Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 05, Issue: 06 (NOV-DEC, 2025)
Available online at http://www.agriarticles.com

A Comprehensive Review on Genetic Engineering: Application in Fruit Crops

*Arunima Sinha
Dept. of Horticulture, Naini Agricultural Institute (NAI), Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Naini, Prayagraj, (U.P.), India
*Corresponding Author's email: arunimasinha3109@gmail.com

Genetic engineering has become a powerful tool to accelerate trait improvement in fruit crops, tackling diseases, post-harvest losses and quality traits that are slow or difficult to change through conventional breeding. This review summarizes historical milestones, major molecular approaches (transgenesis, RNA interference, cisgenesis, and genome editing), representative success stories, regulatory and socioeconomic considerations, biosafety challenges, and future directions.

Introduction

Fruit crops are typically perennial, heterozygous and long-lived; these biological features make conventional breeding slow and often impractical for rapidly emerging threats (diseases, pests, changing climate) or for precise quality traits. Genetic engineering provides routes to introduce, silence, or precisely edit genes to deliver targeted changes in much shorter timeframes than classical breeding. Recent advances in CRISPR/Cas and other gene-editing tools in particular have greatly expanded feasible targets and reduced the time and cost of developing improved cultivars.

Short history and milestones

- **Early transgenic examples:** One of the earliest and most cited commercial successes is the development of papaya resistant to Papaya ringspot virus (PRSV) in Hawaii (Sun Up and the hybrid Rainbow), which helped rescue a devastated industry in the 1990s–2000s. This success demonstrated that virus-derived resistance could be durable and commercially accepted in some markets.
- **Virus resistance in stone fruit:** 'Honey Sweet' plum, developed using RNA-mediated virus resistance, has shown strong and durable resistance to plum pox virus (PPV) in long-term trials.
- **Quality trait commercialization:** The Arctic® non-browning apple (PPO suppression) is a prominent example of a quality trait modified via genetic engineering and commercially introduced in North America.
- **Gene editing era:** From ~2013 onward, CRISPR/Cas systems enabled precise knockouts and targeted edits in fruit species; increasingly they are used to target disease susceptibility genes, shelf-life traits, and quality attributes. Recent literature shows rapid adoption of CRISPR methods for citrus, banana, grape, apple and other fruit trees.

Major technologies and mechanisms

Transgenesis (introduction of foreign genes)

Traditional transgenic approaches insert one or more genes (coding or regulatory) into the plant genome using Agrobacterium or biolistics. Applications in fruit crops have included virus coat protein genes for pathogen resistance, expression of antimicrobial peptides, and enzymes that alter ripening or browning.

RNA interference (RNAi) / gene silencing

RNAi constructs (hairpin RNAs, antisense) have been prominent where silencing of endogenous or viral genes confers resistance — e.g., RNAi–based strategies were central to both PRSV-resistant papaya and PPV-resistant plums.

Cisgenesis and intragenesis

Cisgenic approaches use genes from sexually compatible species (or the same species) to avoid introducing "foreign" DNA; this can ease regulatory or public acceptance in some jurisdictions but still requires transformation.

Genome editing (CRISPR, TALENs, base editors, prime editing)

Genome editors allow precise modifications: targeted knockouts of susceptibility genes, promoter edits to modulate expression, base changes that mimic natural alleles, and removal of transgenic selection cassettes. CRISPR/Cas systems dominate recent work because of ease of design and multiplexing potential; fruit tree research has shown successful edits conferring disease tolerance, altered ripening, and reduced browning.

Representative success stories (selected examples)

Papaya — PRSV resistance (Hawaii)

Transgenic papaya expressing PRSV coat protein (RNA-mediated resistance) protected Hawaii's industry after severe epidemics; the commercialization of SunUp and Rainbow papaya is a cornerstone example demonstrating agricultural, economic and social benefits from genetic engineering.

Plum — Honey Sweet (PPV resistance)

Honey Sweet plum uses a silencing-based mechanism to provide durable resistance to plum pox virus. Field trials over years reported stable resistance and minimal negative agronomic effects. Regulatory and market uptake have been constrained in some regions, but the variety is an important proof-of-concept for perennial tree crops.

Apple — Arctic® non-browning

By down-regulating polyphenol oxidase (PPO), Arctic apples show substantially reduced browning after slicing. This trait targets a clear consumer and supply-chain need (fresh-cut convenience) and illustrates engineering for quality rather than yield.

Citrus — HLB and canker resistance

Huanglongbing (HLB) and canker threaten global citrus production. Recent CRISPR and transgenic strategies aim to knock out susceptibility genes, enhance innate immunity, or express antimicrobial peptides. Progress in citrus gene editing and field testing shows real promise but also underscores the difficulty in controlling vectored bacterial diseases.

Banana, tomato and others

Banana (clonal, sterile) has been a target for gene editing to introduce disease resistance and improve shelf life; tomato continues to be a model/rapid system for testing gene edits that later inform fruit tree work (e.g., sugar content edits reported recently).

Regulatory, socio-economic and acceptance issues

- **Regulation varies widely.** Some countries treat certain gene-edited plants differently from transgenics (depending on presence of foreign DNA), while others regulate them the same as GMOs. This patchwork affects field trials, commercial release, and trade.
- **Public acceptance depends on use case.** Consumer-facing changes (non-browning fruit) face different scrutiny than producer-facing disease resistance (which can reduce pesticide use). The historic papaya case shows that local economic benefits can shift public and farmer acceptance.

Biosafety, environmental and technical challenges

- **Off-target edits and soma clonal variation:** Gene editing reduces but does not eliminate unintended changes; careful molecular characterization is required.

- **Durability of resistance:** Pathogen evolution can overcome single-gene resistance; stacking multiple mechanisms (e.g., gene edits + transgenes + cultural controls) is preferable.
- **Transformation bottlenecks:** Many fruit trees are difficult to transform and regenerate; genotype dependence and low transformation efficiency slow applications. Advances in delivery (protoplasts, viral vectors, improved tissue culture, in planta transformation) are active research areas.

Future directions and priorities

1. **Precision editing to mimic natural alleles** (allele-replacement, base editing) to reduce regulatory hurdles and improve public acceptance.
2. **Multiplex editing and trait stacking** (combine disease tolerance, improved shelf life, and quality traits) to build durable, commercially valuable cultivars.
3. **Improved transformation/delivery systems** for recalcitrant woody crops (transient expression, viral vectors, nano deliver.
4. **Integrative biosafety and socio-economic research** to guide deployment — cost-benefit analyses, market acceptance studies, and clear traceability/labelling strategies.

Conclusions

Genetic engineering — and especially CRISPR/Cas-based editing — has moved from proof-of-concept to practical application in several fruit crops. Successful cases (papaya, Honey Sweet plum, Arctic apple) highlight tangible benefits for disease control and quality improvement. Nonetheless, biological constraints (transformation difficulty, perennial life cycles), regulatory complexity, and stakeholder acceptance remain major determinants of how quickly and widely engineered fruit varieties will be adopted. Continued methodological innovation plus careful, transparent engagement with regulators, growers and consumers will be essential.

References

1. Olson, M. et al., *Gene Technology for Papaya Ringspot Virus Disease Management.* (review) PMC.
2. USDA-ARS, *Honey Sweet Plum Trees* (overview of PPV resistance).
3. Xu, *Arctic Apples: A Look Back and Forward.* (NY Fruit Quarterly PDF)
4. Review: *CRISPR/Cas as a Genome-Editing Technique in Fruit Tree Breeding.* PMC.
5. Frontiers review: *Genetic amelioration of fruit and vegetable crops to increase biotic ...* (2023).
6. Recent articles on citrus editing and HLB: Frontiers / ScienceDirect summaries.