



Accelerated Breeding Methods in Fruit Crops: Innovations for Rapid Genetic Improvement

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Fruit crops are vital for global food security, nutrition, and economic sustainability. They provide important sources of vitamins, antioxidants, and dietary fiber, which are essential for a healthy human diet. However, fruit breeding has historically lagged that of annual crops like cereals and legumes because of longer juvenile phases, complex reproductive biology, polyploidy, and perennial characteristics. Traditional breeding programs for fruit crops often take 10 to 30 years to develop and release a new cultivar, creating a significant obstacle in addressing emerging issues such as climate change, disease outbreaks, and market demands. Consequently, developing and adopting accelerated breeding methods has become crucial to speed up fruit crop improvement.

Accelerated breeding integrates advanced genetic, biotechnological and physiological approaches to shorten the breeding cycle, reduce costs and improve selection efficiency. This article delves into the key methods, applications, advantages and challenges associated with accelerated breeding in fruit crops.

Speed Breeding

Speed breeding involves manipulating environmental conditions such as light, temperature and photoperiod to promote rapid growth and early flowering, enabling multiple generations per year. While this method has been extensively adopted in annual crops like wheat and barley, its adaptation in fruit crops is still in experimental stages due to longer juvenile periods and complex architecture.

Application in Fruit Crops

Efforts have been made to utilize controlled environments such as growth chambers, greenhouses and even vertical farming setups to shorten the generation time in certain fruit crops, particularly:

- **Strawberries** (short-day varieties can be induced to flower under controlled photoperiod)
- **Bananas** (micropropagation and early flowering under controlled conditions)
- **Papaya** (semi-annual cropping cycle can be optimized)

Limitations

- Less effective in woody perennials (e.g., mango, citrus)
- Requires expensive infrastructure and energy

Early Flowering via Genetic Engineering

The overexpression of flowering genes like **FLOWERING LOCUS T (FT)** or **LEAFY (LFY)** can induce early flowering in transgenic fruit trees, drastically reducing the juvenile phase. Cisgenesis and intragenesis techniques have been primarily applied in apple, with successful reports also emerging in crops such as grapevine, grapefruit and sweet orange. In apples, cisgenic lines have been developed to confer resistance against major diseases like fire blight and apple scab, demonstrating enhanced disease resistance. One notable example is the cisgenic C11.153 apple line, which exhibited strong resistance to scab, minimal presence

of foreign DNA and a single genome insertion. Although some allergen-related genes were differentially expressed, this did not significantly alter protein levels and caused only minor unintended growth changes. Field trials further validated the scab resistance of this clone, though its impact on tree growth and fruit quality traits remains unexplored. Additionally, a resistance gene originating from a wild apple species was successfully transferred into a susceptible apple variety through cisgenesis, improving its fire blight resistance at the shoot level.

Example

- **Apple:** Transgenic expression of *BpMADS4* from birch reduces juvenile period to 7–10 months.
- **Citrus:** FT gene integration has led to flowering within 1 year.

CRISPR-Cas and Genome Editing

The CRISPR locus and its associated Cas proteins form an adaptive immune system found in most archaea and many bacteria, providing defense against invading genetic material such as nucleic acids. This natural system has been transformed into a versatile genome editing tool, now widely applied in plants, animals and other eukaryotic organisms. The CRISPR-Cas9 system, classified as a Class 2, Type II system, was the first to be adapted for precise genome engineering.

Applications in Fruit Crops

- **Banana:** Editing the *MusaPDS* gene for proof-of-concept
- **Tomato (fruit crop model):** CRISPR used to modify shelf life and nutrient content
- **Citrus:** Knockout of susceptibility genes to confer resistance to canker

Benefits

- High specificity and efficiency
- Regulatory ease in some countries (considered non-GMO if no foreign DNA)

Advantages of Accelerated Breeding

Feature	Benefit
Time Efficiency	Reduces breeding time by 30–80%
Precision	Increases accuracy of selection
Cost-Effectiveness	Reduces cost per released variety
Climate Adaptation	Speeds up development of climate-resilient cultivars
Disease Management	Faster deployment of resistant varieties

Challenges and Future Prospects

Technical Limitations

- Lack of transformation protocols in many woody fruit species
- Limited availability of molecular markers in under-researched crops

Regulatory and Ethical Issues

- Unclear regulatory status of gene-edited crops in several countries
- Public acceptance of transgenic approaches still limited

Capacity and Infrastructure

- High cost of tissue culture, controlled environments and molecular labs
- Need for training and interdisciplinary collaboration

Conclusion

Accelerated breeding methods hold immense promise for the improvement of fruit crops, offering a pathway to meet future demands for quality, yield and resilience. While some methods are still evolving, particularly for woody perennials, integration of approaches such as marker-assisted selection, genomic selection and gene editing has already begun to transform the breeding landscape. As technology becomes more accessible and regulatory clarity improves, accelerated breeding is set to become the cornerstone of modern fruit crop improvement programs, ensuring faster, smarter and more sustainable horticultural innovation.