Technology in Horticulture

REVIEW

Open Access

https://doi.org/10.48130/tihort-0025-0005
Technology in Horticulture **2025**, 5: e010

Exploring the diversity, propagation, impacts, and market dynamics of houseplants: current trends and future prospects

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Abstract

Houseplant propagation has surged in popularity among plant enthusiasts, fueled by growing interests in sustainability, cost-effectiveness, and the therapeutic joy of cultivating new life. Traditional propagation techniques—such as stem cuttings, leaf cuttings, division, and air layering—are widely practiced for their simplicity and high success rates. Social media has significantly influenced this trend, serving as a powerful tool for sharing propagation knowledge and building communities among hobbyists. The rising demand for rare and exotic houseplants has further intensified interest in propagation, as collectors seek affordable ways to expand their collections. Recent advancements in plant science and biotechnology, including tissue culture, genetic engineering, and genome editing, present promising opportunities for enhancing propagation efficiency, particularly for delicate and rare species. This comprehensive review systematically classifies various houseplants and delves into cutting-edge propagation technologies, with a focus on *in vitro* micropropagation, new cultivar development, and their environmental and economic implications. Additionally, the review explores current marketing strategies and provides a forward-looking perspective on the future of the houseplant industry. By examining the latest innovations, market dynamics, and future prospects, this review aims to provide stakeholders with a deeper understanding of the evolving landscape of houseplant propagation, highlighting its potential for growth and innovation.

Citation: Oboni KA, Hossain MA. 2025. Exploring the diversity, propagation, impacts, and market dynamics of houseplants: current trends and future prospects. *Technology in Horticulture* 5: e010 https://doi.org/10.48130/tihort-0025-0005

Introduction

Houseplants, often cultivated for their visual appeal, are typically placed indoors, on terraces, or on lawns. While their sizes can vary, they usually do not exceed 5.5 feet in height. These plants can range from cacti and succulents to small flowering plants such as orchids and African violets. However, the most significant group among them is foliage plants, which, despite not always producing flowers, are cherished for their unique and attractive leaves[1]. Foliage plants form the backbone of the houseplant industry. As urbanization progresses and living spaces evolve, houseplants have become indispensable for creating environments that provide peace, coziness, and mental comfort. Moreover, the economic impact of the houseplant industry cannot be overlooked. The global market for houseplants has seen substantial growth, driven by increasing consumer awareness of their benefits and the rise of urban living. As people move to cities and living spaces become more compact, the need for greenery and natural elements within homes has intensified[2]. Houseplants offer a solution to this need, providing a touch of nature that can transform urban living spaces into green sanctuaries. This trend is further amplified by social media and digital platforms, where the aesthetic appeal of houseplants is prominently showcased, inspiring more people to adopt indoor gardening as a hobby or lifestyle choice. Beyond their aesthetic value, houseplants offer numerous benefits, including improving air quality, regulating room temperature and humidity, and fostering a positive environment. Research conducted in Japan, Norway, and the USA has demonstrated that indoor plants can alleviate stress, enhance productivity, and promote overall well-being[3]. Due to these benefits and the increasing trend towards modernization, the demand for houseplants and their market is continuously expanding.

Marketing strategies in the houseplant industry have also evolved to keep pace with the growing demand. Retailers and nurseries are increasingly utilizing online platforms to reach a broader audience, offering a wide variety of plants along with detailed care instructions and tips. Subscription services for houseplants have emerged, providing consumers with regular deliveries of new plants and related accessories. These innovative approaches not only make it easier for people to acquire and care for houseplants but also foster a sense of community among plant enthusiasts. The global indoor plants market size is expected to reach USD$14.753 billion by 2030 (market-reports).

Conventional propagation techniques with comparatively higher propagation rates like division, cutting, and water propagation are being used rather than slow propagation techniques like seed propagation[4]. In response to this growing demand, many developed countries have focused on the micropropagation of houseplants, enabling mass production and exportation[5,6]. This surge in demand has also spurred the development of new plant varieties. Advanced technologies such as CRISPR-Cas9, alongside conventional mutation procedures, are now being employed to create new ornamental varieties of houseplants[7,8]. Micropropagation, a form of plant tissue culture, involves the propagation of plants from small tissue sections in sterile conditions. This method allows for the rapid production of a large number of genetically identical plants, ensuring uniformity and high quality. Micropropagation techniques have advanced significantly, allowing for the efficient and cost-effective production of houseplants. This has not only met the rising demand but also facilitated the development of new and improved plant varieties. Through selective breeding and genetic modification, plants with enhanced aesthetic and functional attributes are being cultivated, catering to the evolving preferences of consumers[9].

The prospects for the houseplant industry are promising. Continued advancements in micropropagation and genetic engineering are expected to yield even more diverse and resilient plant varieties. Efforts to improve sustainability in plant production, such as reducing the use of chemical fertilizers and pesticides, are gaining traction. Additionally, the integration of smart technology in plant care, including automated watering systems and sensors for monitoring plant health, is set to revolutionize the way houseplants are maintained. This paper provides a comprehensive review of the status of houseplant production, with a particular emphasis on *in vitro* micropropagation. It examines recent advancements and developments in the field, explores marketing strategies, and considers future prospects. By delving into the challenges and opportunities in this sector, we aim to contribute to the ongoing efforts to enhance the availability and diversity of indoor plants. This review will help stakeholders to understand the dynamic landscape of the houseplant industry and the potential it holds for future growth and innovation.

Types of houseplants

The commercial production of ornamental plants is expanding globally, with its monetary value significantly increasing over the past two decades. This industry shows great potential for continued growth in international markets. In developed countries, major potted plants such as *Begonia, Ficus, Anthurium, Chrysanthemum, Rosa, Saintpaulia, Spathiphyllum, Philodendron,* and many others (Table 1) are commonly kept as houseplants. With the extended variety in size, color, and leaf type, houseplants have some similar properties like aesthetic appeal and a vibrant look (Fig. 1). Driven by elevated value and demand, the rate of houseplant production has surged significantly. As reported by Pierik[10], in 1991, approximately 212.5 million plants were produced, with 157 million of these classified as ornamental plants. This represents a substantial 78% of the total production, underscoring the prominence of ornamental varieties in the market[10]. The variable of houseplant classification is versatile. However, houseplants can broadly be categorized into two types based on their light requirements: indoor and outdoor. Outdoor plants, which need both bright light and shade, include foliage plants, cacti, succulents, and ornamental plants. Popular ornamental houseplants include moth orchids, bougainvillea, and peace lilies. There is also a wide variety of vibrant and unique cacti and succulents favored as houseplants. Cacti are hardy with impressive growth rates, while succulents can be challenging to sustain in warm, humid climates.

Foliage plants are a significant part of the industry due to their lower maintenance needs and their ability to effectively brighten up spaces. Foliage plants can be classified from various perspectives, such as water requirements, leaf size, plant toxicity, growth habits, and care levels needed (beginner-friendly, intermediate, or advanced). Additionally, foliage plants can be either variegated or non-variegated, with variegated ones typically receiving more attention and higher market value[11]. The classification is based on the biological and ecological properties of houseplants, emphasizing their practical care requirements and suitability for specific indoor environments (Fig. 2).

Environmental requirements for indoor plants

Foliage plants are commonly kept indoors due to their low maintenance needs. However, optimal water, temperature, and fertilization are crucial for the growth and health of indoor plants. Most houseplants can tolerate temperatures below 10 °C and up to 30 °C, although growth typically stalls at 15 °C, with the ideal temperature for indoor foliage being around 21 °C. Temperature fluctuations, particularly a difference of 20 °C between day and night, can cause significant stress to indoor plants[12].

Table 1. Some popular houseplants and their scientific names.

Scientific name	Common name	Scientific name	Common name
Aglaonema commutatum	Chinese evergreen	*Chlorphytum comosum*	Spider plant
Alocasia azlanii	Jewel alocasia	*Cissus rhombifolia*	Grape ivy
Aloe barbadensis	Aloe	*Codiaeum variegatum*	Croton
Anthurium andraeanum	Lace leaf	*Cordyline terminalis*	Ti plant
Aphelandra squarrosa	Zebra plant	*Crassula argentea*	Jade plant
Araucaria heterophylla	Norfolk island pine	*Cycas revolute*	Sago palm
Araucaria heterophylla	House pine	*Cyclamen persicum*	Florist's cyclamen
Asparagus densiflora	Asparagus fern	*Dieffenbachia seguine*	Dumb cane
Aspidistra elatior	Cast iron plant	*Dizygotheca elegantissima*	False aralia
Asplenium nidus	Bird's nest fern	*Dracaena marginata*	Dragon tree
Beaucarnea recurvata	Ponytail palm	*Dracaena sanderiana*	Lucky bamboo
Brassaia actinophylla	Umbrella plant	*Dracaena trifasciata*	Snake plant
Chamaedorea elegans	Parlor plant	*Epipremnum aureum*	Pathos
Euphorbia milli	Crown of thorns	*Philodendron erubescens*	Pink princess
Ficus benjamina	Weeping fig	*Philodendron scandens*	Heart leaf philodendron
Ficus elastic	Rubber plant	*Pittosporum tobira*	Pittosporum
Ficus lyrata	Fiddle-leaf fig	*Platycerium bifurcatum*	Staghorn fern
Fiscus lyrata	Fiddle leaf	*Pleomele reflexa*	Pleomele
Gardenia augusta	Gardenia	*Podocarpus macrophyllus*	Podocarpus
Gynura aurantiaca	Purple passion plant	*Saintpaulia ionantha*	African violet
Hedera helix	English ivy	*Schefflera actinophylla*	Umbrella plant
Helxine soleirolii	Baby tears	*Schefflera arboricola*	Hawaiian schefflera
Hoya carnosa	Wax plant	*Schlumbergera bridgesii*	Cuistmas cactus
Maranta leuconeura	Prayer plant	*Semperflorens Cultorum*	Begonia
Monstera deliciosa (*Albo borsigiana*)	Variegated monstera	*Soleirolia soleirolii*	Corsican creeper
Monstera obliqua	Broken heart plant	*Spathiphyllum wallisii*	Peace lily (white flag)
Nephrolepsis exaltata	Boston fern	*Syngonium podophyllum*	Nephthytis
Peperomia obtusifolia	Peperomia	*Tolmiea menziesii*	Piggyback plant
Phalaenopsis amabilis	Moon orchid	*Variegated Philodendron Minima*	Mini monstera

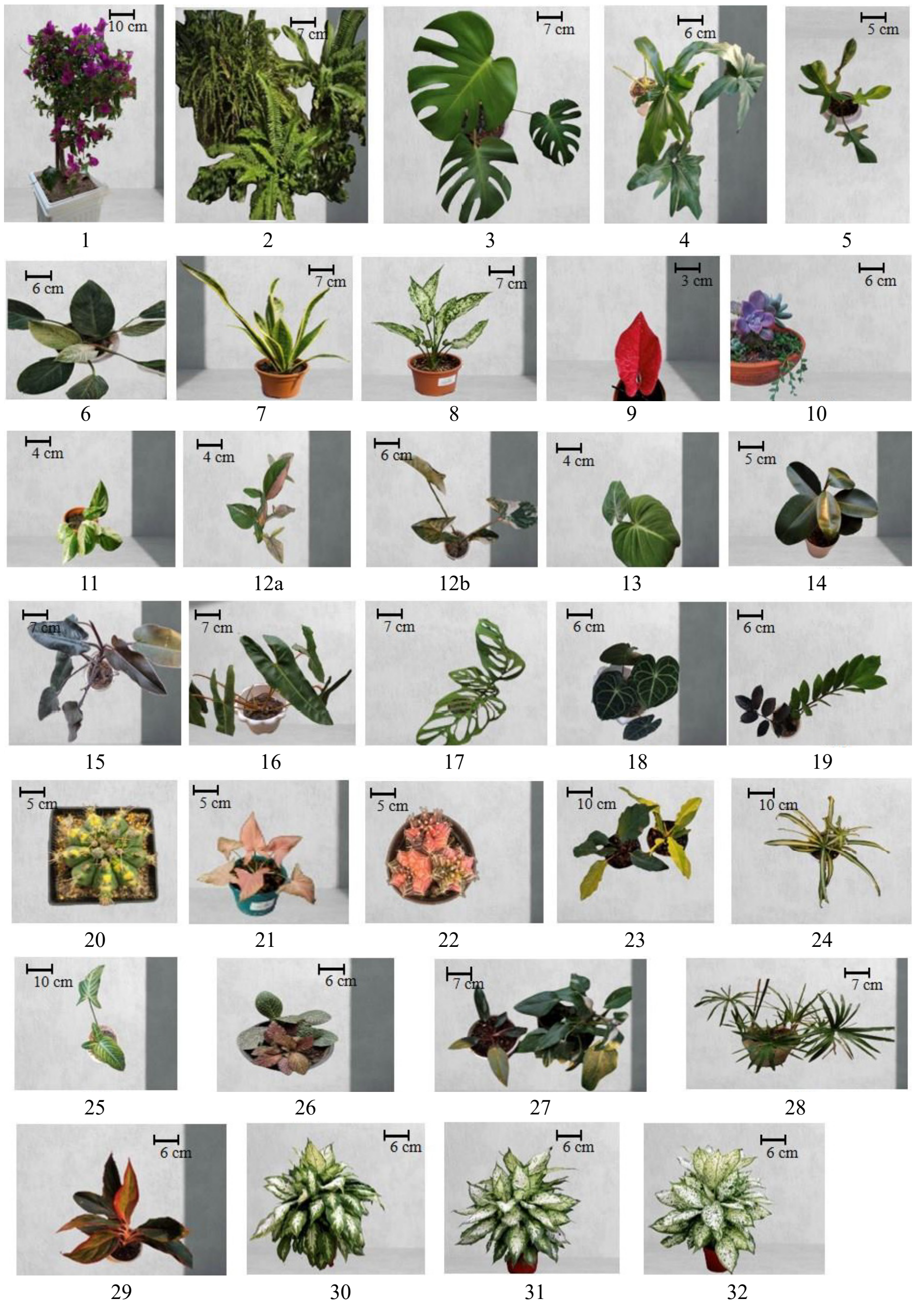

Fig. 1 Pictures of common houseplants. 1. *Bougainvillea glabra*, 2. *Nephrolepis cordifolia*, 3. *Monstera deliciosa*, 4. *Philodendron angela*, 5. *Philodendron Florida*, 6. *Philodendron Birkin*, 7. *Dracaena trifasciata*, 8. *Aglaonema commutatum*, 9. *Caladium bicolor*, 10. *Echeveria gibbiflora*, 11. *Epipremnum aureum*, 12a. *Syngonium podophyllum* (pink), 12b. *Syngonium podophyllum* (white), 13. *Philodendron melanochrysum*, 14. *Ficus elastic,* 15. *Philodendron Majesty*, 16. *Philodendron domesticum*, 17. *Monstera adansonii*, 18. *Anthurium crystallinum*, 19. *Zamioculcas zamiifolia*, 20. *Gymnocalycium damsii variegata*, 21. *Syngonium podophyllum*, 22. *Gymnocalycium mihanovichii*, 23. *Philodendron wendlandii*, 24. *Chlorophytum comosum*, 25. *Caladium lindenii*, 26. *Fittonia albivenis*, 27. *Philodendron erubescens*, 28. *Cyperus alternifolius*, 29. *Aglaonema Schott*, 30. *Carina*, 31, *Rebecca*, 32. *Sarah*. Images 1−29 were collected from local nurseries located in 24°22'26" N, 88°36'04" E and images 30−32 were adopted from Chen et al.[1].

Watering houseplants is an essential and sensitive step. Active growing plants, kept in comparatively hot weather with thin or large leaves require much water. When the plant media is hard on the surface or feels lighter, the plants require watering. Water can be sprayed over plants, simply poured into soil, or following the bottom watering process depending on the plant species. Hard water, containing high mineral levels can damage pH-sensitive plants[12].

Light source is another vital factor for indoor plant growth. Decades ago, incandescent bulbs were commonly used, but these emit red and orange light, which is not ideal for photosynthesis. Today, LED lights are more prevalent; while they do not replace sunlight, they support sufficient photosynthesis for plant survival[13]. Fluorescent lights are considered the best option for indoor plants, as they provide suitable wavelengths for photosynthesis without risking leaf burn. This type of light can also enhance the development of variegated plants, significantly increasing their value[14].

Fertigation is essential for potted plants, as there are no alternative nutrient sources available. During the growing phase, applying fertilizers every 14 to 28 d is recommended, using lower doses more

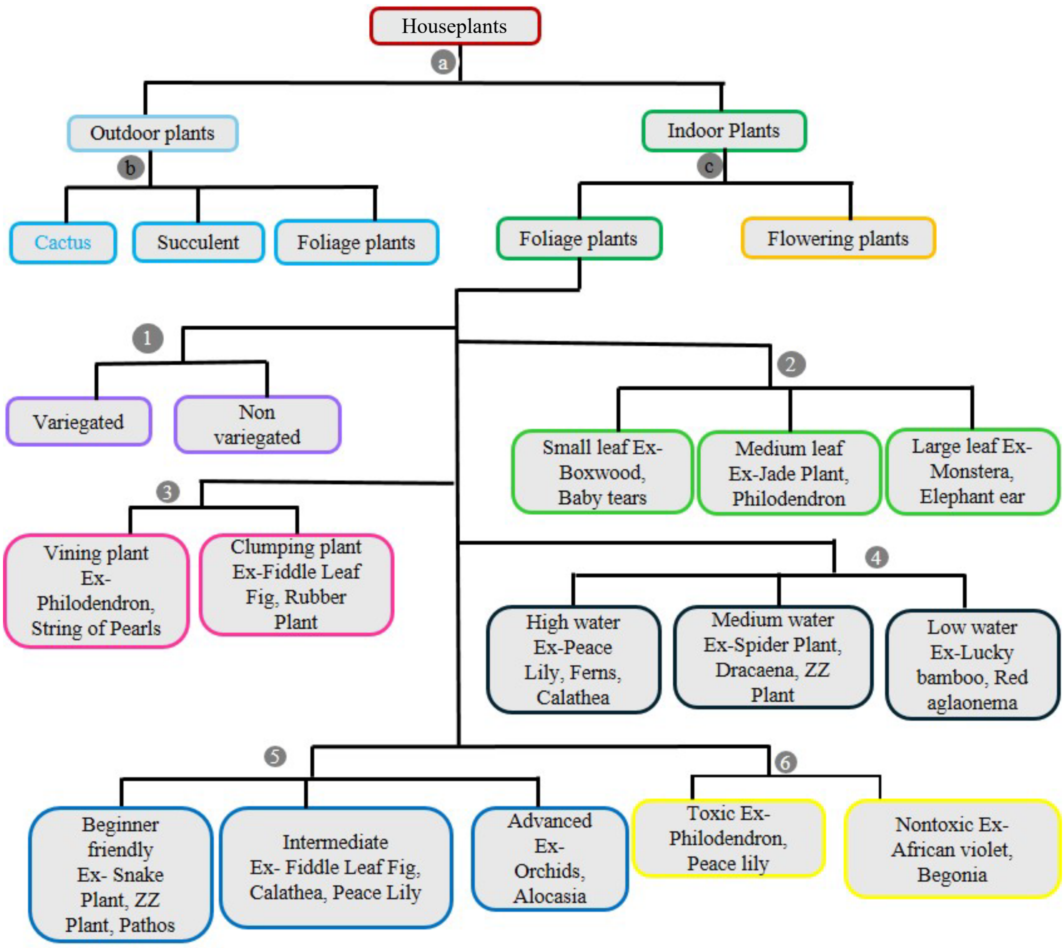

Fig. 2 Classification of houseplants. 1. Based on variegation, 2. based on leaf size, 3. based on growing structure, 4. based on water requirement, 5. based on care requirements, 6. based on toxicity.

frequently rather than high concentrations infrequently[15]. Indoor plants require both macronutrients—such as nitrogen, phosphorus, and potassium—and micronutrients for optimal growth[12].

Houesplant propagation

Propagation can be broadly classified into two categories, sexual propagation, and asexual propagation. Under asexual propagation they are propagated by leaf cuttings, stem cuttings, and division of suckers[4]. Propagation of houseplants can be by different processes like propagation by seed, cutting, division, layering, water propagation, and micropropagation (Fig. 3).

Seed propagation

Seed propagation is common for cactus and some flowering plants. The foliage and succulent produce hardly any seeds to propagate[16]. The succulents that can propagate through seeds are *S. acrem, S. album, S. kamtschatticum*, and *S. reflexum* including many others[17]. Though many of foliage plants produce seeds but this is not as popular a propagation method. *Hypoestes, Agrave, Cordyline, Dracaena, Nolina, Aocasia, Anthurium, Monstera, Philaodendron, Staphylium, Zamioculcas,* and many others are reported as seed-producing foliage plants[18].

Cutting propagation

Cutting propagation is one of the most convenient methods for foliage plants, often more cost-effective than tissue culture. A portion of the stem with a node can develop into a new plant under suitable conditions. The new plant is genetically identical to the mother plant. Cuttings can be categorized as cane, eye, leaf buds, or tip cuttings (Fig. 3a). This method is highly effective for succulents[19] and is used for many houseplants, such as *Pothos* and *Philodendron*[20].

Fig. 3 Propagation techniques of houseplants. (a) Cutting propagation, (b) layering, (c) water propagation, (d) micropropagation.

Types of cuttings:

(1) Stem cuttings: common for many houseplants like *Pothos* and *Philodendron*[20].

(2) Leaf cuttings: used for plants like African violets and begonias[21].

(3) Root cuttings: less common but used for plants like snake plants[22].

Advantages: faster growth compared to seeds, and clones of the parent plant[20].

Disadvantages: some plants are difficult to propagate this way[22].

Layering

Layering involves bending a stem to the ground or a pot of soil, covering part of it with soil, and waiting for roots to develop before severing it from the parent plant (Fig. 3b).

Types of layering:

(1) Air layering: common for larger houseplants like rubber plants and monstera[21].

(2) Ground layering: less common indoors but used for vining plants[20].

Advantages: high success rate, less stress on the parent plant[22].

Disadvantages: slower process can be cumbersome for indoor settings[20].

Water propagation

Water propagation is similar to cutting propagation where clean water is involved instead of soil or coco peat (Fig. 3c). This process is mainly a method of root formation but many foliage like lucky bamboo, philodendron, and pathos can easily propagate and grow in clear water. Water propagation is easy, cheap, and convenient for a commercial approach. The popular houseplant *Ficus benjamina* is difficult to propagate in soil but can be easily propagated in water[23]. *Dracaena sanderiana* (common name lucky bamboo), may not only propagate in water but also can be grown on clear water due to it's aesthetic appeal[24].

Advantages: high propagation success rate, genetic makeup is similar to the ex-plant[20].

Disadvantages: in water propagation nutrients are limited so growth can stall and roots may rot with time[25].

Propagation by division

Propagation by division involves dividing a plant containing plant roots or bulbs. It is the easiest method for plants that have bulbs or crowns[26]. Houseplants like *Zamioculcas zamiifolia*, *Aloe vera, Chlorophytum comosum*, and *Spathiphyllum* can be propagated in this manner.

In vitro micropropagation (tissue culture)

In vitro propagation is the most effective method to grow large-scale healthy plants in a short period. This technique, also known as micropropagation, can be carried out in various ways, such as meristem culture, somatic embryogenesis, and micropropagation via thin cell layers. Although micropropagation is not as convenient as traditional propagation techniques due to high production costs and the need for specialized laboratory facilities, it is particularly useful for producing new or variegated indoor plants (Fig. 3d). Industrial orchid cultivation, for instance, has successfully employed micropropagation as the primary propagation technique, proving to be both successful and economically beneficial[27].

Despite the challenges, micropropagation remains the most widely practiced method in the plant industry due to the high demand and price range of plants. However, successful micropropagation procedures used in industries are rarely documented as scientific discoveries due to business strategies and other issues.

The first successful micropropagation of *Anthurium* was reported in 1974[28]. Subsequent reports have documented the micropropagation of several *Anthurium* varieties. Several indoor plants, such as *Dracaena sanderiana*[29], and *Paphiopedilum orchid*[30] have been successfully micropropagated. Micropropagation of Lacy Tree Philodendron was reported in 2020[31]. *Monstera acuminata* Koch and *Monstera deliciosa* Liebm have been propagated *in vitro* recently[32]. Very recently *in vitro* propagation of *Philodendron erubescens* 'Pink princess' has been successful and claimed to be suitable for large scale production[33].

The practice of indoor plant micropropagation is increasing dramatically due to high market demand and its acceptability for maintaining variegation. However, maintaining aseptic conditions and selecting appropriate media components are crucial for successful micropropagation. Recent studies on developing micropropagation protocols for popular indoor plants are included here. Table 2 includes sterilization techniques, and Table 3 presents the culture media for several successful foliage plant tissue cultures with suitable media.

Table 2. Step-by-step protocols for surface sterilization.

Plant	Sterilization steps	Ref.
Ficus elastica, Ruby	1. Young upper leaves were washed with soapy water and washed again by tap water; 2. Washed with 1% $KMnO_4$ for 25 min; 3. Washed with 70% C_2H_5OH for 1 min; 4. Washed with 2%–6% chloramine B containing 25%–29% active chlorine for 5, 10, 15 min or with Domestos for 25 min; 5. Washed three times with distilled water.	[34]
Spathiphyllum, Peace lily	1. Explants were washed under running tap water for 1 h; 2. Washed with 70% ethanol for 30 min; 3. Washed with 15% sodium hypochlorite NaOH (Clorox + 0.01% Tween 20) for 7 min; 4. Rinsed with sterile water three times; 5. Dipped in 0.1% $HgCl_2$ solution for 5 min; 6. Rinsed five times with sterile water.	[35]
Zamioculcas zamiifolia, Black ZZ	1. Leaves were washed with dishwashing liquid for 20 min; 2. Explants placed under running tap water for 30 min; 3. Treated with 10% sodium hypochlorite (active chloride) for 10 min; 4. Disinfected with 0.1 mg/L $HgCl_2$ solution for 10 min; 5. Washed with ethanol 70% for 1 min; 6. Washed three times with sterile distilled water for 5 min.	[36]
Dracaena sanderiana, Lucky bamboo	1. Explants were rinsed 3–4 times with sterilized double distilled water. 2. Surfaces disinfected for 10 min in H_2O_2 (1%) solution.	[29]
Monstera deliciosa Liebm, Thai constellation	1. Washed in the sink with soap and water; 2. Surface sterilized using 2% sodium hypochlorite (NaClO) for 20 min; 3. Rinsed in dH_2O; 4. Washed with 2% sodium hypochlorite for another 20 min; 5. Lastly rinsed three times with water.	[37]
Monstera deliciosa, Liebm	1. Immersed in fungicidal antioxidant solution for 3 min with vacuum pump agitation; 2. Double immersion in 1.25% NaClO + three drops of Tween-20 for 15 min; 3. Immersion in 0.83% NaClO + three drops of Tween-20 for 10 min; 4. Two washes between each NaClO immersion, three final washes with sterilized distilled water; 5. Final immersion in antioxidant solution.	[32]
Monstera acuminata, Koch	1. Immersed in fungicidal antioxidant solution for 3 min with vacuum pump agitation; 2. Double immersion in 1.25% NaClO + three drops of Tween-20 for 15 min; 3. Immersion in 0.83% NaClO + three drops of Tween-20 for 10 min; 4. Two washes between each NaClO immersion, three final washes with sterilized distilled water; 5. Final immersion in antioxidant solution.	[32]

Table 3. Tissue culture media.

Plant	Basic media	Plant hormones and other nutrients	Culture process	Explant type	Ref.
Ficus elastica, Ruby	MS media pH 5.8–5.9	1.5 mg/L IAA and 0.5–4.0 mg/L BAP, 0.7% agar, 1 mg/L pyridine, 1 mg/L thiamine, 15 mg/L ascorbic acid, 40 g/L sucrose	*In vitro* regeneration of the plantlets	2–3 months old upper young leaves	[34]
Spathiphyllum, Peace lily	MS media, pH 5.7–5.8	BA 1.0–2.0 ppm, NAA 0.1–0.2 ppm, 0.8% agar, sucrose 25 g/L, Cu ion 2.5 ppm	Embryogenic suspension culture and regeneration	About 1.0 cm leaf blade from meristem	[35]
Zamioculcas zamiifolia, Black ZZ	MS media, pH 5.6–5.8	30g/L sucrose, 0.7% agar, 0.5 mg/L, NAA and 2 mg/L BA	*In vitro* regeneration of the plantlets	15 mm ×15 mm leaf	[36]
Philodendron erubescens, Pink princess	MS media	BAP 1.0 mg/L, 1-naphthaleneacetic acid (NAA) 0.5 mg/L, indole-3-butyric acid 3.0 mg/L (IBA), and 2,4-dichlorophenoxyacetic acid (2,4-D), Peat moss	*Ex vitro* acclimatization of the plantlets	1.0–1.5 cm, 4–5 leaves, and at least three roots	[33]
Dracaena sanderiana, Lucky bamboo	MS media, pH 5.6-5.8	6.78 μM 2,4-D, 46.5 μM CPA, 0.0–10.20 2,4-5-triacetic acids, 0.0–9.86 μM IBA, 0.0–10.73 μM NAA, 0.0–11.41 μM IAA	*In vitro* regeneration from nodal explants	Node 1 cm, internodal stem 1 cm, leaf 1 cm, axillary buds 1 cm and roots 1 cm	[29]
Monstera deliciosa Liebm, Thai constellation	MS media, pH 5.6–5.8	B5 vitamins supplemented with vitamin B5, 30 g/L sucrose, 2.5 g/L gellan gum, 7.5 mg/L BAP (6-benzylaminopurine), and 0.5 mg/L NAA, Bio stimulant IQ forte 3ml/L	*In vitro* clonal propagation	Axillary buds	[37]
Monstera deliciosa Liebm	MS media, pH 5.6–5.8	BAP 1 mg/L, 2,4-D 0.2 mg/L, PPM 1 mL/L	*In vitro* propagation and organogenesis	Mature leaves	[32]
Monstera acuminata, Koch	MS media, pH 5.6–5.8	benomyl solution, cysteine, BAP 1 mg/L, IAA 0.5 mg/L, NAA 0.1 mg/L	*In vitro* propagation and organogenesis	Mature leaves	[32]

Variegated houseplants

Variegated plants are characterized as plants possessing leaves with regular or irregular spots or patches. Patches are generated naturally or chemically, though plants with pathological infection, chlorophyll deficient lesions, or variegated areas outside of leaf blades are excluded from this group[38]. Several research articles[39] identify five anatomical categories of variegated plants: (1) Presence of non-green leaf areas due to chlorophyll deficiency. (2) Presence of intercellular air spaces just below the epidermis. (3) Specific morphology of adaxial epidermal cells. (4) Accumulation of non-photosynthetic pigments that conceal the green hue of leaves. (5) Presence of more epidermal cells and thicker outer tangential cell walls.

Additionally, variegation can be classified macroscopically; fishbone-shaped, blotched-shaped, V-shaped, spotted, striped, reticulate, and pinnate.

The main area of interest at present is understanding how plants can be rendered variegated. Variegation can occur naturally or be induced artificially. While natural variegation often stems from genetic factors and environmental conditions, artificial methods—including chemical treatments and light manipulation—can also create these patterns. This discussion examines both natural and induced variegation, highlighting recent horticultural techniques used to achieve and control these decorative effects (Fig. 4). Natural variegation occurs due to transposons, beneficial viruses, chimeras, gene expression manipulation, and controlled light exposure[40,41]. Variegation can also serve as a defensive mechanism or help plants resist environmental stress. For instance, the variegated leaves of *Arum italicum* accommodate photosystem-II, which increases photosynthesis under low light conditions[42]. Similarly, variegated leaves of *Hydrophyllum virginianum* protect against herbivory[43].

In modern horticulture, plants are intentionally variegated through light adjustments, chemical mutagens, or physical mutations to enhance their aesthetic appeal and market values. Popular methods include gamma rays, ion beams, colchicine, and metabolic route alterations. Ionizing radiation, such as X-rays and gamma rays, can cause chromosome rearrangement, while ion beam radiation produces single or double-strand breaks[44,45]. This mutation can cause shifting flower color in chrysanthemum and promote changes in chlorophyll production by carbon ion buildup[46]. The natural and chemical inducers of variegation are shown in Fig. 4.

Currently, few strategies for inducing variegation in indoor plants have been explored. Selective breeding and targeted propagation have established key foliage plants like *Aglaonema, Dieffenbachia, Dracaena, Epipremnum, Ficus, Hedera, Philodendron,* and *Syngonium*[47]. The latest trend focuses on developing propagated plants with induced variegation. Research by Taguchi shows that treatment with 4-methoxy-3,3'-dimethylbenzophenone can induce tiger stripe or partial leaf whitening variegation in plants such as *Philodendron oxycardium*, *Spathiphyllum patinii*, *Musa spp*, *Anthurium, Cymbidium*, and *Dracaena surculosa*. Additionally, 2,3,5-trichloro-4-hydroxypyridine induces tiger stripe variegation in *Dracaena fragrans*, while α-(2-naphthoxy) propionanilide induces similar variegation in *Epiphyllum pumilum*[48].

Development of new varieties

Developing new plant cultivars can be approached through several innovative techniques (Fig. 5) beyond the random use of physical and chemical mutagens. These include isolating unique mutants, somaclonal variation, controlling gene expression, genetic rearrangement using transgenes, and editing metabolic pathways. For example, physical and chemical mutagens can induce leaf color changes, which can be maintained through tissue culture. These changes can result in albino, greenish-white, white emerald, light green, greenish-yellow, etiolation, yellow-green, and striped varieties, affecting chlorophyll, anthocyanin, and other pigment production[49]. Treating *Zamioculcas zamiifolia* with colchicine can produce a dwarf variety with unusual black leaves, known as the black ZZ plant[7]. Chlorophyll synthesis involves 15 steps, and mutations in early enzyme production genes can cause albino or yellow leaves. Mutations in genes encoding aminolevulinic acid dehydratase, porphobilinogen deaminase, and uroporphyrinogen III cosynthase, involved in photosynthesis can lead to albino or yellow leaf phenotypes. This type of mutation in genes is responsible for patches or stripes on leaves[50]. In *Populus canadensis*, overexpression of the PtrMYB119 gene increases anthocyanin accumulation, leading to strong red pigmentation[51]. Similarly, overexpression of *Arabidopsis PAP1* induces high anthocyanin accumulation, resulting in dark purple leaves[52]. In *Setaria italica*, the *bHLH* transcription factor PPLS1 controls purple pigmentation in the pulvinus and leaf sheath. The V shaped variegation of *Trifolium repens* is regulated by *Rm, Rid,* and *Rl* genes[53]. Manipulating metabolic pathways by

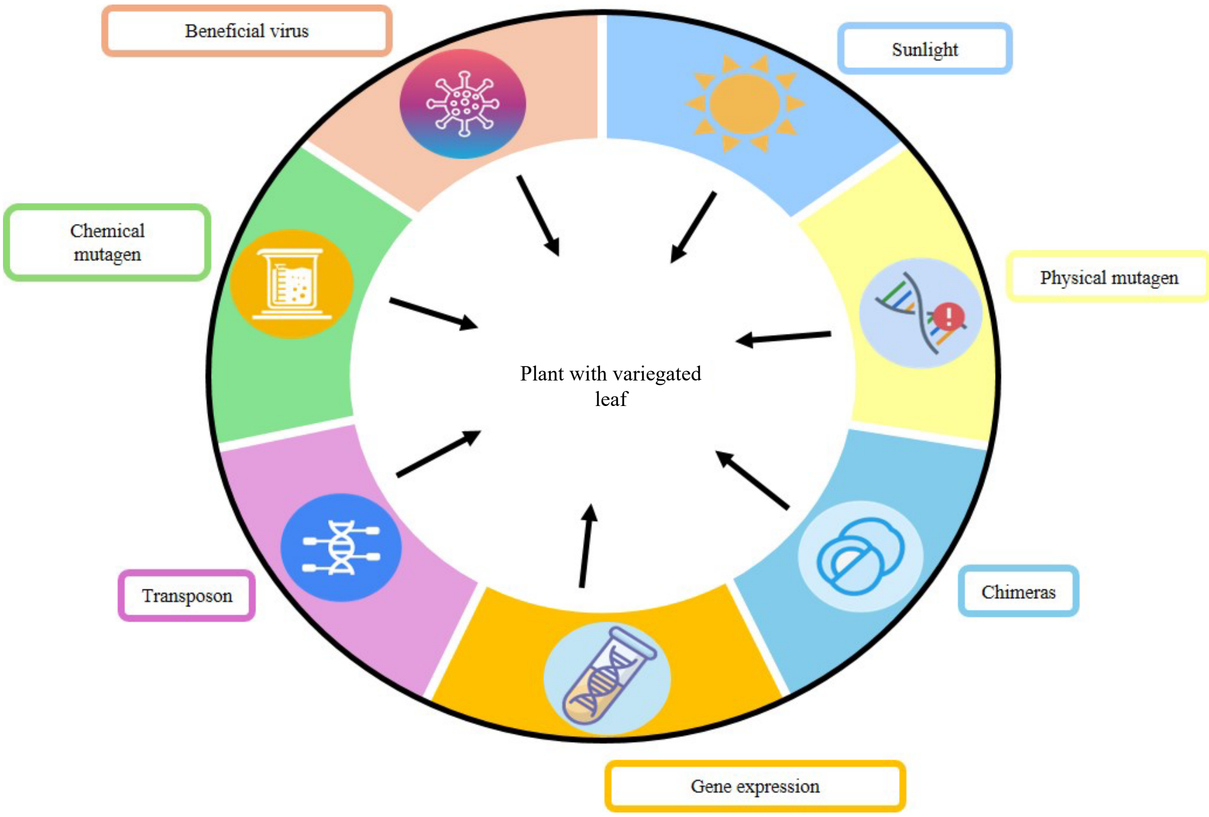

Fig. 4 Natural and chemical inducers of variegated houseplants.

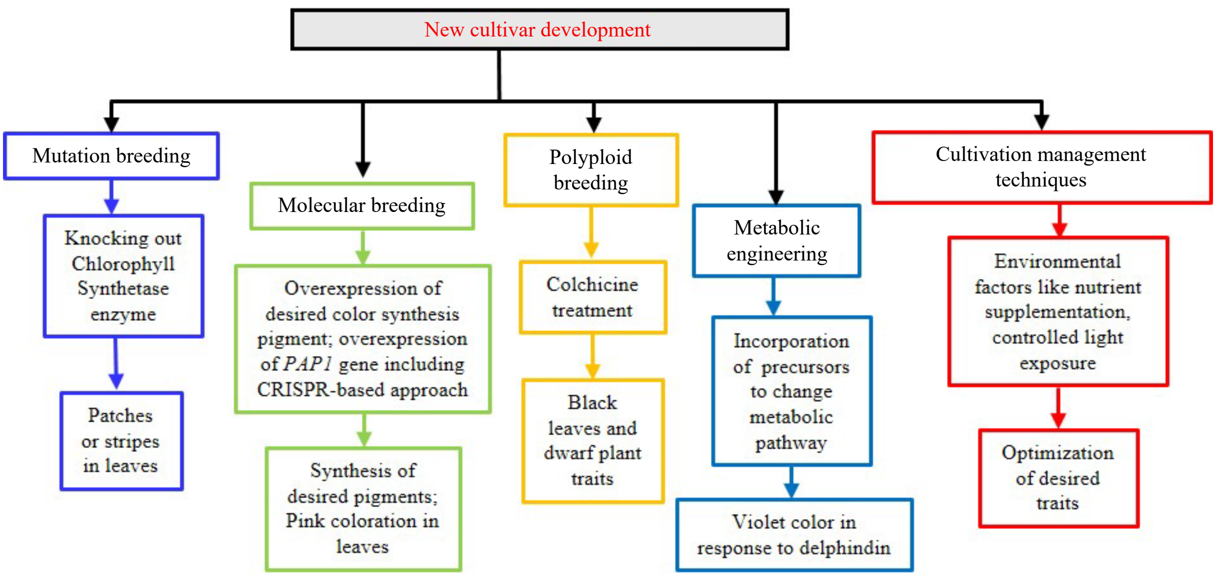

Fig. 5 Proposed approach for developing new cultivars of houseplants.

feeding selective precursors can induce desired traits. A study by Brugliera et al. showed that feeding delphindin precursor to *Chrysanthemums* can induce the desired violet color[54]. Genes like Bo9g058630 coding dihydroflavonol 4-reductase (DFR) and Bo3g 019080 coding shikimate O-hydroxycinnamoyltransferase (HCT) are studied in differentially expressed gene (DEG) approach and they affect anthocyanin, chlorophyll production in shades pink leaves, green-pink combined colored leaf. While transcription factors TT8, MYBL2, GATA21, GLK2, and RR1 are potential regulators of leaf color change in *Brassica oleracea* var. acephala[55]. RT-PCR analysis of leaf variegation of *E. aureum* 'Golden Pothos' showed little expression differences of a marker gene, *EaZIP* between green and whitish plants or between green and whitish sectors of a variegated leaf[56].

Somaclonal variation is an important source for the cultivar development of houseplants. Somaclonal variation can be defined as the phenotypic variation found among the houseplants regenerated through the passage of tissue culture[57]. It may occur during the plant's regeneration process through either organogenesis or somatic embryogenesis. *In vitro* culture houseplants generate somaclonal variants that can be novel and can be fixed through vegetative propagation. The variation includes morphological traits, response to biotic or abiotic factors, and production of specific compounds.

The extent of somaclonal variation can be determined as the percentage of plants showing alternation of one or more defined characteristics. Such plants are called 'somaclones'[57]. Plant tissue culture causes the wounding of explants, and it causes transposon activation[58]. *In vitro* explant culture can result in cell dedifferentiation, induction, and differentiation. During this process, cells may reset the genome expression due to exogenous stress and not follow the same orderly sequence that is usually followed under natural conditions[59]. Instead, the genome may be abnormally reprogrammed or decidedly restructured. This restructuring can give rise to wide ranges of altered phenotypes in the regenerated plants[60,61]. As a result, a longer regeneration process will produce more somaclones. Table 4 represents the number of somaclonal variants released so far based on the information available from open access resources.

CRISPR-Cas is another promising tool for developing new ornamental plant varieties. This technology allows for the silencing, overexpression, or point mutation of specific genes responsible for desired traits. Although its use in ornamental plants is still limited, it has shown revolutionary changes in fruit, vegetables, and medicinal plants. *Petunia hybrida* is the first ornamental plant edited with CRISPR-Cas9, with many others in development[7].

Impact of houseplants

Houseplants have a significant impact on various aspects of life. They improve air quality by absorbing toxins and releasing oxygen, enhancing overall well-being. Houseplants also reduce stress and boost mood by creating a calming environment. Additionally, they can increase productivity and concentration, making them beneficial for both homes and workplaces. The presence of houseplants stimulates economic growth through increased sales in the gardening and home decor industries. In workplaces, they can reduce absenteeism and indirectly benefit businesses financially. Furthermore, houseplants may enhance property values by improving the aesthetic appeal of homes and offices.

Mental and physiological health

Humans have a long-standing connection with plants, and the practice of keeping indoor plants is ancient due to their mental and physiological health benefits. Over the past three decades, numerous studies have confirmed these benefits[71]. Indoor plants create a soothing environment, improve air quality, and help alleviate respiratory and anxiety-related conditions. A Norwegian study of 385 office workers found that indoor plants positively impact stress management and productivity[72]. In the USA, employees reported an improved quality of life, with men showing a better response to indoor plants[73].

Table 4. Number of houseplants released from the selection of somaclonal variants.

Genera	No. of cultivars	Common cultivars derived from somaclonal variants	Ref.
Aglaonema	13	Diamod Bay, Emerald Bay, Moonlight Bay	[62,63]
Alocasia	2	Polly, Purpley	[63]
Anthurium	5	Lady Carmen, Orange Hot, SmallTalk Red, SmallTalk purple.	[63]
Calathea	7	Angela, Cora, Dottie, Eclipse, Rosey Roseo Picta, Satum	[64]
Dieffenbachia	20	Camouflage, carina, Rebecca, Sarah	[65]
Ficus	1	Cleo	[66]
Musa	1	French Reversion	[67]
Philodendron	4	Baby Hope, Hope Compact, Hope2, Gold Queen	[63]
Spathiphyllum	5	Cristina, Domino, Gayle's Green, Hi Ho Silver, White lightening	[63]
Syngonium	23	Banana Allusion, Berry Allusion, Bob Allusion, Bold Allusion, Cream allusion, Pink allusion	[63,68]
Torenia	1	Uconn white	[69,70]

NASA's Clean Air Study highlighted the air-purifying abilities of plants like the spider plant (*Chlorophytum comosum*) and peace lily (*Spathiphyllum*). Research in Japan and the USA indicates that indoor plants enhance productivity, reduce anxiety, improve mood, and increase energy and concentration[74,75]. Indoor plants are effective in managing anxiety and respiratory conditions, with foliage plants significantly helping symptoms related to mucous membrane neurophysiology[76]. A study showed that hospital patients exposed to plants for just 10 min experienced higher pain tolerance, lower self-rated pain intensity, and reduced electrodermal activity[77]. Patients recovering from surgeries with plants in their rooms had faster recovery, lower blood pressure, reduced fatigue, and less need for analgesics[78].

While the benefits of indoor plants are evident, further homogeneous research is needed for definitive conclusions. Existing studies, however, indicate that indoor plants positively affect human physical and mental health.

Improvement indoor air quality

Improving indoor air quality is essential, especially in spaces where volatile organic compounds (VOCs) from paints and furnishings can cause respiratory issues, irritation, and allergies, particularly in children[3]. Research has shown that indoor plants can reduce organic pollutants like benzene, toluene, ethylene, formaldehyde, xylene, and harmful compounds such as carbon monoxide, ozone, aldehydes, and ketones. Key species like *Sansevieria trifasciata*, *Chlorophytum comosum*, and *Epipremnum aureum* are effective in this process[79].

Indoor plants can decrease VOC concentrations by around 35%, though some ornamental plants may emit VOCs themselves[76,80]. Species such as *Hedera helix*, *Chrysanthemum morifolium*, *Dieffenbachia compacta*, and *Epipremnum aureum* can remove up to 96% of formaldehyde within 24 h[81]. Similarly, *Pelargonium domesticum*, *Ficus elastica*, *Chlorophytum comosum*, and *Kalanchoe blossfeldiana* can eliminate 85%–95% of benzene within the same period[82]. *Azalea indica* can remove 95% of toluene within 72 h[83], while *D. deremensis* and *O. microdasys* can eliminate 95% of toluene, xylene, and ethylbenzene within 48 h[79]. Furthermore, they have shown the capability to clear 95% of ozone within 2 h[84]. However, recent studies suggest that achieving substantial purification may require 10 to 1,000 plants per square meter[85].

Sustainability and environmental considerations

As environmental awareness grows, sustainability is becoming central to houseplant propagation. The industry faces scrutiny over its environmental footprint, especially regarding non-renewable resources like peat moss and carbon emissions from plant transport[86]. Future trends emphasize sustainability, with techniques like aeroponics showing success in cultivating varieties such as *Ficus*, *Philodendron*, and *Dracaena*[87]. Innovations like vertical farming, green walls, and green roofs enhance urban aesthetics and promote a healthy atmosphere. These solutions are increasingly integrated with advanced technologies, including IoT and robotics, to streamline maintenance and irrigation, furthering their environmental benefits[88,89].

Social and economic importance

Houseplants offer significant social and economic benefits. Aesthetically, they enhance the appeal of homes and workplaces, fostering inviting environments that encourage social interaction and community building. Economically, the houseplant industry has seen substantial growth, fueled by rising interest in home gardening and indoor plants. In recent years, rare varieties have driven this market to new heights. For example, *Philodendron Minima* (mini Monstera) sold for USD$8,150 in 2020, and a variegated *Monstera deliciosa* fetched USD$5,000 on Trade Me. In 2022, a variegated *Monstera adansonii* was sold for USD$38,000 on eBay due to limited supply and high demand (www.gardenista.com).

Prices for houseplants vary based on size, demand, and availability. Popular species like the Monstera Thai Constellation are priced between USD$99 and USD$140 due to their unique variegation. The *Monstera deliciosa* ranges from USD$48 to USD$228, influenced by size and variegation. *Zamioculcas zamiifolia* is priced from USD$48 to USD$198, while the Philodendron White Wizard and Pink Princess are around USD$98. More affordable options include the Bird's Nest Fern (USD$48–USD$78), *Apoballis lavallaei* (USD$78), and *Aglaonema pictum Tricolor* (USD$98–USD$128). The Stromanthe Triostar, with a price range of USD$58–USD$78, offers vibrant foliage at moderate cost. Budget-friendly choices like Devil's Ivy (USD$41–USD$51) and red Anthurium (USD$64) are popular among beginners and those seeking cost-effective greenery.

Current market for houseplants

The worldwide market for houseplants is witnessing significant growth due to their appeal for decorative purposes, the wide variety of available species, aesthetic value, ability to create refreshing and soothing environments, and the belief in their air-purifying properties. Additionally, houseplants add a new dimension to interior decor and enhance the visual appeal of living spaces. The monetary value of indoor plants has experienced a substantial increase since the 1980s, with considerable potential for further growth in both domestic and international markets[90]. Leading the forefront of indoor plant production are companies such as DÜMMEN ORANGE (USA), Syngenta (Switzerland), Beekenkamp Group (Netherlands), Hofland Flowering Plants (Netherlands), SAKATA (USA), DUTCH FLOWER GROUP (Netherlands), MARGINPAR BV (Netherlands), Walter Bloom Plants BV (Netherlands), Selecta Klemm, Double H Nurseries Ltd (Germany), ARCANGELI GIOVANNI (Italy), KP Holland (Netherlands), and Ball Horticultural Company (USA) (Indoor Plants Market By 2031)[91].

The indoor plant industry amounted to a business of USD$16.2 billion by 2022 solely in developed countries, a significant leap from the mere USD$13 million in 1949 and USD$574 previously (Indoor Plants Market Size, Share, Trends | Forecast, 2032)[92]. In the early 20th century, successful micropropagation of 156 species was achieved, with the Netherlands contributing 33%, Japan 24%, Italy 11%, and Thailand 10%, indicating a global effort to commercially produce ornamental plants[93]. Now the Netherlands is the leading exporter of micro-propagated plants, contributing 59% of global exports. Following the Netherlands are Italy with 16%, Colombia with 10%, Israel with 4%, Spain with 2%, Kenya with 1%, and other countries collectively making up 18% (Fig. 6). According to OEC world report 2022 the houseplant market has been taken over by Netherlands, Canada, USA, China and some others country (oec.world).

Future prospects in houseplant propagation

Houseplants have surged in popularity over the past decade, becoming a staple in homes, offices, and public spaces. This trend has not only transformed interior design but also spurred a growing interest in plant care and propagation. The future of houseplant propagation holds exciting potential, driven by advancements in technology, shifts in consumer preferences, and increasing awareness of the benefits of indoor greenery. The future prospects of houseplant propagation are explored by considering factors such as technological innovations, sustainability, and market trends.

The future of houseplant propagation is likely to see significant advancements in biotechnology. Tissue culture, also known as micropropagation, involves growing plants from small tissue samples in sterile, controlled environments. This method allows for the rapid production of large numbers of identical plants, ensuring uniformity and quality[9]. Advances in gene editing and nanotechnology are significantly influencing the ornamental plant industry, enhancing the efficiency and outcomes of micropropagation[94]. Current

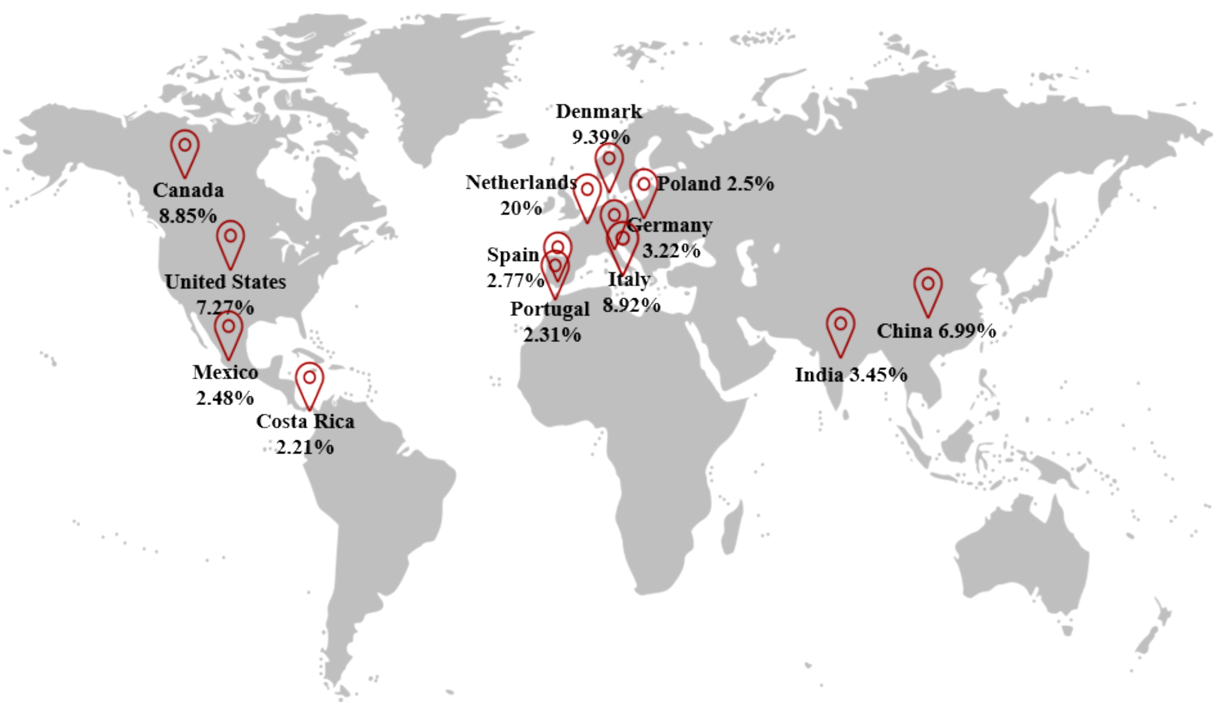

Fig. 6 Major houseplant exporter countries worldwide.

trends in micropropagation focus on optimizing tissue culture media by incorporating various plant growth stimulators, biostimulants, and light spectra[37,95,96]. The use of light spectra, a novel approach introduced in 2023, has shown promise in embryo production for terrestrial orchids[96]. AI models are increasingly applied to improve various stages of tissue culture, including *in vitro* sterilization, callus induction, shoot multiplication, and acclimatization. By analyzing a wide range of data—such as binary inputs (e.g., embryogenic vs non-embryogenic callus), discrete variables (e.g., number of roots and shoots), continuous variables (e.g., shoot length), time-series data, fuzzy inputs (e.g., callus color), and categorical variables (e.g., types of phytohormones)—AI facilitates a comprehensive understanding of the interactions among these variables[97]. Looking ahead, smart greenhouse technology promises to further enhance production efficiency by optimizing water supply, temperature, humidity, and lighting conditions for plants[98].

Genetic engineering tools such as CRISPR-Cas9 hold revolutionary potential by enabling precise gene editing to express desired traits. Manipulating genes responsible for color pigments can produce plants with uniquely vibrant hues, as seen experimentally in colorful Caladium varieties[99]. Furthermore, tissue culture technology offers substantial production scalability in short periods, essential for meeting increasing market demands globally.

Automation and artificial intelligence could revolutionize houseplant propagation by optimizing growing conditions and automating routine tasks. This could lead to higher success rates and lower labor costs[100].

Conclusions

The future of houseplant propagation is bright, driven by technological advancements, a focus on sustainability, and evolving consumer preferences. As the industry evolves, we can expect more accessible and innovative propagation methods, environmentally friendly practices, and a diverse market catering to a wide range of tastes and needs. Houseplants will continue to play a vital role in our lives, offering beauty, health benefits, and a connection to nature. The propagation of these plants, whether for personal enjoyment or commercial purposes, will be a dynamic and thriving field, reflecting broader trends in technology, sustainability, and lifestyle.

Author contributions

The authors confirm contribution to the paper as follows: study conception, project design, execution, data analyses, manuscript writing, revision and overall supervision: Hossain MA; data collection, analysis and manuscript drafting: Oboni KA. All authors reviewed the results and approved the final version of the manuscript.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors declare that they have no conflict of interest.

Dates

Received 4 September 2024; Revised 24 January 2025; Accepted 6 February 2025; Published online 17 March 2025

References

1. Chen J, Henny RJ, Chao CT. 2003. Somaclonal variation as a source for cultivar development of ornamental aroids. *Research Development in Plant Science* 1:31−43
2. Manaker GH. 1996. *Interior plantscapes: installation, maintenance, and management*, 3rd edition. (Cited July 15 2024). https://agris.fao.org/search/en/providers/123819/records/647361432c1d629bc97e8769
3. Deng L, Deng Q. 2018. The basic roles of indoor plants in human health and comfort. *Environmental Science and Pollution Research International* 25:36087−101
4. Cabahug RAM, Nam SY, Lim KB, Jeon JK, Hwang YJ. 2018. Propagation techniques for ornamental succulents. *Flower Research Journal* 26(3):90−101
5. Murray Ev, Rao Krp. 2006. Export opportunities for Indian floriculture. *Proc of the International Exposure Programme to Europe on Agribusiness Enterprises held from June 30 to July 9, India, 2005*. CAB, India. doi: 10.13140/RG.2.2.30202.82883
6. Schiva T. 2000. Strategies for development of commercial floriculture in Asia and the Pacific. *Report, SYP-41-99*. APO, New Delhi. pp. 27−38
7. Subburaj S, Chung SJ, Lee C, Ryu SM, Kim DH, et al. 2016. Site-directed mutagenesis in *Petunia* × hybrida protoplast system using direct delivery of purified recombinant Cas9 ribonucleoproteins. *Plant Cell Reports* 35:1535−44
8. Seneviratne KACN, Kuruppu Arachchi KAJM, Seneviratne G, Premarathna M. 2020. Zamioculcas zamiifolia novel plants with dwarf features and variegated leaves induced by colchicine. *Ceylon Journal of Science* 49(2):203−07
9. Mehbub H, Akter A, Akter MA, Mandal MSH, Hoque MA, et al. 2022. Tissue culture in ornamentals: cultivation factors, propagation techniques, and its application. *Plants* 11(23):3208
10. Pierik RLM. 1991. Micropropagation of ornamental plants. *Acta Horticulturae* 289:45−54
11. Demirarslan D, Gündoğdu Ş. 2021. Indoor plants: their use and importance. In *Housing Architecture and Design from the Past to the Future*, eds Demirarslan D, Tunalı SK. Lyon: Livre de Lyon. pp. 405−31
12. Rather DAMUD, Hajam DMA, Bhat MSA, Malik MI. 2023. *Horticulture: principles and practices*. India: Academic Guru Publishing House
13. Rehman M, Ullah S, Bao Y, Wang B, Peng D, et al. 2017. Light-emitting diodes: whether an efficient source of light for indoor plants? *Environmental Science and Pollution Research* 24(32):24743−52
14. Corth R, Jividen GM, Downs RJ. 1973. New fluorescent lamp for plant growth applications. *Journal of the Illuminating Engineering Society* 2:139−42
15. Haynes C, Hoyer J, Steil A. 2005. *Indoor Plants*. University Extension, Iowa State University
16. Mihalte L, Sestras RE, Feszt G. 2011. Methods to improve seed germination of Cactaceae species. *Bulgarian Journal of Agricultural Science* 17:288−95
17. Monterusso MA, Rowe DB, Rugh CL. 2005. Establishment and persistence of *Sedum* spp. and native taxa for green roof applications. *HortScience* 40(2):391−96
18. Chen J, Stamps RH. 2006. Cutting propagation of foliage plants. In *Cutting Propagation: A Guide to Propagating and Producing Floriculture Crops*. US: Ball Publishing. pp. 203−28
19. Baldwin DL. 2013. *Succulents simplified: growing, designing, and crafting with 100 easy-care varieties*. US: Timber Press. 272 pp
20. Hartmann HT, Kester DE, Davis FT Jr. 2010. *Hartmann & Kester's plant propagation: principles and practices*, 8th edition. Boston: Pearson
21. Rathour A, Kumar R. 2023. Plant Propagation Techniques in Horticulture. In *Recent Trend in Agriculture*. India: Integrated Publications New Delhi. pp. 125−40
22. Dole JM, Wilkins HF. 2005. *Floriculture: principles and species*. US: Prentice Hall. 613 pp
23. Tawfik AA. 2001. Fast and efficient mass-propagation of some ornamental plants using simple water air-flow medium. *Acta Horticulturae* 548:611−18

24. Gunathilake CC, Abeywickrama K. 2011. Growth promotion and preservation of bare rooted plants of *Dracaena sanderiana* for commercialization. *Tropical Agricultural Research and Extension.* 14:1–4
25. Tootoonchi M, Gettys LA, Ferrell JA, Erickson JE, Bhadha JH. 2023. Salt tolerance assessment of aquatic and wetland plants: increased salinity can reshape aquatic vegetation communities. *Hydrobiologia* 850:4575–87
26. Bryant G. 1995. *Propagation Handbook: basic techniques for gardeners*. US: Stackpole Books. 124 pp
27. Yam TW, Arditti J. 2018. Orchid micropropagation: an overview of approaches and methodologies. In *Orchid Propagation: From Laboratories to Greenhouses—Methods and Protocols*, eds. Lee YI, Yeung ECT. New York, NY: Humana Press. pp. 151–78. 10.1007/978-1-4939-7771-0_7
28. Pierik RLM, Steegmans HHM, Van Der Meys JAJ. 1974. Plantlet formation in callus tissues of *Anthurium andraeanum* Lind. *Scientia Horticulturae* 2(2):193–98
29. Aslam J, Mujib A, Sharma MP. 2013. *In vitro* micropropagation of *Dracaena sanderiana Sander* ex Mast: an important indoor ornamental plant. *Saudi Journal of Biological Sciences* 20:63–68
30. Ng CY, Saleh NM. 2011. *In vitro* propagation of *Paphiopedilum* orchid through formation of protocorm-like bodies. *Plant Cell, Tissue and Organ Culture (PCTOC)* 105(2):193–202
31. Alawaadh AA, Dewir YH, Alwihibi MS, Aldubai AA, El-Hendawy S, et al. 2020. Micropropagation of lacy tree *Philodendron* (*Philodendron bipinnatifidum* schott ex Endl.). *HortScience* 55(3):294–99
32. Casanova Palomeque NM, Bertolini V, Iracheta Donjuan L. 2021. *In vitro* establishment: *Monstera acuminata* Koch and *Monstera deliciosa* Liebm. *Trends in Horticulture* 4:13
33. Klanrit P, Kitwetcharoen H, Thanonkeo P, Thanonkeo S. 2023. *In vitro* propagation of *Philodendron erubescens* 'Pink Princess' and ex vitro acclimatization of the plantlets. *Horticulturae* 9(6):688
34. Mokshin E, Lukatkin A, Teixeira da Silva J. 2008. Aseptic culture and simple, clonal micropropagation of *Ficus elastica* Roxb. *Floriculture and Ornamental Biotechnology* 2:52–54
35. Ibrahim SMM, Hashish KI, Taha LS, Mazher AAM, Kandil MM. 2016. *In vitro* culture protocol, micropropagation, acclimatization and chemical constituents of *Spathiphyllum cannifolium* plant under copper concentration effect. *International Journal of PharmTech Research* 9:33–41
36. Pourhassan A, Kaviani B, Kulus D, Miler N, Negahdar N. 2023. A complete micropropagation protocol for black-leaved *Zamioculcas zamiifolia* (lodd.) Engl. 'Dowon'. *Horticulturae* 9(4):422
37. Jing Y, Beleski D, Vendrame W. 2024. Micropropagation and acclimatization of *Monstera deliciosa* Liebm. 'Thai Constellation'. *Horticulturae* 10:1
38. Zhang JH, Zeng JC, Wang XM, Chen SF, Albach DC, et al. 2020. A revised classification of leaf variegation types. *Flora* 272:151703
39. Campitelli BE, Stehlik I, Stinchcombe JR. 2008. Leaf variegation is associated with reduced herbivore damage in *Hydrophyllum virginianum*. *Botany* 86:306–13
40. Chen J, Wang Q, Henny RJ, McConnell DB. 2005. Response of tropical foliage plants to interior low light conditions. *Acta Horticulturae* 669:51–56
41. Marcotrigiano M. 1991. Understanding foliar variegation as it relates to propagation. *Combined proceedings - International Plant Propagators' Society*. Vol 41. pp. 410–15. https://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=6476538
42. Wang ZX, Yu YF, Chen L, Qin HY, Liu YX, et al. 2016. Advances in leaf pigment composition, structure and photosynthetic characteristics of colored-leaf plants. *Plant Physionlogy Journal* 52:1–7
43. Campitelli BE, Stehlik I, Stinchcombe JR. 2008. Leaf variegation is associated with reduced herbivore damage in *Hydrophyllum virginianum*. *Botany* 86(3):306–13
44. van Harten AM. 1998. *Mutation breeding: theory and practical applications*. Cambridge: Cambridge University Press. 353 pp. https://research.wur.nl/en/publications/mutation-breeding-theory-and-practical-applications
45. Goodhead DT. 1995. Molecular and cell models of biological effects of heavy ion radiation. *Radiation and Environmental Biophysics* 34:67–72
46. Yamaguchi H, Shimizu A, Hase Y, Tanaka A, Shikazono N, et al. 2010. Effects of ion beam irradiation on mutation induction and nuclear DNA content in *Chrysanthemum*. *Breeding Science* 60(4):398–404
47. Chen J, McConnell DB, Henny RJ, Norman DJ. 2010. The foliage plant industry. In *Horticultural Reviews*, ed. Janick J. US: John Wiley & Sons, Inc. Volume 31. pp. 45–110. doi: 10.1002/9780470650882
48. Taguchi M. 1988. *Method of producing variegated plant*. *European Patent Office*. EP0257845A3
49. Awan MA, Konzak CF, Rutger JN, Nilan RA. 1980. Mutagenic effects of sodium azide in rice. *Crop Science* 20(5):663–68
50. Sakuraba Y, Schelbert S, Park SY, Han SH, Lee BD, et al. 2012. STAY-GREEN and chlorophyll catabolic enzymes interact at light-harvesting complex II for chlorophyll detoxification during leaf senescence in *Arabidopsis*. *The Plant Cell* 24(2):507–18
51. Cho JS, Nguyen VP, Jeon HW, Kim MH, Eom SH, et al. 2016. Overexpression of *PtrMYB119*, a R2R3-MYB transcription factor from *Populus trichocarpa*, promotes anthocyanin production in hybrid poplar. *Tree Physiology* 36(9):1162–76
52. Borevitz JO, Xia Y, Blount J, Dixon RA, Lamb C. 2000. Activation tagging identifies a conserved MYB regulator of phenylpropanoid biosynthesis. *The Plant Cell* 12(12):2383–94
53. Bai H, Song Z, Zhang Y, Li Z, Wang Y, et al. 2020. The bHLH transcription factor PPLS1 regulates the color of *Pulvinus* and leaf sheath in foxtail millet (*Setaria italica*). *Theoretical and Applied Genetics* 133(6):1911–26
54. Brugliera F, Tao GQ, Tems U, Kalc G, Mouradova E, et al. 2013. Violet/blue chrysanthemums—metabolic engineering of the anthocyanin biosynthetic pathway results in novel petal colors. *Plant and Cell Physiology* 54(10):1696–710
55. Liu Y, Feng X, Zhang Y, Zhou F, Zhu P. 2021. Simultaneous changes in anthocyanin, chlorophyll, and carotenoid contents produce green variegation in pink-leaved ornamental kale. *BMC Genomics* 22:455
56. Zhao J, Zhang Q, Xie J, Hung CY, Cui J, et al. 2012. Plant regeneration *via* direct somatic embryogenesis from leaf and petiole explants of *Epipremnum aureum* 'Marble Queen' and characterization of selected variants. *Acta Physiologiae Plantarum* 34(4):1461–69
57. Larkin PJ, Scowcroft WR. 1981. Somaclonal variation—a novel source of variability from cell cultures for plant improvement. *Theoretical and Applied Genetics* 60(4):197–214
58. Grandbastien MA. 1998. Activation of plant retrotransposons under stress conditions. *Trends in Plant Science* 3(5):181–87
59. Phillips RL, Kaeppler SM, Olhoft P. 1994. Genetic instability of plant tissue cultures: breakdown of normal controls. *Proceedings of the National Academy of Sciences of the United States of America* 91(12):5222–26
60. Kaeppler SM, Kaeppler HF, Rhee Y. 2000. Epigenetic aspects of somaclonal variation in plants. *Plant Molecular Biology* 43:179–88
61. Mohan Jain S. 2001. Tissue culture-derived variation in crop improvement. *Euphytica* 118(2):153–66
62. Henny RJ, Chen J, Norman DJ. 2003. 'Diamond bay' and 'Emerald bay' *Aglaonema*. *HortScience* 38(7):1446–47
63. Chen J, McConnell DB, Henny RJ, Everitt KC. 2003. Cultural Guidelines for Commercial Production of Interiorscape Aglaonema. *EDIS* 2003:ENH957
64. Chao CT, Devanand PS, Chen J. 2005. AFLP analysis of genetic relationships among *Calathea* species and cultivars. *Plant Science* 168(6):1459–69
65. Henny RJ, Chen J, Norman DJ. 2006. 'Sterling' *Dieffenbachia*. *HortScience* 41(5):1356
66. Kristiansen K. 1992. Micropropagation of *Ficus benjamina* clones. *Plant Cell, Tissue and Organ Culture* 28:53–58
67. Vuylsteke DR, Ortiz R. 1996. Field performance of conventional vs. *in vitro* propagules of plantain (*Musa* spp., AAB group). *HortScience* 31(5):862–65
68. Chen J, Henny RJ, Devanand PS, Chao CT. 2006. AFLP analysis of *Nephthytis* (*Syngonium podophyllum* Schott) selected from somaclonal variants. *Plant Cell Reports* 24(12):743–49
69. Brand AJ, Bridgen MP. 1989. 'UConn white': a white-flowered *Torenia fournieri*. *HortScience* 24(4):714–15

70. Henny RJ, Chen J. 2008. Tropical foliage plant development: origin of new cultivars. *EDIS* 2008(2):ENH1092
71. Bringslimark T, Hartig T, Patil GG. 2009. The psychological benefits of indoor plants: a critical review of the experimental literature. *Journal of Environmental Psychology* 29(4):422−33
72. Bringslimark T, Hartig T, Patil GG. 2007. Psychological benefits of indoor plants in workplaces: putting experimental results into context. *HortScience* 42(3):581−87
73. Dravigne A, Waliczek TM, Lineberger RD, Zajicek JM. 2008. The effect of live plants and window views of green spaces on employee perceptions of job satisfaction. *HortScience* 43:183−87
74. Seiji S, Naoto S. 2002. Effects of the foliage plant on task performance and mood. *Journal of Environmental Psychology* 22:265−72
75. Lohr VI, Pearson-mims CH. 1996. Particulate matter accumulation on horizontal surfaces in interiors: influence of foliage plants. *Atmospheric Environment* 30(14):2565−68
76. Fjeld T. 2000. The effect of interior planting on health and discomfort among workers and school children. *HortTechnology* 10:46−52
77. Park SH, Mattson RH, Kim E. 2004. Pain tolerance effects of ornamental plants in a simulated hospital patient room. *Acta Horticulturae* 639:241−47
78. Park SH, Mattson RH. 2009. Therapeutic influences of plants in hospital rooms on surgical recovery. *HortScience* 44:102−05
79. Mosaddegh MH, Jafarian A, Ghasemi A, Mosaddegh A. 2014. Phytoremediation of benzene, toluene, ethylbenzene and xylene contaminated air by *D. deremensis* and *O. microdasys* plants. *Journal of Environmental Health Science and Engineering* 12:39
80. Yang DS, Son KC, Kays SJ. 2009. Volatile organic compounds emanating from indoor ornamental plants. *HortScience* 44(2):396−400
81. Aydogan A, Montoya LD. 2011. Formaldehyde removal by common indoor plant species and various growing media. *Atmospheric Environment* 45(16):2675−82
82. Cornejo JJ, Muñoz FG, Ma CY, Stewart AJ. 1999. Studies on the decontamination of air by plants. *Ecotoxicology* 8(4):311−20
83. De Kempeneer L, Sercu B, Vanbrabant W, Van Langenhove H, Verstraete W. 2004. Bioaugmentation of the phyllosphere for the removal of toluene from indoor air. *Applied Microbiology and Biotechnology* 64(2):284−88
84. Papinchak HL, Holcomb EJ, Best TO, Decoteau DR. 2009. Effectiveness of houseplants in reducing the indoor air pollutant ozone. *HortTechnology* 19(2):286−90
85. Cummings BE, Waring MS. 2020. Potted plants do not improve indoor air quality: a review and analysis of reported VOC removal efficiencies. *Journal of Exposure Science & Environmental Epidemiology* 30(2):253−61
86. Din A, Qadri ZA, Ahmad Wani M, Iqbal S, Ali Malik S, et al. 2022. Developing an efficient *in vitro* callusing and regeneration protocol in *Dendranthema* × *grandiflorum* Kitam. *Journal of Crop Science and Biotechnology* 25(4):393−405
87. Hayden AL. 2006. Aeroponic and hydroponic systems for medicinal herb, rhizome, and root crops. *HortScience* 41(3):536−38
88. Dhanaraju M, Chenniappan P, Ramalingam K, Pazhanivelan S, Kaliaperumal R. 2022. Smart farming: Internet of Things (IoT)-based sustainable agriculture. *Agriculture* 12(10):1745
89. Oliveira LFP, Moreira AP, Silva MF. 2021. Advances in agriculture robotics: a state-of-the-art review and challenges ahead. *Robotics* 10:52
90. Jain SK, Lettis WR, Murty CVR, Bardet JP. 2002. Introduction. *Earthquake Spectra* 18:1−4
91. Data Bridge Market Research. 2024. *Global indoor plants market – industry trends and forecast to 2031*. www.databridgemarketresearch.com/reports/global-indoor-plants-market
92. Acumen Research and Consulting. 2023. *Indoor plants market size - global industry, share, analysis, trends and forecast 2023–2032*. www.acumenresearchandconsulting.com/indoor-plants-market
93. Rout GR, Mohapatra A, Jain SM. 2006. Tissue culture of ornamental pot plant: a critical review on present scenario and future prospects. *Biotechnology Advances* 24(6):531−60
94. Zuzarte M, Salgueiro L, Canhoto J. 2024. Plant tissue culture: industrial relevance and future directions. In *Plants as Factories for Bioproduction*, ed. Steingroewer J. Cham: Springer. Vol 188. pp. 1–15. doi: 10.1007/10_2024_254
95. Ricroch AE, Hénard-Damave MC. 2016. Next biotech plants: new traits, crops, developers and technologies for addressing global challenges. *Critical Reviews in Biotechnology* 36(4):675−90
96. Naderi Boldaji H, Dianati Daylami S, Vahdati K. 2023. Use of light spectra for efficient production of PLBs in temperate terrestrial orchids. *Horticulturae* 9(9):1007
97. Hesami M, Jones AMP. 2020. Application of artificial intelligence models and optimization algorithms in plant cell and tissue culture. *Applied Microbiology and Biotechnology* 104(22):9449−85
98. Koukounaras A. 2021. Advanced greenhouse horticulture: new technologies and cultivation practices. *Horticulturae* 7(1):1
99. Zhou Y, Ye Y, Zhu G, Xu Y, Tan J, et al. 2023. Diversity, classification, and EST-SSR-based association analysis of *Caladium* ornamental traits. *Physiologia Plantarum* 175:e13841
100. Mihailović BM, Radosavljević K, Popović V. 2023. The role of indoor smart gardens in the development of smart agriculture in urban areas. *Ekonomika Poljoprivrede* 70(2):453−68