balanced source-sink relationships, and enhanced stress tolerance, and should be incorporated into multi-trait selection frameworks.

Multi-omics studies further reveal that certain key regulatory factors can simultaneously influence sucrose accumulation, cell wall composition, and stress responses, providing opportunities for coordinated improvement of high sugar-high biomass-high resilience. For mechanization requirements, ideal varieties should also exhibit uniform plant architecture, strong lodging resistance, and synchronous maturity, traits that have begun to be elucidated at molecular and metabolic levels (Li et al., 2024). In terms of stress resistance, greater use of wild germplasm resources is needed to broaden the genetic base, combined with molecular markers, genomic selection, and gene editing technologies to achieve coordinated improvement of stress tolerance, yield, and sugar content (Lu et al., 2024). At the same time, future varieties should also meet the needs of processing and biorefinery applications, with cell wall structures optimized for both sugar extraction and bioenergy conversion (Wang et al., 2025), thereby promoting the transition of sugarcane from a single-purpose crop to a multifunctional industrial resource.

## 9 Conclusion

Sugarcane yield and sugar content are the two core traits determining the economic value of raw cane and sugar yield per unit area. Their formation is not governed by a single factor but results from the coordinated interaction of agronomic traits, physiological processes, and molecular regulatory networks. At the agronomic level, traits such as tiller number, millable cane number, single stalk weight, plant height, and stalk diameter jointly determine cane yield, while sucrose content, maturity, and juice quality directly influence sugar levels. At the physiological level, photosynthetic efficiency, dry matter accumulation, source-sink relationships, and assimilate transport and partitioning are key processes linking biomass production and sugar accumulation. From a genetic perspective, these traits are typical complex quantitative traits controlled by multiple genes with significant non-additive effects. Their essence lies in the dynamic balance of carbon allocation between biomass and sugar, rather than a fixed antagonistic relationship.

The realization of high yield and high sugar content in sugarcane depends on the synergistic interaction of genotype × environment × management (G×E×M). Relying solely on genetic improvement or agronomic practices is insufficient to achieve optimal performance. In breeding, it is necessary to optimize parental combinations, broaden the genetic base, and apply multi-trait selection strategies, combined with molecular markers, genomic selection, and gene editing technologies to identify genotypes with both high biomass and strong sugar accumulation potential. In agronomic management, optimizing variety selection, nutrient supply, and input levels-particularly the balance of nitrogen, potassium, magnesium, and calcium-is essential to promote tillering, population structure formation, and sucrose accumulation. Studies indicate that under suitable environmental conditions and appropriate management, high biomass and high sugar content can coexist, highlighting the importance of an integrated genotype-environment-management framework for stabilizing sugar yield.

For the high-quality development of the sugarcane industry, future efforts should focus on advancing coordinated improvement of yield and sugar content at theoretical, resource, and technological levels. Theoretically, an NTrait-based framework should integrate outcome traits (e.g., tillering, stalk number, single stalk weight, sugar content, and fiber) with mechanistic traits such as carbon allocation, nutrient use efficiency, and maturation regulation to enable precise ideotype design. In terms of resources, pan-genomics, whole-genome resequencing, and GWAS should be used to identify key loci and favorable haplotypes. Technologically, integrating genomic selection, rapid breeding approaches, and CRISPR-based gene editing will improve the efficiency of complex trait improvement. Meanwhile, incorporating high-throughput phenotyping, digital agriculture, and artificial intelligence into breeding and management, along with strengthening germplasm innovation and international collaboration, will facilitate the development of a modern sugarcane breeding system that integrates theoretical models, molecular tools, and region-specific applications, thereby supporting the sustained improvement of high yield and high sugar content and the sustainable development of the sugarcane industry.