so conservation-oriented cultivation and value-chain design are necessary preconditions for expansion (Volenzo and Odiyo, 2020). This supports a shift from extractive utilization toward forest-based composite industries that include standardized cultivation, conservation education, and ecological branding.

Forest wellness research suggests that forests support psychological, physiological, and social wellbeing, but effective initiatives require integrated management across forestry, health, planning, and community sectors rather than forest management alone (Doimo et al., 2020). Applied tourism studies further emphasize protecting diverse tourism resources, improving infrastructure, building eco-friendly facilities and educational trails, and using adaptive, cross-sector governance with community participation, sustainability certification, and environmental education. These studies provide a transferable reference for *Polygonatum*-producing areas, this supports an integrated model in which understory cultivation landscapes, medicinal-food culture, wellness experiences, and conservation education are jointly developed to create employment, diversify rural income, and keep ecological protection as the limiting condition of industrial growth (Wang et al., 2024).

5 Key Issues and Optimization Strategies for the Integrated Development of the *Polygonatum* Industry

5.1 Strengthening germplasm conservation and genetic improvement research

The first key issue is that *Polygonatum* industrial expansion is constrained by wild resource depletion, germplasm degradation, and persistent confusion among closely related species and cultivars (He et al., 2025; Cheng et al., 2026). Morphological identification alone is often unreliable because *Polygonatum* shows strong phenotypic variation, interspecific similarity, hybridization, seasonal dormancy, and environmentally plastic rhizome traits, which can lead to uneven quality and even medication-safety risks (Figure 2) (Huang et al., 2026). Research across SCoT, ISSR, SSR, transcriptome-derived SSR, IRAP, and molecular fingerprinting systems consistently shows high genetic diversity in *Polygonatum germplasm* and supports molecular identification as a practical basis for conservation, classification, and breeding (Jiao et al., 2018). Core-collection construction is especially important because it preserves maximum allelic diversity with lower redundancy and management cost; in one recent study, a C78 core set retained 84.59% of alleles and was proposed to streamline ex situ conservation and germplasm regeneration (Zhu et al., 2025).

The main optimization strategy is to combine in situ conservation, ex situ core collections, and marker-assisted breeding into one germplasm innovation system. Multi-site provenance trials show highly significant genotype, site, and genotype-by-environment effects for growth and medicinal traits, with strong repeatability and clear selective-breeding potential (Cheng et al., 2026). Songyang and Yunhe provenances performed best in *P. cyrtonema* and are already recommended as elite breeding materials, while common-garden experiments indicate that *P. cyrtonema* is particularly suitable for introduction and cultivation in Zhejiang-like environments (Liao et al., 2023). Marker systems now go beyond diversity description: transcriptome-derived SSRs include markers associated with polysaccharide biosynthesis, and MNP or IRAP fingerprints can support cultivar authentication, seedling purity testing, germplasm protection, and intellectual-property management (He et al., 2025; Huang et al., 2026; Tang et al., 2026). A practical path is therefore to establish a national germplasm bank, define conservation priorities for geographically distinct groups, integrate molecular IDs with medicinal-component traits, and use diverse parental materials for crossbreeding high-yield, high-quality, and understory-adapted varieties (Zhu et al., 2025).

5.2 Improving green cultivation technologies and quality evaluation systems

The second key issue is that *Polygonatum* cultivation still lacks a sufficiently mature green production technology system and stable quality-evaluation framework. Species and provenance differ markedly in yield, polysaccharide and saponin contents, and agronomic traits, and these differences are further shaped by the climatic conditions of origin and cultivation environment (Liao et al., 2023). Understory production adds another layer of complexity because yield responds strongly to stand density and soil conditions; in bamboo-*Polygonatum* agroforestry, tuber yield increased as culm density decreased, with the M1 mode at 1750 culms/ha producing the best soil fertility and yield outcome (Xu et al., 2023). Cultivated *P. cyrtonema* also appears to offer quality advantages over wild