

traits, and metabolic profiles, leading to distinct accumulation patterns of flavonoids, amino acids, alkaloids, and aroma precursors even under similar cultivation and processing conditions (Yu et al., 2023; Bassiony et al., 2024). These differences directly affect the freshness, bitterness, and overall flavor balance of the tea infusion. For example, “Longjing 43” and local population varieties differ markedly in chlorophyll composition, amino acid content, and responses to environmental factors, thereby influencing the color and taste of the final product (Teng et al., 2024), while variations in volatile compounds determine characteristic aroma types such as bean-like and chestnut-like notes (Yan et al., 2025). With advances in breeding and molecular biology, several improved cultivars suitable for Longjing tea processing (e.g., Longjing 43, Wuniuzao, and Zhenong series) have been developed and widely adopted. However, differences in processing suitability and quality stability among cultivars remain evident (Teng et al., 2024). Meanwhile, genomic tools such as QTL mapping and molecular markers have provided new insights into the genetic basis of quality traits (Gao et al., 2023a; Ao et al., 2025), yet systematic comparisons among specialized Longjing cultivars are still lacking, highlighting the need for comprehensive multi-dimensional studies (Huang et al., 2024).

This study focuses on different tea plant cultivars used for Longjing tea processing, aiming to analyze their differences in appearance, sensory characteristics, and chemical composition. Special attention is given to the roles of non-volatile and volatile metabolites in quality formation, as well as processing suitability and its molecular regulation mechanisms. Furthermore, by integrating advances in metabolomics and genetics, this study evaluates the potential applications of cultivar differences in quality grading, authenticity identification, and the breeding of high-quality specialized cultivars. The findings are expected to provide a theoretical basis for cultivar selection and precise matching between cultivars and processing techniques, thereby promoting the high-quality development of the Longjing tea industry.

2 Basis of Longjing Tea Quality Formation

2.1 Typical quality characteristics of Longjing tea

Longjing tea, as a typical representative of flat green tea in China, exhibits its quality characteristics mainly in appearance, aroma, taste, liquor color, and infused leaves, forming a stable and highly recognizable style. High-quality Longjing tea is characterized by flat, smooth, straight, and uniform dry leaves, with a tender green or bright green color; the brewed liquor appears bright yellow-green and clear, while the infused leaves are tender, uniform, soft, and well-expanded (Bassiony et al., 2024; Zeng et al., 2024). This distinctive “flat, smooth, straight” appearance results not only from the tenderness and uniformity of fresh leaves but also from key processing steps such as flattening and shaping, serving as an important feature distinguishing it from other green teas. Generally, fresh leaves consisting of one bud with one or two young leaves are more suitable for producing high-quality appearance. Some studies have shown that the appearance quality of Longjing tea can be quantitatively evaluated using colorimetric parameters, where L, a, b values and chlorophyll content are significantly correlated with sensory evaluation. Moderate brightness and yellow-green coloration are favorable for high-quality appearance, whereas excessive chlorophyll may lead to darker color and reduced visual quality (Shan et al., 2023a; Bassiony et al., 2024; Zhang et al., 2024). In addition, higher-grade samples often exhibit lighter and brighter liquor, reflecting more tender raw materials and more precise processing control (Shan et al., 2025).

Aroma and taste are the core dimensions in evaluating Longjing tea quality. Longjing tea is typically characterized by a fresh aroma, with high-quality samples exhibiting prominent bean-like and chestnut-like notes, often accompanied by floral or sweet nuances, resulting in a delicate, persistent, and layered aroma profile (Teng et al., 2024). Its aroma is mainly derived from volatile compounds such as linalool, geraniol, hexanal, and various aldehydes, ketones, and pyrazines, whose combinations can effectively reproduce the characteristic Longjing aroma (Bassiony et al., 2024). Aroma formation depends on both precursor compounds in fresh leaves and transformations during processing, with the initial pan-firing stage playing a critical role, while subsequent steps modulate aroma composition (Zeng et al., 2024). In terms of taste, Longjing tea is characterized by freshness, mellow sweetness, moderate bitterness and astringency, and a lasting aftertaste (Zhang et al., 2024). Its flavor is