and cultivated populations have also shown that higher available phosphorus and potassium levels and distinctive rhizosphere microbial structures in wild habitats are associated with higher total flavonoid content and phenylalanine ammonia-lyase activity in roots. In addition, an appropriate amount of nitrogen is beneficial to the growth of *T. hemsleyanum*, whereas excessive nitrogen suppresses growth and reduces flavonoid and phenolic contents, indicating that high-quality understory production requires balanced nutrient supply rather than simply increasing fertilizer input (Fu et al., 2019). Therefore, understory ecological cultivation of *T. hemsleyanum* should follow the principles of "moisture retention without waterlogging" and "balanced fertilization" to create a stable rhizosphere environment for tuberous root formation and medicinal substance accumulation.

3.3 Growth performance of *Tetrastigma hemsleyanum* in different forest stand environments

Different forest stand environments vary markedly in shading degree, soil fertility, root competition, ventilation conditions, and management convenience, thereby affecting the growth performance of *T. hemsleyanum*. Field and controlled-environment studies have shown that intercropping *T. hemsleyanum* under moso bamboo stands combined with the application of biochar-based organic fertilizer can significantly increase plant biomass, indicating that *T. hemsleyanum* can grow well under relatively dense bamboo canopies when soil conditions are improved (Zhang et al., 2019a). Bamboo understories are characterized by relatively high humidity and stable shading, making them suitable for vine growth in *T. hemsleyanum*. However, dense bamboo rhizomes may compete with *T. hemsleyanum* for nutrients and space, and poor ventilation in some bamboo forests may increase disease risk. Therefore, when cultivating *T. hemsleyanum* under bamboo forests, bamboo culms should be appropriately thinned to improve light transmission and ventilation, while soil fertility supplementation and water drainage should be strengthened.

Cultivating *T. hemsleyanum* under fruit forests offers good advantages in spatial utilization. Fruit tree spacing is relatively regular, which facilitates land preparation, trellising, fertilization, and harvesting management. Understory light can also be regulated through canopy pruning, making this model suitable for the development of forest-medicine compound management. Although systematic trials on fruit forest-*T. hemsleyanum* cultivation remain relatively limited, fruit forests can be regarded as an important potential type for understory ecological cultivation of *T. hemsleyanum* based on its requirements for moderate shading, humid conditions, and vertical space utilization. However, fertilization, pesticide application, and irrigation measures in fruit tree management may affect the growth and medicinal material safety of *T. hemsleyanum*. Therefore, water and fertilizer management as well as pest and disease control for fruit trees and *T. hemsleyanum* should be coordinated to avoid interference between management practices.

Broad-leaved forests or near-natural stands are closer to the wild habitats of *T. hemsleyanum*, with advantages such as abundant litter, higher soil humus content, and stronger ecological stability, making them suitable for the development of simulated wild ecological cultivation models. In mixed broad-leaved forests with approximately 70% canopy density, soils containing a relatively high proportion of gravel can support the formation of larger tuberous roots and distinctive microbial communities in *T. hemsleyanum*, indicating that broad-leaved forest stands with moderate canopy closure, stony soils, and stable microclimates can provide a suitable ecological niche for cultivation. Seasonal climate analysis showed that moderate temperatures of 17.5°C~24.1°C, humidity of approximately 67%~80%, relatively low precipitation, and shorter sunshine duration are conducive to the formation of higher total flavonoid content in tuberous roots (Shi et al., 2022). Overall, different forest stands can provide certain conditions for understory cultivation of *T. hemsleyanum*, but suitable models should be selected according to stand structure, canopy closure, soil conditions, and management objectives. At the same time, regulation experience from greenhouse and stereoscopic planting systems can be used as a reference to further optimize understory ecological cultivation schemes (Xie et al., 2022; Hu et al., 2023).

4 Construction of Understory Ecological Cultivation Models for *Tetrastigma hemsleyanum*

4.1 *Tetrastigma hemsleyanum*-bamboo forest compound cultivation model

The *Tetrastigma hemsleyanum*-bamboo forest compound cultivation model is a forest-medicine compound model that uses the relatively stable shaded environment and humid microclimate under bamboo forests to cultivate *T.*