

Enhancement of specialized metabolites in carvone-mints through modulation of environmental conditions

Mentha (mint) is a well-known genus of aromatic plants, economically valued for fragrant essential oils. Commercially cultivated mints typically produce one of the two major terpenoid compounds as their marker metabolite: menthol or carvone. Since spearmint (*Mentha spicata*) is the only widely cultivated carvone-rich species and is highly sensitive to environmental fluctuations, there is a growing need to understand how key environmental factors such as temperature and light quality influence its growth and specialized metabolism. Further it is necessary to evaluate the adaptation potential of an alternative carvone-rich mint, particularly *Mentha rotundifolia*. To examine the impact of changing air temperatures, *M. spicata* was grown under a range of five different temperatures in plant growth chamber, keeping glasshouse as the experimental control. Shoot growth was enhanced at 28°C, along with highest density and structural integrity of the peltate glandular trichomes, and sustained accumulation of the marker terpenes carvone and limonene. Further increase in temperature to 32°C caused transient increase but subsequent reduction in terpene levels due to increased trichome collapse, whereas cooler temperatures promoted phenolic accumulation and antioxidant activity, indicating a temperature-dependent metabolic shift. On the other hand, the impact of four spectral LED light conditions was evaluated under constant temperature. Combined red-blue (RB) light increased glandular trichome density and concurrently enhanced major terpenes, including carvone, as well as phenolic compounds such as rosmarinic acid, demonstrating the effectiveness of spectral quality in modulating specialized metabolism. Finally, the adaptability of *M. rotundifolia* to subtropical environment was assessed by comparing their phenotypic parameters and specialized metabolism in glasshouse and open environment. Glasshouse conditions supported higher terpene contents, while open environment-grown plants exhibited stress-adaptive traits such as thicker leaves with increased wax, anthocyanin accumulation in stem, higher antioxidant capacity, and increased phenolics content. Despite environmental stress, *M. rotundifolia* survived well by employing stress-tolerance mechanisms, indicating its potential as an alternative carvone-rich mint. Overall, modulation of temperature, light spectra, and growth environments significantly influenced specialized metabolites and trichome attributes in carvone-mints, providing a basis for improving controlled growth conditions and evaluating adaptability in aromatic plants.