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REVIEW ARTICLE

Advancements in climate-resilient propagation of ornamental plants: Strategies for a changing environment

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Abstract

The increasing impact of climate change has necessitated the development of climate- resilient ornamental plants, which can withstand extreme environmental conditions while maintaining aesthetic value. This paper explores recent advancements in the propagation of these plants, focusing on strategies that enhance their resilience to shifting climate patterns. Key areas of innovation include genetic approaches, such as drought and heat tolerance breeding, as well as the use of CRISPR technology to create stress-resistant plant varieties. The role of modern propagation techniques, including tissue culture, micropropagation and sustainable water-efficient methods, is examined in the context of climate adaptation. Additionally, advances in technology, such as AI, IoT and automated systems, are transforming plant propagation by improving environmental monitoring and optimizing growing conditions. Case studies on the successful cultivation of climate -resilient ornamental plants demonstrate their potential in urban landscaping, where climate-adapted species can contribute to sustainable, low-maintenance green spaces. The paper also highlights the importance of integrating eco-friendly practices, such as regenerative horticulture and water smart landscaping, in creating resilient urban environments.

Keywords: climate; genetic; ornamental; sustainable; tissue; urban

Introduction

Global environmental changes, including rising temperatures, irregular rainfall and extreme weather events are significantly impacting horticulture. Traditional ornamental plants, which are sensitive to heat, drought and pests, struggle to thrive under these altered conditions (1,2). These challenges are especially noticeable in urban areas, where ornamental plants significantly contribute to improve aesthetic appeal and environmental quality. As climate patterns continue to shift, it becomes essential to improve plants that can withstand challenging conditions while maintaining their functional and aesthetic value (3,4). Climate resilient ornamental plants are those that can endure extreme weather conditions such as heat, drought and humidity (5,6). These plants possess traits like water efficiency, pest resistance and the ability to recover from environmental stress. For ornamental plants, resilience also includes preserving their beauty and ecological benefits despite challenging climates, ensuring that they continue to support sustainable landscapes in the face of climate change.

Genetic approaches to enhance climate resilience in ornamental plants

Breeding for drought and heat tolerance in ornamental species

Genetic approaches to enhance climate resilience in ornamental plants focus on improving their tolerance to heat, drought and other environmental stressors. Breeding for drought and heat tolerance aims to select plants with efficient root systems, better water retention and enhanced physiological processes that help them survive under challenging conditions. This involves selecting traits like thicker cuticles, improved stomatal regulation and better water-use efficiency.

Genetic modification and CRISPR technologies for stress resistance

Genetic modification and CRISPR technologies offer a more targeted approach, using gene- editing tools to enhance stress tolerance by modifying genes related to heat shock proteins, water retention and drought stress responses. Transgenic approaches can introduce beneficial genes from other species, while gene stacking combines multiple stress-resistant traits into a single variety.

The contribution of plant genetics to the evolution of propagation practices

In the context of propagation, advanced methods like tissue culture and cloning are used to propagate plants with particular stress-resistant characteristics, ensuring the durability of these plants in future generations. Marker-assisted selection allows breeders to identify desirable traits at the genetic level, speeding up the breeding process. Additionally, genetic screening helps identify and select plants that possess traits related to climate resilience, ensuring that future ornamental plants can thrive in increasingly harsh environmental conditions. These approaches are crucial for maintaining the aesthetic value and sustainability of ornamental plants in the face of climate change (Table 1).

Sustainable practices in plant propagation

Sustainable practices in plant propagation are essential to reduce environmental impact while ensuring the long-term health of both plants and ecosystems (Fig. 1). As the global demand for ornamental plants continues to rise, adopting eco-friendly, water-efficient and regenerative approaches to propagation is becoming increasingly important.

Climate-resilient plant varieties: case studies and best practices

Successful case studies of ornamental varieties resilient to extreme weather

Successful case studies highlight ornamental plants that thrive in challenging climates, including extreme temperatures, droughts and heavy storms (Table 2). These plants are identified for their capability to withstand environmental stress, requiring minimal care and water. Their resilience makes them ideal for regions experiencing more frequent extreme weather events.

Native and adapted plant species for landscaping in a changing climate

Native and adapted plant species are essential for landscaping in a changing climate. These plants have evolved to thrive in specific regional conditions, offering greater resilience to extreme weather, pests and diseases (Table 2). They provide environmental benefits, including water conservation, soil stabilization and habitat support, while reducing maintenance needs.

Selecting abiotic stress tolerant ornamentals for urban environments

Heat- and drought-tolerant ornamentals are vital for urban environments facing rising temperatures and water shortages. These plants are selected based on their ability to endure extreme heat and minimal water availability, making them ideal for urban landscapes. They reduce irrigation demands, support biodiversity and contribute to sustainable, resilient city planning (Table 2).

Climate-adaptive propagation techniques for ornamental plants

The process of plant propagation plays a vital role in ensuring ornamental plants thrive in changing climates. In the context of urban landscaping, propagation techniques need to focus on species that can withstand harsher conditions, while ensuring fast and effective growth for landscape integration. Propagation of *Bougainvillea* through semi-hardwood cuttings treated with rooting hormones (e.g., IBA) is a climate-resilient method widely adopted in urban landscaping. *Bougainvillea* is drought-tolerant, thrives in poor soils and withstands high temperatures, making it suitable for arid and semi-arid urban areas. The use of mist chambers or polyhouse conditions for propagation enhances rooting success under variable climate conditions. Similarly, Hibiscus (*Hibiscus rosa-sinensis*) can be propagated using stem cuttings treated with rooting hormones under mist chambers or shade nets, allowing successful establishment even in coastal regions with high humidity and salinity. Another excellent example is *Tecoma stans*, propagated through softwood cuttings dipped in IBA and rooted under shade net conditions. This species is well-suited to semi-arid climates and performs well in low-irrigation urban zones.

Designing climate-resilient urban green spaces with ornamental plants

Climate-resilient propagation of ornamental plants involves selecting, growing and multiplying species that can withstand environmental stress, such as drought and extreme temperatures and continue to thrive in urban landscapes. By utilizing advanced methods such as tissue culture, enhancing seed and cutting

Table 1. Different approaches to enhance heat and drought resilience in ornamental species and trees through breeding, genetic modification and advanced propagation

	Ornamental species	Ornamental trees
Breeding for drought and heat tolerance	**Lavender (*Lavandula* spp.)**: Breeding to enhance drought resistance by selecting varieties possessing efficient root structures and stress- responsive genes like dehydrins and LEA proteins (7,8).	**Maple tree (*Acer* spp.)**: Breeding for better root systems, water retention and heat tolerance through traits like stomatal regulation and leaf wax coating (9).
	Echinacea (*Echinacea purpurea*): Developing drought-tolerant varieties through thicker cuticles, robust root systems and heat resistance to maintain flower production in high temperatures (10,11).	**Crabapple (*Malus* spp.)**: Selection for water-use efficiency, robust root systems and higher stress tolerance for urban landscapes (12,13).
	Ornamental grasses (e.g., *Pennisetum* spp., *Miscanthus* spp.): Enhancing drought tolerance by focusing on root-to-shoot ratios and stomatal conductance for improved water-use efficiency (14,15).	**Ginkgo (*Ginkgo biloba*)**: Focus on drought and heat tolerance through enhanced root growth and water-use efficiency (16,17).
Genetic modification and CRISPR technologies for stress resistance	**Petunia (*Petunia* spp.)**: CRISPR used to improve resistance to heat and drought by enhancing heat shock proteins and water retention (18,19).	**Poplar (*Populus* spp.)**: Genetic modification with CRISPR to enhance drought and heat resistance by modifying genes for stress tolerance and water retention proteins (20,21).
	Rose (*Rosa* spp.): Using CRISPR to target genes related to water-use efficiency and stress signaling (e.g., overexpression of DREB genes for drought tolerance) (22,23).	**Willow (*Salix* spp.)**: CRISPR experiments focused on enhancing drought resistance by modifying genes related to water uptake and stress tolerance (24,25).
The role of plant genetics in future propagation techniques	**Tissue culture for drought-tolerant varieties**: Propagation of *Coleus* through tissue culture to clone drought-resistant plants (26,27)	**Tissue culture in oak trees (*Quercus* spp.)**: Using tissue culture to preserve drought-tolerant traits and propagate oak trees with enhanced stress tolerance (28,29).
	Marker-Assisted Selection (MAS) in petunias and begonias: Using MAS to select for drought tolerance and pest resistance in breeding programs (30,31).	**Cloning of ornamental cherry trees (*Prunus* spp.)**: Propagation through cloning methods to ensure heat and drought-resistant cultivars (32,33).
	Cloning of heat-resistant ornamental plants: Cloning heat-resistant species like *Fuchsia* and *Impatiens* to preserve desirable traits (34).	**Marker-Assisted Selection (MAS) in red maple (*Acer rubrum*)**: Using MAS to select for drought and heat tolerance in red maples, speeding up the breeding process (35).

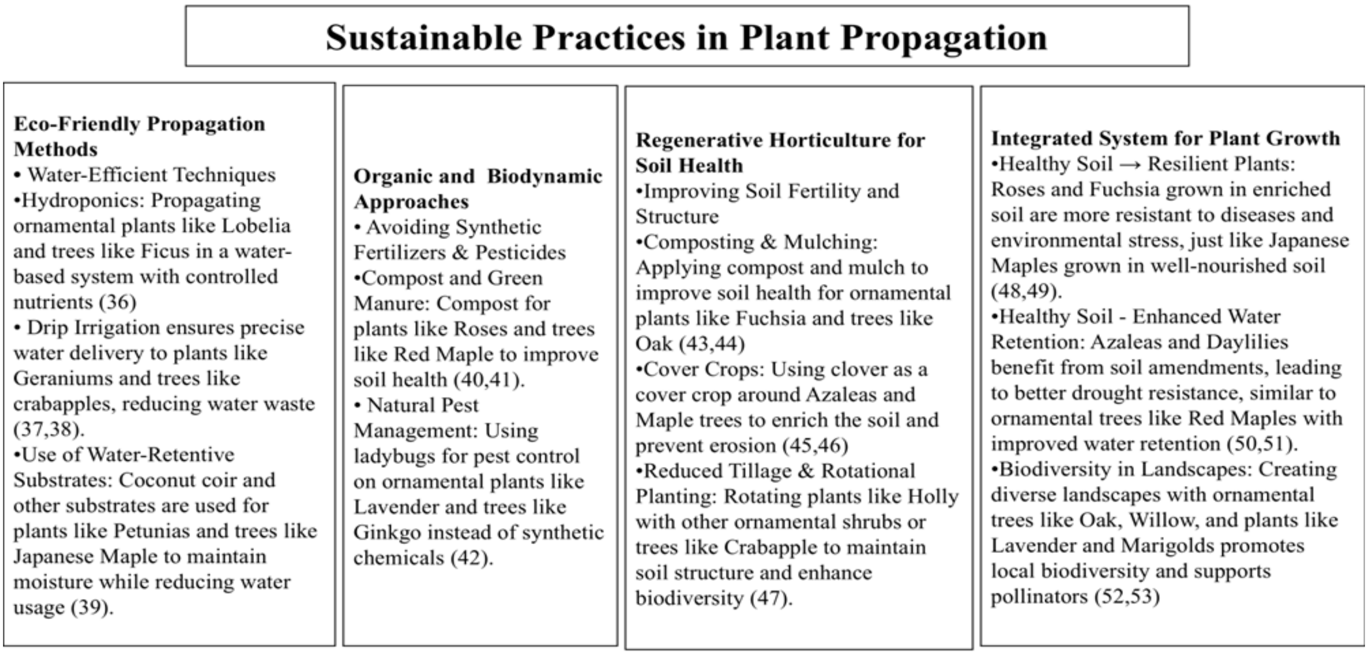

Fig. 1. Sustainable propagation practices for resilient ornamental plants and trees.

Table 2. The climate-resilient plant varieties based on case studies and best practices across different regions

Category	Case study	Plant species	Key characteristics	Benefits
Successful case studies of ornamental varieties resilient to extreme weather	Drought tolerant ornamental grass in california (54,55), urban greening in Sydney, Australia	*Pennisetum setaceum* (fountain grass), *Festuca glauca* (blue fescue), *Miscanthus sinensis*, *Callistemon* (bottlebrush), *Grevillea* sp.	Drought- resistant, minimal irrigation needed, adds texture and colour, ideal for water-scarce regions. heat-tolerant, drought-resistant, native to Australia, helps cool the urban environment and manage stormwater runoff.	Provides colour and texture, conserves water and manages soil erosion. Enhances aesthetic value, reduces urban heat island effect and mitigates stormwater runoff.
Native and adapted plant species for landscaping in a changing climate	Native shrubs and wildflowers in the Midwest United States (56,57)	*Echinacea purpurea* (purple coneflower), *Rudbeckia hirta* (black-eyed susan), *Asclepias* species (milkweeds), *Amelanchier* (serviceberry), *Symphoricarpos* (snowberry)	Adapted to fluctuating rainfall patterns and temperature extremes, native to the region, supports pollinators, combats soil erosion.	Provides habitat for wildlife, enhances biodiversity, reduces maintenance and controls soil erosion.
	Native and adapted plants for coastal landscaping in Florida (58,59)	*Ilex vomitoria* (yaupon holly), *Baccharis halimifolia* (groundsel bush), *Lantana camara*, *Helianthus debilis* (Beach Sunflower)	Tolerates drought, saltwater and high winds, ideal for coastal gardens.	Resilient to coastal conditions, attracts pollinators and provides vibrant colour in harsh environments.
Selecting heat- and drought- tolerant ornamentals for urban environments	Best practices for heat-tolerant ornamentals (60,61)	*Sedum* species (e.g., Sedum 'Autumn Joy), *Lantana camara*, *Lavandula angustifolia* (English lavender)	Heat- and drought-tolerant, thrives in hot, sunny conditions, low-maintenance, attracts pollinators.	Reduces water usage, enhances urban aesthetics, attracts pollinators and reduces the urban heat island effect.
	Best practices for drought-tolerant ornamentals (62)	*Agave*, *Yucca*, *Perovskia atriplicifolia* (Russian sage), *Eschscholzia californica* (California poppy)	Drought- tolerant, minimal irrigation required, architectural forms, thrives in dry conditions, ideal for xeriscaping.	Adds bold architectural elements, reduces water consumption, thrives in dry climates and supports pollinators.

propagation for drought-resistant species and tapping into local seed banks, cities can develop sustainable, water-conserving and visually appealing landscapes. These strategies are integral in ensuring that urban green spaces remain vibrant and functional in the face of a changing climate, supporting both ecological and human well-being.

Key Strategies

Use of tissue culture for mass propagation

Tissue culture (micropropagation) allows the rapid propagation of plants that are difficult to grow from seeds or cuttings. This technique can be specifically useful for developing huge numbers of resilient plants like *Sedum* (stonecrop) or *Thymus* (thyme), which are often used in hot, dry urban environments, including green roofs or vertical gardens (63,64).

Climate-resilient propagation for green roofs and vertical gardens

As green roofs and vertical gardens become more popular in urban planning, the propagation of plants suitable for these applications is essential to ensure their sustainability in hotter climates (65-67).

Propagation techniques

Hardening off propagated plants: plants propagated in controlled environments like greenhouses need to be gradually acclimatized to outdoor conditions-a process called "hardening off." This step is especially critical for plants used in green roofs and vertical gardens, where they must endure extreme heat and UV exposure. For example, plants like *Sedum* (used in green roof applications) are grown in controlled settings before being placed on roofs.

Cuttings for vertical gardens: Many vertical gardens rely on fast-growing plants that can be propagated from cuttings. Vines like *Trachelospermum jasminoides* (star jasmine) or *Clematis* can be propagated and used to cover vertical surfaces quickly. These plants must also be selected for their drought resistance, ensuring they flourish with minimal water supply (68,69).

Water-smart propagation for xeriscaping landscapes

In xeriscaping, where water conservation is a central focus, propagating plants that are adapted to dry conditions is crucial. Successful propagation methods need to ensure that these plants are both drought-tolerant and able to establish quickly in landscape settings without requiring excessive watering (70,71) (Table 3).

Propagation techniques

Succulent and xerophytic plant propagation: succulent species such as *Aloe vera, Agave* and *Echeveria* are perfect for xeriscaping and can be propagated through leaf cuttings, offsets or division. These plants store water in their leaves, which helps them thrive in dry conditions. The propagation of these species ensures that xeriscape landscapes are both water-efficient and aesthetically attractive (72).

Rooting cuttings for drought-tolerant shrubs: for ornamental shrubs that are well-suited for dry landscapes, propagation through softwood or hardwood cuttings is common plants like *Lavandula angustifolia* (lavender) and *Rosmarinus officinalis* (rosemary) are often propagated from cuttings to quickly establish hardy specimens for water-smart landscaping (73,74).

Leveraging local seed banks and localized propagation techniques

One of the most effective ways to propagate climate-resilient plants is through the use of local seed banks and native plant propagation. This approach not only ensures that the plants are well-adapted to the local climate but also supports biodiversity and ecosystem resilience.

Local seed banks and native plant propagation:

Seed collection and propagation of native species: seed banks dedicated to local species are becoming critical tools for maintaining plant diversity in urban areas. Many ornamental plants, including flowering natives such as *Rudbeckia* (black-eyed susan) or *Echinacea purpurea* (purple coneflower), can be propagated using seeds collected from local populations. These plants are more resilient to the changing climate, as they are naturally suited to the region's temperature and precipitation patterns (75,76).

Collaborative propagation programs: cities are starting to implement programs that involve local communities in collecting seeds and propagating native plants. These initiatives help increase the availability of plants suited to urban climates while fostering public engagement in climate resilience.

Mitigating climate change through plant selection and propagation

Mitigating climate change through the selection and propagation of ornamental plants is a key strategy in sustainable horticulture. Climate change adaptation requires the selection of plants that are both resilient to extreme conditions, such as heat stress, drought and variable rainfall and capable of supporting ecosystem services in urban environments. Propagation techniques, including seed propagation, cuttings and tissue culture, facilitate the mass production of these resilient plant species. By choosing drought-tolerant, native or climate- adapted varieties, plant propagation supports the development of green infrastructures like green roofs and xeriscaping, which aid in carbon sequestration, water management and temperature regulation in cities (Table 3).

Role of ornamental plants in carbon sequestration and climate mitigation

Ornamental plants, particularly trees and shrubs, play a pivotal role in mitigating climate change by acting as carbon sinks. Through photosynthesis, these plants capture carbon dioxide (CO_2) from the atmosphere, storing it in their biomass, including roots, stems and leaves. The global importance of urban greening has increased as cities strive to enhance carbon sequestration through landscaping practices. Various research findings suggest that large trees can sequester up to hundreds of kilograms of CO_2. Propagating carbon-storing species like *Quercus robur* (English oak) and *Pinus sylvestris* (Scots pine) in urban areas can significantly offset emissions and improve air quality.

Strategies for reducing water and energy consumption in plant propagation

Reducing the consumption of water and energy in ornamental plant propagation is essential for sustainable practices, particularly in regions facing water scarcity or energy demands. Efficient irrigation methods, such as drip irrigation and the use of hydroponics, reduce water waste by delivering water directly to plant roots. Furthermore, water-retaining soil amendments, like hydrogel or compost, can enhance moisture retention in soil during propagation. Energy consumption can be minimized using passive design techniques in greenhouses, such as natural ventilation, thermal mass and solar-powered systems for lighting and heating. These methods, combined with the selection of drought- resistant species, help reduce the environmental footprint of propagation processes.

Technological innovations in climate-smart horticulture

Role of IOT and AI in monitoring climate stress and plant health

IoT devices and AI technologies play a crucial role in monitoring climate stress and plant health. IoT sensors collect real-time environmental data, while AI analyses trend and detects stress indicators. This integrated approach enables early intervention, ensuring plant health is maintained despite climate fluctuations (Table 4).

Automated systems for optimized propagation in varying environmental conditions

Automated systems use sensors and data analytics to control environmental variables such as temperature, humidity and light, ensuring optimal conditions for plant propagation. These systems adapt to changing conditions, promoting consistent plant growth and enhancing resilience. Automation reduces human error and improves propagation efficiency across varying environments (Table 4).

Table 3. Mitigating climate change via plant selection and propagation, emphasizing ornamental plants' role in carbon sequestration, climate mitigation and strategies to reduce water and energy use

Topic	Examples
Role of ornamental plants in carbon sequestration and climate mitigation	**Carbon sequestration in trees**: Large trees like *Quercus robur* (English oak) and *Pinus sylvestris* (Scots pine) act as major carbon sinks, absorbing CO_2 from the atmosphere and storing it in their wood and roots (77-79). **Shrubs and perennials**: Plants such as *Echinacea purpurea* (purple coneflower) and *Lavandula angustifolia* (lavender) also contribute to carbon sequestration in urban landscapes, storing carbon in their roots and stems (80,81). **Green spaces in urban areas**: By integrating ornamental plants into green roofs, parks and public spaces, cities can increase their carbon absorption capacity, mitigating the effects of urban heat islands(82,83).
Strategies for reducing water consumption in plant propagation	**Drought-tolerant plants**: Propagate species that are well-adapted to dry conditions, such as *Agave* and *Sedum* (stonecrop), which need less water to thrive (84,85). **Hydroponic systems**: Use hydroponics or aquaponics for growing plants like *Lobelia* and *Petunias*, which use less water compared to conventional soil-based methods. Water in these systems is recirculated, minimizing waste (86). **Mulching**: Use organic mulches, such as wood chips or straw, to preserve moisture in the soil and reduce evaporation in propagated plants like lavender or thyme (87,88). **Rainwater harvesting**: Integrate rainwater harvesting systems in greenhouses or nurseries to capture and reuse water for irrigation during dry spells (89,90).
Strategies for reducing energy consumption in plant propagation	**Solar-powered greenhouses**: Use solar panels to power greenhouse lighting, heating and cooling systems, reducing reliance on fossil fuels (91,92). **LED grow lights**: Employ energy- efficient LED lights that use less power compared to traditional incandescent lights, reducing overall energy consumption for plant propagation (93,94). **Cold frames and shade cloth**: Use passive techniques like cold frames or shade nets to regulate temperature, reducing the need for artificial heating or cooling in plant propagation facilities. These methods are especially useful for propagating hardy plants like *Rudbeckia* (black-eyed susan) or *Salvia* (sage) (95,96). Incorporate energy-efficient materials and natural ventilation systems to reduce heating and cooling requirements, making the propagation process more energy-efficient(97,98).
Overall strategies for sustainable plant propagation	**Propagating climate-adapted varieties**: Use resilient ornamental plants such as *Lavender*, *Thymus* (thyme) and *Canna* (cannas), which are drought-tolerant and energy-efficient, reducing the need for intensive care. **Grafting for stress resistance**: Propagate ornamental species on rootstocks that are tolerant to extreme weather, poor soils, or water scarcity, ensuring long-term plant health in changing climates (99,100). **Soil health and water retention**: Improve propagation success by enriching soil with organic matter to improve water retention, making plants more resilient to drought conditions. Use methods like composting or adding biochar to soils used in propagation (101,102)

The use of drones and remote sensing for monitoring climate-resilient crops

Drones equipped with remote sensing technology capture high-resolution images and multispectral data of crops. This allows for detailed observation of plant health, detecting stressors like water deficiency, pests and diseases. Drones offer a cost-effective, efficient method for managing climate-resilient crops, providing data for timely interventions and improved productivity (Table 4).

Future directions and research needs

Interdisciplinary approaches for advancing climate-resilient horticulture

Advancing climate-resilient horticulture demands a multidisciplinary framework combining plant biology, environmental science, genetic engineering and advanced technological tools. For instance, the propagation of drought-resistant ornamental plants such as *Echinacea purpurea* (purple coneflower) has benefited from both ecological studies and genetic research. Understanding its natural mechanisms of drought tolerance such as deep root systems and reduced stomatal conductance has informed breeding programs. Interdisciplinary teams leveraging molecular biology and climate modelling can pinpoint specific genes related to these adaptive traits, facilitating the selection of cultivars suited to increasingly erratic climates. Similarly, the study of *Lavandula angustifolia* (lavender), which naturally thrives in Mediterranean climates, has demonstrated the importance of optimizing soil water retention strategies to enhance plant survival under water-limited conditions. Therefore, integrating such findings with systems biology is essential for improving ornamental propagation practices under a changing environment.

Emerging technologies and collaborative efforts in climate-resilient propagation

Table 4. The role of IoT, AI, automated systems and drones in enhancing plant propagation

	Impact on propagation
IoT sensors and AI algorithms	Soil moisture sensors automate irrigation in propagation beds. Prevents water stress and overwatering, increasing cutting survival rates (103,104)
	AI analyses environmental data to adjust humidity and temperature. Early stress detection and control improve rooting success (105).
	Smart propagation chambers control misting, temperature and light automatically. Maintains optimal rooting environment, enhancing uniformity and speed of root formation (106).
Automated system application	Sensor-controlled misting to regulate humidity. Maintains ideal moisture, improving rooting percentages (107).
	Automated temperature control in propagation rooms. Provides stable temperatures, reducing stress and promoting faster root growth (108,109).
	Automated lighting systems adjusting light intensity and duration. Enhances shoot development and synchronizes rooting stages (110).
	Integrated climate control systems adjusting multiple variables simultaneously. Creates uniform and optimal microclimates, increasing overall propagation success (111).
Drone/remote sensing application	Multispectral imaging detects early water stress in propagation beds. Allows targeted irrigation, increasing survival rates of cuttings (112,113).
	Thermal imaging identifies uneven moisture in rooting zones. Enables precise misting control, improving rooting percentages (114).
	NDVI mapping monitors health and vigor of cuttings and seedlings. Facilitates early pest/ disease detection, reducing propagation losses (115).
	High-resolution imaging tracks growth uniformity and vigor. Supports adjustments in environmental controls for better rooting (116).

Technological advancements play a pivotal role in enhancing the resilience of ornamental plants, particularly when it comes to genetic modification and tissue culture techniques. A prime example is the use of CRISPR-Cas9 technology to introduce genes that improve salt tolerance in species like *Nicotiana alata* (flowering tobacco), which is a popular ornamental. By targeting specific genes that control ion transport and osmotic stress, researchers can create plants that are more resilient to soil salinization-a growing concern in coastal and arid regions due to climate change. Similarly, emerging tissue culture techniques, such as micropropagation, have been instrumental in rapidly producing large numbers of resilient ornamental plants like *Calibrachoa* (million bells), which are sensitive to environmental fluctuations but can be bred to thrive in a variety of climates. Collaborative international research efforts are essential for optimizing these technologies, as demonstrated by the global initiatives aimed at improving ornamental plant propagation via genetic engineering and micropropagation.

Prioritizing research on ornamental plants considering climate change

Research into climate-resilient ornamental plants must be prioritized to ensure their adaptability to shifting environmental conditions. An exemplary case is the propagation of *Fuchsia* spp. a popular ornamental that is vulnerable to temperature extremes and water stress. By focusing on its genetic variability, researchers have identified certain cultivars of *Fuchsia* that exhibit greater cold tolerance, facilitating their cultivation in regions previously unsuitable for this species. Similarly, *Chrysanthemum* (a widely cultivated ornamental) research has focused on enhancing its tolerance to high temperatures and humidity, which are expected to increase due to climate change. Studies have identified key physiological traits, such as enhanced transpiration efficiency and heat shock protein expression, that contribute to improved resilience under high-temperature conditions. Furthermore, the exploration of interspecific hybridization, where wild relatives with greater drought tolerance are crossed with ornamental species, has led to the creation of more robust cultivars. This highlights the need for targeted research that not only considers the ecological and physiological resilience of ornamental plants but also their aesthetic and economic value to horticultural industries globally.

Conclusion

The development and propagation of climate-resilient ornamental plants are increasingly vital as urban ecosystems face rising challenges due to climate change. Unpredictable weather patterns, extended droughts, rising temperatures, salinity stress and increased urbanization necessitate the cultivation of plant species that can thrive under adverse conditions while still providing aesthetic and ecological value. In this context, recent advancements in plant propagation have opened new pathways for ensuring the survival and success of ornamental species in shifting environments. Innovative approaches such as the use of rooting hormones, controlled propagation environments and tissue culture techniques have enhanced the efficiency and adaptability of vegetative propagation. Moreover, genetic advancements, including the application of CRISPR-based genome editing, are enabling scientists to develop varieties with enhanced tolerance to drought, heat, salinity and pollutants. Alongside these, the integration of sustainable and low-input propagation practices supports the reduction of environmental impact while maintaining plant quality. Additionally, digital technologies such as Artificial Intelligence (AI), Internet of Things (IoT) and automation are revolutionizing nursery and greenhouse management. These technologies optimize microclimatic conditions for propagation, monitor plant health and reduce resource wastage-ensuring higher survival rates and improved plant performance in urban landscapes.

Real-world applications and case studies have demonstrated that climate-resilient ornamental plants, when propagated using advanced and eco-friendly methods, significantly contribute to low-maintenance, sustainable and visually appealing urban green spaces. From drought-tolerant *Bougainvillea* to pollution-resistant *Plumbago*, these species exemplify the direction in which ornamental horticulture must evolve to align with environmental needs. In conclusion, the strategic integration of modern propagation technologies, genetic tools and climate-smart practices holds the key to building a greener, more resilient future. As highlighted throughout this article, "Advancements in climate-resilient propagation of ornamental plants: strategies for a changing environment", it is imperative to prioritize innovations that not only enhance plant survivability but also promote sustainable urban greening in the face of escalating climatic pressures.

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Authors' contributions

SP conducted the primary literature search and drafted major sections of the manuscript. PS supervised the preparation of the manuscript and performed the final proofreading. SK organized thematic content and assisted in structuring the review. YA compiled and formatted references. VB contributed to the analysis of recent advancements and wrote the conclusion and future scope. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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