

stage, multiplication generation, and production operations can solve fragmented recordkeeping and provide a practical tool for quality control and supervision. IoT-based greenhouse traceability systems extend this principle by continuously tracking luminosity, humidity, temperature, and water consumption, while also enabling automated environmental control and internal traceability from early growth to final output. More general production frameworks likewise emphasize four linked layers: genetic integrity, field or nursery production standards, post-harvest or post-production handling and testing, and certification with traceability. Therefore, the standardized seedling production system for *T. hemsleyanum* should assign each cutting lot a unique identity linked to mother plant source, collection date, cutting specification, pretreatment formula, substrate batch, environmental records, rooting and hardening results, grading outcome, release destination, and any later field feedback, thereby establishing a closed-loop quality traceability system from elite mother plant to commercial seedling.

7 Current Problems and Future Directions

Insufficient selection of elite mother plants and high-rooting propagules remains a major problem, because clonal propagation only delivers stable medicinal quality when the source genotype is first screened for desirable agronomic and phytochemical traits. Studies in medicinal species show that wild collections are often heterogeneous and produce variable end products, whereas clonal lines derived from selected accessions improve uniformity of essential oil or metabolite profiles. Mother stock management is equally important, since homogeneous juvenile explants produced under controlled ex situ conditions are more suitable for protocol development than irregular materials taken directly from the wild. Evidence across medicinal and woody species also shows that rooting capacity depends on propagule type and source, including apical versus basal position, cutting girth, tissue maturity, and leaf retention, but the optimal combination is genotype-specific rather than universal. For *T. hemsleyanum*, this means future work should shift from general collection of mother vines toward the establishment of elite source gardens, with selection based on genotype identity, growth vigor, medicinal constituent stability, and repeatable rooting performance of defined cutting types.

The lack of unified technical parameters for cutting propagation and seedling quality evaluation remains a recognized barrier even in other medicinal crops already under commercialization. Reviews of medicinal and aromatic plants show strong consensus that standardization of vegetative propagation is essential for cultivation, conservation, and commercial uniformity, yet rooting success still varies widely with cutting maturity, season, length, hormone concentration, substrate, and greenhouse environment. Species-specific studies illustrate how large these parameter effects can be: apical shoots outperformed basal stem cuttings in one medicinal cannabis system, apical cuttings with 2 000 ppm IBA rooted best in *Chrysanthemum indicum* at 25°C in vermiculite:perlite 1:1, and selected *Valeriana jatamansi* clones required 50 ppm NAA for 30 min with media such as sand or cocopeat for reliable large-scale multiplication. At the seedling stage, the absence of grading standards also weakens quality control, because high-quality planting material is the precondition for standardized herb production and formal grading criteria can be built around measurable vigor indices. For *T. hemsleyanum*, the next step is to convert current empirical experience into unified SOPs that specify mother plant age, cutting position and size, leaf retention, pretreatment formula, substrate composition, environmental set points, rooting benchmarks, and nursery release grades for qualified seedlings.

Seedling production systems remain insufficiently facility-based, large-scale, and digital, even though commercial propagation increasingly depends on controlled environments and process automation. Large-scale medicinal plant propagation has already shown that root trainers, shade structures, and multi-tier nursery layouts can sharply expand output while reducing land demand; in *Valeriana jatamansi*, three multiplication cycles from ten starter plants could produce about 80 000 plants, and vertical nursery arrangements could further reduce space requirements. Recent engineering studies also show that automation can improve seedling handling efficiency and reproducibility: machine-vision systems can guide robotic implantation and tray logistics, automated plug-seedling equipment can integrate sowing, covering, fertilizing, watering, and cloud-based monitoring of depth, temperature, and humidity, and smart transplanting frameworks using sensors and PLC control can reduce missed seedlings and improve operational reliability. Digital twin systems go further by linking real-time sensing,