6.2 Improvement of processing quality and internal quality evaluation indicators

While external specifications provide initial sorting criteria, internal quality evaluation must account for the significant chemical transformations that occur during primary processing. Tissue-specific analysis has emerged as a powerful tool for linking internal morphology with bioactive component distribution, as demonstrated in PMR where laser microdissection combined with UPLC-QqQ-MS/MS mapped the accumulation patterns of twelve secondary metabolites across six distinct tissue types. This approach revealed that stilbene glucosides, combined anthraquinones, and polyphenols predominantly accumulated in the cork tissue, while free anthraquinones concentrated in the phloem, establishing that transverse section features directly correlate with medicinal quality. Such tissue-specific profiling provided a morphological grading criterion in the material studied; an analogous approach in *Polygonatum* would require direct histological and chemical validation rather than extrapolation from PMR (Liang et al., 2018).

The improvement of internal quality indicators also requires addressing the significant variation in chemical composition that occurs across processing methods and cycles. In PO, the average content of polygonatumoside F, a furostanol saponin serving as a key quality control marker, differed significantly between commercial specifications, with GPO containing 329.35 μg/g compared to 195.49 μg/g in XPO, indicating that saponin profiles must be evaluated as processing-sensitive indicators. Additionally, the total content of three marker compounds varied dramatically across batches within the same specification, ranging from 137.70 to 1 005.55 μg/g in XPO, highlighting the need for processing standardization to reduce batch-to-batch variability. The application of UHPLC-Q-TOF/MS for comprehensive qualitative analysis enabled the identification of 62 compounds in PO, including 43 steroidal saponins, 11 flavonoids, and 8 alkaloids, establishing a full chemical profile that can serve as a reference for monitoring processing-induced changes in *Polygonatum*. These methods demonstrate that internal quality evaluation must move beyond single-marker assays to multi-component quantitative profiling that captures the full spectrum of processing-induced chemical transformations (Nan et al., 2023).

6.3 Construction of a multi-indicator comprehensive commercial grading system

The construction of a comprehensive grading system requires integrating external morphological features, tissue-specific chemical distribution, and multi-component quantitative analysis into a unified evaluation framework. The PMR study demonstrated that tissue-specific analysis of secondary metabolites can create new morphological criteria-such as broader cork and phloem regions in transverse sections-that reliably predict quality better than traditional size and weight measurements (Liang et al., 2018). This methodological principle could be tested in Polygonati Rhizoma by examining external appearance, internal histology, and chemical markers jointly; the PMR results alone do not validate those criteria for Huangjing. The successful application of OPLS-DA models with 99% explained variation and 97% predictive ability in differentiating PO specifications confirms that multivariate statistical approaches can robustly classify commercial grades when appropriate chemical markers are selected (Nan et al., 2023).

A multi-indicator system must also account for the fact that different commercial specifications may serve different end-use applications, requiring tailored quality criteria. In PO, XPO is more frequently used as a raw material for dietary supplements while GPO is more inclined toward medicinal use, meaning that grading systems should incorporate use-case-specific indicators rather than applying a universal standard. The identification of specific chemical markers unique to each specification, such as isomers of hydroxylwattinoside C and 3β-hydroxy-25S-spirost derivatives found only in GPO, provides the chemical basis for application-specific grading. Furthermore, the timosaponin H1-to-polygodoraside G ratio provides a published example of specification-specific grading for *P. odoratum*, but it has not been validated as a grading threshold for Huangjing . By integrating these quantitative chemical markers with traditional morphological features and tissue-specific distribution patterns, a comprehensive commercial grading system for *Polygonatum* can be constructed that ensures accurate quality assessment, supports appropriate end-use allocation, and provides a scientific foundation for industry standardization.