initial costs, technical skill requirements, data management complexity, interoperability problems, privacy concerns, and weak connectivity in remote areas all still limit adoption (Fuentes-Peñailillo et al., 2024; Miller et al., 2025). Even so, the direction is clear that future *Polygonatum* production will increasingly rely on sensor networks, remote monitoring, AI analytics, and user-friendly decision systems to support standardized, efficient, and sustainable understory cultivation (Sishodia et al., 2020).

7 Conclusion

The medicinal-and-edible development of *Polygonatum* has substantially enhanced the utilization value of its resources because the genus combines nutritional attributes with diverse pharmacological functions and therefore supports both traditional medicine and food-oriented applications. *Polygonatum rhizomes* are officially recognized medicinal materials derived mainly from *P. cyrtonema, P. sibiricum*, and *P. kingianum*, while their inclusion in medicine-food use reflects the practical convergence of health care and dietary consumption. Their value is rooted in abundant active and nutritional constituents, especially polysaccharides and saponins, which are widely treated as major quality markers and linked to hypoglycemic, immune-regulating, anti-aging, antioxidant, and other health-promoting activities. At the same time, *Polygonatum* has food-security and nutritional significance because it has been described as having potential to address chronic and hidden hunger, and *P. cyrtonema* rhizomes historically served as a famine food with carbohydrate content comparable to staple grains. This dual value supports a transition from simple raw-resource use toward higher-value development based on breeding, quality control, extraction, and differentiated medicinal-food products.

Understory cultivation promotes the green development of the *Polygonatum* industry because it aligns with the plant's natural ecological traits while reducing dependence on increasingly depleted wild resources. *Polygonatum* naturally thrives in shaded forest habitats, and studies identify it as a key understory economic crop with strong potential in forest-based cultivation systems. Evidence from bamboo-polygonatum agroforestry shows that intercropping can significantly improve soil quality compared with monoculture, and that a bamboo density of 1750 culms/ha produced the best combination of soil fertility improvement and tuber yield. These systems also help restore ecological and economic functions of forest land by improving productivity, diversifying output, and creating more sustainable use pathways for shaded land resources. Yet green development depends on standardization rather than simple expansion, because cultivation outcomes vary significantly across species, provenances, and environments, and current production still faces germplasm confusion, weak technical systems, and the need for standardized seedling, field, and dormancy management. The long-term significance of understory cultivation is therefore not only higher output, but the formation of an ecologically compatible production mode that links conservation, artificial domestication, and quality-oriented forest farming.

Industrial integration is the key pathway for the sustainable upgrading of the *Polygonatum* industry because isolated cultivation cannot by itself solve bottlenecks in value realization, market access, and competitiveness. Broader medicinal-plant value-chain research shows that supply chains are often long, weakly integrated, and dependent on poorly coordinated actors, with middlemen playing a large role and with limited communication, innovation, and market responsiveness. For *Polygonatum*, this means that sustainable upgrading requires coordinated development of germplasm conservation, standardized cultivation, processing technologies, quality evaluation, certification, and branded product systems rather than continued reliance on raw rhizome sales. Molecular identification tools, core germplasm construction, and rapid quality assessment methods already provide technical support for this transition by improving variety authentication, breeding efficiency, and raw-material grading. At the market end, future competitiveness depends on product innovation, certification and labeling, digital upgrading, actor agreements, and stronger partnerships that connect producers, processors, and downstream markets. Taken together, the sustainable upgrading of the *Polygonatum* industry depends on transforming a fragmented resource-based sector into an integrated system that combines understory cultivation, deep processing, value-chain coordination, and ecological economic development.