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The Breeding of Elite Fresh Sugarcane Varieties: Comprehensive Evaluation of Flavor, Disease Resistance, and Market Adaptability

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Abstract This study takes fresh sugarcane as the object, comprehensively reviews the research progress in recent years in the aspects of flavor quality evaluation and improvement, disease resistance gene mining and utilization, market adaptability evaluation system construction, and multi-target breeding strategies, and analyzes its flavor, disease resistance and adaptability characteristics through typical excellent varieties. The results show that the flavor of fresh sugarcane is determined by high sugar content (mainly sucrose, fructose and glucose in sugarcane juice) and a variety of aromatic volatiles. Sensory evaluation can be combined with quantitative descriptive analysis and consumer preference testing for improvement and selection; key QTLs and genes affecting disease resistance have been identified through molecular markers and multi-omics methods, providing tools for genetic improvement; a comprehensive evaluation system based on multi-environment experiments (combining indicators such as yield, sugar, and stress resistance) can screen out strains with high stability and wide adaptability. At the same time, modern molecular breeding technologies (such as whole genome selection and gene editing) are accelerating the process of multi-target aggregation breeding. This study also puts forward suggestions such as strengthening germplasm innovation, multi-trait molecular marker-assisted selection, genome editing-directed improvement, and precise evaluation of ecological niches, in order to promote new breakthroughs in the breeding of excellent fresh sugarcane varieties.

Keywords Fresh sugarcane; Flavor quality; Disease-resistant breeding; Market adaptability; Multi-trait breeding

1 Introduction

Fresh sugarcane (*Saccharum officinarum* L., fruit cane) is not only an important energy and sugar raw material crop, but also one of the fruit crops that are deeply loved by consumers. According to statistics, more than 120 countries in the world grow sugarcane, with an annual output of more than 2 billion tons. In some countries, fresh sugarcane accounts for a significant proportion. For example, in Nigeria, about 70% of sugarcane is used for raw consumption rather than sugar production. Asian countries such as China and India also have a tradition of planting and consuming a large amount of fresh sugarcane. However, fresh sugarcane breeding has long been subject to many limitations. Modern sugarcane is a high-ploid hybrid bred by distant hybridization of multiple species of the genus *Saccharum*. The genome is highly complex and heterologous. About 80% of the genome comes from cultivated sugarcane, 10%~20% comes from wild sugarcane, and the rest is recombinant fragments (Pompidor et al., 2021; Healey et al., 2024). The high polyploidy and high heterozygosity of the sugarcane genome pose great challenges to gene localization cloning and precise improvement (Li et al., 2023). Although the reference genome sequences of wild sugarcane and some cultivated sugarcane have been released in recent years, the whole genome analysis of modern sugarcane hybrids is still insufficient.

The breeding cycle of fresh sugarcane is long and the screening cost is high. Traditional hybrid breeding uses the "five-generation method" and other methods, and it takes more than 10 years of continuous screening and identification in different fields and environments to launch new varieties. The breeding goals of fresh sugarcane are multidimensional, requiring not only economic traits such as high stem yield and high sugar content, but also excellent flavor and taste and strong disease resistance and stress resistance to meet the dual needs of consumers and growers. However, multi-objective aggregation often has negative correlation and trade-offs between traits, requiring a large amount of material evaluation and data support (Abu-Ellail et al., 2020). In addition, the market preferences and ecological conditions in different regions vary greatly, which also increases the difficulty of breeding. Therefore, how to break through the bottleneck of traditional breeding and cultivate new excellent fresh sugarcane varieties with good flavor, strong resistance and wide adaptability is a topic of urgent concern in the current sugarcane scientific research and industrial development (Lu et al., 2024).

In recent years, with the application of analytical chemistry, genomics and biotechnology in sugarcane research, fresh sugarcane breeding has ushered in new development opportunities. On the one hand, scientific characterization and improvement of flavor quality have become possible; on the other hand, the discovery of disease-resistant genes and the development of precision breeding technology have improved the efficiency of improving multiple traits at the same time (Wang et al., 2021; Sandhu et al., 2022). What's more, through multi-environment experiments and big data analysis, an objective market adaptability evaluation index system can be established to guide the direction of variety selection.

This study will introduce in detail the evaluation indicators and improvement strategies for the flavor quality of fresh sugarcane, analyze the screening and identification of major disease resistance traits and the construction of a comprehensive evaluation system for genetic mechanisms and market adaptability, summarize the breeding techniques and strategies for multi-objective and superior varieties, and by summarizing the comprehensive characteristics and breeding inspirations of typical excellent fresh sugarcane varieties, put forward future development trends and suggestions, and provide scientific reference and new ideas for the breeding of excellent fresh sugarcane varieties.

2 Evaluation and Improvement of Flavor Quality of Fresh Sugarcane

2.1 Analysis of flavor components

The flavor of fresh sugarcane is mainly composed of sweetness, aroma and texture. Among them, sweetness comes from total soluble sugar, especially the ratio of sucrose, glucose and fructose; high sugar content gives fresh sugarcane a strong sweetness and a good sensory first impression (Rohit et al., 2024). In addition, secondary metabolites such as aromatic substances such as aldehydes, alcohols, esters, and ketones determine the fruity aroma characteristics. These compounds mainly come from fatty acid metabolic pathways and aromatic amino acid degradation. Ge et al. (2021) studied the aroma changes in the process of dehydrating clarified sugarcane juice to make non-centrifugal sugar, and detected that volatiles such as furans and alcohols were generated during the heating and concentration of molasses. GC-MS technology detection showed that there are more than 50 volatile flavor compounds in the variety "Badila", which gives it a unique flavor characteristic. In addition to smell and sweetness, texture characteristics such as fiber content, juice richness and crispness determine the chewing experience. Varieties with more juice, less cell walls, and fine and soft fibers that are easy to chew are more likely to be favored by consumers.

2.2 Flavor evaluation method and standard system construction

The scientific evaluation of flavor quality is inseparable from the combination of physical and chemical testing and sensory analysis. Common physical and chemical indicators include Brix value (soluble solids), pH, acid-sugar ratio, etc., which are used to measure the balance between sweetness and acidity. These indicators can be quickly obtained with the help of instruments such as refractometers and acidometers, and have good repeatability and objectivity. In terms of sensory evaluation, quantitative descriptive analysis (QDA) can be used to standardize the scoring of attributes such as "sweetness intensity", "sugarcane aroma", and "mellow taste", and CATA (check-all-that-apply) and preference tests can be used to understand consumers' preference structure for different attributes (de Queiroz Bomdespacho et al., 2021). For example, studies have shown that "sweetness", "fruity aroma" and "chewing uniformity" have the greatest impact on consumer acceptance. In addition, in order to fully reflect the multi-dimensionality of flavor evaluation, a weighted scoring system or decision-making model can be established, such as TOPSIS, analytic hierarchy process (AHP) and other multi-index decision-making methods, which can rank and optimize the comprehensive flavor scores among varieties.

2.3 Genetic and environmental factors affecting flavor

The formation of fresh sugarcane flavor is affected by both genotype and environment. In terms of genetic control, studies have identified key QTL loci and candidate genes that control sugar accumulation and volatile synthesis. For example, the use of TRAP molecular markers associated with specific loci can achieve genetic improvement of sucrose content (Govindakurup and Mohanraj, 2024). In addition, Shanmuganathan et al. (2024) found through metabolomics that some esters and alcohol compounds may be regulated by specific fatty acid metabolism genes, providing a direction for future metabolic engineering.

In terms of environmental factors, light intensity, day and night temperature difference, soil fertility and maturity can significantly affect the accumulation of sucrose and aromatic components (Wang et al., 2020). For example, the sugar accumulation curves and aroma spectra of sugarcane in cultivation areas at different altitudes are different, suggesting that the ecological environment has a profound impact on flavor. In breeding practice, in order to improve the stability and adaptability of flavor, flavor testing and sensory scoring should be carried out in multiple environments to evaluate the flavor consistency of candidate varieties (Vinu et al., 2024). At the same time, phenotypic screening and molecular marker-assisted selection (MAS) should be combined to accumulate excellent flavor alleles in the early stages of breeding and improve the efficiency of flavor improvement.

3 Screening and Genetic Basis of Disease Resistance Traits in Fresh Sugarcane

3.1 Overview of common diseases of fresh sugarcane

Fresh sugarcane faces a variety of disease threats during the planting process, mainly including red rot, leaf blight, mosaic virus disease, smut, powdery mildew and brown rust. Among them, sugarcane mosaic disease is caused by *Sugarcane mosaic virus* (SCMV) and *Sorghum mosaic virus* (SrMV). It is one of the most serious virus diseases in the main sugarcane producing areas in southern China. It can cause mottled leaf patterns and dry leaf edges, seriously affecting photosynthesis and sugar production (Figure 1) (Vamsi Krishna et al., 2023).

Figure 1 Mosaic symptoms varied from cultivar to cultivar (Adopted from Vamsi Krishna et al., 2023)

Image caption: (a) chlorotic areas on pale green lamina; (b) systemic yellowing and marginal drying of leaf lamina; (c) systemic yellowing, drying, and stunting; (d) pale yellow-green leaves; (e) chlorotic streaks expand to large chlorotic patches; (f) chlorotic streaks; (g) systemic yellowing and complete drying; and (h) yellow chlorotic areas on green lamina (Adopted from Vamsi Krishna et al., 2023)

Smut is infected by smut fungus, and the typical symptom is the emergence of "black smut" from the terminal bud, which destroys the growth point and seriously affects tillering and yield. Brown rust is caused by sugarcane rust fungus, which can form a large number of rust spots and sporangia. When the disease is severe, the sugarcane yield loss can be as high as 50% (Islam et al., 2025). In addition, fungal diseases such as powdery mildew, red rot and leaf blight also occur frequently in areas with suitable temperature and humidity, especially in perennial sugarcane or high-density planting conditions, where the disease spreads rapidly. The above diseases not only affect the growth and development and sugar production capacity of sugarcane, but also directly threaten the commercial quality and appearance quality of sugarcane. Therefore, disease-resistant breeding is an important task for the improvement of fresh sugarcane.

3.2 Disease resistance evaluation methods

Traditional disease resistance evaluation methods include natural field induction and artificial inoculation. Field induction relies on the natural occurrence of diseases. In areas with high incidence of diseases, the disease resistance level of varieties is judged by multi-point performance observations for many years. It has the advantage of strong ecological authenticity, but is greatly affected by climate and pathogen pressure fluctuations. In order to improve the screening efficiency, artificial inoculation is often combined in recent years, that is, artificially aggravating the occurrence of diseases through leaf friction inoculation, injection inoculation or spray inoculation, so as to stabilize the symptoms and facilitate the distinction between resistance and sensitivity. For example, Lu et al. (2023) supplemented artificial inoculation of mixed virus sources based on 11 natural environment points, which significantly improved the accuracy of mosaic disease resistance identification.

Disease resistance scores are usually graded based on incidence, lesion area, disease grade index, etc., and are supplemented by repeated tests in multiple environments to ensure the stability and representativeness of the data. In order to reduce human errors, some studies use image analysis software to quantify the lesion area, which improves the objectivity of disease resistance evaluation. In recent years, molecular detection methods have been gradually introduced into the disease resistance diagnosis process. For example, qPCR technology can accurately quantify the content of viruses or pathogens in plants, and the ELISA method can be used for rapid screening of specific virus or fungal antigens, especially for rapid detection of pathogen-carrying status of germplasm resources in the seedling stage. These molecular-assisted methods have unique advantages in seedling disease screening and latent infection detection.

3.3 Disease resistance-related genes and genetic mechanisms

At the molecular level, disease resistance is usually determined by major disease resistance genes (such as R genes) and multiple regulatory genes. Recent studies have shown that disease resistance in fresh sugarcane is a quantitative trait characterized by multi-gene co-regulation. For mosaic disease, Lu et al. (2023) combined QTL positioning and GWAS association analysis in a resistant and susceptible hybrid population to identify 7 QTLs and 9 candidate genes significantly associated with disease resistance. Most of these genes are related to plant defense signaling pathways such as PR proteins, RNA silencing, and hormone regulation, providing targets for subsequent molecular marker development and breeding.

In terms of the mechanism of smut resistance, the study found that it is closely related to lignin synthesis. Li et al. (2024) identified 64 sugarcane Dirigent genes (ScDIRs), of which ScDIR5, ScDIR7, ScDIR11, and ScDIR40 were significantly induced to express under smut infection, and functional verification confirmed that they can enhance plant cell wall structure and improve defense capabilities. ScDIRs participate in the cell wall reinforcement process by regulating the accumulation of lignin precursors such as syringaresinol. In addition, Wu et al. (2023) conducted a whole genome analysis of the sugarcane CAT (catalase) gene family and found that ScCAT1 was highly expressed in smut-resistant varieties, participating in the removal of reactive oxygen species (ROS), reducing pathogen-induced oxidative stress, and improving resistance.

For brown rust, the Bru1 gene is currently the most widely used major rust resistance gene, which comes from wild sugarcane. Chen et al. (2025) reported that about 86% of the newly bred rust-resistant sugarcane varieties in China carry the Bru1 gene, indicating that this gene is widely used in breeding. However, since pathogens are prone to mutation, relying on a single source of resistance may bring the risk of resistance failure. Islam et al. (2025) and Li et al. (2022) further identified multiple new rust resistance-related loci and candidate genes through SNP marker association analysis, providing new materials for the construction of multi-gene composite resistance.

In terms of disease-resistant breeding technology, molecular marker-assisted selection (MAS) and CRISPR/Cas9 gene editing are becoming important tools to improve breeding efficiency. Wu et al. (2024) used the BSR-Seq method to locate QTLs for resistance to smut and developed related SNP markers for rapid screening of disease-resistant genotypes at the seedling stage. Govindakurup and Mohanraj (2024) pointed out that knocking out SWEET-type susceptibility genes or regulatory transcription factors in sugarcane through CRISPR technology is expected to give plants new disease-resistant traits. A Chinese research team has established a sugarcane gene editing platform for mature embryos and stem tips, and has initially achieved target gene knockout and stable inheritance, laying the foundation for the future targeted breeding of disease-resistant fresh-eating sugarcane varieties.

4 Comprehensive Evaluation System for Market Adaptability

4.1 Multi-environment test and stability analysis

In sugarcane breeding, multi-environment test (MET) is often used to evaluate the adaptability and stability of varieties. For example, Mehareb et al. (2022) conducted multi-year and multi-location trials on multiple sugarcane varieties, and used AMMI (additive model) and GGE biplot to analyze variety × environment interactions. They found that some varieties had stable stem yield and sucrose content at different ecological points and had wide adaptability. Statistical analysis showed that the dominant factors affecting the stability of sugarcane sugar yield include 11 agronomic and quality indicators such as stem yield, stem weight, number of effective stems, Brix%, sucrose content and purity. Using discriminant function analysis, these indicators can significantly distinguish high-yield and high-sugar genotypes from low-yield genotypes, thus serving as key parameters for comprehensive evaluation.

In addition, some specialized stability parameters such as coefficient of variation (CV), AMMI stability value (ASV), average environmental coordinates, etc. are also used to quantify the stability performance of varieties. Through comprehensive analysis of multi-point data, high-yield and stable varieties can be selected for regional promotion. For example, in the Egyptian trial, only one new clone had a yield that exceeded the control at all locations with small fluctuations, and was recommended as a wide-adaptability variety.

4.2 Construction of comprehensive evaluation index

In order to facilitate the quantitative comparison of the market adaptability of candidate varieties, a comprehensive evaluation index or decision model can be constructed. Common methods include weighted index method, principal component analysis and hierarchical analysis method (AHP). For example, Abu-Ellail et al. (2020) used discriminant analysis to construct a comprehensive score DS, which combined multiple yield and quality indicators into a score to rank the comprehensive performance of 30 sugarcane clones. Results The DS score can explain 79.2% of the variation in sugar yield and has a significant correlation with the measured sugar yield (r=0.89**), indicating that the comprehensive index better reflects the quality of the variety. In the DS ranking, stem weight, stem height, purity%, Brix% and stem yield are the most important contributing factors. This comprehensive index helps to quickly identify high-yield and high-sugar superior genotypes. For fresh sugarcane, the weight of commodity traits, such as appearance (stem color, morphological uniformity), flavor score and stress resistance score, can also be added to the comprehensive index to form a more comprehensive evaluation system.

4.3 Evaluation of market and consumer preferences

Market adaptability refers not only to biological adaptation, but also to the degree of fit with market demand. On the one hand, market research can be used to obtain information on preferences for sugarcane appearance, sweetness and taste in different consumer regions, and incorporate it into variety evaluation. For example, the Guangdong market prefers yellow sugarcane that is thick, juicy, sweet but not greasy. The inland market in Guangxi may be more accepting of purple-skinned high-sugar sugarcane. This requires attention to the selection of traits preferred by the target market during breeding, and to add sensory tasting links in the later stages of regional trials, so that target consumers can score and feedback on candidate varieties.

On the other hand, adapting to the market also means that the variety needs to match the local cultivation model and supply and marketing system. For example, whether it is suitable for mechanized planting and harvesting, whether the hardness of the stem nodes is conducive to long-distance transportation, and whether the perennial root is suitable for multi-year stubble retention are also part of the evaluation indicators. In recent years, with the advancement of mechanization in sugarcane production, breeding varieties suitable for mechanization has become a new trend. Mechanization-adapted varieties usually have medium plant height, upright stems, strong lodging resistance, and easy leaf shedding (Liang et al., 2025), such as "Guitang 66" (GT66) cultivated in the regional trial of new sugarcane varieties in Guangxi, which is superior to the standard variety (Figure 2).

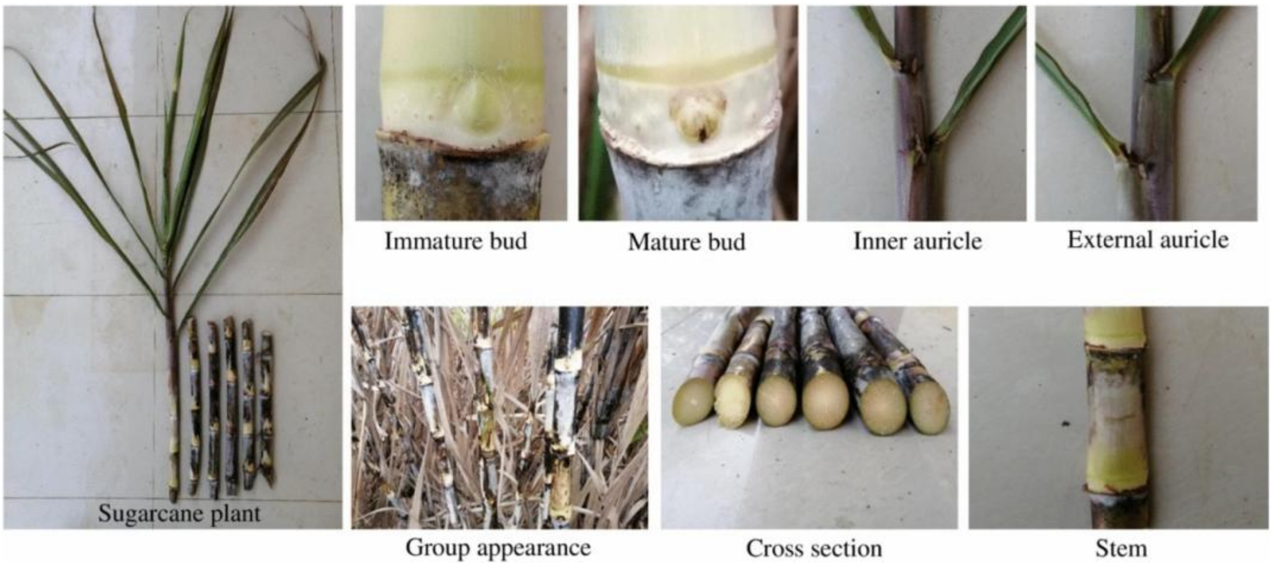

Figure 2 The morphological development of *Saccharum officinarum* L. cultivar GT66 (Adopted from Liang et al., 2025)

5 Breeding Strategies for Multi-target Superior Varieties

5.1 Germplasm innovation and trait discovery

The basis of multi-target breeding lies in the rich germplasm diversity and trait variation (Lu et al., 204). Therefore, the innovative utilization of germplasm resources related to fresh sugarcane should be strengthened. Make full use of wild species and special varieties in the existing sugarcane germplasm bank. Wild relatives (such as bamboo sugarcane and wild sugarcane of the genus *Saccharum*) contain favorable genes such as disease resistance, stress resistance and special flavor. For example, there is a broad-spectrum rust resistance gene Bru1 in wild sugarcane (*S. spontaneum*) (Chen et al., 2025). Some wild genotypes also have the characteristics of high fiber and unique flavor. These excellent genes can be introduced into the cultivated variety gene pool through distant hybridization and multi-generation backcrossing (Li et al., 2023).

In addition, new mutations can be created by mutagenesis and biotechnology. For example, unconventional plant height, stem color or flavor mutants can be obtained through physical and chemical mutagenesis or somatic mutation; exogenous pathway genes (such as aromatic substance synthesis genes, antioxidant metabolism genes, etc.) can be introduced through genetic engineering to broaden the spectrum of sugarcane traits (Govindakurup and Mohanraj, 2024). Promoting multi-parent composite hybridization is also a way to increase trait diversity, that is, incorporating the traits of multiple excellent parents into a hybrid combination, and screening offspring that inherit multiple target traits at the same time.

5.2 Intelligent multi-trait selection

In multi-target breeding, it is difficult to handle the selection decision of multiple traits at the same time. Traditionally, breeders rely on their experience to balance various traits, while modern technology can introduce intelligent data analysis to assist decision-making. Use genomic selection (GS) to achieve simultaneous improvement of multiple traits. GS establishes a genome-wide breeding value (GEBV) prediction model by measuring a large number of molecular markers and trait expressions in the training population, and then directly screens the selection population based on molecular information. This method has been explored in sugarcane, and studies have shown that GS is expected to shorten the sugarcane breeding cycle by about 30% and improve yield, sugar content, and disease resistance in earlier generations.

On the other hand, high-throughput phenotyping and artificial intelligence can also be used to achieve intelligent selection. For example, drone hyperspectral imaging is used to monitor the growth, physiology, and disease status of field sugarcane, and these data are combined with flavor quality determination. Machine learning models are used to predict the comprehensive breeding value of each strain to assist in screening (Mahadevaiah et al., 2021). At present, studies have used machine learning to explore sugarcane rust resistance genetic regions and predict the impact of sugar reduction policies on sugarcane planting (Aono et al., 2020; Thow et al., 2021). Similar methods can also be used for the trade-off optimization of multiple traits in fresh sugarcane. In addition, decision support systems (DSS) can also be applied. A database of multi-trait data from breeding trials for many years is established, and decision support software is developed. After entering the target weight, candidate strains that meet the requirements can be automatically recommended.

5.3 Phased multi-objective aggregation strategy

Multi-objective breeding does not require that all traits be improved in the same generation. In actual breeding, a phased aggregation strategy is often used. The first stage focuses on basic agronomic traits, such as yield and disease resistance screening, and eliminates obviously poor materials; the second stage introduces and selects quality traits while retaining high-quality agronomic traits. Specifically, yield and stress resistance can be mainly examined in large groups of early generations, such as inoculating and identifying smut resistance at the seedling stage, investigating rust resistance in the field, and measuring sugar content at the same time, leaving high-yield, high-sugar and disease-resistant materials. Then, the flavor quality of the selected materials is measured and evaluated in the mid-generation, including sensory tasting and physical and chemical analysis (de Queiroz Bomdespacho et al., 2021). For those with poor flavor, they can be discarded even if the yield is high, so as to ensure that the remaining lines have a certain level in both yield and flavor. Finally, in the regional trial stage, adaptability and commerciality are comprehensively examined, and the final selection is made based on the aforementioned comprehensive index.

5.4 Molecular design and gene editing-assisted breeding

With the deepening of understanding of sugarcane functional genome, molecular design breeding can be carried out, that is, genotype design and modification based on the genetic mechanism of target traits (Govindakurup and Mohanraj, 2024). For multi-target traits, the ideal genotype may involve the optimal combination of multiple genes. With the help of genotype data and system biology models, the effects of different allele combinations on phenotypes can be simulated to guide hybridization. For example, genome prediction can be used to select complementary parent hybrids to make the offspring have both high sugar and high resistance allele combinations (Mahadevaiah et al., 2021). Gene editing provides a means to directly modify key genes. For example, for acid metabolism genes that affect flavor and susceptibility genes that affect disease resistance, CRISPR/Cas9 can be used to knock out or edit them, thereby improving sweetness or resistance without introducing exogenous fragments. Recent studies have edited the sugarcane CHI gene and found that it can change the plant's immune response and improve disease resistance (Chen et al., 2025).

6 Case Analysis of Typical Excellent Fresh Sugarcane Varieties

6.1 Case 1: comprehensive trait balanced variety "Guitang 42"

Guitang 42 is a sugarcane variety bred by the Sugarcane Research Institute of Guangxi Academy of Agricultural Sciences. As a star representative of Guangxi's "Gui" series of varieties, it passed the Guangxi variety approval around 2014. The reason why this variety is typical is that it achieves a balance between high yield, high sugar, disease resistance and wide adaptability, and is known as an excellent variety with "multi-resistance and high sugar". GT42 has tall plants, strong stems, strong tillering ability and perennial rooting, and has early maturity characteristics. Generally, it can reach sugar production maturity in November. In terms of disease resistance, GT42 shows strong resistance to major sugarcane diseases. For example, it is reported that GT42 carries the rust resistance Bru1 gene, so it is immune to brown rust; at the same time, it also has a medium resistance level to black smut and is resistant to sugarcane mosaic (Li et al., 2023). In addition, GT42 has an upright plant shape, strong stems, and outstanding lodging resistance (Figure 3). Li et al. (2023) pointed out that GT42 was obtained through conventional hybrid breeding, and has strong comprehensive excellent traits such as strong lodging resistance and early maturity, and has become one of the main varieties in Guangxi.

Figure 3 Lodging events of GT42 and GF98-296 sugarcane varieties during different developmental stages (Adopted from Li et al., 2023)

Image caption: Growth stage and lodging in (A, B) September, (C, D) October, and (E, F) November. Plants in A, C, and E represent GT42, and plants in B, D, and F represent GF98-296 (Adopted from Li et al., 2023)

6.2 Case 2: "Yunzhe 05-51", a variety with extremely high sugar content and stress resistance

Yunzhe 05-51 is a high-sugar, high-yield and fresh-eating variety bred by the Yunnan Sugarcane Research Institute. This variety was born in 2005 from the hybrid combination YC90-56 × ROC23, and is one of the representative achievements of Yunnan's "double high" sugarcane variety innovation. The "Yunzhe" series represents local breeding varieties in Yunnan. Yunzhe 05-51 plants are tall and strong, with medium and large stems, neat stem nodes, wax powder, dark green leaves, and vigorous growth (Figure 4). Its outstanding features are extremely high sucrose content and strong comprehensive stress resistance. In the trials from 2015 to 2018, the sucrose content of Yunzhe 05-51 remained stable at more than 18% during maturity, reaching a maximum of 18.75%, which was about 1.4 percentage points higher than the control ROC22. Regarding flavor quality, Yunzhe 05-51 has a very high sugar content, and the sweetness is rich and mellow when chewed, but it is "sweet but not greasy", and the taste is well received by consumers (Wu et al., 2024).

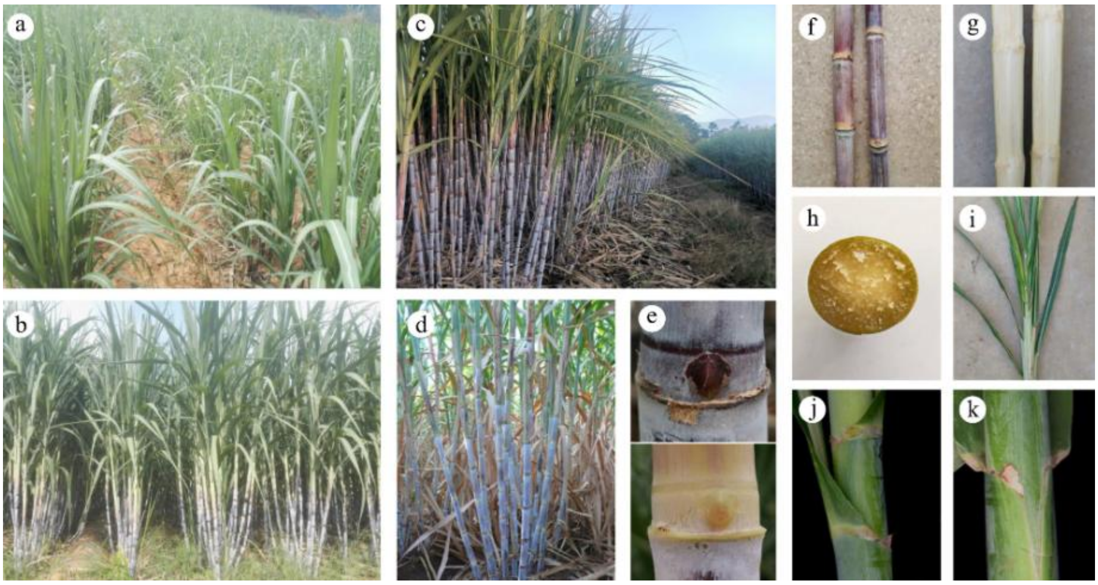

Figure 4 Genetic characteristics of sugarcane variety YZ05-51 (Adopted from Wu et al., 2024)

Image caption: (a) seedling stage, (b) elongation stage, (c) maturity stage, (d) plant type, (e) bud, (f) stem, (g) stem longitudinal section, (h) stem transverse section, (i) leaf, (j) leaf sheath, (k) leaf auricle (Adopted from Wu et al., 2024)

7 Future Development Trends and Suggestions

7.1 Establishment of intelligent breeding and precision evaluation system

From the perspective of breeding, a breeding information management system can be developed to integrate experimental design, data collection, analysis and decision-making functions to improve the scientificity and transparency of breeding decisions. From the perspective of production, the promotion of new varieties needs to match precision cultivation technology. For example, according to the characteristics of different varieties (light and fertilizer degree, drought resistance, etc.), corresponding cultivation procedures are formulated to maximize the potential of varieties. At the same time, remote sensing and sensor technology can be used to monitor the performance of different varieties in the field, and timely feedback on variety adaptability information can be provided to feed back breeding selection. The intelligent breeding system should also include multi-departmental collaboration, such as information connectivity between breeding units and promotion departments and processing enterprises, timely understanding of market changes and demands, and dynamic adjustment of breeding goals. For example, if the market tends to prefer a certain appearance or flavor, the breeding plan can be tilted accordingly.

7.2 Collaborative optimization of variety promotion and regional layout

With the emergence of new varieties of fresh sugarcane, disorderly introduction and homogeneous competition need to be avoided. Regional planting layout of superior varieties should be promoted according to local ecological and market conditions. For example, early-maturing and high-sugar varieties are suitable for planting in South China, while cold-resistant and drought-resistant varieties are promoted in the southwestern plateau (Luo et al., 2015). Through reasonable layout, the advantages of varieties can be maximized. At the same time, it is encouraged to combine excellent fresh sugarcane varieties with production areas to create regional characteristic brands and increase product added value. For example, Guangxi can create the "Guitang Sugarcane" brand to highlight the sweet and juicy characteristics of the Guitang series of varieties; Yunnan can create the "Highland Rich Sugarcane" brand to emphasize the advantages of high sugar and high nutrition. Variety branding helps promote the large-scale planting and market awareness of excellent varieties and form a virtuous circle. In addition, branding also requires the establishment of a sound variety protection and authorization mechanism to protect the rights and interests of breeders and encourage continuous innovation.

7.3 Strengthen international cooperation and gene exchange

Fresh sugarcane breeding has common technical needs and challenges worldwide. It is recommended to strengthen international scientific research cooperation, such as conducting germplasm resource exchanges and joint breeding experiments with advanced sugarcane breeding countries (Brazil, Australia, India, etc.) (Wang et al., 2024). Through international cooperation, we can share the special germplasm and key genes from various regions, such as introducing high-juice material from Brazil, special black-skinned sugarcane from India, and high-disease-resistant germplasm from China, integrating different advantages into one. In addition, in terms of flavor quality evaluation standards, we can also explore internationally unified or mutually recognized sensory evaluation methods to facilitate data comparison and exchange of excellent materials in different regions. Global climate change and the spread of pests and diseases are common threats to the sugarcane industry. Through international cooperation, sugarcane varieties that respond to global problems (such as new disease-resistant and extreme climate-resistant varieties) can be cultivated more quickly. International organizations such as the international society of sugarcane technology (ISSCT) can play a platform role, strengthen information exchange and talent training, and jointly promote the improvement of fresh sugarcane breeding levels.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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