

populations should be urgently targeted for ex situ germplasm collection to preserve adaptive diversity. Earlier field-resource surveys and recent metabolomic studies also show that conserving wild populations is important not only for species survival but also for maintaining ecological, chemical, and regional diversity that underpins future breeding, quality evaluation, and rational utilization.

Artificial replacement cultivation of *A. roxburghii* is the core pathway for relieving resource pressure because market supply can no longer rely on wild harvesting, and artificial cultivation already serves as the main source of propagated material. Rapid propagation systems now provide a practical basis for large-scale replacement, including nodal culture with 91.67% shoot formation, 93.33% rooting, and 90.2% transplant survival, PLB systems with 89% induction, 400% secondary proliferation, 98% rooting, and full acclimatization survival, and tetraploid propagation systems that support both germplasm conservation and commercial multiplication. Beyond simple yield replacement, wild-imitated cultivation, under-forest cultivation, and karst-forest imitation-wild systems provide additional routes for reducing pressure on wild resources while improving medicinal continuity and ecological compatibility. Climate projections further suggest that establishing future cultivation bases in newly suitable northern regions such as Hubei, Anhui, and southern Henan could simultaneously meet market demand and reduce harvesting pressure on vulnerable southern wild populations.

Scientific and technological innovation will promote *A. roxburghii* resource conservation and high-quality industrial development because the main remaining bottlenecks are low breeding efficiency, unstable cultivated quality, weak quality systems, and limited industrial innovation capacity. Innovation is already improving propagation efficiency and product quality through optimized media, light regulation, elite tetraploid propagation, and alternative production systems such as rhizome bioreactors and PLB-based kinsenoside production. Molecular and omics tools are expanding the breeding and management toolbox, including DNA barcode identification, transcriptome resources, a high-quality reference genome, drought-tolerance gene modules, and metabolome-transcriptome analyses showing that red-blue light can strongly promote functional metabolite biosynthesis. At the cultivation end, microbial engineering, endophyte management, and environmentally controlled production can improve biomass, disease resistance, and active-ingredient accumulation, while industrial upgrading should extend toward standardized extraction, purification, quality markers, and diversified products in medicine, health food, and cosmetics.

Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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