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LED Lighting in Ornamental Foliage Plants: Enhancing Growth, Quality, and Sustainability

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Ornamental foliage plants have gained immense commercial importance due to their aesthetic value and increasing demand for indoor landscaping and urban greening. However, conventional lighting systems often limit year-round production while increasing energy consumption and production costs. Light-emitting diode (LED) technology has emerged as an efficient and sustainable alternative, offering precise control over light spectrum, intensity, and photoperiod to optimize plant growth and quality. Different LED wavelengths influence key physiological and morphological processes, including photosynthesis, chlorophyll synthesis, biomass accumulation, leaf coloration, variegation, and plant architecture. The application of LEDs in greenhouses, indoor farming, vertical farming, tissue culture, and retail display has significantly improved production efficiency and ornamental quality while reducing heat generation and energy use. Integration of LED lighting with precision horticulture and controlled environment agriculture further enhances resource-use efficiency and environmental sustainability. Despite challenges such as high initial investment and species-specific lighting requirements, continuous technological advancements are expanding its commercial potential. LED lighting therefore represents a promising tool for sustainable, energy-efficient, and high-quality production of ornamental foliage plants, supporting the future development of modern ornamental horticulture.

Keywords: LED lighting, ornamental foliage plants, controlled environment agriculture, light spectrum, precision horticulture, sustainable production, plant quality.

Introduction

Ornamental foliage plants have gained significant commercial and aesthetic importance owing to rapid urbanization, increasing indoor gardening trends, and growing awareness of the health and environmental benefits of green spaces. Species such as *Aglaonema, Philodendron, Monstera, Syngonium, Dieffenbachia, Dracaena, Calathea,* and *Spathiphyllum* are valued for their attractive foliage, diverse leaf forms, vibrant colours, and adaptability to indoor environments. Their commercial value depends on superior foliage characteristics, including leaf size, colour intensity, variegation, compact growth, and shelf life, all strongly influenced by light conditions (Trivellini et al., 2023).

Light is a key environmental factor regulating plant growth and development. Besides driving photosynthesis, it controls chlorophyll biosynthesis, leaf expansion, stomatal movement, photomorphogenesis, pigment accumulation, and stress responses. Plant performance is influenced by light quality, intensity, and photoperiod, making light optimization essential for producing high-quality ornamental foliage plants under controlled environments (Paradiso & Proietti, 2022; Zheng et al., 2019).

Conventional lighting systems, including incandescent, fluorescent, and high-pressure sodium (HPS) lamps, are limited by high energy consumption, excessive heat generation, and poor spectral control. Light-emitting diode (LED) technology has transformed horticulture by

providing energy-efficient lighting with low heat emission, long operational life, and precise control of light spectrum, intensity, and photoperiod (Morrow, 2008; Singh et al., 2015).

Unlike conventional lighting, LEDs deliver specific wavelengths that regulate plant growth through photoreceptors such as phytochromes, cryptochromes, phototropins, and UVR8. Blue light promotes chlorophyll synthesis and compact growth, whereas red light enhances photosynthesis and biomass accumulation. Green, far-red, and white light further influence leaf expansion, pigmentation, and ornamental quality (Hogewoning et al., 2010; Bantis et al., 2018).

Recent advances in precision horticulture have expanded LED applications through sensors, automation, and smart production systems, improving energy efficiency and crop quality. This article reviews the principles of LED lighting, its effects on ornamental foliage plant growth and quality, technological advances, and its role in sustainable foliage production (Paucek et al., 2020; Trivellini et al., 2023).

Principles of LED Lighting in Ornamental Foliage Plants

Light-emitting diodes (LEDs) are semiconductor-based light sources that convert electrical energy into light with high efficiency and minimal heat generation. Unlike conventional lighting systems, LEDs emit narrow wavelengths, enabling precise control of light quality, intensity, and photoperiod according to plant requirements. This spectral flexibility allows growers to manipulate plant growth, morphology, and physiological processes while reducing energy consumption and production costs (Morrow, 2008; Bantis et al., 2018).

Plants perceive different wavelengths through specialized photoreceptors that regulate growth and development. Phytochromes absorb red (600–700 nm) and far-red (700–750 nm) light, controlling seed germination, stem elongation, branching, and shade avoidance. Cryptochromes and phototropins respond to blue light (400–500 nm), regulating chlorophyll synthesis, stomatal opening, leaf expansion, phototropism, and compact plant architecture. The UVR8 photoreceptor detects ultraviolet-B radiation and activates antioxidant production and pigment accumulation (Paradiso & Proietti, 2022).

The physiological response of ornamental foliage plants depends on light spectrum, intensity, photoperiod, and daily light integral (DLI). Optimizing these factors enhances photosynthesis, biomass accumulation, leaf coloration, and overall plant quality, whereas unsuitable lighting reduces growth and ornamental value (Zheng et al., 2019; Hogewoning et al., 2010).

Since ornamental foliage plants are valued primarily for their leaves, precise spectral management using LEDs effectively improves foliage colour, variegation, compactness, and market quality while supporting sustainable greenhouse and indoor production (Trivellini et al., 2023).

Effects of Different LED Spectra on Ornamental Foliage Plants

Light quality is one of the most influential factors regulating the growth, physiology, and ornamental value of foliage plants. Different LED wavelengths trigger specific physiological and biochemical responses through plant photoreceptors, allowing growers to manipulate plant architecture, leaf colour, biomass production, and overall quality (Bantis et al., 2018; Paradiso & Proietti, 2022).

Red light (600–700 nm)

Red light is highly efficient in driving photosynthesis and promoting biomass accumulation. It enhances leaf expansion, stem growth, and carbohydrate production, resulting in vigorous vegetative growth. However, when used alone, red light may induce excessive stem elongation and reduce leaf thickness; therefore, it is generally combined with blue light for balanced plant development (Massa et al., 2008; Zheng et al., 2019).

Blue light (400–500 nm)

Blue light regulates chlorophyll synthesis, stomatal opening, and leaf development. It promotes compact growth, thicker leaves, improved photosynthetic efficiency, and enhanced leaf coloration, making it particularly beneficial for ornamental foliage crops where visual

quality is the primary economic trait. Blue light also increases chlorophyll concentration and improves stress tolerance (Hogewoning et al., 2010; Trivellini et al., 2023).

Green and white light

Although less efficiently absorbed by chlorophyll, green light penetrates deeper into the plant canopy, contributing to whole-plant photosynthesis. White LEDs provide a broad spectrum that closely resembles natural sunlight, supporting balanced growth, improved foliage appearance, and consumer-preferred plant quality in indoor production systems (Paradiso & Proietti, 2022; Zheng et al., 2019).

Far-red and ultraviolet light

Far-red light influences stem elongation, leaf expansion, and canopy architecture through phytochrome-mediated responses, while ultraviolet (UV) light stimulates antioxidant activity, pigment accumulation, and protective stress responses. Controlled use of these wavelengths can improve foliage colour intensity and plant quality, although excessive exposure may adversely affect growth (Paradiso & Proietti, 2022; Bantis et al., 2018).

Combined LED spectra

Most ornamental foliage plants perform best under combinations of red and blue LEDs supplemented with white or green light. Balanced spectral lighting improves photosynthesis, leaf size, compactness, chlorophyll content, and ornamental quality while reducing energy consumption compared with conventional lighting systems (Paucek et al., 2020; Trivellini et al., 2023).

Table 1. Influence of LED lighting on ornamental foliage plants

Plant species	Recommended LED spectrum	Major response	Supporting reference
Aglaonema	Red + Blue + White	Improved leaf colour and compact growth	Trivellini et al. (2023); Paradiso & Proietti (2022)
Philodendron	Red + Blue	Increased leaf size and biomass	Trivellini et al. (2023); Zheng et al. (2019)
Monstera deliciosa	White + Blue	Enhanced leaf expansion and chlorophyll content	Paradiso & Proietti (2022); Bantis et al. (2018)
Syngonium podophyllum	Blue + White	Improved variegation and compact canopy	Trivellini et al. (2023); Zheng et al. (2019)
Dieffenbachia seguine	Red + Blue	Improved foliage quality and vegetative growth	Bantis et al. (2018); Paradiso & Proietti (2022)
Dracaena fragrans	White + Red	Increased biomass and leaf brightness	Zheng et al. (2019); Bantis et al. (2018)
Calathea spp.	Blue + White	Enhanced pigmentation and ornamental appeal	Trivellini et al. (2023); Paradiso & Proietti (2022)
Spathiphyllum wallisii	Red + Blue + White	Better growth, leaf quality, and marketability	Trivellini et al. (2023); Bantis et al. (2018)

Growth and Quality Responses of Ornamental Foliage Plants under LED Lighting

LED lighting significantly influences the morphological, physiological, and biochemical characteristics of ornamental foliage plants, thereby improving their commercial value. By regulating light spectrum, intensity, and photoperiod, LEDs enhance photosynthetic efficiency and optimize plant growth under greenhouse and indoor production systems (Bantis et al., 2018; Paradiso & Proietti, 2022).

One of the most notable effects of LED lighting is improved vegetative growth. Appropriate combinations of red and blue light increase leaf area, biomass accumulation, root development, and overall plant vigor while maintaining compact architecture desirable for ornamental foliage crops. Such spectral optimization also minimizes excessive stem elongation and promotes uniform canopy development (Massa et al., 2008; Hogewoning et al., 2010).

LEDs also improve leaf quality, the primary economic attribute of foliage plants. Blue-enriched spectra enhance chlorophyll synthesis, resulting in darker green leaves with greater colour intensity, while balanced spectral combinations improve leaf thickness, variegation, texture, and visual appeal. These improvements increase the marketability and consumer acceptance of ornamental foliage plants (Trivellini et al., 2023; Zheng et al., 2019).In addition to morphological improvements, LED lighting enhances several physiological and biochemical processes. Optimized light spectra increase photosynthetic efficiency, stomatal regulation, and carbohydrate accumulation while stimulating antioxidant enzyme activity and pigment synthesis. These responses improve stress tolerance, prolong shelf life, and maintain foliage quality during storage and transportation (Paradiso & Proietti, 2022; Bantis et al., 2018).

Furthermore, LEDs contribute to resource-use efficiency by reducing electricity consumption and heat generation compared with conventional lighting systems. Lower radiant heat minimizes plant stress and reduces cooling requirements in controlled environments, making LED technology an environmentally sustainable option for commercial foliage production (Singh et al., 2015; Paucek et al., 2020).

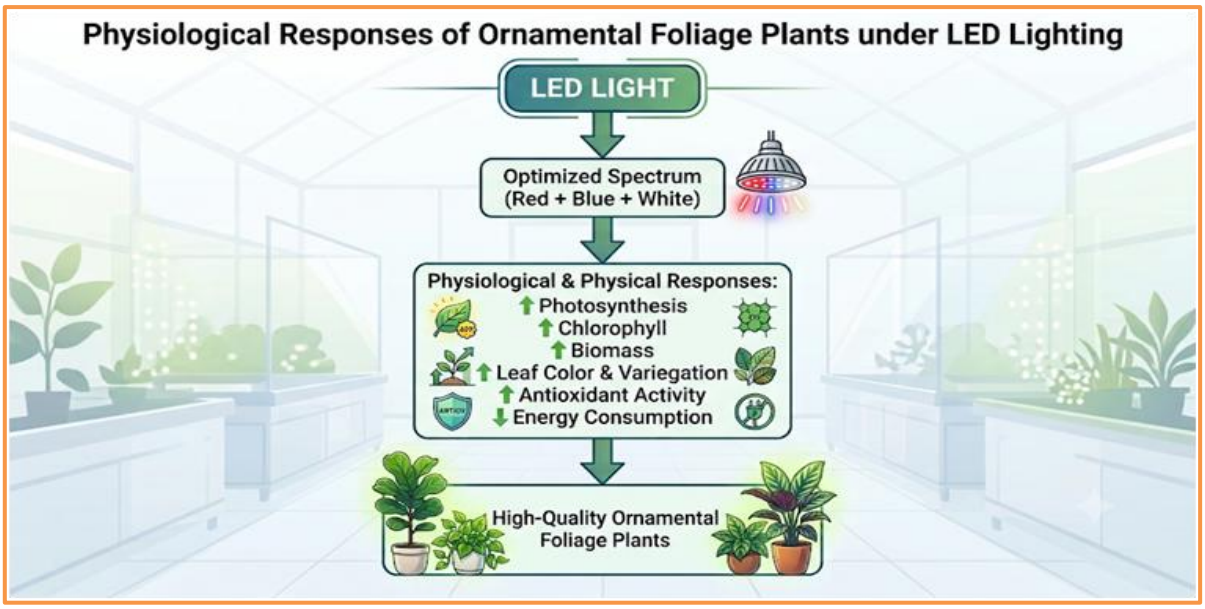

Figure 1. Physiological and morphological responses of ornamental foliage plants to optimized LED lighting.

Applications of LED Lighting in Ornamental Foliage Plant Production

- **Greenhouse production:** Supplements natural light to promote uniform growth, compact plants, and superior foliage quality (Morrow, 2008; Bantis et al., 2018).
- **Indoor and vertical farming:** Provides optimized lighting for year-round, resource-efficient production under controlled environments (Paucek et al., 2020).
- **Propagation and tissue culture:** Enhances shoot multiplication, rooting, and successful acclimatization of plantlets (Trivellini et al., 2023).
- **Retail display and interiorscaping:** Maintains leaf colour, delays senescence, and extends shelf life during marketing and indoor use (Paradiso & Proietti, 2022).
- **Precision horticulture:** Integrates with sensors and automation for efficient light management and energy savings (Zheng et al., 2019).

Benefits of LED Lighting in Ornamental Foliage Plant Production

- **Improves plant quality** by enhancing leaf colour, variegation, and overall ornamental appeal (Trivellini et al., 2023).
- **Enhances photosynthesis** and promotes healthy vegetative growth (Hogewoning et al., 2010).
- **Produces compact, uniform plants** with better market value (Paradiso & Proietti, 2022).
- **Reduces energy consumption** and operational costs compared with conventional lighting (Singh et al., 2015; Paucek et al., 2020).
- **Minimizes heat generation**, reducing the risk of plant stress and leaf damage (Morrow, 2008).
- **Supports sustainable production** through efficient resource utilization and lower carbon emissions (Bantis et al., 2018).

Challenges and Limitations of LED Lighting

- **High installation cost** limits adoption, especially among small-scale growers (Singh et al., 2015).
- **Species-specific light requirements** demand precise optimization of spectrum and intensity (Paradiso & Proietti, 2022).
- **Technical expertise** is required for effective lighting management (Bantis et al., 2018).
- **Dependence on electricity** increases operational risks during power interruptions (Paucek et al., 2020).
- **Limited species-specific research** restricts standardized LED recommendations for many foliage plants (Trivellini et al., 2023).

Conclusion

LED lighting has emerged as a transformative technology for ornamental foliage plant production by improving plant growth, leaf quality, and resource-use efficiency under controlled environments. Its ability to precisely regulate light spectrum, intensity, and photoperiod enables year-round production while reducing energy consumption and environmental impact. Despite challenges such as high initial costs and species-specific lighting requirements, continued advances in LED technology, automation, and precision horticulture are expected to drive wider adoption. Overall, LED lighting offers a sustainable and efficient solution for producing high-quality ornamental foliage plants and meeting the growing demand for premium indoor and landscape greenery.

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