

CHS, CHI, F3H, and FLS, thereby enhancing flavonoid accumulation. Reviews on medicinal plants also point out that the MYB, WRKY, bHLH, AP2/ERF, and NAC families are core regulatory factors mediating stress- and light-induced secondary metabolite biosynthesis (Tong et al., 2024; Rabeh et al., 2025). Based on these conserved mechanisms, it can be inferred that shading effects in *T. hemsleyanum* are likely mediated by regulating light-signaling hubs such as UVR8-COP1-HY5, which further control MYB/WRKY/bHLH regulatory networks and the expression of key enzyme genes in phenylpropanoid and flavonoid metabolic pathways, ultimately influencing medicinal quality formation.

7 Optimization Strategies for Shading Cultivation of *Tetrastigma hemsleyanum*

7.1 Reasonable determination of shading intensity

Physiological studies on *Tetrastigma hemsleyanum* provide clear evidence for determining an appropriate shading level. Under five light intensity treatments ranging from full sunlight to 90% shading, photosynthetic pigments and most photosynthetic indicators increased with increasing shading intensity and reached their peak at approximately 70% shading before declining. This indicates that 70% shading can maintain the highest net photosynthetic rate (Pn), maximum photosynthetic rate (Pmax), light saturation point, and stomatal conductance during both the rapid and slow growth stages (Xu et al., 2018). Another experiment conducted under full sunlight, 50% shading, 67% shading, and 90% shading showed that 67% shading produced the largest leaves and the highest photosynthetic rate. Light stronger than that under 50% shading inhibited photosynthesis and growth, whereas irradiance below that under 75% shading restricted carbon assimilation (Dai et al., 2009). Together, these findings suggest that approximately 65%-70% shading can serve as a reasonable baseline for field and greenhouse cultivation.

Experience from other medicinal plants also supports this principle, namely that moderate shading or medium light intensity can usually optimize both biomass and active component accumulation. In the shade-loving medicinal plant *Panax notoginseng*, the combination of three-layer shading, an appropriate red-blue light ratio, and moderate soil moisture produced the highest biomass and saponin content; in contrast, light under single-layer shading was still “excessive” relative to its physiological requirements and could damage photosynthesis and secondary metabolism. In *Pinellia ternata*, 55% full sunlight treatment increased chlorophyll content, photosynthetic rate, and succinic acid content compared with full sunlight, with succinic acid increasing by 27%, indicating that moderate shading can improve medicinal quality (Gao et al., 2025). Meanwhile, excessive shading, such as 72%-90% shading, may significantly reduce biomass and active component content in certain species (Deng et al., 2024). Therefore, for *T. hemsleyanum*, using 65%-70% shading as the core target and making slight adjustments within this range according to local light climate and quality objectives is a relatively reasonable cultivation strategy.

7.2 Stage-specific light environment regulation

The light requirements of *T. hemsleyanum* differ among developmental stages, and therefore a dynamic shading strategy is needed. The photosynthetic indicators of this species during the rapid growth stage are 41%-67% higher than those during the slow growth stage, yet 70% shading remains suitable in both stages. This suggests that, while maintaining the same basic shading intensity, other factors such as temperature and humidity can be further adjusted (Xu et al., 2018). However, studies on other herbaceous medicinal plants indicate that using full sunlight or relatively high light intensity at the early growth stage, followed by increased shading or spectral adjustment at later stages, may better coordinate biomass accumulation and quality formation. In *Origanum majorana*, 100% light produced the highest dry weight, whereas essential oil content peaked under 70% light; therefore, researchers suggested using high light during the early growth stage and 70% light transmittance shading treatment during the later growth cycle (Hashemifar et al., 2024).

Studies on understory medicinal plants and shade-tolerant plants further emphasize the importance of stage-specific light quality regulation. In *Scutellaria baicalensis*, compared with UV-A, green light, or mixed blue-red light treatments, monochromatic blue light (R0B4) better promoted growth and flavonoid accumulation, indicating that enhancing the blue-light component during stages targeting flavonoid synthesis may improve