et al., 2023). Electronic eye technology combined with chemometrics offers a rapid, environment-friendly method for determining whether samples have reached sufficient processing time, with specific color parameter ranges serving as quantitative thresholds for quality acceptance. These tools collectively enable the construction of digitized processing records that link raw material origin to final product quality.

7.3 Coordination between commercial grading and market circulation requirements

Aligning commercial grading with market circulation requires multidimensional evaluation models that integrate external appearance traits with internal metabolite profiles. A weighted TOPSIS-GRA fusion model combining eight appearance traits and six functional metabolite contents successfully differentiated *Polygonatum sibiricum* slices from different regions, with PCA clustering 16 batches into three distinct quality categories. The correlation coefficients from gray relation analysis ranged from 0.3895 to 0.8094 for the optimal reference sequence, effectively distinguishing superior-quality samples from inferior ones. OPLS-DA identified differential quality-affecting markers, providing a scientific basis for categorizing commercial grades that correspond to actual market quality variation. The established multi-index content determination method demonstrated accuracy and reliability with recovery rates between 98.54% and 103.07%, supporting analytical repeatability under the conditions investigated (Wang et al., 2025); wider interlaboratory reproducibility would require further validation.

Effective coordination between grading and market circulation also demands rapid assessment tools and standardized variety selection to meet diverse consumer and industrial demands. Near-infrared spectroscopy combined with chemometrics enables rapid quantitation of polysaccharide and saponin contents, providing a practical tool for preliminary quality screening during market transactions. Stem diameter has been identified as a practical agronomic indicator for variety screening and harvest assessment, offering a morphological marker that correlates with yield and facilitates preliminary grading at the cultivation stage (Liao et al., 2023). The *Polygonatum* industry currently faces challenges including germplasm confusion, unclear functional composition, and decentralized small-scale processing, all of which undermine consistent market quality. Addressing these issues requires accelerating the selection of improved varieties, ensuring high-quality seedling supply, and eliminating unauthentic species to stabilize the raw material basis for commercial grading. Future market growth depends on technological innovation, brand strategy, and internet-based traceability platforms that integrate processing standards with commercial grading to ensure sustainable industry development (Su et al., 2018).

8 Summary and Prospects

Standardizing primary processing requires precise control of key parameters to prevent over-processing and preserve bioactive components. The traditional nine-steaming and nine-drying method induces significant chemical transformations, but some studies suggest that four processing cycles can provide favorable results for selected constituents under specified conditions; this cannot establish a universally optimal cycle number for all species and processing routes. Low molecular weight fructans undergo significant degradation within the first three processing cycles, with complete degradation by the seventh cycle, suggesting the traditional technique is often excessive. Polysaccharide content decreases progressively with increasing cycles, stabilizing at approximately 5.2 g/100 g after four cycles, a 45.81% reduction from raw rhizomes, while saponins, phenols, and flavonoids exhibit an increasing trend with slight fluctuations after the fourth cycle. 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. The lack of precise control over processing parameters has led to uneven quality of processed *Polygonatum*, underscoring the need for quantitative prediction models that correlate processing methods, component contents, and biological activity. A CRITIC-based prediction model has been developed to optimize processing by correlating method, component contents, and biological activity, ensuring consistent quality and efficacy. Establishing standard operating procedures also requires elucidating the toxicity-reducing and efficacy-enhancing mechanisms of processing. Calcium oxalate raphides are among the irritating components of raw *Polygonatum*, and processing disintegrates these raphide bundles, particularly at their tips, reducing throat irritation. Processing-induced chemical mechanisms include hydrolysis, oxidative decomposition, dehydration, Maillard reaction, and polymerization, with processing stages divisible into raw (0 h), middle (1–6 h), and late (8–18 h) phases. Polysaccharides partially degrade into oligosaccharides during