## 7 Standardized Application of Primary Processing and Specification Grading of *Polygonatum*

### 7.1 Promotion of graded processing and control of key processing parameters

Optimizing traditional processing methods requires precise control over key parameters to prevent over-processing and preserve bioactive components. The traditional nine-steaming and nine-drying method induces significant chemical transformations, but the first six processing cycles account for the most drastic changes in functional component accumulation, while subsequent cycles yield no further benefits and may even reverse enhancing effects. Most functional components are significantly enhanced after the first three cycles and stabilize after six, indicating that the full nine cycles are often excessive (Shen et al., 2024). Response surface methodology (RSM) has been successfully applied to optimize specific processing parameters, such as the solid-to-liquid ratio, decocting temperature, and time, achieving a highly reliable model with significant predictability for standardized processing protocols. Parameters established under particular experimental conditions should be validated for the botanical source, processing scale, and target indicators before being adopted as industrial operating standards.

Graded processing must also account for species-specific chemical reactivity and volatile compound transformations. Different *Polygonatum* species exhibit distinct aroma trajectories during processing, with early-stage losses of green aldehydes reflecting suppressed lipid-oxidation pathways and later-stage increases in roasted notes consistent with Maillard reactions and Strecker degradation. Species-specific differences in ester, ketone, and phenolic formation suggest variations in precursor pools and thermal reactivity that necessitate tailored processing parameters rather than a universal protocol (Sabier et al., 2026). Processing with auxiliary materials such as black bean juice significantly alters chemical fingerprints, increasing lower-polarity compounds and generating six new compounds while degrading medium-polarity constituents. This processing method significantly increases polysaccharide content from an average of 12.19% in raw samples to 32.28% in processed samples, alongside enhanced antioxidant and antidiabetic activities (Zhang et al., 2023). These findings underscore the necessity of controlling key processing parameters to maximize therapeutic outcomes and standardize commercial quality.

### 7.2 Improvement of processing records and quality traceability systems

Establishing comprehensive quality traceability systems requires integrating macroscopic, microscopic, and chemical characterization data into processing records. Color quantization based on the CIE L*a*b* system provides objective metrics for tracking processing levels, with parameters h, L, and ΔE demonstrating significant differentiation ability across *Polygonatum sibiricum* samples. The inner transverse section of processed rhizomes gradually turns moist black with specular luster, consistent with the traditional identification standard of "brightness like oil and color like black lacquer," providing a reliable visual marker for processing records. Microscopic characterization of calcium oxalate needle crystals offers an additional traceability marker, as the change rate of needle crystal morphology increases with processing level and exceeds 90% by the fifth cycle. High correlations between color parameters and needle-like crystals confirm the potential applicability of these features for classifying samples from different processing levels, enabling processors to document and verify processing adequacy (Cheng et al., 2022).

Advanced analytical technologies further strengthen traceability by linking processing records to chemical fingerprints and volatile profiles. Flash GC-E-nose profiling of volatile transitions across ten processing stages tentatively identified 71 compounds, providing foundational knowledge for aroma-based authentication tools that can verify processing consistency. Multivariate analyses, including PCA and hierarchical cluster analysis, clearly discriminate both species and steaming stages, revealing consistent chemical transformation patterns that can serve as reference standards in traceability databases (Sabier et al., 2026).

Untargeted GC-MS and FT-NIR spectroscopy identified 333 metabolites across 14 processing methods, with FT-NIR-based PLS-DA models reporting recognition rates of 71.43%–96.43% under the conditions studied (Xu