

4.2 Establishment of efficient propagation technology systems

The second technical pathway is the establishment of efficient, scalable propagation systems that overcome the slow growth, long seed dormancy, and low multiplication efficiency of *Paris* spp. (Kumar et al., 2025). Conventional rhizome cutting remains useful, but its multiplication rate is limited by axillary meristem number and it can reduce net rhizome yield while increasing susceptibility to insects, disease, and rot (Wang et al., 2023). Improved rhizome-based techniques therefore focus on increasing bud activation without damaging the parent rhizome. Stratification-induced latent-bud propagation and related rapid seedling systems can raise propagation coefficient, preserve genetic stability, and produce robust field-surviving seedlings, while avoiding some of the losses associated with direct segment cutting. Hormone regulation offers another effective route: GA₃ can break rhizome dormancy within two weeks and induce polyapical shoots at 100%, with about 7.2 apical shoots per treated rhizome, markedly improving clonal multiplication efficiency (Wang et al., 2021).

Tissue culture and somatic embryogenesis now appear to be the most promising high-efficiency restoration platform for large-scale artificial germplasm production (Thapa et al., 2022; Wang et al., 2023). Direct regeneration systems based on thin cell layer culture, mini-rhizome induction, and optimized hormone combinations have achieved 86.6% mini-rhizome formation, more than 95% acclimatization in greenhouse conditions, and strong shoot regeneration under defined medium compositions. Somatic embryogenesis is especially valuable because it can generate about 63 embryos per gram of callus within six weeks, shorten plantlet production by 12~15 months, and maintain high transplant establishment, thereby enabling rapid multiplication of elite lines (Figure 2) (Wang et al., 2023). However, the evidence also shows that propagation success depends strongly on explant position, developmental stage, photoperiod, temperature, sucrose concentration, and plant growth regulator regime, so the next step is not merely inventing more methods but integrating them into standardized, stage-specific propagation systems for different germplasm types (Kumar et al., 2025).

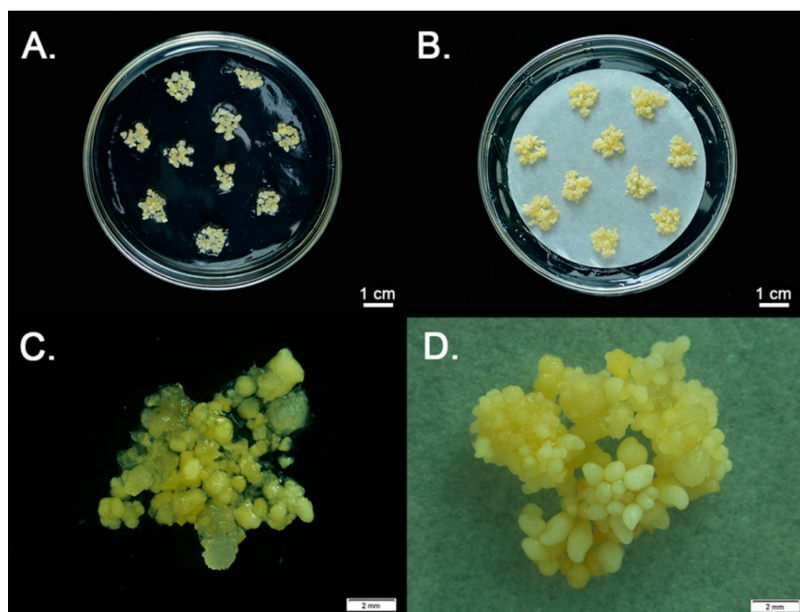


Figure 2 Somatic embryo innovation platform for *Paris polyphylla* (Adopted from Wang et al., 2023)

Image caption: Somatic embryos grown on medium (A,C) compared with stronger growth on filter paper+medium (B,D) (Adopted from Wang et al., 2023)

4.3 Quality control and standardized production of artificial germplasm

Artificial germplasm restoration cannot be judged by survival and multiplication alone; it must also ensure stable medicinal quality, especially for steroidal saponins, which are the main active constituents of *Paris* spp. (Thapa et al., 2022; Kumar et al., 2025). A central quality-control challenge is that interspecific hybridization and morphological similarity can reduce uniformity of medicinal raw materials and complicate seed-based breeding, making genotype authentication essential (Wang et al., 2023). Molecular-marker systems linked to diversity