

under sustained pressure from overexploitation, habitat degradation, illegal trade, and anthropogenic disturbance, and multiple studies describe continuing decline or vulnerability across the Himalayan region and Southwest China.

Artificial restoration is equally important because dependence on wild rhizomes is not compatible with current medicinal demand or with the species' biology. Demand for *Paris* rhizomes has risen sharply, annual trade volume is large, and cultivation remains the only realistic way to reduce extraction pressure while maintaining pharmaceutical supply. Artificial propagation is especially necessary because *Paris* has a long growth cycle, long seed dormancy, low seed germination, and frequent reliance on vegetative regeneration, all of which slow natural recovery. Recent propagation research shows that somatic embryogenesis, clonal regeneration, mini-rhizome systems, and improved vegetative techniques can produce restoration-ready material at higher speed and survival than conventional methods. The strongest conclusion from the current literature is therefore that in situ conservation and artificial restoration are complementary rather than alternative strategies, and sustainable utilization depends on linking the two.

Future germplasm innovation in *Paris* spp. will depend first on better evaluation and identification systems that connect provenance, genetic background, and medicinal quality. Existing evidence shows that cultivated populations often derive from mixed provenances and contain substantial admixture and gene flow, which complicates variety identification and quality consistency. This problem is intensified by interspecific hybridization and morphological similarity among taxa, which can reduce the uniformity of medicinal raw materials and weaken seed-based breeding. Future work should therefore integrate AFLP, SSR, EST-SSR, SCoT, SRAP, chloroplast haplotypes, and species-specific barcodes into a more complete germplasm evaluation framework. Molecular infrastructure is beginning to support that transition, as PPDP already provides the first dedicated biomolecular database for *Paris* and is designed to expand with additional genomic resources.

Sustainable utilization will also require breeding and cultivation systems that are ecologically adaptive and quality-oriented rather than focused on multiplication alone. Environmental conditions strongly shape both performance and metabolite accumulation in *Paris*, with naturally forest-grown plants showing enrichment of steroidal saponins and related metabolites relative to greenhouse-grown plants. Suitable cultivation zones also differ between var. *chinensis* and var. *yunnanensis*, and future climate and human disturbance are expected to shift those zones, making taxon-specific ecological planning increasingly important. At the production level, microbial inoculants, in vitro mini-rhizome culture, and elite clonal propagation all show potential to increase biomass and polyphyllin accumulation while supplying standardized planting stocks. Long-term restoration mechanisms should therefore combine protected wild source populations, traceable cultivated supply chains, community participation, stricter harvest governance, and continued innovation in propagation and molecular breeding.

Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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