades to deliver improved crop varieties. Genetic engineering accelerated this process but it also sparked regulatory complexity and public debate. Now, a new approach is reshaping plant biotechnology: **RNP-based genome editing**. It offers the precision of modern molecular science without permanently inserting foreign DNA. For many scientists, this represents the next logical step in crop improvement.

From CRISPR to RNP: What's the Difference?

Most people have heard of CRISPR, the revolutionary gene-editing system adapted from bacteria. At the heart of CRISPR technology is a molecular tool known as Cas9, which works like highly precise scissors. Guided by a short piece of RNA, it cuts DNA at a specific location, allowing scientists to modify genes with remarkable accuracy. This system originates from CRISPR — a natural immune defense bacteria use to protect themselves from viruses. In plant biotechnology, researchers typically insert DNA encoding the Cas9 protein and its guide RNA into plant cells. The plant then produces the editing machinery internally. RNP-based editing takes a different approach: Instead of inserting DNA instructions, scientists deliver the editing tool directly as a **pre-assembled ribonucleoprotein (RNP) complex**: a combination of the Cas protein and its guide RNA. The complex performs its editing function and then naturally degrades. No foreign DNA remains integrated in the plant genome. In simple terms: it edits the gene and leaves.

Why RNP Editing Is a Turning Point for Modern Agriculture

The distinction may seem subtle, but it has profound implications. When DNA encoding Cas9 is inserted into the genome, it may remain active for extended periods. That increases the theoretical possibility of unintended changes elsewhere in the DNA known as off-target effects. In contrast, RNPs are transient. They operate for a short time before breaking down, reducing prolonged exposure and potential off-target activity. More importantly, because no foreign DNA is integrated, the final plant may be indistinguishable from one that developed a similar mutation naturally. This has regulatory significance. In some countries, genome-edited crops that do not contain transgenes are evaluated differently from traditional genetically modified organisms (GMOs). For plant breeders and policymakers alike, that distinction could accelerate innovation.

How RNP Editing Works

The process begins with identifying a gene linked to an important trait perhaps drought sensitivity, susceptibility to a fungal disease, or inefficient nitrogen use. Scientists design a short guide RNA that matches a specific DNA sequence within that gene. The guide RNA is

then combined with the Cas protein in the laboratory to form the RNP complex. Next comes delivery. Because plants have rigid cell walls, introducing molecules into plant cells is not trivial. Researchers use techniques such as protoplast transformation (where the cell wall is temporarily removed), particle bombardment (a gene gun), or electroporation. Once inside the cell, the RNP locates its DNA target and creates a precise break. The plant's own repair machinery fixes the break — often introducing a small mutation that alters gene function. After completing this task, the RNP complex degrades. What remains is a plant with a subtle, targeted genetic change — and no foreign DNA sequence lingering in its genome.

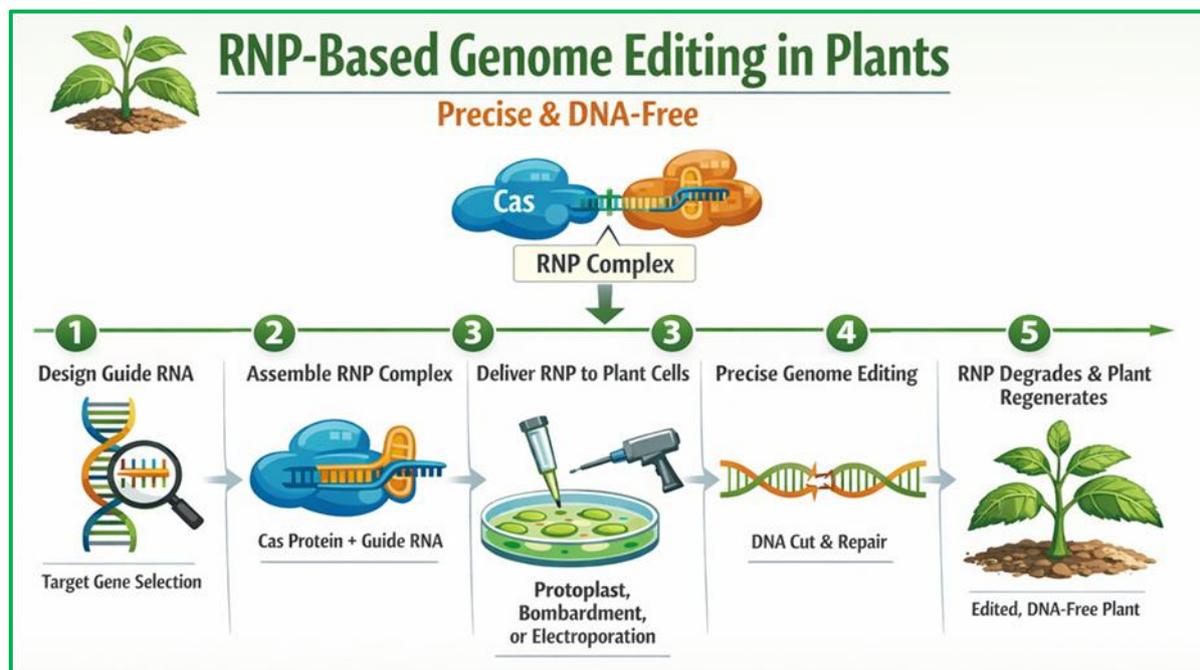


Figure: Schematic illustration demonstrating workflow of RNP-mediated genome editing in plants

Practical Applications in Crop Improvement

The promise of RNP-based genome editing spans major agricultural challenges.

- **Drought resilience:** By modifying genes involved in stress perception or water-use efficiency, crops can be better equipped to withstand water scarcity.
- **Disease resistance:** Targeting susceptibility genes can make plants naturally resistant to pathogens without introducing resistance genes from other species.
- **Nutritional improvement:** Editing metabolic pathways may enhance oil composition, protein quality, or micronutrient content.
- **Reduced anti-nutritional factors:** Crops like legumes can be improved by knocking out compounds that reduce digestibility.

Because the approach is precise and relatively rapid, it is especially valuable for functional gene validation. Researchers can quickly test the role of candidate genes identified through transcriptomics or stress-response studies.

Accelerating Next-Generation Plant Breeding Programs

One of the strongest appeals of RNP-based editing is its “clean” profile. In traditional transgenic approaches, introduced DNA can integrate randomly into the genome, requiring extensive screening and backcrossing to remove unwanted sequences. RNP editing eliminates that step. The resulting plant carries only the intended mutation similar to what might arise through spontaneous natural mutation, but achieved in a controlled and targeted manner. This efficiency can significantly shorten breeding timelines. For crops facing climate-driven stress, time is a critical factor.

Current Limitations and Technical Hurdles

Despite its promise, RNP-based genome editing is not without hurdles. Delivery remains technically demanding, particularly for crops that are difficult to regenerate from tissue culture. Efficient transformation systems are still being optimized for many species. Regeneration of whole plants from edited cells can also be a bottleneck. Additionally, large-scale field validation is necessary before commercial deployment. Regulatory frameworks vary widely between countries, and policy clarity will influence adoption speed.

Building Climate-Resilient Crops with Precision Editing

As extreme weather events become more frequent, crop resilience is no longer optional, it is essential. Precision technologies like RNP-based genome editing provide a way to respond quickly to emerging threats while minimizing genetic disruption. The technology does not replace conventional breeding. Instead, it complements it acting as a precision scalpel alongside the breeder's toolbox. In the coming years, we may see crops developed using RNP editing that require less water, resist devastating diseases, and maintain yield stability under stress. And because these plants contain no foreign DNA, they may bridge the long-standing divide between biotechnology innovation and public acceptance. In a world where food security depends on adaptability, RNP-based genome editing represents a powerful step forward: precise, efficient, and elegantly simple.

Conclusion

RNP-based genome editing marks an important shift in plant biotechnology from introducing foreign genes to making precise, targeted changes without leaving behind genetic footprints. By delivering pre-assembled Cas protein and guide RNA complexes directly into plant cells, this approach combines accuracy, efficiency, and molecular cleanliness in a single platform. The editing machinery performs its task and then disappears, leaving only the intended genetic improvement. As agriculture faces mounting pressures from climate change, water scarcity, and evolving pathogens, such precision tools are becoming indispensable. RNP-based editing offers a faster route to developing drought-resilient, disease-resistant, and nutritionally enhanced crops while potentially navigating regulatory pathways more smoothly in regions that distinguish DNA-free edits from transgenic modifications. Although technical challenges such as delivery efficiency and plant regeneration remain, rapid advances in transformation systems and tissue culture technologies are steadily overcoming these barriers. With continued research and responsible deployment, RNP-based genome editing has the potential to redefine modern crop improvement — delivering innovation that is not only powerful, but also precise, sustainable, and future-ready.

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