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Growth Responses of *Mentha* spp. to Varying LED Light Intensities in Indoor Greening Applications

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Abstract. **Indoor greening using edible aromatic herbs such as mint provides aesthetic, therapeutic, and environmental benefits; however, knowledge about appropriate lighting conditions remains limited. This study evaluated the growth responses of three mint species (*Mentha canadensis* var. *piperascens*, *M.* ×*piperita*, and *M. spicata*) under varying photosynthetic photon flux densities (PPFD: 20, 100, 150, 200, and 250 μmol·m^{-2}·s^{-1}) provided by LED lights. On the basis of trends in dry shoot weight and soil plant analysis development values, PPFD levels around 150 to 200 μmol·m^{-2}·s^{-1} appeared suitable for cultivating *Mentha* spp., although no statistically significant differences occurred among some PPFD levels within species. Photoinhibition at 250 μmol·m^{-2}·s^{-1} resulted in decreased photosynthetic efficiency and chlorosis, and stem elongation occurred at 20 μmol·m^{-2}·s^{-1} due to light deficiency. These findings contribute to understanding species-specific responses of mint to indoor LED lighting, to inform suitable light level choices for indoor greening.**

Indoor greening is gaining popularity for its environmental and psychological benefits, such as air purification and stress reduction (Liu et al. 2022). Edible and aromatic herbs such as mint have demonstrated positive effects on well-being in indoor settings by stimulating multiple senses and creating therapeutic environments (Kubota et al. 2017). Unlike commercial indoor farms that prioritize productivity, indoor greening spaces emphasize visual comfort, aesthetics, and energy efficiency, requiring distinct lighting (Stamford et al. 2023) (Supplemental Table 1). Light-emitting diode (LED) lighting is widely used due to its energy efficiency, adjustable spectral composition, and minimal heat output. Previous research has shown the significance of LED spectral quality on plant morphology and growth (Paradiso and Proietti 2022). However, the typically employed red and blue LED spectra in plant factories, although effective for growth optimization, may be visually unappealing or uncomfortable in residential or office environments. Thus, determining suitable photosynthetic photon flux densities (PPFD) levels for indoor greening with visually comfortable LED lighting is essential. This study aimed to evaluate the growth responses of different mint species under varying PPFD levels provided by LED lighting in an indoor setting.

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Materials and Methods

The experiment was conducted from 19 Nov 2021 to 27 Jan 2022 in an office room (27 m^2) located in Chiba City, Japan (35°N, 140°E). Four open growth chambers (IRIS OHYAMA, Sendai, Japan; dimensions: 76 × 36 × 156 cm) equipped with LED light tapes (Lepro SMD 2835, 10 m, 600 LED) were used (Supplemental Fig. 1). LED lights emitted prominent peaks in blue (460 to 470 nm) and yellow wavelengths (570 to 580 nm), achieving a correlated color temperature around 4000 K. Temperature (20 to 27 °C) and humidity (30% to 60%) were controlled. Five LED lighting intensities [PPFD: 20 μmol·m^{-2}·s^{-1} (1200 lx), 100 μmol·m^{-2}·s^{-1} (5000 lx), 150 μmol·m^{-2}·s^{-1} (7500 lx), 200 μmol·m^{-2}·s^{-1} (10,000 lx), and 250 μmol·m^{-2}·s^{-1} (12,500 lx)] were selected based on previous literature on mint cultivation and typical indoor plant conditions (Hassani et al. 2010). The spectral composition showed ∼30% blue photons (460 to 470 nm) and 70% yellow photons (570 to 580 nm). The correlated color rendering index (CRI) of the LED lighting was ∼85. Light levels at each shelf were assessed at the base of each of the three plants and adjusted so that the average was the PPFD value set for that particular treatment. Lights operated daily for a 14-h photoperiod (8:00 AM to 10:00 PM). Three common mint species, *Mentha canadensis* var. *piperascens*, *Mentha* × *piperita*, and *Mentha spicata* (Supplemental Table 2), sourced from Park Corporation (parkERs 2024). Plants were nursery-grown in Shizuoka for 1 year under standard protocols. Initial plant sizes were uniform. Plants were potted in hexagonal 0.9-L containers filled with sustainable parkER soil (coffee grounds, coconut husks, bamboo charcoal). Three pots per species were randomized in trays (23.8 × 34.0 × 7.3 cm). Plants received weekly irrigation via bottom watering, with no additional fertilizer applied throughout the experiment. The SPAD values of five leaves were measured using SPAD-502Plus chlorophyll meter (Konica Minolta, Tokyo, Japan) biweekly and the average was treated as the SPAD value of the plant. Shoot dry weight was measured after drying at 70 °C for 72 h. Statistical analyses employed R software version 4.3.2. Dry shoot biomass was evaluated by one-way analysis of variance (ANOVA), with Tukey's honestly significant difference for post hoc comparisons. Before ANOVA, normality of data distribution was assessed using the Shapiro–Wilk test, and homogeneity of variances was checked using Levene's test. Soil plant analysis development (SPAD) trends were based on biweekly observations. SPAD values were analyzed using linear mixed models with PPFD as fixed and block as random factors, and Bonferroni's method for post hoc analyses.

Results

The mean dry shoot weight of each plant species at the end of the experiment is shown in Fig. 1. *M.* ×*piperita* had the highest shoot weight, followed by *M. spicata* and *M. canadensis* var. *piperascens*. Overall, the dry shoot weight increased as PPFD increased; however, growth was limited at 250 μmol·m^{-2}·s^{-1} because of photoinhibition. Photoinhibition is a state of physiological stress that occurs in all oxygen-evolving photosynthetic organisms exposed to excessive light (Adir et al. 2005). In *M. canadensis* var. *piperascens*, there were no significant differences between light treatments, and the plants exhibited low dry shoot weights regardless of PPFD. For *M.* ×*piperita*, the best growth was observed at 150 μmol·m^{-2}·s^{-1}, with yellow leaves appearing above 200 μmol·m^{-2}·s^{-1}. In *M. spicata*, the best growth occurred at 200 μmol·m^{-2}·s^{-1}, and yellowing occurred at 250 μmol·m^{-2}·s^{-1}, similar to the other two species (Supplemental Fig. 2). In all *Mentha* spp., significant differences were observed in SPAD values (Fig. 2). A high SPAD value was observed at 100 μmol·m^{-2}·s^{-1} in *M. canadensis* var. *piperascens.* In *M.* ×*piperita,* SPAD values decreased as PPFD increased, with the highest SPAD value at 20 μmol·m^{-2}·s^{-1} and the lowest at 250 μmol·m^{-2}·s^{-1}. *M. spicata* showed that SPAD values increased as PPFD increased, with higher SPAD values at 150 μmol·m^{-2}·s^{-1}, 200 μmol·m^{-2}·s^{-1}, and 250 μmol·m^{-2}·s^{-1}.

Discussion

This study demonstrates that LED lighting can support successful cultivation of *Mentha* spp. if light levels are appropriately selected (Supplemental Fig. 2). PPFD levels around 150 to 200 μmol·m^{-2}·s^{-1} were found to be suitable for *Mentha* spp. cultivation, although no statistically significant differences occurred among some PPFD levels within species. In general, low light intensities induce stem and

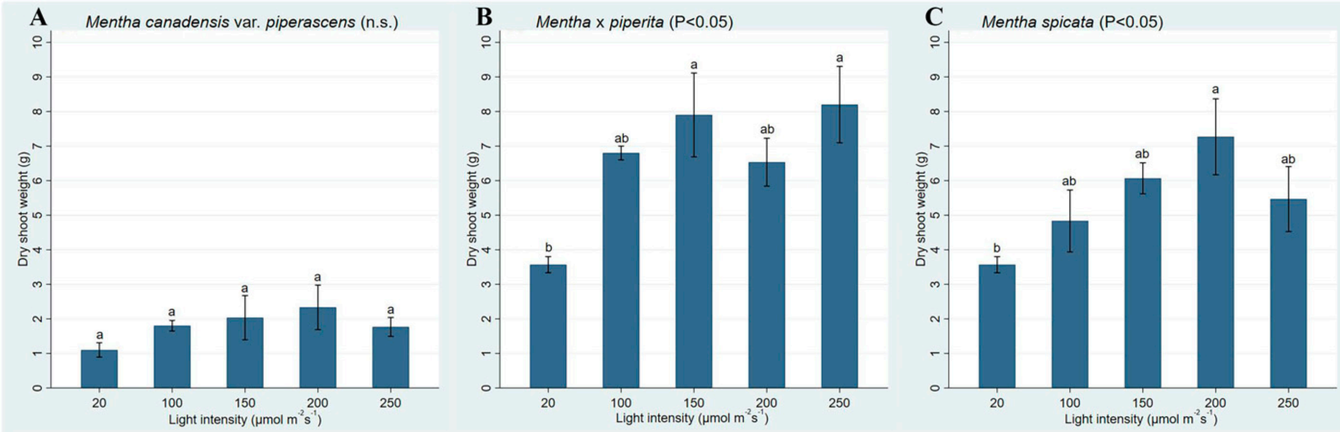

Fig. 1. Mean dry shoot weight of each plant species under different photosynthetic photon flux densities at the end of the experiment (n = 3). Error bars represent standard errors. Means with the same letter do not differ significantly from each other.

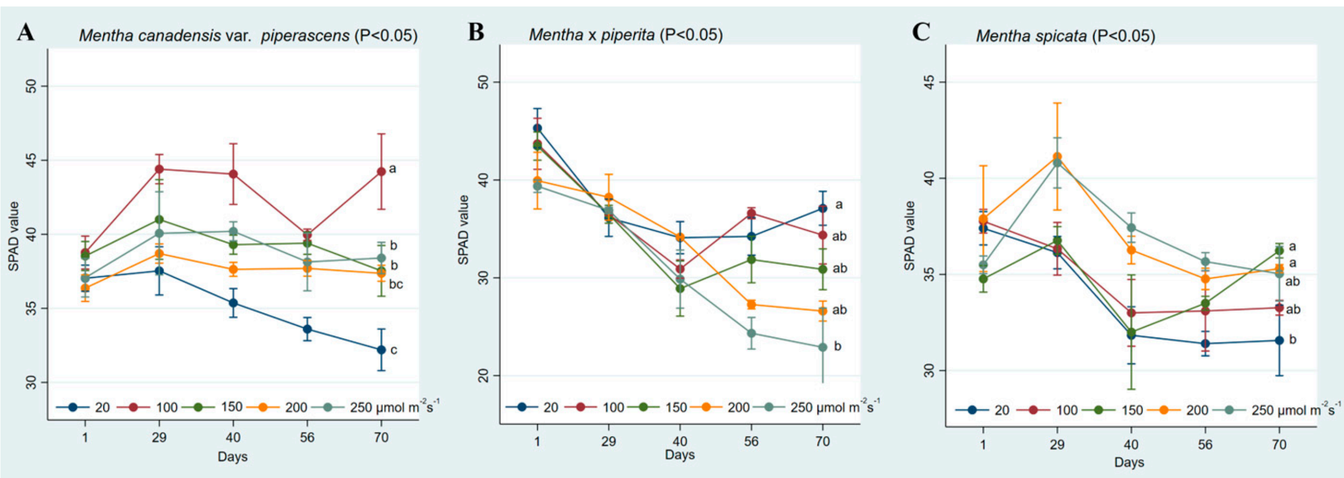

Fig. 2. Change of soil plant analysis development (SPAD) under different photosynthetic photon flux densities levels over time (n = 3). Error bars represent the standard errors. Means with the same letter do not differ significantly from each other.

internode elongation as an adaptation to overcome shade conditions (Mariani and Ferrante 2017). These findings support previous studies, suggesting that *Mentha* spp. generally require moderate-light levels for optimal growth (Syahirah Deraman et al. 2019). High PPFD levels caused photoinhibition, leading to leaf yellowing and reduced growth, as is commonly observed under strong light stress (Larcher 2003). Shoot height and internode length were also measured and showed similar elongation trends under low PPFD (Supplemental Fig. 3), further supported by species-specific growth trajectories over time (Supplemental Figs. 4–6), which reflect typical shade avoidance responses (Lecharny and Jacques 1980).

The different SPAD responses among species reflect their adaptive strategies. *M.* ×*piperita* showed higher values under low PPFD, indicating shade tolerance, while *M. canadensis* var. *piperascens* and *M. spicata* had lower values. Under high PPFD, SPAD values decreased in all species, consistent with photoinhibition effects (Sato et al. 2015). These results underscore the importance of tailoring light conditions to the specific needs of each species to maximize growth and maintain healthy foliage. Because all tested PPFD levels were higher than typical office lighting conditions (usually less than 20 $\mu mol \cdot m^{-2} \cdot s^{-1}$), dedicated plant lighting systems are necessary for successful mint cultivation in indoor environments. It should be noted that the limited number of replicates (n = 3) per treatment may reduce the robustness of statistical inferences, and future studies should increase the sample size to account for biological variability.

Conclusion

This study suggests that PPFD levels around 150 to 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ are suitable for *Mentha* spp. indoor greening. Excessively high and low PPFD levels caused photoinhibition and stem elongation, respectively. Real-world applications such as office or residential greening often involve fluctuating light and temperature conditions. For example, air conditioning may be turned off during nonworking hours, leading to growth changes. Investigating the combined effects of light and temperature fluctuations will provide a more comprehensive understanding of how to integrate herbs, such as mint, into indoor greening practices effectively. The results of this study offer practical guidance for plant selection based on maintenance requirements. Faster-growing species, such as *M.* ×*piperita* are ideal for environments where frequent pruning is feasible, whereas slower-growing species, such as *M. canadensis* var. *piperascens* are better suited for low-maintenance settings. This adaptability makes mint an excellent candidate for indoor greening for visual and therapeutic benefits.

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