

stage (Zhang et al., 2020; Zhang et al., 2022). During the recovery period, disease management should therefore combine clean substrate, careful watering, adequate ventilation, and targeted use of beneficial fungi, while avoiding overly complex fungal mixtures because synthetic combinations did not show synergistic effects and sometimes produced offset effects (Wu et al., 2025).

## 8 Conclusions and Prospects

Tissue culture rapid propagation is the most practical basis for producing high-quality *Dendrobium officinale* seedlings because conventional propagation provides limited offspring and does not support industrial-scale seedling supply, whereas in vitro systems can establish continuous regeneration from germination, protocorm induction, proliferation, rooting, hardening, and transplanting. Direct studies on *D. officinale* have shown that stage-specific optimization of medium composition can support efficient germination, shoot proliferation, rooting, and transplant preparation, although the best formula differs by explant and culture phase. The same body of work indicates that high-quality seedlings are not defined only by multiplication rate, but by uniformity, strong rooting, and later transplant competence, which is why complete propagation systems are more valuable than isolated induction protocols. Broader *Dendrobium* evidence further supports this conclusion by showing that tissue culture is already an established propagation route for the genus and also provides the technical basis for germplasm conservation, clonal fidelity control, synthetic seed, bioreactor, and transformation technologies. In related medicinal *Dendrobium* species, optimized protocols produced about 87% transplant survival with 96.89% monomorphism after transfer, while *D. nobile* showed high genetic stability and 82.3% acclimatization survival, indicating that rapid propagation can support both scale and seedling quality when protocol stability is maintained.

Improving the transplant survival rate of *D. officinale* requires multi-stage coordination because losses arise not from a single step, but from cumulative mismatches among rooting quality, acclimatization intensity, substrate properties, and post-transplant stress response. Reviews of *Dendrobium* acclimatization show that plantlets must be gradually adapted to lower humidity and higher light so they can restore stomatal regulation, root function, and autotrophic growth before field or greenhouse establishment. Direct *D. officinale* studies also show that survival changes markedly with substrate and transplant management, with high-performing systems reported for pure bark, bark-moss bases, and vermiculite:perlite:humus soil mixtures, while broader orchid studies similarly favor porous, moisture-buffering media rather than overly compact substrates. Biological coordination is another important layer, because *Mycena dendrobii* significantly enhanced survival and growth of *D. officinale* seedlings by inducing defense- and stress-response proteins and promoting new root or mycorrhizal formation. Mycorrhizal evidence further shows that fungal effects are development-dependent and strain-specific: some fungi promote germination, others favor biomass, rooting, tillering, or polysaccharide accumulation, while synthetic fungal combinations do not necessarily produce synergistic effects. Therefore, future survival-improvement strategies for *D. officinale* should integrate strong-seedling culture, graded acclimatization, substrate matching, and targeted microbial assistance into one continuous technical chain rather than optimizing each step in isolation.

Standardization and intelligent management appear to be the clearest future directions for *D. officinale* seedling propagation because current orchid tissue-culture research is increasingly focused on medium optimization, endophytic-fungal regulation, and systematic solutions to contamination, browning, and vitrification, yet protocol fragmentation still limits reproducibility across genotypes and production sites. Recent bioreactor work in *Dendrobium* shows that liquid culture, temporary immersion systems, anti-browning additives such as ascorbic acid, and banana-extract-based regeneration media can markedly improve multiplication efficiency and may provide a foundation for standardized commercial systems, although genotype-specific optimization remains necessary. Orchid studies outside *D. officinale* also show that medium formulation depends on cultivation system and that combining optimized media with temporary immersion technology can reduce cost while balancing regeneration efficiency and genetic stability, which is directly relevant to future seedling industrialization. At the management level, intelligent greenhouse technology can already identify orchid growth status with 98.6% recognition accuracy and support environmental control and decision-making, suggesting practical value for digital monitoring of seedling vigor, environmental fluctuations, and transplant recovery. Taken together, the