5.3 Problems in the existing commercial grading system

The existing commercial grading system for *Polygonatum* faces significant challenges due to germplasm confusion, lack of good varieties, and the indiscriminate introduction of seedlings across regions (Liao et al., 2023). These issues impede the development of the industry and lead to inconsistent product quality in the market . A major limitation is that traditional classification methods based on appearance and origin lack systematic chemical validation. For instance, no comparison had been made between the small molecule chemicals of the two main PO commercial specifications prior to recent instrumental analysis, making it difficult to objectively distinguish XPO and GPO based solely on traditional criteria. Furthermore, the quality of different batches within the same specification varies greatly; the total content of three marker compounds in XPO ranged from 137.70 to 1 005.55 μg/g, while GPO quality was comparatively stable between 349.19 and 859.64 μg/g (Nan et al., 2023).

Current quality evaluation methods are also insufficient for comprehensive commercial grading. The traditional colorimetric method for determining polysaccharide and saponin contents is time-consuming and labor-intensive, rendering it unsuitable for determining the contents of large quantities of samples needed for market grading. While near-infrared spectroscopy (NIRS) combined with chemometrics has been established for the rapid determination of saponin content in Huangjing, with a residual prediction deviation (RPD) of 2.25 indicating potential for quantitative grading-the model for polysaccharide content achieved an RPD of only 1.15, restricting its use to preliminary screening rather than precise commercial classification. The lack of precise control over processing parameters further exacerbates grading inconsistencies, leading to uneven quality of processed *Polygonatum* products (Nan et al., 2023). These shortcomings highlight the need for a multidimensional grading system that integrates morphological traits, chemical markers, and rapid detection technologies to standardize *Polygonatum* commodity quality.

6 Optimization of the Commercial Grade Classification System for *Polygonatum*

6.1 Establishment of quantitative indicators for raw materials and external specifications

Traditional commercial grading of medicinal materials relies heavily on external morphological features such as size, weight, and color, but modern research indicates these criteria do not always correspond to actual chemical quality. In the case of Polygoni Multiflori Radix (PMR), an unrelated medicinal material considered here only as a methodological comparison, wholesalers grade material into three classes based strictly on weight, yet quantitative analysis of twelve major bioactive components revealed no significant chemical differences across these size-based grades. This shows that size alone was insufficient to distinguish internal quality in PMR, suggesting a hypothesis that should be evaluated directly in Polygonati Rhizoma with quantitative chemical testing (Liang et al., 2018). For *Polygonatum odoratum* (PO), the market is divided into two commercial specifications, Xiangyuzhu (XPO) and Guanyuzhu (GPO), based on appearance and origin, but these distinctions also lacked systematic chemical validation until recently (Nan et al., 2023).

To establish reliable quantitative indicators, researchers have turned to advanced analytical techniques to differentiate commercial specifications. Ultra-high-performance liquid chromatography coupled with charged aerosol detection (UHPLC-CAD) was successfully validated for the absolute determination of three key saponins-polygodoraside G, polygonatumoside F, and timosaponin H1, across 27 batches of PO, providing a precise chemical basis for specification differentiation. The ratio of timosaponin H1 to polygodoraside G emerged as a robust quantitative indicator, with ratios below 2 identifying XPO and ratios above 5 identifying GPO. Furthermore, multivariate statistical analyses, including principal component analysis (PCA) and orthogonal partial least squares discriminant analysis (OPLS-DA), successfully screened 13 chemical markers, comprising six flavonoids and seven steroidal saponins-that reliably distinguish the two commercial specifications. These findings provide a methodological example of quantitative indicator development, although the specific ratios were established for *P. odoratum* (Yuzhu) and cannot be directly applied to Huangjing, moving beyond subjective appearance-based grading to objective chemical marker evaluation (Nan et al., 2023).