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ADVANCES IN PROPAGATION, GENETIC FIDELITY ASSESSMENT AND CONSERVATION OF *JASMINUM* SPECIES

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ABSTRACT
Jasminum species are economically important ornamental and aromatic crops valued for their fragrant flowers and essential oil production. Efficient propagation is essential for the large-scale multiplication, conservation, and utilisation of elite genotypes. Conventional propagation methods, particularly stem cuttings and layering, remain widely used because of their simplicity and low cost, but their effectiveness is often limited by seasonal dependence, low multiplication rates, and inconsistent rooting responses. *In vitro* propagation offers an alternative approach for the rapid production of uniform and disease-free planting material under controlled conditions. This review critically compares conventional and micropropagation systems in *Jasminum*, focusing on factors influencing rooting, shoot multiplication, acclimatisation, and plant establishment. The roles of plant growth regulators, culture media, environmental conditions, and rooting substrates in improving propagation efficiency are examined. The review also discusses somaclonal variation and highlights the use of molecular markers, particularly RAPD and ISSR, to assess genetic fidelity in micropropagated plants. Although micropropagation requires specialised infrastructure and technical expertise, it provides significant advantages for the rapid multiplication and conservation of superior germplasm. An integrated propagation strategy combining conventional and *in vitro* approaches offers a sustainable framework for large-scale production, conservation, and genetic improvement of *Jasminum* species.

KEYWORDS: *Jasminum* spp.; vegetative propagation; micropropagation; genetic fidelity; somaclonal variation; molecular markers

1. INTRODUCTION

The genus *Jasminum* L. (Oleaceae) comprises more than 200 species of evergreen and deciduous shrubs and climbers valued for their fragrant flowers, ornamental appeal, and essential oil production. Among them, *Jasminum sambac*, *J. grandiflorum*, and *J. auriculatum* are the principal commercially cultivated species, contributing significantly to the floriculture, fragrance, cosmetic, and pharmaceutical industries, particularly in Asia and the Mediterranean region (1-4).

Commercial cultivation of jasmine depends largely on vegetative propagation through stem cuttings, layering, and suckers. These methods are simple and economical but are constrained by low multiplication rates, seasonal dependence, limited availability of quality planting material, and inconsistent rooting responses (5, 6). Root induction in jasmine is often genotype-dependent, resulting in variable propagation success and restricting the rapid multiplication of elite cultivars (7).

Micropropagation offers an alternative approach to the rapid production of uniform, disease-free planting material year-round. In *Jasminum* spp., plant regeneration is commonly achieved through axillary bud proliferation from nodal explants, followed by *in vitro* rooting and acclimatisation under controlled conditions (8, 9). Despite its advantages, commercial adoption remains limited due to high establishment costs, technical requirements, risks of somaclonal variation, and acclimatisation losses (8, 10).

This review critically evaluates conventional and *in vitro* propagation approaches in *Jasminum* spp., with emphasis on multiplication efficiency, rooting behaviour, acclimatisation, genetic fidelity, and economic feasibility. The review further highlights emerging biotechnological interventions and future research priorities for sustainable and large-scale propagation of jasmine.

2. Propagation Bottleneck in *Jasminum* species:

While *Jasminum* spp. holds immense economic value, but its commercial propagation is constrained by its biology. Some of the species are naturally triploid (2n=3x=39), a genetic anomaly that disrupts meiosis, leading to high pollen sterility and the failure of viable seed set (11). Even in rare cases of pollination, embryo development

is aborted, making sexual propagation impossible (12). Consequently, growers rely entirely on vegetative methods. Traditionally, ground layering has been used, but it produces bulky, difficult-to-transport propagules (13).

2.1 Genetic constitution:

Cytogenetic information on *Jasminum* remains limited because of the small size and adhesive nature of its chromosomes, which complicate karyotype analysis (14). Most commercially important species, including *J. auriculatum*, *J. grandiflorum, and J. multiflorum,* are diploid (2n=2x=26), whereas *J. sambac* is predominantly triploid (2n=3x=39) (14). Although the genus generally exhibits a basic chromosome number of X = 13, deviations have been reported in *J. sambac*, suggesting the occurrence of aneuploidy (15).

Variations in ploidy level, ranging from diploid to hexaploid forms, have been reported in several *Jasminum* species and are frequently associated with reduced fertility and altered vegetative performance (16). In *J. sambac*, reproductive limitations arise from triploidy, poor pollen viability, abnormal embryo sac development, and low seed set, resulting in restricted sexual reproduction (12), Madhavi, Awati (17). Recent genomic studies further indicate that domestication of *J. sambac* has largely relied on the selection and clonal perpetuation of desirable floral morphotypes, as demonstrated by the chromosome-level genome assembly of the cultivar 'Double Petal'(18). Consequently, vegetative propagation remains the principal method for multiplication and maintenance of elite jasmine cultivars.

2.2 Viral load accumulation & cultivar degeneration:

Prolonged clonal propagation can contribute to cultivar degeneration through the progressive accumulation and transmission of viruses in vegetatively propagated crops (19). In jasmine, nursery-based studies have demonstrated the presence of virus infections even in apparently healthy plants, indicating that visual inspection alone is insufficient for maintaining disease-free mother stock (20). The persistence of latent infections poses a significant challenge to conventional propagation and underscores the need for pathogen indexing, clean planting material, and disease-free propagation systems to sustain cultivar performance and planting stock quality.

3. Conventional Propagation:

Despite advances in biotechnological propagation, commercial jasmine production continues to rely largely on conventional vegetative methods. In several *Jasminum* species, low seed viability necessitates asexual propagation to maintain genetic integrity. Historically, layering was widely practised; however, its labour-intensive nature and low multiplication rate restrict its suitability for large-scale nursery production (6). Consequently, stem cuttings have become the preferred method for commercial propagation because of their simplicity, cost-effectiveness, and ability to produce genetically uniform planting material more efficiently than layering or grafting (21). Nevertheless, propagation success depends on several factors, including cutting type, physiological status of the stock plant, environmental conditions, and rooting treatments (13).

3.1 Characteristics of Stem Cuttings:

Stem cuttings are the most widely adopted method for the commercial propagation of *Jasminum* species because of their simplicity, cost-effectiveness, and suitability for large-scale multiplication (22). Unlike layering, which limits the number of propagules that can be obtained from a mother plant, cuttings permit rapid multiplication of planting material. Depending on stem maturity, cuttings are generally classified as hardwood, semi-hardwood, softwood, or herbaceous types (23). In several *Jasminum* species, particularly those with limited seed production, stem cuttings remain the principal propagation method for maintaining and multiplying elite cultivars.

The success of propagation through stem cuttings in *Jasminum* spp. is influenced by the physiological condition and maturity of the propagule. Root initiation is regulated by factors such as carbohydrate reserves, endogenous auxin levels, rooting cofactors, and the carbon-to-nitrogen ratio (24). Rooting response has also been reported to vary among species, indicating there is no universal propagation protocol for all *Jasminum* taxa. In *J. grandiflorum*, hardwood cuttings exhibited comparatively higher regeneration potential than semi-hardwood and softwood cuttings (25). In contrast, semi-hardwood cuttings have been reported to exhibit superior rooting performance in *J. sambac,* with rooting percentages of about 90% under favourable conditions (7). Cuttings obtained from the middle portion of branches (semi-hardwood) generally outperformed the terminal and basal cuttings, possibly due to higher carbohydrate reserves and better physiological balance (26, 27). Cutting length also influenced propagation success, with 25cm semi-hardwood cuttings showing comparatively higher survival, faster establishment, and increased shoot production during the late kharif season (28).

3.2 Hormonal Regulation:

Auxin application is routinely employed to enhance adventitious root formation and improve propagation efficiency in *Jasminum* cuttings (29). Evidence indicates that different auxins influence specific aspects of propagation success. In *J. sambac*, treatment with IBA at 2000 ppm improved root number, root length, and root biomass, whereas NAA at 1000 ppm increased survival percentage, suggesting distinct physiological roles of these auxins during root establishment (30). Similarly, IBA at 1500 ppm enhanced sprouting, shoot growth, rooting, and survival of cuttings, highlighting the importance of optimising auxin concentration for efficient vegetative propagation (31).

The effects of cutting type and auxin treatments on rooting and establishment of *Jasminum* cuttings are summarised in **Table 1**.

Table 1. Effect of auxin treatments on rooting percentage in stem cuttings of *Jasminum* spp.

Note: a-IBA = indole-3-butyric acid; b-NAA = naphthaleneacetic acid; c-ppm = parts per million.

Species	Cutting Type	Auxin Type	Concentration (ppm)	Rooting / Survival (%)	Reference
Jasminum sambac	Semi-hardwood	IBA	1500 ppm	88.33	Netam, Shukla (31)
Jasminum sambac	Semi-hardwood	IBA	1000 ppm	88.60	Keerthivasan, Ganga (7)
Jasminum sambac	Semi-hardwood	IBA	1500 ppm	66.11	Makwana, Rathva (32)
Jasminum grandiflorum	Hardwood	NAA	4000 ppm	84.33	Zaghloul, Hassan (33)
Jasminum sambac	Stem cutting	NAA + Kinetin	750 ppm NAA + 75 ppm kinetin	90.0	TARIA (34)
Jasminum multiflorum	Terminal	IBA+ NAA	500 ppm IBA + 250 ppm NAA		Kumaresan, Kannan (22)
Cestrum nocturnum	Hardwood	IBA	2000 ppm	100	Patil, Malshe (35)
Murraya paniculata	Semi-hardwood	IBA+ NAA	3000 ppm	85.0	Manjunath D. R. (36)
Cestrum nocturnum	Hardwood	IBA	100 ppm	76.53	Singh, Rawat (37)
Jasminum azoricum	semi-hardwood	IBA	1500 ppm	82.15	Nirmala (38)

Rooting/survival percentage values represent reported responses under specific experimental conditions and may vary with genotype and environmental factors**.**

3.3 Environmental Factor:

Environmental conditions substantially influence the rooting and establishment of *Jasminum* cuttings, often determining propagation success even when suitable propagules and auxin treatments are employed. Although mist chambers are commonly used to maintain humidity and reduce transpiration losses, a comparative study at TNAU, Coimbatore, showed that terminal and semi-hardwood cuttings of *J. grandiflorum, J. auriculatum, and J. nitidum* achieved superior rooting under low poly-tunnel conditions than under mist chambers (39). The improved performance under poly-tunnels was attributed to favourable temperature and relative humidity conditions that reduced moisture stress and promoted root initiation during early establishment.

3.4 Rooting media:

The composition of the rooting medium significantly influences rooting, survival, and subsequent growth of *Jasminum* cuttings. Studies have shown that substrate combinations containing soil, sand, and farmyard manure (FYM) generally outperform simpler media, resulting in improved rooting and establishment (40-42). These responses have been attributed to a favourable balance of aeration, drainage, moisture retention, and nutrient availability. Similarly, media containing soil, vermicompost, and cocopeat enhanced sprouting, survival, and shoot growth under humid tropical conditions, highlighting the importance of substrate optimisation for commercial propagation (43).

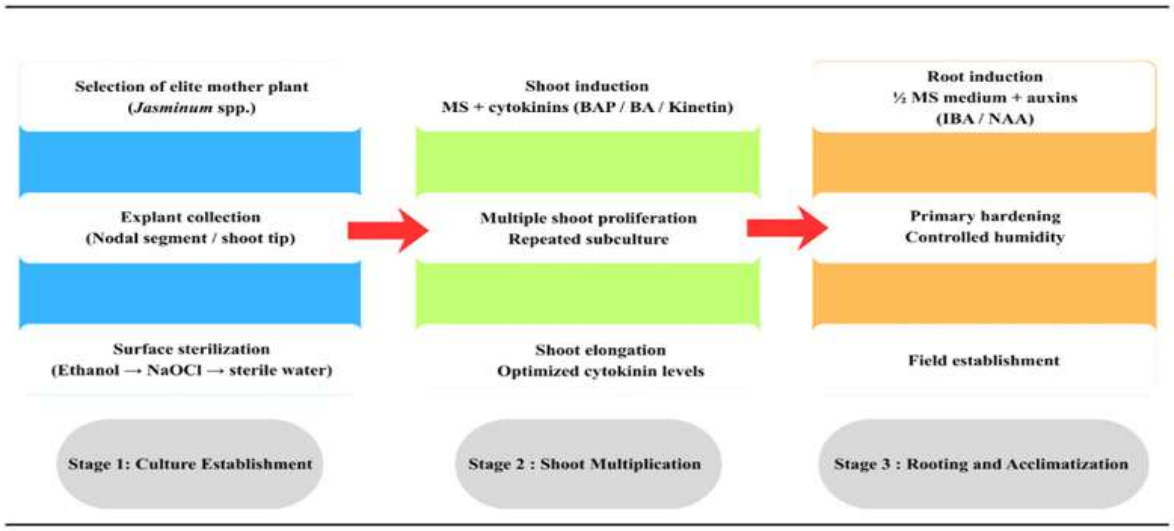
However, micropropagation further improves multiplication efficiency by enabling large-scale production of healthy and genetically uniform plants under controlled conditions.

4. *In Vitro Propagation:*

The limitations of conventional propagation, particularly low multiplication rates, seasonal dependence, and the restricted availability of propagules, have stimulated the adoption of *in vitro* propagation in *Jasminum* species. Micropropagation enables year-round production, maintenance of genetic uniformity, and conservation of valuable germplasm (6).

This section examines the major stages of *Jasminum* micropropagation, including explant sterilisation, shoot multiplication, rooting, and acclimatisation. Key technical factors influencing propagation success at each stage are illustrated in **Figure 1**.

Figure 1. Generalised micropropagation protocol for *Jasminum* spp. Illustrating the major stages.



4.1 Establishment:

Successful culture establishment in *Jasminum* depends largely on explant selection and sterilisation efficiency (44). Nodal segments obtained from actively growing shoots are widely preferred for micropropagation and have shown reliable establishment in *J. nitidum* (8). Similarly, nodal, apical, and axillary explants of *J. sambac* have been successfully established under aseptic culture conditions following appropriate surface sterilisation treatments (44, 45). Although combined sterilant treatments improve contamination control, excessive sterilant concentrations or repeated disinfection steps may reduce explant survival because of phytotoxic effects (8). Therefore, optimisation of sterilisation protocols remains critical for achieving a balance between asepsis and explant viability during culture establishment.

4.2 Shoot multiplication:

Shoot multiplication in *Jasminum* is largely regulated by cytokinin supplementation, with benzyladenine (BA) being the most widely used growth regulator. In *J. azoricum*, nodal explants cultured on MS medium (Murashige & Skoog) exhibited enhanced shoot regeneration in response to BA, demonstrating the importance of cytokinin optimisation for efficient shoot induction (46). Similar responses have been reported in *J. grandiflorum*, where cytokinin-supplemented media improved shoot proliferation and elongation from nodal explants (47). Collectively, these studies indicate that successful shoot multiplication in *Jasminum* depends largely on the appropriate type and concentration of cytokinin used during culture.

4.2.1 Cytokinin Optimisation:

Cytokinin supplementation is central to shoot multiplication in *Jasminum* tissue culture, with BA/BAP being the most widely used growth regulator. Studies in *J. azoricum, J. officinale*, and other *Jasminum* species have demonstrated that MS or modified WPM media supplemented with BA alone or in combination with kinetin effectively promote bud break and multiple shoot formation (8, 44, 48, 49). Enhanced shoot proliferation is often achieved when cytokinins are combined with low concentrations of auxins such as IBA or NAA, highlighting the importance of cytokinin-auxin balance during regeneration. A dose-dependent response to BA has been reported, with moderate concentrations producing optimal shoot multiplication, whereas excessively low or high concentrations reduce regeneration efficiency (50). Cytokinin treatments may also influence shoot quality, as increased shoot proliferation is frequently accomplished by reduced shoot elongation and node development (50). Furthermore, liquid culture systems have been reported to support greater shoot multiplication than agar-solidified media, possibly because of improved nutrient availability and explant contact with the culture medium (44).

4.2.2. Shoot elongation:

Following shoot multiplication, elongation is required to obtain well-developed shoots suitable for rooting. Studies have shown that transferring cultures to MS medium supplemented with kinetin promotes shoot extension and developmental maturity, whereas prolonged maintenance on multiplication media may result in shortened internodes and stunted growth (51). Improved shoot elongation has also been achieved by reducing growth regulator concentrations, producing elongated shoots with greater internode development prior to rooting (52).

The optimal media formulations and growth regulator combinations reported for shoot multiplication and elongation in *Jasminum* species are summarised in **Table 2**.

Table 2. *In vitro* regeneration and shoot multiplication responses of different *Jasminum* spp.

Species	Explant type	Basal medium	Cytokinin (mg L^{-1})	Auxin (mg L^{-1})	Optimal Hormonal combination	Shoot multiplication response	Reference
Jasminum sambac	Axillary bud	MS medium	BA 1.0	_	BA	2.6 shoots per node	Faizy, Al Nooh (45)
Jasminum sambac	Nodal explant	MS medium	BAP 2.0 + Kn 1.0	_	BAP + Kn + Ads	88.4% shoot proliferation	Biswal, Palai (44)
Jasminum grandiflorum	Shoot tip	MS medium	BAP 1.0	_	BAP + Coconut water	75% shoot proliferation	Rahman, Mouri (47)
Jasminum nudiflorum	Nodal segment	MS medium	BAP 3.0 + Kn 0.5	_	BAP + Kn	77.78% shoot proliferation	Bhat, Rather (8)
Jasminum sambac	Young stem	MS medium	BAP 3.0	NAA 1.0	BAP + NAA	20% shoot regeneration	Farzinebrahimi, Rashid (53)
Jasminum sambac	Axillary bud	MS medium	BA 1.5	NAA 0.3	BA + NAA	Maximum shoot induction was observed with this combination	Cai Han, Chen XiaoQiang (54)
Jasminum officinale	Nodal segment	MS medium	BA 4.0	NAA 0.1	BA + NAA	4-5 shoots per node	Bhattacharya and Bhattacharyya (55)
Jasminum sambac	Nodal segment	MS medium	BAP 2.0	NAA 0.5	BAP + NAA + 2,4-D + ADS	85% shoot initiation	Sapra and Pandya (52)
Jasminum leptophyllum	Nodal explant	MS medium	BAP 0.4	_	BAP	Highest shoot number: **2**.48 shoots/explant	KAUSAR, SHAH (56)

Note: a- MS = Murashige and Skoog medium; b-BAP = 6-benzylaminopurine; c- BA = benzyladenine; d- Kn = kinetin; e- NAA = naphthaleneacetic acid; f- ADS = adenine sulphate. Shoot multiplication responses are influenced by explant type, genotype, and culture conditions.

4.3 Callus induction:

Callus induction in *Jasminum* has been achieved from leaf, stem, petiole, and shoot tip explants cultured on MS medium supplemented with auxin-cytokinin combinations (Rajasekaran et al., 2000;(53). Among the explants evaluated, leaves of *J. grandiflorum* exhibited superior callus induction and proliferation, indicating their suitability for indirect regeneration (57). Explant-specific responses have also been reported under identical hormonal conditions, with stem explants producing the highest frequency of friable green callus (89%), followed by petiole (64%) and leaf explants (58%) (53). Although callus-mediated regeneration expands propagation opportunities, prolonged callus phases may increase the risk of somaclonal variation during micropropagation.

Phenolic exudation and subsequent callus browning represent important constraints in *Jasminum* tissue culture, as they may reduce callus growth, regeneration efficiency, and explant viability (58). The use of antioxidants and adsorbents such as polyvinylpyrrolidone, activated charcoal, ascorbic acid, and citric acid has been reported to minimise oxidative browning and improve culture establishment (59, 60). Similar improvements have also been achieved through modifications in culture medium composition and explant handling procedures (61, 62).

4.4 *In vitro* rooting*:*

Successful rooting of micropropagated *Jasminum* shoots depends largely on the composition of the culture medium and the type and concentration of auxins employed (8, 51).

4.4.1. Auxin Type and Concentration:

Rooting responses in *Jasminum* are strongly influenced by auxin type and concentration. Root induction in *J. sambac* has been achieved using NAA-supplemented half-strength media (9, 54); however, comparative studies generally indicate that IBA produces superior rooting performance, including greater rooting efficiency, root number, and root length across several *Jasminum* genotypes (8, 47, 63). Efficient root formation has also been reported in diluted MS media supplemented with combined IBA and NAA treatments (64). The variability observed among studies suggests that optimal rooting responses are influenced by genotype, auxin concentration, and culture conditions.

4.4.2. Medium Strength and Nutrient Composition:
Medium strength and nutrient composition play an important role in the rooting of micropropagated *Jasminum* shoots. Half-strength MS and WPM media generally support superior rooting compared with full-strength media, possibly because of reduced nitrogen balance (65). Successful rooting of *J. sambac* has been achieved on half-strength media supplemented with IBA or NAA (54, 66). In addition, temporary auxin exposure followed by transfer to growth regulator-free media has been shown to enhance direct root formation while reducing callus development, highlighting the importance of optimising nutrient and hormone balance during rooting (9, 48).

4.4.3. Acclimatisation:
Successful acclimatisation of micropropagated *Jasminum* plantlets depends on both root quality and the selection of suitable hardening substrates. Before transfer, removal of residual culture medium and fungicidal treatment helps reduce contamination and transplant losses (63). During primary hardening, porous substrates such as perlite and vermiculite support gradual adaptation to *ex vitro* conditions and improve plantlet survival. Plantlets rooted on IBA-supplemented media have shown superior survival during acclimatisation, highlighting the importance of effective *in vitro* root development (8). Following primary hardening, transfer to nutrient-rich substrates promotes further root growth and field establishment (67). Substrates enriched with organic matter, particularly soil-cow dung mixtures, have also been reported to improve rooting and survival during field establishment (47).

5. Comparative evaluation of conventional and *in vitro* propagation methods

Conventional and *in vitro* propagation systems differ considerably in multiplication efficiency, infrastructure requirements, production costs, and planting material quality. While conventional methods remain attractive for their simplicity and lower operational costs, micropropagation offers advantages in rapid multiplication, clonal uniformity, and the production of disease-free planting material. The major differences between these propagation approaches are summarised in **Figure 2 and Table 3**.

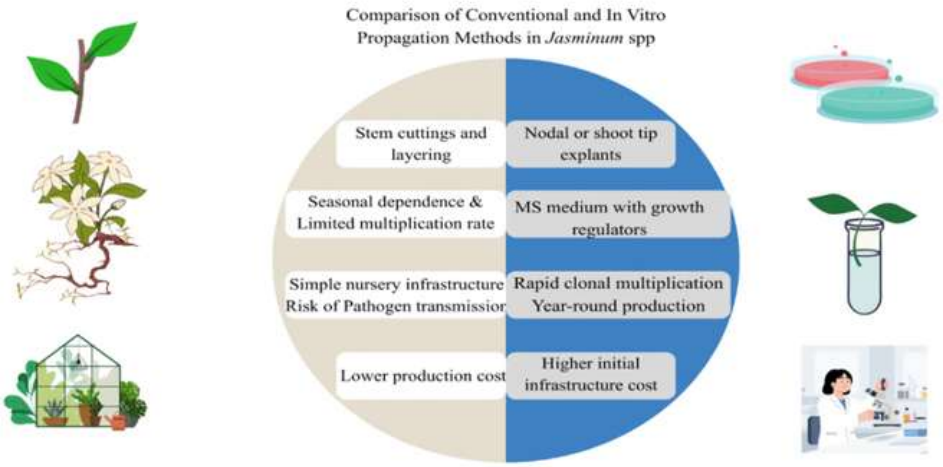


Figure 2. Comparison of conventional vegetative propagation and *in vitro* micropropagation methods in *Jasminum* spp., highlighting differences in propagation technique, multiplication rate, infrastructure requirements, and production efficiency.

Table 3. Comparative evaluation of conventional and *in vitro* propagation systems in *Jasminum* spp.

Parameter	Conventional propagation	*In vitro* propagation	References
Propagation method	Stem cutting and layering	Micropropagation using nodal, shoot tip, and leaf explants	(6, 51)
Multiplication rate	Moderate and season-dependent	Rapid and continuous under controlled conditions	(6, 8)
Seasonal dependence	High	Minimal	(6, 8)
Rooting efficiency	High with semi-hardwood cuttings and auxin treatments	High under optimised auxin-media combinations	(7, 8)
Hormonal requirement	Auxin-based rooting treatments (IBA, NAA)	Balanced cytokinin-auxin combination	(31, 50)

Rooting medium	Soil:sand:FYM and cocopeat mixtures	MS and WPM media	(41, 45)
Disease transmission risk	Possible transmission from infected mother plants	Reduced through aseptic and meristem culture	(6, 51)
Clonal fidelity	Declines over prolonged propagation	High genetic fidelity	(8, 68)
Plant uniformity	variable	High uniformity among regenerated plants	(6, 44)
Infrastructure requirement	Basic nursery structures are sufficient	Requires specialised laboratory facilities	(69, 70)
Technical skill requirement	Low to moderate	High	(71, 72)
Initial establishment cost	Lower	High	(69, 70)
Operational cost	Minimum under nursery-scale production	Higher due to media and skilled labour	(71, 72)
Scalability	Limited by stock plant availability	Suitable for rapid mass multiplication	(6, 8)
Germplasm conservation	Limited	Effective for long-term conservation	(2, 51)
Acclimatisation	Direct nursery establishment possible	Requires hardening and acclimatisation	(47)Bhat et al. 2022)
Commercial suitability	Economical for the routine nursery production	Suitable for elite and disease-free mass multiplication	(Chaitanya, Nataraja, and Krishnappa 2018;(73)

5.1 Multiplication Efficiency:

5.1.1 Tissue Culture Multiplication in Jasmine: Exponential Growth:

Micropropagation offers substantially higher multiplication rates than conventional propagation methods, making it suitable for rapid, large-scale production of *Jasminum* planting material. Shoot tip and nodal explants cultured on cytokinin-supplemented MS media have shown favourable regeneration responses and high multiplication efficiency (74). These advantages enable year-round production of genetically uniform plants from limited source material. However, successful commercial application requires careful optimisation of culture conditions to maintain consistent regeneration performance during repeated subculturing and large-scale production.

5.1.2 Conventional Cutting Propagation; Linear Growth Constraint:

Conventional propagation through stem cuttings remains the dominant method for commercial jasmine multiplication because of its simplicity and low infrastructure requirements. However, multiplication rates are constrained by the availability of propagules, seasonal influences, and species-specific rooting responses. High rooting success has been reported in semi-hardwood and terminal cuttings under favourable conditions (6), Although optimal cutting type varies among species, with *J. grandiflorum* and *J. sambac* responding favourably to apical cuttings and *J. auriculatum* performing better with semi-hardwood cuttings (75). Longer semi-hardwood cuttings have also been associated with improved survival and establishment (28).

Despite these advantages, conventional propagation remains limited by its linear multiplication rate, seasonal dependence, and labour-intensive practices such as layering. Long-term clonal propagation may also contribute to cultivar degeneration through the accumulation of pathogens and a gradual decline in planting material quality (54).

5.1.3 Comparison of Multiplication Efficiency:

Micropropagation offers substantially greater multiplication efficiency than conventional propagation by enabling rapid production of large numbers of plants from limited explant material within 8–9 weeks under controlled conditions, irrespective of season. In contrast, conventional cutting propagation is constrained by the availability of propagules and seasonal influences, although rooting success rates of 92–100% have been reported under favourable conditions. Consequently, tissue culture is better suited for rapid large-scale multiplication and production of disease-free planting material, particularly when elite stock plants are scarce. Conventional propagation, however, remains a practical and economically viable option for nursery production where healthy mother plants are readily available.

5.2 Cost-Benefit Analysis:

5.2.1 Infrastructure Requirements:

Infrastructure requirements represent a major distinction between conventional and *in vitro* propagation systems. Conventional propagation relies primarily on basic nursery facilities, such as shade nets and simple greenhouse structures, resulting in relatively low establishment and operational costs (70, 76). In contrast, micropropagation depends on specialised laboratory infrastructure, including aseptic workspaces, controlled culture environments, and specialised equipment, leading to substantially higher initial investment and maintenance costs (69)

Despite these limitations, recent developments in low-cost tissue culture systems, including simplified sterilisation methods, alternative culture vessels, and energy-efficient lighting, have demonstrated potential for reducing infrastructure costs and improving the accessibility of micropropagation technologies for small-scale production systems (71).

5.2.2 Labour and Unit Economics:

Labour and operational costs represent major economic components of both conventional and *in vitro* propagation systems, although their requirements differ substantially. Conventional propagation relies largely on routine nursery activities such as cutting preparation, planting, irrigation, and maintenance, whereas micropropagation requires skilled personnel for media preparation, aseptic culture management, contamination control, and acclimatisation (71, 72). Consequently, tissue culture generally incurs higher labour and operational costs than conventional nursery production. However, its high multiplication rate and year-round production capacity may improve economic viability at a commercial scale.

Several approaches have been proposed to reduce micropropagation costs, including the use of starch-based gelling agents, commercial sugar as a substitute for laboratory-grade sucrose, and fertiliser-grade chemicals in place of analytical-grade reagents. Such modifications have the potential to improve the affordability and wider adoption of tissue culture technologies for commercial propagation (71, 77).

5.2.3 Cost Comparison:

Conventional propagation remains the more economical option for small-scale nursery production because of its low infrastructure and operational requirements. In contrast, the economic benefits of micropropagation become more evident in large-scale commercial systems, where rapid multiplication, year-round production, uniform plant quality, and disease-free planting material can offset higher production costs (72, 73).

5.3 Plant Quality and Health:

5.3.1 Tissue culture quality advantages:

Micropropagation enables the rapid production of genetically uniform, disease-free, and high-quality planting material, making it particularly valuable for commercial jasmine production (78). Meristem culture is one such approach that helps produce healthy plants that can be utilised for the rapid reproduction of various horticultural plants (79). In addition to high multiplication efficiency, tissue culture facilitates the maintenance and large-scale propagation of elite genotypes while preserving genetic fidelity across successive generations. These attributes make micropropagation particularly valuable for commercial production systems that require uniform, healthy planting material.

5.3.2 Quality limitations in Conventional propagation:

Long-term clonal propagation through cuttings and layering may contribute to cultivar degeneration and increased disease incidence, particularly when infected mother plants are repeatedly used as sources for propagation (54). The effectiveness of conventional propagation is also influenced by season and location. For example, cuttings collected during March have been reported to root more successfully than those harvested during June, September, or December, highlighting the importance of seasonal timing for propagation success (6). In addition, conventional propagation can facilitate the transmission of systemic pathogens from infected mother plants to progeny propagules. Diseases such as blight, rust, fusarium wilt, and viral infections have been reported to spread through infected cuttings and layered materials, contributing to progressive disease buildup within planting stocks (80).

6. Genetic Fidelity and Molecular Analysis:

6.1 Risk of somatic clonal variation:

Although micropropagation is used to produce genetically uniform planting material, genetic alterations may arise during *in vitro* culture, a phenomenon commonly referred to as somaclonal variation(81, 82). Such variations result from mutations induced during tissue culture and may compromise clonal fidelity in regenerated plants (83). The occurrence of somaclonal variation is influenced by several factors, including explant wounding, exposure to sterilising agents, physiological stress during culture, and the use of high concentrations of growth regulators such as auxins and cytokinins (83). Environmental conditions within the culture system, including humidity, transpiration, and light regime, may further contribute to genetic instability during prolonged *in vitro* propagation.

6.1.1 Mode of regeneration:

The mode of regeneration is a major determinant of genetic stability during micropropagation. Plants regenerated through axillary bud proliferation generally maintain greater genetic fidelity than those regenerated through a callus phase, which is associated with increased chromosomal variation and mutation(84, 85).The higher incidence of variation in callus-derived plants is attributed to cellular dedifferentiation and prolonged periods of rapid cell division, which increase physiological and genetic instability (86). The extent of variation is largely influenced by the explant source, with meristematic or embryonic tissues generally producing more stable regenerants than mature, differentiated tissues (10). Consequently, regeneration systems based on axillary bud proliferation or somatic embryogenesis are generally preferred when maintaining genetic fidelity is a primary objective.

6.1.2 Effect of long-term culture:

The risk of somaclonal variation increases with prolonged *in vitro* culture and repeated subculturing (87, 88). In indirect regeneration systems, increasing callus age is often associated with a higher frequency of genetic variants in successive subcultures (84). Genetic instability may arise from the accumulation of mutations as well as

epigenetic modifications, including DNA methylation and transposon activation, induced by prolonged culture stress (89). Consequently, limiting the duration and the number of subcultures is considered an important strategy for maintaining genetic fidelity and regeneration potential during micropropagation (90).

6.1.3 Effect of Growth Regulators:

Plant growth regulators play a role in somaclonal variation by influencing cell division and multiplication rates (88). High concentrations can induce genetic instability, including alterations in ploidy and the occurrence of mutations (91). The synthetic auxin 2,4-D, in particular, has been associated with ploidy changes in callus cultures following prolonged exposure, leading to abnormal chromosome numbers (92). For example, in Haplopappus suspension cultures, a shift from diploid to tetraploid status was observed within six months under 2,4-D treatment (10).

6.1.4 Minimisation strategy:

Direct organogenesis is favoured over callus-based techniques to minimise somaclonal variation. Plants of *Tylophora indica* derived via direct organogenesis from leaves exhibited cytological stability, with no abnormalities detected (93). Plants that are produced through axillary shoots usually don't promote much variation (84). Axillary bud culture is generally considered the most reliable approach for maintaining genetic stability because meristematic tissues are less prone to genetic alterations than callus-derived tissues (94).

Limiting the number of subcultures is also a factor in minimising genetic variability; in the case of the banana, it is said that 5-7 subcultures are considered safe (95). Limiting the duration and number of subcultures remains an effective strategy for reducing somaclonal variation and maintaining regeneration potential during micropropagation (96).

At the commercial level, a variation rate of around 3–5% is generally considered acceptable, although higher levels, up to 10%, have been reported in crops such as banana (97). In practice, soma clonal variation is a measurable phenomenon rather than a theoretical concern. For instance, approximately 6% of *Musa* plants derived through tissue culture exhibit phenotypic variation. In the Cavendish banana, this issue can be more pronounced, with reported off-type frequencies ranging from 6% to 38%. Across different banana and plantain cultivars, studies have documented variation, with incidence ranging from negligible to 69% (95).

6.2 Assessment of Genetic Fidelity Using Molecular Markers:

Somaclonal variation remains a potential limitation of micropropagation, necessitating the assessment of genetic fidelity in tissue culture-derived plants (98). Although morphological, physiological, biochemical, and cytological approaches can be used to evaluate genetic stability, their reliability may be influenced by environmental conditions, culture practices, and explant source. In contrast, DNA-based molecular markers provide a more precise and dependable means of detecting genetic variation because they are largely unaffected by environmental factors (85, 99).

Several marker systems have been employed for fidelity assessment, including RAPD, AFLP, SSR, and ISSR markers (100). In particular, PCR-based techniques such as RAPD and ISSR are widely employed for monitoring genetic stability in tissue culture-derived plants (101).

6.2.1 RAPD markers:

Random Amplified Polymorphic DNA (RAPD) is a PCR-based marker system widely used for genetic fidelity assessment because it enables rapid analysis of multiple genomic regions without prior sequence information and requires only small quantities of DNA (91). RAPD markers have been successfully employed to confirm genetic stability in several micropropagated crops, including date palm and Morus alba, where monomorphic banding patterns indicated high genetic uniformity among regenerated plants (98, 102). In *Jasminum* spp., RAPD markers have also been used to evaluate genetic relationships among genotypes, revealing 71.43% polymorphism among 30 accessions (103).

6.2.2 Inter-simple sequence repeat (ISSR) markers:

Inter-simple sequence repeat (ISSR) markers are PCR-based markers that amplify genomic regions located between microsatellite sequences and are widely used for genetic fidelity assessment because of their high reproducibility and discriminatory power (99). ISSR markers have been widely used to confirm genetic stability in micropropagated plants and to assess genetic diversity in *Jasminum* species. In *Jasminum* spp., ISSR markers have proven useful for both genetic diversity analysis and fidelity assessment, with studies reporting high levels of polymorphism and efficient discrimination among genotypes (104, 105).

Furthermore, ISSR markers validated in the jasmine genus have demonstrated near-complete polymorphism detection (98.26%), highlighting their suitability for monitoring genetic stability in commercially important species such as *J. sambac and J. grandiflorum* (106).

The molecular marker systems commonly used for genetic diversity and fidelity assessment in *Jasminum* are summarised in **Table 4.**

Table 4. Molecular marker approaches for assessing genetic diversity and fidelity in *Jasminum* spp.

Species	Type of Marker	No. of Primers / Loci	Polymorphism Detected	Purpose	Reference

Jasminum spp. (26 species)	AFLP	Multiple loci	90.5% polymorphism	Genetic diversity and phylogenetic relationship	Nirmala, Champa (107)
Jasminum spp. (8 species, 53 accessions)	ISSR	21 primers	90.64% polymorphic bands	Molecular diversity assessment	Ghasemi Ghehsareh, Salehi (104)
Jasminum spp. (9 species, 28 accessions)	ISSR	21 primers	98.26% 562 polymorphic bands	Genetic diversity analysis	Akhtar, Hafiz (106)
Jasminum spp. (23 species, 40 accessions)	ISSR	10 primers	100% polymorphism	Genetic diversity analysis	Yohanan, Jeyarani (108)
Jasminum sambac	SSR (microsatellite)	31 loci tested	6 polymorphic loci	Germplasm characterisation and marker development	Li and Zhang (105)
Jasminum spp. (30 accessions)	RAPD	Multiple primers	71.43% 155 polymorphic bands out of 217 bands	Genetic diversity and phylogenetic analysis	Phithaksilp, Ruangrungsi (103)
Jasminum spp. (32 cultivars)	RAPD	8 primers	134 amplified RAPD fragments	Genetic diversity and cultivar identification	Mukundan (109)
Jasminum spp. (21 accessions)	RAPD	14 primers	195 alleles detected	Genetic diversity assessment	Mahmood, Hafiz (110)
Jasminum spp. (8 species)	RAPD	10 primers	75–48 bands amplified	DNA fingerprinting of jasmine species	Shekhar, Sriram (111)

Note: a- RAPD = Random Amplified Polymorphic DNA; b- ISSR = Inter-Simple Sequence Repeat; c- AFLP = Amplified Fragment Length Polymorphism; d- SSR = Simple Sequence Repeat. Polymorphism values indicate the level of genetic variation detected and may vary depending on primer selection and sample size.

7. Future Perspectives:

Future research on *Jasminum* propagation should focus on developing cost-effective, scalable, and commercially viable micropropagation systems. Optimisation of culture media, rooting protocols, and acclimatisation procedures remains essential for improving propagation efficiency and reducing production costs. Greater emphasis should also be placed on the routine use of molecular markers to monitor genetic fidelity and minimise somaclonal variation during large-scale multiplication. Emerging approaches such as somatic embryogenesis, molecular breeding, genome-assisted selection, and nanotechnology-based applications may further enhance propagation efficiency, germplasm conservation, and genetic improvement of economically important *Jasminum* species. The integration of conventional propagation, micropropagation, and modern biotechnological tools is expected to support sustainable jasmine production and conservation in the future.

The integration of these complementary propagation approaches is illustrated in **Figure 3.**

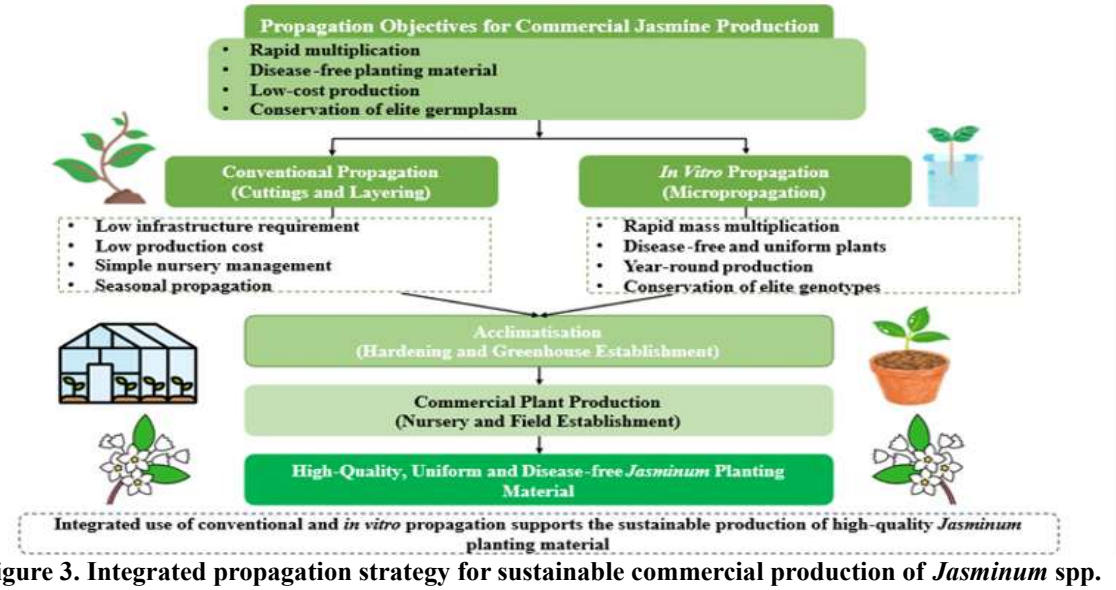


Figure 3. Integrated propagation strategy for sustainable commercial production of *Jasminum* spp.

8. CONCLUSION

Jasminum species are commercially important ornamental and aromatic plants that require efficient propagation strategies for large-scale production and conservation. Conventional propagation methods remain practical and economical but are constrained by limited multiplication rates, seasonal dependence, and the risk of pathogen transmission. In contrast, micropropagation enables rapid multiplication of elite genotypes and production of uniform, disease-free planting material, although its commercial adaptation is limited by higher costs and the potential occurrence of somaclonal variation. Molecular marker systems, particularly RAPD, ISSR, SSR, and AFLP, provide reliable tools for assessing genetic fidelity and ensuring clonal stability in tissue culture-derived plants. Overall, the integration of conventional propagation, micropropagation, and molecular fidelity assessment offers a sustainable approach for the propagation, conservation, and genetic improvement of *Jasminum* species.

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