accumulation, contributing substantially to cane yield (Navya et al., 2025). In addition, physiological traits such as leaf area index, canopy structure, stay-green ability, root distribution, and nutrient balance support yield formation by enhancing photosynthetic efficiency and resource acquisition (Lu et al., 2025). Genetic studies further indicate that key yield-related traits-including stalk number, plant height, stalk diameter, and single stalk weight-are polygenically controlled and have been consistently targeted during sugarcane improvement (Li et al., 2024).

2.2 Major quality traits related to sugar content accumulation

Sugar content is a key indicator of cane quality, processing efficiency, and sugar yield, and is typically evaluated using traits such as Brix, Pol, juice purity, commercial cane sugar (CCS), and fiber content. Among these, Brix reflects total soluble solids, Pol represents sucrose concentration, purity indicates the proportion of sucrose within soluble solids, and CCS more directly reflects industrial value. These traits are generally positively correlated with each other and with sugar yield, suggesting a shared genetic and metabolic basis (Eltaher et al., 2025).

Physiologically, sucrose accumulation mainly occurs in stem internodes during the maturation stage and depends on continuous assimilate supply, phloem transport, and sink storage capacity. Leaves function as the primary carbon source, while assimilates are transported in the form of sucrose to stem sink tissues, where they accumulate in parenchyma cells. Therefore, sugar accumulation depends not only on assimilate production but also on transport efficiency, internode maturation, and sink strength. Genotypic differences in maturity timing and sugar accumulation patterns underpin the classification of early-, mid-, and late-maturing varieties.

At the biochemical and genetic levels, key enzymes such as sucrose phosphate synthase (SPS), sucrose synthase (SuSy), and invertases (INV) regulate sucrose synthesis, degradation, and storage, while cell wall-related processes influence carbon partitioning between structural and storage carbohydrates. High-sugar genotypes typically exhibit enzyme activity and expression patterns favorable for sucrose accumulation, along with structural features such as higher stem maturity, greater parenchyma proportion, and appropriate fiber content (Lu et al., 2025). Genome-wide and candidate gene studies have identified numerous loci associated with Brix, Pol, CCS, and fiber content, providing a molecular basis for improving sugar-related traits (Li et al., 2024; Eltaher et al., 2025).

2.3 Common trait basis for coordinated improvement of yield and sugar content

Although sugarcane yield and sugar content may exhibit negative correlations under certain genotypes and environments, they are not independent breeding targets. Instead, they share a common trait basis involving plant structure, source-sink relationships, carbon allocation patterns, and genetic networks. Sugar yield is the combined outcome of cane yield and sugar content; therefore, traits that enhance biomass production while maintaining or increasing sugar concentration are key targets for coordinated improvement.

Photosynthetic efficiency and assimilate production serve as the common source for both yield formation and sugar accumulation. Traits such as higher leaf area index, optimized canopy structure, prolonged functional leaf duration, and enhanced photosynthetic efficiency increase total carbon assimilation, providing substrates for both stem growth and sucrose accumulation (Lu et al., 2025). In addition, assimilate transport and partitioning efficiency represent the key physiological link between these traits. Efficient transport to stem tissues, coupled with progressive allocation toward sucrose storage, enables the simultaneous improvement of stalk weight and sugar concentration (Singh et al., 2024).

Furthermore, maturation dynamics and shared genetic bases play critical roles in coordinated improvement. An optimal maturation pattern allows extended biomass accumulation followed by efficient sucrose deposition, reducing the risk of either insufficient biomass or delayed sugar accumulation (Singh et al., 2024). Multivariate and genome-wide analyses have identified SNPs and haplotypes associated with both yield-related traits (e.g., stalk number, plant height, and diameter) and sugar-related traits, indicating a shared genetic basis (Li et al., 2024).