

other shade-tolerant medicinal plants also support this pattern, indicating that moderate shading can improve growth, photosynthetic performance, and secondary metabolite accumulation, whereas full sunlight and deep shading may both have adverse effects. For example, in medicinal plants such as *Eleutherococcus senticosus*, *Pinellia ternata*, *Paris polyphylla* var. *chinensis*, and *Polygala fallax*, moderate shading can increase chlorophyll content, optimize photosystem function, and increase biomass or certain active components, whereas excessively strong or weak light may lead to growth inhibition, light damage, or reduced accumulation of active components (Xu et al., 2020; Liang et al., 2022; Gao et al., 2025; Liu et al., 2026). Reviews on light-regulated secondary metabolism further indicate that precise control of light intensity and light quality is an important means of enriching valuable medicinal metabolites, which also highlights the importance of shading regimes in quality-oriented cultivation of *T. hemsleyanum* (Zhang et al., 2021).

Therefore, establishing a rational shading management model not only helps improve the adaptability of *T. hemsleyanum* to artificial cultivation environments, but also provides important technical support for high-quality, efficient, and standardized cultivation. Especially in medicinal plant cultivation, yield improvement does not necessarily equate to quality enhancement. How to achieve coordination among tuberous root yield, active component content, and commercial traits of medicinal materials is a core issue in optimizing *T. hemsleyanum* cultivation technology. In the future, shading cultivation of *T. hemsleyanum* should be based on a clear understanding of its ecological habits and photosynthetic adaptation mechanisms, and should further integrate shading intensity, light quality regulation, cultivation models, and quality evaluation indicators to establish a widely applicable standardized light environment management scheme, thereby supporting resource conservation, stable medicinal material quality, and industrial development of *T. hemsleyanum*.

3 Effects of Shading Environment on Morphogenesis and Biomass Accumulation of *Tetrastigma hemsleyanum*

3.1 Effects on plant height, vine growth, and branching

The shading environment first affects the aboveground morphogenesis of *Tetrastigma hemsleyanum*, especially in terms of plant height, vine elongation, and branch growth. As a perennial vine, *T. hemsleyanum* often grows in understory or semi-shaded and humid environments in the wild, where it receives scattered light filtered through the forest canopy. Therefore, its artificial cultivation also requires light regulation to approximate its natural ecological niche requirements as closely as possible (Ji et al., 2020). Vine growth capacity is directly related to spatial expansion, leaf distribution, and light resource acquisition in *T. hemsleyanum*. Under moderate shading conditions, plants can enhance their utilization of scattered light by increasing vine length, adjusting internode distance, and improving the spatial arrangement of leaves. This morphological change represents an adaptive response to low-light environments, which helps expand the photosynthetic area and improve the light interception efficiency of the plant canopy under limited light resources.

The effects of shading on vine growth in *T. hemsleyanum* vary significantly with shading intensity. Shading experiments have shown that under full sunlight or only 50% shading, photosynthetic electron transport and photochemical quenching in *T. hemsleyanum* are inhibited, while photosynthetic activity and plant growth decline, indicating that strong light conditions suppress overall plant growth. In contrast, when light is reduced to approximately 67%~70% shading, the net photosynthetic rate, light saturation point, and maximum photosynthetic rate are higher than those under weaker shading treatments, indicating that this shading level is more conducive to carbon assimilation and vegetative vine growth (Xu et al., 2018). However, if shading is excessive, such as reaching 75%-90% or higher, insufficient photosynthetically active radiation restricts carbon assimilation and slows growth (Dai et al., 2009). Therefore, plant height, vine elongation, and branch formation in *T. hemsleyanum* are jointly constrained by photoinhibition under strong light and insufficient carbon supply under deep shading, while moderate to relatively high shading is more favorable for vine extension and coordinated plant structure formation.

From the general perspective of plant responses to shading, reduced light or a decreased red/far-red ratio can induce shade-avoidance responses, manifested as stem and internode elongation, but often at the cost of reduced