sweetness and strawberry flavor intensity and is undermined when sucrose and total volatile content are reduced by environmental or agronomic factors (Fan et al., 2021a). Quantitative analyses further demonstrate that relatively small increases in soluble solids content (SSC), strongly correlated with total sugars, can markedly increase the probability of a fruit being perceived as “sweet enough”, emphasizing the sensitivity of consumers to sugar levels within the commercial range. At the same time, excessive acidity or unbalanced sugar-acid ratios are associated with “not sweet enough” or overly sour perceptions even when sugar content is adequate, underscoring the importance of coordinated control of both traits.

Beyond sugars and acids, specific volatile compounds can enhance perceived sweetness independently of sugar concentration, effectively modulating the sensory impact of a given sweetness-acidity matrix (Liu et al., 2023). In large consumer panels and descriptive analyses, particular esters, terpenes, lactones, and other volatiles have been shown to correlate positively with sweetness intensity and liking, whereas green, astringent, or overripe notes detract from preference. These findings imply that breeding solely for higher SSC or lower titratable acidity is insufficient; instead, breeding and management must consider how sweetness and acidity interact with volatiles to shape overall flavor perception and market acceptance.

Internationally, research on strawberry flavor has progressed from simple physicochemical characterization toward integrated sensory, metabolomic, and genomic approaches aimed at resolving the complex basis of sweetness and acidity traits. Large-scale studies combining multi-season sensory data with profiles of sugars, acids, and up to more than 100 volatiles have identified chemical drivers of sweetness, sourness, and liking and provided predictive models that outperform those based on SSC and titratable acidity alone (Liu et al., 2023). Parallel advances in genomics, high-density SNP arrays, phased octoploid reference genomes, and transcriptomics have enabled the mapping of quantitative trait loci and identification of candidate genes for volatile synthesis, sugar accumulation, and organic acid metabolism, paving the way for marker-assisted and genomic selection targeting flavor components (Porter et al., 2023).

Recent reviews emphasize that cultivated strawberry, like tomato, is poised to benefit from genome-based breeding and even genome editing to restore and enhance key flavor attributes, including sweetness intensity and balanced acidity, while maintaining agronomic performance (Scott et al., 2021). Integrative metabolome-transcriptome analyses have begun to pinpoint nonvolatile compounds and biosynthetic pathways—such as citrate cycle and flavonoid metabolism—underlying sweetness, acidity, and related mouthfeel traits, providing new targets for manipulating taste quality. Looking forward, the convergence of consumer-driven sensory work, high-throughput chemistry, and multi-omics frameworks is expected to accelerate the development of cultivars with optimized sugar-acid profiles adapted to diverse environments, thereby aligning breeding outcomes more closely with evolving consumer expectations for flavor-rich strawberries (Lewers et al., 2020).

2 Material Basis and Metabolic Mechanisms of Strawberry Sweetness Formation

2.1 Major sugar components and their dynamic changes (glucose, fructose, sucrose)

Strawberry sweetness is mainly determined by three soluble sugars—glucose, fructose, and sucrose—which together account for about 99% of total fruit sugars and increase markedly during development from green to red stages (Xu et al., 2024). In many cultivated genotypes, glucose is often the most abundant carbohydrate and sucrose relatively low, although the exact proportions vary with cultivar and environment. Developmental profiling shows that total sugars and each of the three components are lowest in green fruit and highest in red fruit, paralleling the rise in total soluble solids and perceived sweetness (Topçu et al., 2022).

The dominant sugar can differ among genetic backgrounds. In some germplasm sets, sucrose is the main sugar in high-sugar cultivars, whereas fructose predominates in low-sugar types, indicating that sweetness depends not only on total sugar but also on sugar composition (Xu et al., 2024). In white-fleshed ‘Snow White’, fructose and glucose are at very low levels and often undetectable, while sucrose becomes the principal soluble sugar during ripening and is tightly associated with flavor formation. Similar patterns of strong sucrose accumulation during ripening, sometimes exceeding hexoses, have also been observed in wild species such as F. nilgerrensis, underscoring sucrose as a key driver of sweetness in some genetic backgrounds.