2.3 Differences in raw material characteristics and criteria for preliminary grading

The substantial variation in raw material characteristics across species, origins, growth years, and harvest seasons creates a clear need for systematic preliminary grading criteria. Agronomic and quality traits of five *Polygonatum* species showed coefficients of variation ranging from 14.57% for leaf width to 42.93% for total inflorescence diameter, with polysaccharide and saponin contents varying by 27.55% and 24.63%, respectively. Stem diameter has been proposed as a practical indicator for variety screening and harvest assessment, providing a morphological marker that correlates with yield and quality (Liao et al., 2023). Among 40 cultivated germplasm resources, multivariate analyses including PCA, membership function scoring, and hierarchical clustering were applied to comprehensively rank nutritional quality, demonstrating that statistical methods can effectively differentiate accessions for grading purposes (Li et al., 2025). The five rhizome types of *P. cyrtonema* and *P. sibiricum* also differ in mucilage cell area ratio, with Baiji-type reaching 6.14% and Cylinder-type as low as 1.17%, providing a microscopic basis for quality differentiation.

Recent studies have begun integrating external appearance traits with multi-index metabolite quantification to establish objective grading frameworks. A quality evaluation of 16 batches of *P. sibiricum* slices from different regions quantified eight appearance traits and six functional metabolites, using PCA and OPLS-DA to cluster samples into three categories by origin and identify differential quality-affecting markers. A weighted TOPSIS-GRA fusion model combining appearance traits and metabolite contents confirmed significant quality differences among slices from different regions, providing a scientifically reliable method for quality control and standardization (Wang et al., 2025). Near-infrared spectroscopy combined with chemometrics has also been validated for rapid polysaccharide and saponin quantitation in *P. cyrtonema*, offering a non-destructive tool for preliminary grading (Liao et al., 2023). For the distinct medicinal commodity *P. odoratum* (Yuzhu), comparisons of round-leaf and long-leaf strains across two-and three-year growth periods found that long-leaf strains consistently outperformed round-leaf strains and that three-year rhizomes surpassed two-year rhizomes in drying rate, water extract, and polysaccharide content, suggesting that strain type and age can serve as preliminary grading criteria. Together, these findings indicate that a multidimensional grading system integrating botanical type, morphological traits, growth year, harvest season, and key chemical markers is both feasible and necessary for standardizing *Polygonatum* commodity quality.

3 Major Steps in Primary Processing of *Polygonatum* and Their Effects on Quality

3.1 Postharvest cleaning, sorting, and pretreatment

Fresh *Polygonatum* rhizomes contain 75~85% moisture and irritant components such as saponins that induce tongue numbness, making postharvest pretreatment essential for dehydration, enzyme inactivation, and component transformation (Wang, 2026). Raw rhizomes are irritating and can cause allergic reactions in their unprocessed form, necessitating thorough cleaning and sorting before further processing (Zhu et al., 2025). Initial preparation typically involves removing fibrous roots, washing with water to remove soil and impurities, and sorting rhizomes by size and quality to ensure uniform processing. Only fresh and undamaged rhizomes within a similar weight range and size are selected for optimal processing outcomes (Sabier et al., 2026).

Pretreatment practices also include preliminary grading based on morphological characteristics, which significantly influences final product quality. Among different lengths of *Polygonatum cyrtonema*, short-length rhizomes with younger tissues showed better performance after processing, indicating that raw material sorting by size and maturity serves as an effective pretreatment strategy. Fresh rhizomes may be stored at 4℃ for short periods prior to thermal processing, or sliced and quick-frozen in liquid nitrogen for laboratory sample preparation (not routine commercial primary processing) (Figure 1) (Shen et al., 2024). The selection of the appropriate raw material state-whether whole rhizomes or slices-further affects drying kinetics and component retention, with sliced samples requiring different processing parameters than whole rhizomes (Wang, 2026).

3.2 Steaming, boiling, and other thermal processing treatments

Thermal processing is the most critical step in *Polygonatum* primary processing, with steaming being the predominant method that considerably influences rhizome quality. Traditional methods include atmospheric