

2020; Gu et al., 2025). Even after harvest, active compounds continue to change: polysaccharides, kinsenoside, and flavonoids all decline during storage, vacuum packaging better preserves polysaccharides and flavonoids, and kinsenoside degradation is influenced more by endogenous enzymes than packaging method (Wei et al., 2022).

Improving quality stability requires shifting from simple yield-oriented cultivation to process-oriented quality regulation. Cultivation standards should define target light formulas, substrate composition, humidity, temperature, and culture duration for different production objectives, since both bioreactor rhizome culture and greenhouse systems show clear optimum windows for metabolite accumulation (Jin et al., 2017; Chen et al., 2021). Microbial management should become part of routine cultivation, with prioritized use of beneficial endophytes, mycorrhizae, and AM fungi that simultaneously improve growth, quality, and disease resistance (Ye et al., 2020; Zhang et al., 2020; Gu et al., 2025). Harvest timing and elicitation strategies should also be optimized, because kinsenoside accumulation peaks at defined developmental stages and can be significantly enhanced by yeast extract, salicylic acid, or methyl jasmonate under controlled rhizome culture conditions (Jin et al., 2018; Luo et al., 2018). Finally, post-harvest drying, packaging, and storage must be standardized together with multi-component chemical monitoring, so that quality stability is controlled across the full chain rather than judged only at harvest (Wei et al., 2022).

6.3 The standardized industrial system of *Anoectochilus roxburghii* still needs improvement

Although artificial cultivation has supported expanding production, the industry still lacks a unified system linking germplasm, seedling production, cultivation management, quality evaluation, processing, storage, and downstream product development (Su et al., 2017; Wei et al., 2022). One major weakness is the absence of consistent quality standards across regions and products, compounded by species confusion and adulteration in the market because morphologically similar *Anoectochilus*, *Goodyera*, and *Ludisia* materials are sometimes used as substitutes (Ye et al., 2020; Fang et al., 2025). Another weakness is that industrial production often emphasizes planting scale more than chain integration, even though research already points to the importance of greenhouse management, harmless pest control, controlled environmental regulation, and post-harvest quality preservation (Zhang et al., 2020; Chen et al., 2021). The gap is therefore systemic: production technologies exist, but they are not yet assembled into a unified industrial specification from upstream breeding to midstream processing and downstream high-value utilization (Ye et al., 2020).

The optimization pathway is to build a full-chain standardized industrial system centered on traceability, quality markers, and coordinated industrial upgrading. Upstream, authenticated elite germplasm should be linked to standardized propagation and protected breeding-resource management, using DNA barcoding, chemotype classification, and molecular markers to prevent varietal confusion and improve source control (Ye et al., 2020; Fang et al., 2025). Midstream, production should be standardized through facility cultivation protocols, microbial-assisted quality enhancement, optimized drying and storage methods, and process specifications for extraction and purification of active ingredients (Ye et al., 2020; Gu et al., 2025). Downstream, the industry should expand from crude medicinal material sales toward functional foods, oral liquids, cosmetics, and pharmaceutical preparations, while using multi-component analytical tools to define stable Q-markers and improve product consistency (Wang et al., 2018; Zhang et al., 2020). Overall, the standardized industrial system of *A. roxburghii* still needs improvement because the next stage of artificial replacement cultivation is not simply more planting, but tighter integration of breeding, cultivation, quality control, processing, and high-value product development (Wei et al., 2022).

7 Conclusion and Prospects

Conservation of wild *Anoectochilus roxburghii* resources is the foundation for sustainable industrial development because natural populations have been severely reduced by over-collection, habitat loss, slow growth, low natural propagation, and narrow ecological requirements. Its threatened status is reflected in formal protection designations, including listing as a protected plant in China and recognition as vulnerable, near-threatened, or endangered in international conservation frameworks. Conservation planning now has clearer spatial guidance, because climate-based distribution modeling identifies Fujian, Guangdong, Guangxi, Yunnan, and Guizhou as stable highly suitable habitats that should be prioritized for in situ protection, while contracting peripheral