

# Advances in Micropropagation and In Vitro Techniques for Rapid Multiplication of Horticultural Plants

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## ABSTRACT

Micropropagation and in vitro culture technologies have emerged as powerful tools for rapid multiplication and improvement of horticultural crops. These techniques enable the production of large numbers of genetically uniform and disease-free planting materials within a short period, independent of seasonal limitations. Advances in tissue culture methods, bioreactor systems, molecular diagnostics, and automation have significantly enhanced propagation efficiency and plant quality. Micropropagation is widely used in fruits, vegetables, ornamentals, plantation crops, and medicinal plants to support commercial horticulture and germplasm conservation. Recent developments also integrate molecular tools and biotechnology for trait improvement and disease elimination. This review discusses principles, recent advances, applications, challenges, and future prospects of micropropagation and in vitro techniques for rapid multiplication of horticultural crops, emphasizing their role in sustainable horticultural production.

**Keywords:** Micropropagation, in vitro culture, tissue culture, horticultural crops, rapid multiplication, plant biotechnology.

## 1. Introduction

Horticultural crops play a critical role in global food security, nutrition, and economic development. Demand for quality planting material has increased due to expanding cultivation areas, adoption of improved varieties, and the need for disease-free propagules. Conventional propagation methods such as seeds, cuttings, grafting, and layering often face limitations including slow multiplication rates, seasonal dependency, and disease transmission [1].

Micropropagation, an in vitro plant tissue culture technique, enables rapid clonal multiplication under controlled laboratory conditions. Since its commercial adoption in the late twentieth century, it has become an important component of modern horticulture. The technology allows production of uniform, disease-free, and high-quality planting materials throughout the year [2]. Recent technological advances have enhanced culture efficiency, reduced production costs, and improved plant survival rates during acclimatization. Integration of automation, temporary immersion systems, and molecular diagnostics has further expanded its applications. This review summarizes current progress and innovations in micropropagation techniques and their application in horticultural crop production.

## 2. Principles of Micropropagation

Micropropagation involves growing plant tissues, organs, or cells on artificial nutrient media under sterile conditions. The technique relies on the principle of plant cell totipotency, which allows cells to regenerate into complete plants.

The micropropagation process typically involves four stages:

- 1. Initiation stage** where explants are sterilized and cultured.
- 2. Multiplication stage** where shoots are proliferated.
- 3. Rooting stage** where regenerated shoots form roots.
- 4. Acclimatization stage** where plantlets adapt to external conditions.

Various explants such as shoot tips, nodal segments, leaves, and meristems are used depending on crop species and propagation objectives.

## 3. Advances in In Vitro Propagation Techniques

### 3.1 Improved Culture Media and Growth Regulators

Advances in nutrient formulations and growth regulator combinations have improved regeneration efficiency [3]. Optimization of auxin and cytokinin ratios enhances shoot multiplication and rooting responses. Additives such as vitamins, amino acids, and organic supplements further promote growth.

### 3.2 Temporary Immersion and Bioreactor Systems

Liquid culture systems and temporary immersion bioreactors have significantly increased multiplication rates while reducing labor and production costs. These systems provide better nutrient uptake and aeration, supporting large-scale commercial production.

### 3.3 Automation and Robotics

Automation in tissue culture laboratories, including automated media preparation, explant transfer, and culture monitoring, reduces labor dependency and contamination risks [4].

Robotic systems are increasingly used for handling plant cultures in commercial facilities.

### 3.4 Use of LED Lighting Systems

Modern culture rooms utilize LED lighting systems to optimize plant growth. Specific light wavelengths influence shoot elongation, rooting, and secondary metabolite production while reducing energy consumption.

## 4. Applications in Horticultural Crops

Micropropagation has become an indispensable technology in modern horticulture due to its ability to produce large numbers of uniform, high-quality, and disease-free planting materials within a relatively short time [5]. The technique supports both commercial crop production and conservation programs by enabling rapid multiplication of elite genotypes and rare plant species. Its application spans fruit, vegetable, ornamental, medicinal, and aromatic crops, making it a key contributor to the global horticultural industry.

### 4.1 Fruit Crops

Micropropagation is extensively applied in fruit crop production to meet the increasing demand for uniform and pathogen-free planting materials [6]. Conventional propagation methods in many fruit crops are slow and often result in the transmission of viral and systemic diseases. Tissue culture techniques overcome these limitations by enabling large-scale production of healthy and genetically uniform plants.

Banana is one of the most commercially propagated crops through tissue culture, with millions of plantlets produced annually to ensure uniform plantations and higher yields. Similarly, strawberry plants are micropropagated to eliminate viral infections and maintain varietal purity. Pineapple, grapevine, apple, citrus, and pomegranate industries increasingly depend on micropropagation for rapid multiplication of elite cultivars. In perennial fruit crops, micropropagation reduces the juvenile phase and accelerates orchard establishment. It also facilitates rapid dissemination of newly released varieties to growers. Furthermore, in vitro propagation plays an important role in conservation and multiplication of rare or endangered fruit species, thereby preserving valuable genetic resources.

**Table. Applications of Micropropagation in Major Horticultural Crop Groups**

Crop Group	Major Crops Propagated	Purpose of Micropropagation	Key Benefits
Fruit Crops	Banana, strawberry, pineapple, grape, apple, citrus, pomegranate	Rapid multiplication of elite cultivars and disease-free plants	Uniform orchards, higher productivity, early establishment
Vegetable Crops	Potato, sweet potato, cassava, garlic	Production of pathogen-free planting material and hybrid multiplication	Improved yield, disease control, rapid variety dissemination
Ornamental Plants	Orchids, gerbera, lily, chrysanthemum, anthurium, carnation	Commercial floriculture plant production	Uniform flowering, year-round plant supply, export quality
Medicinal Plants	Withania, Aloe vera, Bacopa, Rauwolfia, medicinal herbs	Conservation and mass multiplication of valuable species	Sustainable supply and protection of wild populations
Aromatic Plants	Mint, lemongrass, patchouli, basil	Rapid multiplication for essential oil production	Uniform quality and increased commercial cultivation

### 4.4 Medicinal and Aromatic Plants

Medicinal and aromatic plants are increasingly propagated through micropropagation to meet growing demand from pharmaceutical, nutraceutical, and cosmetic industries. Many medicinal plants are harvested directly from wild populations, leading to depletion of natural resources. In vitro propagation offers a sustainable solution by enabling rapid multiplication of valuable species under controlled conditions.

### 4.2 Vegetable Crops

In vegetable crops, micropropagation is particularly important for species that are vegetatively propagated or exhibit poor seed viability. Potato micropropagation through nodal culture is widely used to generate disease-free seed tubers, which significantly improves crop productivity and quality.

Vegetatively propagated vegetables such as sweet potato, cassava, and garlic benefit from tissue culture multiplication programs aimed at supplying pathogen-free planting materials to farmers. Rapid in vitro multiplication also accelerates dissemination of improved hybrids and elite varieties. Tissue culture further supports vegetable breeding programs by enabling rapid multiplication of parental lines used in hybrid seed production. It also assists in conservation and maintenance of elite germplasm lines. With increasing adoption of protected cultivation systems, micropropagated seedlings have become important planting materials for high-value vegetable production.

### 4.3 Ornamental Plants

The ornamental plant industry relies heavily on tissue culture for large-scale production of uniform and high-quality planting materials. Many ornamental species are difficult to propagate conventionally or require long propagation cycles, making micropropagation an efficient alternative. Orchids represent one of the most successful examples of commercial tissue culture propagation, with millions of plantlets produced annually to meet global floriculture demand. Crops such as lilies, gerberas, carnations, chrysanthemums, and anthuriums are also widely propagated through in vitro methods to ensure uniform flowering characteristics and high-quality blooms. Tissue culture enables rapid introduction of new ornamental varieties into markets and supports export-oriented floriculture industries. It ensures year-round availability of planting materials and reduces dependence on seasonal propagation cycles. Additionally, micropropagation aids conservation of rare ornamental species threatened in their natural habitats.

Plants producing important secondary metabolites such as alkaloids, flavonoids, phenolics, and essential oils are multiplied through tissue culture to ensure consistent quality and supply. Species such as *Withania somnifera*, *Aloe vera*, *Bacopa monnieri*, and various aromatic herbs are now commercially propagated using in vitro techniques. Micropropagation also supports conservation of endangered medicinal plants and facilitates research on bioactive compound production.

Advanced methods such as cell suspension cultures and organ cultures are being explored to enhance production of valuable phytochemicals under laboratory conditions, micropropagation contributes significantly to sustainable utilization and commercialization of medicinal and aromatic plants while reducing pressure on natural ecosystems.

### 5. Disease-Free Plant Production

Meristem culture combined with thermotherapy or chemotherapy is widely used for elimination of viruses and systemic pathogens. Disease-free plants ensure higher productivity and quality, particularly in vegetatively propagated crops. Molecular diagnostic tools enable early detection of pathogens, improving quality control in tissue culture plants.

### 6. Germplasm Conservation and Genetic Improvement

*In vitro* conservation methods, including slow-growth storage and cryopreservation, support long-term preservation of valuable plant genetic resources. Tissue culture also facilitates genetic transformation and somatic hybridization for crop improvement. Somaclonal variation generated during tissue culture can sometimes produce useful traits, although genetic stability must be carefully monitored.

### 7. Challenges in Micropropagation

Micropropagation faces several challenges:

- High initial infrastructure and operational costs
- Risk of contamination
- Somaclonal variation affecting genetic uniformity
- Acclimatization losses
- Skilled manpower requirements

Reducing production costs and improving survival rates remain major priorities.

### 8. Future Prospects

Emerging technologies such as artificial intelligence-based culture monitoring, nanotechnology applications, and molecular breeding integration promise to enhance efficiency. Development of cost-effective media and decentralized tissue culture units could improve accessibility for small farmers. Integration of micropropagation with precision horticulture and protected cultivation systems is expected to further enhance productivity and sustainability.

### 9. Conclusion

Micropropagation and *in vitro* culture techniques have emerged as indispensable tools in modern horticulture, enabling rapid and large-scale multiplication of elite, uniform, and disease-free planting materials. These technologies support sustainable crop production by overcoming limitations of conventional propagation methods and ensuring year-round availability of quality plants. Continuous advancements in culture media optimization, automation, bioreactor systems, and molecular diagnostics are improving propagation efficiency while enhancing commercial feasibility. In addition to supporting commercial cultivation, tissue culture also contributes to germplasm conservation and crop improvement programs. However, challenges related to production cost, contamination control, and genetic stability still require attention. Future research efforts aimed at reducing operational costs, improving automation, and ensuring clonal fidelity will further expand the adoption of micropropagation technologies. Strengthening technology transfer and accessibility will play a key role in maximizing the contribution of tissue culture to global horticultural development and sustainable agricultural production systems.

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