

improving disease and pest management, and establishing economically and environmentally sustainable production systems. Practical green technologies already supported in the literature include pine-bark or woody breathable substrates, organic nutrient inputs, understory shading, mist irrigation, and ecological pest-control designs, as well as mycorrhizal or endophytic-fungal application to improve drought resistance, disease resistance, and quality stability (Zhang et al., 2024). In addition, precision cultivation should shift from post-harvest correction to pre-plantation zoning, because machine-learning evidence shows that facility agriculture changes the key environmental drivers of polysaccharide accumulation and shifts high-quality production areas geographically (Yang et al., 2026).

6.3 Improving quality evaluation systems and standardized production systems

A major bottleneck in future development is that current quality evaluation still relies too heavily on polysaccharide content alone. Multiple studies state that polysaccharides are the main or even sole pharmacopoeial quality marker now in use (Tan et al., 2023), but metabolomics evidence shows that this standard is incomplete because secondary-metabolite patterns can move in the opposite direction from polysaccharide rankings across regions and cultivation environments (He et al., 2022). Recent multidimensional work strengthens this point by identifying 1 929 metabolites in stems from different cultivation environments and showing that stone-epiphytic samples had 58 up-regulated metabolites, especially flavonoids, along with stronger cell-level protective effects (Hou et al., 2025). Future quality evaluation should therefore move toward multi-index systems that jointly consider polysaccharides, flavonoids, alkaloids, polyphenols, oligosaccharide markers, and bioactivity-linked fingerprints (Wong et al., 2019).

Analytical technology for this transition is already available. Near-infrared spectroscopy combined with chemometrics can rapidly predict polysaccharides, polyphenols, total flavonoids, and total alkaloids and can identify geographical origin with very high accuracy (Yang et al., 2022). Oligosaccharide-marker methods and spectrum-effect approaches also provide rapid, validated, and functionally meaningful routes for polysaccharide-related quality control (Wong et al., 2019). Standardized production must advance in parallel, because the mixing of germplasm has already caused major variation in yield and quality, while national production standards are still lacking despite existing technical procedures, provincial food standards, and ongoing ISO alignment. Accordingly, future development should build a full-chain standardized system covering germplasm identification, seedling production, cultivation-mode matching, harvest timing, processing, and rapid quality verification, so that *D. officinale* can develop toward high-quality, green, and industrially consistent production (Gu et al., 2017; Hou et al., 2025).

7 Conclusion of Cultivation Modes

Wild-simulated cultivation and facility cultivation represent the two major production modes of *Dendrobium officinale* in current industrial development. Wild-simulated cultivation reconstructs the natural habitat and epiphytic environment of *D. officinale* through forest, rock, or tree-attached cultivation, allowing plants to grow under ecological conditions closer to the wild state. This mode promotes secondary metabolism through environmental adaptation, microbial interactions, and moderate ecological stress, and generally contributes to the formation of wild-like morphological characteristics and improved comprehensive quality. Facility cultivation, in contrast, relies on greenhouse-based environmental regulation, standardized seedlings, and precise water-fertilizer management to achieve stable and large-scale production. It has clear advantages in yield stability, production efficiency, and industrial supply capacity. However, artificial environments may alter plant metabolic characteristics and quality formation processes, and further optimization of quality regulation technologies is still required.

The selection of cultivation mode should be determined according to specific production objectives rather than based on a single evaluation criterion. For large-scale raw material supply, standardized production, and integration with pharmaceutical, food, and health-product industries, facility cultivation is more suitable due to its stable yield, standardized management, and high production efficiency. In contrast, wild-simulated cultivation has greater potential for premium medicinal materials, ecological branding, and high-value products, owing to its