local soil microbial communities, litter cycling, and water regulation mechanisms, while highlighting ecological cultivation and simulated wild-quality characteristics.

Seasonal field studies have shown that under cool, humid spring conditions with shorter sunshine duration, the total flavonoid content and antioxidant activity of *T. hemsleyanum* tuberous roots are relatively high, and its flavonoid biosynthesis pathway is closely coupled with environmental factors throughout the annual cycle (Figure 2) (Shi et al., 2022). Light-intensity experiments further demonstrate that excessive radiation and high temperature reduce photosynthetic activity in *T. hemsleyanum*, whereas approximately 70% shading can optimize pigment content and photosynthesis (Xu et al., 2018). Therefore, in the broad-leaved forest simulated wild model, understory locations with moderate canopy shading, stable microclimates, and moist but non-waterlogged soils should be prioritized, so that the ecological conditions can approximate those required for the natural growth of *T. hemsleyanum*. The outstanding advantage of this model is that the ecological environment is close to nature and the medicinal material has a favorable quality image, making it suitable for the development of ecological medicinal materials, geo-authentic medicinal materials, and branded products. However, its management and harvesting are relatively difficult, and yield stability may be lower than that of intensive cultivation models. Therefore, in promotion and application, the model should be positioned according to production objectives. If ecological quality and resource conservation are prioritized, a low-density and low-intervention simulated wild model can be adopted. If stable yield and large-scale management are the goals, cultivation management should be moderately strengthened on the basis of simulated wild cultivation to balance ecological value and productivity.

5 Key Cultivation Techniques for Understory Planting of *Tetrastigma hemsleyanum*

5.1 Propagation and planting of high-quality *Tetrastigma hemsleyanum* seedlings

The foundation of understory ecological cultivation of *Tetrastigma hemsleyanum* lies in obtaining high-quality seedlings and carrying out standardized planting. Seedling quality directly affects plant survival rate, later growth vigor, tuberous root formation, and the stability of medicinal material quality. Therefore, seedlings with clear provenance, stable traits, no pests or diseases, complete root systems, and vigorous growth should be selected as cultivation materials. Traditional seed propagation and cutting propagation are limited by low natural fruiting rate and restricted propagation quantity, making it difficult to fully meet the demand for large-scale understory cultivation. As a result, rapid propagation technologies have attracted increasing attention (Hu et al., 2021). In production, tuberous root propagation, cutting propagation, and tissue culture can be used for seedling propagation, among which tissue culture is conducive to the rapid propagation of seedlings with uniform morphology, genetic stability, and a high degree of disease-free quality (Pang et al., 2024).

Tissue culture is an important direction for the large-scale propagation of high-quality *T. hemsleyanum* seedlings. Tissue culture techniques based on axillary bud proliferation or shoot organogenesis can produce a large number of tissue-cultured seedlings with stable morphology, relatively stable flavonoid content, and high uniformity, thereby meeting both resource conservation needs and commercial production requirements. Studies have shown that when leaves and petioles are used as explants and induced on Murashige and Skoog (MS) medium supplemented with appropriate combinations of 6-benzylaminopurine and auxins, a relatively high adventitious shoot proliferation rate can be obtained within 30 days. Optimized rooting media can achieve a 100% rooting rate, and the survival rate of tissue-cultured seedlings after acclimatization in a peat-sand substrate can exceed 98% (Pang et al., 2024).

For large-scale seedling production suitable for understory transplantation, cutting propagation remains a practical and relatively low-cost method. Cutting propagation experiments have shown that when 2- to 3-year-old cuttings are treated with 1 000 mg/L indole-3-butyric acid for 10 s and then planted in loess, rooting performance is relatively good, providing a technical basis for standardized production of robust seedlings. Both tissue-cultured seedlings and cutting-derived seedlings should be fully hardened before transplantation into understory environments, so that they can gradually adapt to understory temperature, humidity, low-light, and ventilation conditions, thereby reducing transplanting stress and improving establishment speed (Zhang et al., 2019a; Hu et