

work further showed that an R2B1 light regime substantially increased amino acids, polyphenols, and kinsenoside, with kinsenoside rising by 81.25% in leaves and 72.24% in stems relative to white light (Wu et al., 2023; Luo et al., 2025).

The cultivation substrate, habitat-like microclimate, and microbial symbiosis also strongly regulate medicinal quality. Habitat metabolomics showed that flavonoid accumulation is significantly associated with temperature and humidity, while morphological performance was better in more humid habitats (Lyu et al., 2024). Practical cultivation studies identified suitable conditions of 23~28 °C, about 90% relative humidity, pH 4.75, and shaded management, with peat-based mixed substrates supporting 94.3%~97.6% seedling survival (Xu et al., 2017). Wild-imitated cultivation increased kinsenoside-associated quality by shifting the endophytic community toward that of wild-tending plants, and bacterial diversity showed a significant positive correlation with kinsenoside content, especially for *Burkholderia-Caballeronia-Paraburkholderia*. Beneficial fungi and bacteria exert similar effects: endophytic fungal strains increased biomass and induced flavonoids, kinsenoside, and polysaccharides, while dual *Bacillus velezensis* inoculation increased fresh weight by 82.6% and 106.6%, raised kinsenoside by 9.33% and 21.65% per gram, and enhanced flavonoids and rhizosphere enzyme activities (Ye et al., 2020; Wei et al., 2020).

4.3 Construction of a whole-process quality control system for *Anoectochilus roxburghii*

A whole-process quality control system for *A. roxburghii* must begin at the source with authenticated germplasm and continue through cultivation, harvesting, processing, storage, and final product evaluation. Current reviews agree that quality is jointly shaped by germplasm, producing area, harvesting, processing, preparation, and storage. Germplasm authentication should combine morphological identification with molecular tools, because SSR markers and DNA barcoding have been proposed for classification, resource preservation, and varietal discrimination (Zou et al., 2025). Because content differs markedly among strains and origins, source control should include elite-variety selection, origin traceability, and chemotype classification rather than simple species confirmation (Wang et al., 2025). During cultivation, quality control should integrate standardized light, substrate, humidity, and microbial-management protocols, since each of these factors measurably alters active-compound accumulation (Xu et al., 2017; Wei et al., 2020; Chen et al., 2021).

Post-harvest control is equally necessary because active components decline during processing and storage. Different drying temperatures affect kinsenoside, total flavonoids, eight individual flavonoids, and six nucleosides (Zou et al., 2025). Among drying methods, vacuum drying at (60±2) °C best preserved appearance, aroma, and active ingredients overall, although freeze-drying better maintained natural appearance and hot-air or microwave drying preserved specific sensory or polysaccharide traits. Storage studies showed that polysaccharides, kinsenoside, and flavonoids all declined over eight months, vacuum packaging better preserved polysaccharides and flavonoids, and kinsenoside degradation was driven mainly by endogenous enzymes rather than packaging method (Wei et al., 2022). At the analytical end, single-index control is inadequate, so multi-component methods such as LC-MS/MS, metabolomics, and integrated phenotype-barcode-chemotype-transcriptome frameworks should be used to establish Q-markers and comprehensive specifications; this is particularly important because *A. roxburghii* still lacks a unified pharmacopoeial standard and consistent cross-provincial evaluation system (Zhang et al., 2022; Wang et al., 2025).

5 Standardized Production and Industrial Pathways

5.1 Construction of a standardized production system for *Anoectochilus roxburghii*

A standardized production system for *Anoectochilus roxburghii* should begin with stable seedling supply, because wild resources are endangered, conventional propagation is inefficient, and industrial cultivation depends on reproducible micropropagation rather than continued wild collection (Hong et al., 2016; Wang et al., 2022). Current evidence already provides workable technical benchmarks for standardized seedling production: nodal-segment culture achieved 91.67% shoot induction, a proliferation rate of 4.33, 93.33% rooting, and 90.2% transplant survival under optimized media and substrate conditions. PLB-based systems further improved efficiency, reaching 89% PLB induction, 400% secondary PLB proliferation, 98% rooting, and full survival after acclimation, which makes them especially suitable for large-scale factory seedling production. More recent