

4 Effects of Shading Environment on Photosynthetic Physiology and Stress Resistance of *Tetrastigma hemsleyanum*

4.1 Effects on photosynthetic pigments and light-harvesting capacity

Photosynthetic pigments are an important material basis for light energy absorption, transfer, and conversion in *Tetrastigma hemsleyanum*, and changes in their content and composition directly reflect the plant's adaptability to shading environments. Shading treatment can significantly alter the pigment system of *T. hemsleyanum* and related shade-tolerant plants, thereby reshaping their light-harvesting capacity. Studies have shown that, in *T. hemsleyanum*, chlorophyll a, chlorophyll b, and total chlorophyll contents gradually increase with increasing shading intensity, while the chlorophyll a/b ratio decreases, indicating a typical shade-leaf adaptive expansion of the light-harvesting complex. This adjustment helps enhance the absorption of scattered and weak light under low-light conditions (Dai et al., 2009; Xu et al., 2018). In particular, the increase in chlorophyll b content is important for expanding the light-harvesting antenna system and improving light energy utilization efficiency under weak light. Similar phenomena have also been observed in other shade-managed crops, in which shading promotes the accumulation of chlorophyll and carotenoids and, compared with full sunlight, helps maintain greener leaves and a higher net photosynthetic rate (Elango et al., 2023).

In addition to chlorophylls, auxiliary pigments such as carotenoids also participate in light absorption, energy transfer, and photoprotection. Under suitable shading conditions, increases in chlorophyll and carotenoid contents can enhance light absorption capacity and improve the processing efficiency of absorbed light energy. At the same time, they reduce strong light-induced photooxidative pressure and decrease damage caused by excessive light energy accumulation in leaves. Shade-grown leaves usually show a reduced chlorophyll a/b ratio along with structural adjustments, which helps improve the utilization of transmitted light and avoid photoinhibition (Sagun et al., 2022). In overwintering tea plants and other shade-managed crops, shading can also upregulate genes related to chlorophyll and carotenoid metabolism as well as core photosystem protein genes, thereby enhancing light-harvesting capacity under low-light conditions (Simkin et al., 2022; Han et al., 2023). Therefore, moderate shading can enhance the adaptability of *T. hemsleyanum* to weak-light environments by optimizing pigment composition and the light-harvesting system. However, if shading is excessive, although leaves may exhibit apparent features such as deeper green color and increased chlorophyll content, insufficient incident light energy will still restrict light reactions and carbon assimilation, ultimately reducing photosynthetic production capacity.

4.2 Effects on photosynthetic efficiency and stomatal regulation

Photosynthetic efficiency is an important indicator for evaluating the growth potential of *T. hemsleyanum* under different light environments. Moderate shading can alleviate physiological stress caused by strong light, high temperature, and excessive water transpiration, helping maintain favorable stomatal opening and photosynthetic system activity. Across a series of shading treatments, the net photosynthetic rate, stomatal conductance, transpiration rate, light saturation point, and maximum net photosynthetic rate of *T. hemsleyanum* all increased with enhanced shading and reached relatively high levels under approximately 70% shading, before declining under deeper shading. Across different growth stages, the 70% shading treatment consistently showed superior photosynthetic characteristics (Xu et al., 2018). Another shading experiment also showed that under 67% shading, *T. hemsleyanum* had the largest leaves, the highest net photosynthetic rate, and a light saturation point of $600 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, whereas stronger light and excessive shading both reduced carbon assimilation capacity and plant growth (Dai et al., 2009). These findings indicate that the photosynthesis of *T. hemsleyanum* exhibits an obvious "moderate optimum" response to shading intensity.

Shading also reshapes stomatal regulation and photochemical processes in *T. hemsleyanum*. Under suitable shading conditions, stomatal conductance and transpiration rate remain relatively coordinated, which helps ensure carbon dioxide entry into leaves for carbon assimilation. Meanwhile, the milder microclimate under shading can reduce leaf water deficit and decrease photosynthetic limitation caused by stomatal closure. Studies have shown that stomatal conductance and transpiration rate in *T. hemsleyanum* increase as shading rises to 70%, and then decline; unsuitable conditions such as strong light and high temperature reduce photosynthetic activity and slow plant growth (Xu et al., 2018). Under full sunlight and low-shading conditions, electron transport rate and