

sunshine duration of 3.4~5.8 h from April to May, total flavonoid content reached relatively high levels, and the flavonoid biosynthetic pathway showed clear environmental responsiveness (Shi et al., 2022). Genomic evidence indicates that climatic variation explains more genomic variation than geographical distance, with winter precipitation acting as the strongest predictor of contemporary genetic structure, which supports the view that producing-area differences reflect local climate adaptation rather than simple geographic separation. Even under cultivation, habitat conditions remain decisive: dryland systems can show 30~35% lower flavonoid concentrations than forest understory systems, while biochar-mediated improvement of soil enzymes and fungal communities can partly bridge this quality gap, demonstrating that local soil microecology is a major component of resource quality formation (Zhang et al., 2026).

2.3 Conservation of local characteristic resources and utilization of elite germplasm

The conservation of local characteristic *T. hemsleyanum* resources has become urgent because wild populations have been sharply reduced by overharvesting, slow natural growth, and strict habitat requirements. Reviews and field investigations note that the species usually needs 3~5 years to reach commercial medicinal standards, while excessive collection and ecological change have caused rapid contraction of wild distribution areas and serious depletion of natural reserves (Ji et al., 2021). In Guangxi, surveyed reserves were only about 24 441.20 kg, and the study explicitly recommended active protection measures to ensure sustainable utilization. Genetic evidence suggests that conservation should focus not only on preserving populations in situ, but also on promoting gene exchange among populations, because cultivated materials show higher within-group similarity and natural populations contain richer diversity needed for long-term utilization. Climate-change risk adds another layer of urgency, as landscape genomic modelling identified high genomic vulnerability in central-northern parts of the species range and supported proactive management for populations facing future genotype-environment mismatch.

The utilization of elite germplasm should therefore combine origin identification, resistant parent selection, ex situ preservation, and directed breeding. Molecular traceability tools based on chloroplast genomes, mutational hotspots, and trnL-trnN barcodes can distinguish major geographic groups and support the authentication of local characteristic materials, while isotope-element models with machine learning achieved 100% prediction accuracy for origin traceability in tested samples (Bai et al., 2025). For breeding, the Zhejiang ZJWZ strain showed the best overall stress resistance among five provincial strains and was identified as preferred parental material for resistance improvement. Ex situ conservation technologies are also increasingly feasible: slow-growth culture at 8 °C with 0.2 mg/L MH prolonged subculture to at least 10 months while maintaining genetic stability and stable flavonoid content, and callus studies indicate that subculture frequency should be controlled within four cycles for clonal fidelity or extended to 6-8 cycles when somatic variation is intentionally used for germplasm improvement. At the utilization end, differentiated use of roots, stems, and leaves and optimization of cultivation mode can raise the value of elite germplasm, since leaves contain significantly higher flavonoid and phenolic acid levels than roots and stems, and greenhouse plus stereoscopic planting improved both yield and quality, providing practical pathways for converting superior local resources into stable industrial advantages (Hu et al., 2023).

3 Ecological Basis for the Development of the Under-Forest *Tetrastigma hemsleyanum* Industry

3.1 Effects of under-forest light and temperature conditions on growth adaptability

Tetrastigma hemsleyanum is a shade-adapted species whose natural habitat is typically under forest cover, valley shade, rock crevices, moist grasslands, and mountain gullies, indicating that weak light and buffered thermal conditions are part of its basic ecological niche (Shi et al., 2022). Controlled shade experiments consistently show that excessive irradiance suppresses its photosynthetic performance and growth, while moderate canopy filtering improves leaf development and carbon assimilation. In one classic experiment, plants achieved the greatest leaf size and highest net photosynthetic rate under 67% shade, and light levels stronger than 50% shade depressed photosynthetic activity, whereas overly deep shade also reduced growth (Dai et al., 2009). A later gradient study