

protocols for tetraploid or floral-bud-derived materials show that standardized propagation can also be linked to elite-germplasm utilization, with high shoot induction, rooting, and long-term greenhouse survival (Zhang et al., 2025; Luan et al., 2026).

Standardization must then extend from nursery protocols to cultivation management, environmental control, and quality criteria. Industry reviews identify the lag in variety breeding, insufficient quality systems, and weak product innovation as central bottlenecks, so production standards should define improved-variety propagation, substrate and greenhouse management, harmless pest control, and dynamic monitoring from seedling to harvest (Hong et al., 2016). Practical cultivation studies already outline the core variables that can be standardized, including ecological conditions, greenhouse location, seedbed construction, fertilizer and water management, and harvest management. Evidence also supports standardizing light and substrate regimes, because blue light improves biomass, flavonoids, and polysaccharides, while suitable mixed substrates and high humidity favor transplant survival and plant quality (Ye et al., 2020). In practice, a standardized production system should integrate elite germplasm, rapid propagation, controlled environment cultivation, and multi-index quality evaluation so that cultivated material is both consistent and traceable (Wang et al., 2022; Zhang et al., 2025).

5.2 Coordinated development of resource conservation and industry of *Anoectochilus roxburghii*

The coordinated development of conservation and industry is necessary because *A. roxburghii* has high medicinal and economic value, but its wild populations have been severely depleted by over-collection, habitat loss, slow growth, and low natural regeneration. Artificial cultivation is therefore not only an industrial strategy but also a conservation substitute that reduces harvesting pressure on wild populations (Wang et al., 2018; Wang et al., 2022). The conservation side should combine in situ protection of stable habitats with ex situ germplasm preservation, especially for threatened peripheral populations and elite local resources. Distribution modeling further suggests that future cultivation bases can be planned in newly suitable northern regions to meet demand while reducing pressure on vulnerable southern wild populations (Hou et al., 2025).

Industrial development should be coupled to conservation through germplasm protection, regional planning, and wild-imitated cultivation. Earlier resource surveys already argued that preservation and rational exploitation must be considered together, rather than as separate agendas. Wild-imitated cultivation is especially promising because it shifts the endophytic community toward that of wild-tending plants and is associated with higher kinsenoside content, which helps align cultivated material with wild medicinal quality. Beneficial microbial strategies support the same conservation-industry linkage: endophytic fungi and *Bacillus velezensis* strains increase biomass and active compounds, which can raise cultivated yield and quality without increasing collection pressure on wild plants (Ye et al., 2020; Hou et al., 2025). The most sustainable pathway is therefore a coordinated model in which protected germplasm resources feed standardized artificial cultivation, and cultivation success in turn lowers incentives for destructive wild harvesting (Hong et al., 2016).

5.3 Extension of the *Anoectochilus roxburghii* industrial chain and high-value utilization

The industrial chain of *A. roxburghii* can be extended because the species is not only a medicinal plant but also a functional food and ornamental resource with diverse bioactive constituents and broad pharmacological relevance. It is already used in foods, soups, teas, beverages, and several dosage forms, and clinical or quasi-clinical applications have been reported for diabetes, hepatitis B, hyperuricemia, cough-variant asthma, and other conditions (Ye et al., 2020; Gam et al., 2020). These features support downstream diversification into health foods, botanical beverages, standardized extracts, and pharmaceutical intermediates rather than reliance on crude fresh-herb sales alone (Wang et al., 2018; Hou et al., 2025). PLBs and rhizome cultures also offer alternative production units for kinsenoside and polysaccharides, which creates opportunities for ingredient-oriented processing rather than depending exclusively on whole-plant harvests (Wang et al., 2022; Luan et al., 2026).

High-value utilization also depends on strengthening the midstream processing segment and building stronger product innovation capacity. Patent analysis indicates that current research and development already focuses on pharmaceutical preparations, food uses, and downstream products such as anti-inflammatory and anti-infective