

industrial development still faces important bottlenecks, including slow variety breeding, insufficient quality-control systems, weak product innovation, limited brand recognition, and the absence of unified evaluation standards across regions; notably, *A. roxburghii* has not yet been included in the 2020 Chinese Pharmacopoeia, which constrains standardization, safety evaluation, and high-quality industrial development (Hong et al., 2016; Zou et al., 2025).

Despite this high value, wild *A. roxburghii* resources have undergone persistent depletion for more than two decades. Early resource surveys already emphasized the need for rational preservation and exploitation, while later field investigations in Xishuangbanna found that intensive collection had left the species only sporadically distributed in relatively inaccessible places, making artificial reproduction a practical necessity. More recent studies consistently attribute population decline to overexploitation, habitat destruction, ecological deterioration, slow growth, low seed germination, low natural propagation rates, and strict habitat requirements (Wang et al., 2018; Hou et al., 2025). Surveys in central Vietnam similarly recorded only 123 individuals across 9 of 20 survey lines in Bach Ma National Park, illustrating the scarcity and uneven distribution of extant populations even in protected landscapes (Ho et al., 2025). This conservation pressure is now formally recognized: *A. roxburghii* has been described as vulnerable, near-threatened, or endangered in international and national conservation frameworks, and has been listed as a National Level II Protected Plant in China (Wang et al., 2022; Hou et al., 2025). Its vulnerability is intensified by ecological specialization. The species depends strongly on precise light conditions for growth, photosynthesis, and flavonoid accumulation, and its sensitivity to abiotic stress suggests limited buffering capacity under environmental change. Climate modeling therefore indicates that, alongside direct human disturbance, future shifts in temperature and precipitation may further alter suitable habitats, making in situ conservation, germplasm rescue from contracting populations, and regionally guided artificial cultivation increasingly urgent.

This study will explore the key technical pathways for the coordinated development of *Anoectochilus roxburghii* resource conservation and artificial replacement cultivation. Against the background of continuous wild resource decline and increasing market demand, artificial replacement cultivation has become a core approach to relieving resource pressure, ensuring the supply of high-quality raw materials, and promoting sustainable industrial development. In recent years, tissue culture and in vitro rapid propagation technologies have enabled efficient multiplication, genetic consistency, and disease-free seedling production, while large-scale seedling systems and protocorm-like body (PLB) propagation have significantly improved propagation efficiency and transplant survival, providing important technical support for germplasm conservation and industrial production. Meanwhile, technologies such as light-environment regulation, wild-imitated cultivation, endophyte regulation, and under-forest ecological cultivation can further promote active-component accumulation, improve medicinal quality, and strengthen the connection between cultivated materials and wild-type quality. Based on this, this paper systematically analyzes the significance of wild resource conservation of *A. roxburghii*, discusses key technologies including seedling propagation, cultivation model optimization, precise environmental regulation, medicinal quality formation, and whole-process quality control, summarizes pathways for standardized production, coordinated industrial development, and high-value utilization, and proposes optimization strategies for current problems in artificial replacement cultivation, aiming to provide theoretical and practical references for resource conservation, cultivation technology optimization, and high-quality industrial development of *A. roxburghii*.

2 Significance of Wild Resource Conservation

2.1 Genetic value

Wild germplasm resources of *Anoectochilus roxburghii* have irreplaceable genetic value because they preserve the full range of natural variation formed under long-term habitat selection (Priyanka et al., 2021; Yadav et al., 2024). As an endangered medicinal orchid with slow growth, low natural propagation, and narrow habitat requirements, the loss of wild populations would directly reduce the species' adaptive and evolutionary potential. Climate contraction is especially important for peripheral populations, because populations at distribution margins can contain unique adaptive variation and are at greatest risk of disappearance, making targeted germplasm rescue