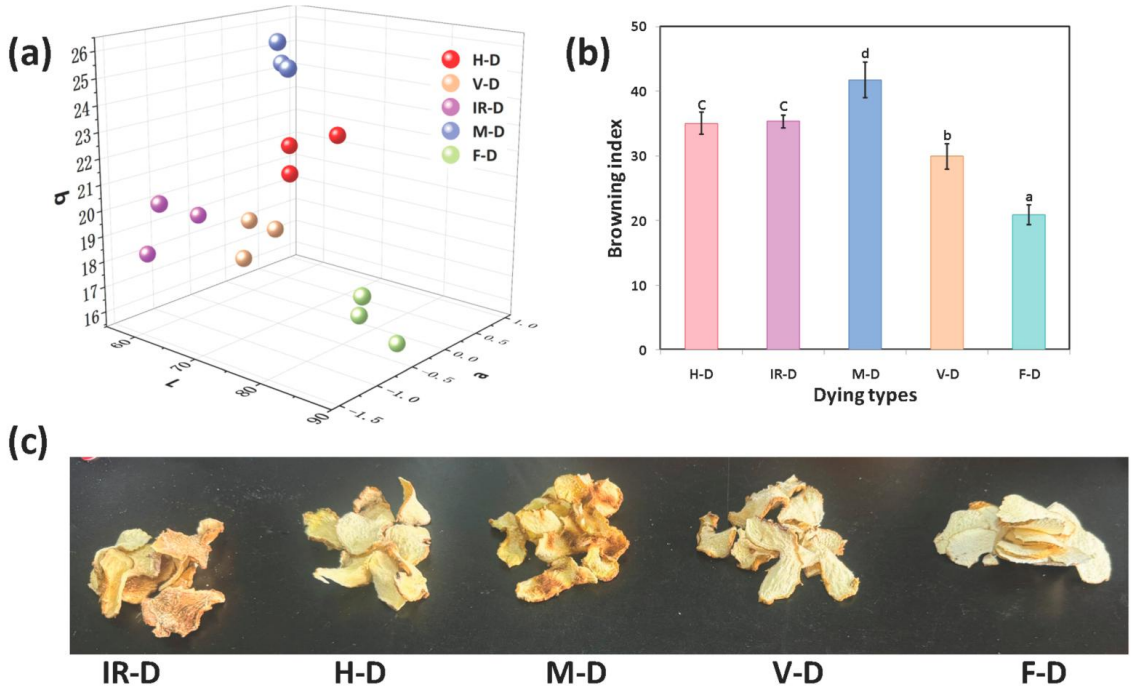


Figure 2 (a) Three-dimensional projection of L*, a*, and b* values; (b) Comparison of browning index of different drying methods. Different lowercase letters indicate significant differences at $p < 0.05$ as determined by the LSD test; (c) Samples of PCH dried by five drying methods (Adopted from Wang, 2026)

Texture modifications accompany color changes, with processed rhizomes exhibiting increased sweetness, strengthened viscosity, and the complete disappearance of tongue-numbing sensations. Wine-processing accelerates these textural transformations, allowing the product to reach the endpoint of "color resembling black lacquer, sweetness akin to syrup" earlier than standard steaming methods. Processing yield and extractable matter content vary significantly by method; water extract and alcohol extract contents gradually increase from crude to steamed to wine-processed products due to enhanced solubility from thermal disruption. However, excessive steaming and drying cycles intensify bitter and sour flavors, causing overall quality to deteriorate and reducing the commercial value of the final product.

4.3 Effects of primary processing on internal quality and commercial grade

Primary processing fundamentally alters the internal chemical composition of *Polygonatum*, dictating its medicinal efficacy and commercial grade classification. Total polysaccharide content decreases progressively with increasing processing cycles, stabilizing at approximately 5.2 g/100 g after four cycles, representing a 45.81% reduction from raw rhizomes. In *Polygonatum sibiricum*, polysaccharide content decreased by 47.38% after nine cycles, with the most significant decline occurring within the first three cycles. Low molecular weight fructans undergo significant degradation within the first three processing cycles, with complete degradation by the seventh cycle, suggesting that the traditional nine-cycle method causes excessive glycan depletion (Mei et al., 2025). Conversely, total saponins, phenols, and flavonoids exhibit an increasing trend during processing, with antioxidant activity peaking after three to four cycles before stabilizing (Yao et al., 2022). Processing with black bean juice significantly increases saccharide and saponin content while enhancing DPPH and ABTS radical scavenging capacities compared to raw samples.

The correlation between external chromatic values and internal chemical composition provides a scientific basis for commercial grade classification. *L. values* are significantly correlated with *Polygonatum cyrtonema* polysaccharide (PCP) content, suggesting that L can objectively characterize the extent of processing and serve as a rapid grading parameter. Multivariate statistical analyses, including PCA and OPLS-DA, successfully cluster processed samples into distinct quality categories based on secondary metabolite and carbohydrate profiles, confirming that chemical composition shifts predictably across processing stages (Shen et al., 2024). The first six