

necessary (Hou et al., 2025). More broadly, work on wild plant germplasm shows that natural populations are valuable gene pools for future breeding, stress resistance, and long-term improvement, a principle that is highly relevant to *A. roxburghii* conservation.

Recent molecular studies also show why wild germplasm should be treated as a strategic breeding resource rather than only a protected object. Transcriptome assembly in *A. roxburghii* generated 138 385 unigenes and identified 44 045 SSRs, providing marker resources for assessing diversity across accessions and supporting more effective breeding and conservation (Zhang et al., 2024). DNA barcode work further indicates that matK and ITS can support reliable species identification, with ITS offering better phylogenetic resolution, which is useful for germplasm authentication and genetic resource management (Nhàn, 2025). At the trait level, tetraploid materials produce more major secondary metabolites than diploids, showing that conserving genetically distinctive materials can directly expand medicinal and breeding value (Zhang et al., 2025).

2.2 Ecosystems and population restoration

Protecting the native ecosystem is fundamental because *A. roxburghii* depends on highly specific forest microhabitats rather than broad environmental tolerance. Field and distribution studies show that the species occurs mainly under evergreen or semi-deciduous broadleaf forest with high humidity, large canopy cover, and limited disturbance, while over-collection, deforestation, and forest conversion have sharply reduced wild occurrence (Ho et al., 2025). Its growth, photosynthesis, and flavonoid accumulation are strongly affected by light conditions, and its narrow ecological amplitude indicates limited buffering capacity under environmental change. Because stable future refugia are predicted mainly in Fujian, Guangdong, Guangxi, Yunnan, and Guizhou, these areas should remain priorities for in situ protection and reserve-gap assessment (Hou et al., 2025).

Population restoration should therefore combine habitat protection with scientifically guided reinforcement. Surveys in Bach Ma National Park found only 123 individuals across 9 of 20 survey lines, usually in small clusters of 4-15 plants, illustrating both rarity and fragmentation (Ho et al., 2025). Earlier regional studies likewise proposed ecological study, tissue-culture multiplication, and wild tending to increase population size and provide a basis for recovery. Restoration also needs to account for stress biology and disease control: drought severely threatens the species, candidate drought-resistance genes have now been identified for molecular breeding, and soft rot can reduce cultivated yield by 70%~80%, which means healthy reintroduction materials require both abiotic and biotic resilience (Xing et al., 2022; Jiang et al., 2025).

2.3 Conservation systems and sustainable utilization

A sustainable conservation system for *A. roxburghii* should integrate in situ protection, ex situ germplasm preservation, dynamic monitoring, improved-variety propagation, and regulated industrial utilization. Industry analyses identify weak wild-resource protection, slow variety breeding, and insufficient quality-system research as key constraints, and recommend stronger breeding-resource protection, dynamic monitoring, and improved propagation systems (Hong et al., 2016). General germplasm research likewise shows that effective conservation requires collection, storage, analysis, documentation, and exchange, using complementary methods such as slow-growth culture, cryopreservation, DNA banks, botanical gardens, and genetic reserves (Priyanka et al., 2021). For rare plants, in situ conservation is generally preferred, but ex situ systems are essential to prevent genetic loss and to maintain material for future recovery and breeding (Yadav et al., 2024).

Sustainable utilization depends on replacing destructive wild harvesting with high-quality artificial cultivation that still maintains medicinal characteristics. Large-scale micropropagation protocols now achieve shoot induction of 91.67%, rooting of 93.33%, and transplant survival of 90.2%, while tetraploid propagation systems also support high rooting and acclimatization rates, showing that ex situ multiplication can relieve harvest pressure on wild populations (Zhang et al., 2025). Tissue culture is already regarded as the main seedling-raising method because it enables rapid, genetically consistent, disease-free propagation and supports germplasm protection (Li and Li, 2025). At the same time, under-forest and wild-imitated cultivation are important because they better align production with ecological requirements, and wild-imitated systems can shift endophytic communities toward