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From variety improvement to a field management system: dual-path breeding of Zhongtang and Zhongfu for modern sugarcane production

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Abstract

Against the backdrop of intensifying global competition in the sugar industry and accelerating domestic agricultural transformation, the Chinese sugarcane industry faces rising production costs and urgent labor shortages. In response, sugarcane (*Saccharum officinarum*) germplasm innovation was conducted to develop high-yield, high-sucrose cultivars with enhanced stress tolerance and suitability for mechanization. This has driven the development of the 'Zhongtang' (ZT) and 'Zhongfu' (ZF) cultivars in Sugarcane Research Center of the Chinese Academy of Tropical Agricultural Sciences. Among these, Zhongtang 3 (ZT3) has emerged as a representative cultivar, demonstrating an increase in yield and improved mechanization compatibility, making it ideal for large-scale mechanical harvesting. Zhongfu 1 (ZF1), a space radiation-induced mutant from the Shenzhou-10 spacecraft mission, offers a distinct yet complementary technological pathway. Recently, ZT3 and ZF1, integrated with solutions that combine superior varietal traits, mechanization, and sustainable cultivation principles, have been widely adopted to drive the modernization of the sugarcane industry. Together, the elite sugarcane cultivars, along with high-efficiency cultivation, are expected to systemically address these challenges in the Chinese sugarcane industry.

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Sugarcane is an allopolyploid and aneuploid crop with an exceptionally complex genetic architecture. Its genome exceeds 10 Gb in size, commercial cultivars are frequently decaploid, and its chromosome numbers typically surpass 120, making the genetic improvement of sugarcane for superior comprehensive traits particularly challenging[1,2]. Against the broader backdrop of accelerating global climate change, persistently rising agricultural production costs, and the growing strategic importance of sugar security, sugarcane (*Saccharum officinarum*)—the primary sugar crop and a key economic commodity in China—faces profound pressures for transformation and structural upgrading[3,4]. Worsening labor shortages are compelling a transition toward mechanized and simplified production systems, while the increasing frequency and severity of diseases and pest outbreaks, coupled with heightened concerns over pesticide residues, underscore the urgent need for cultivars with enhanced intrinsic tolerance and compatibility with green control strategies[5]. Moreover, the increasing normalization of extreme weather events places unprecedented demands on yield stability and abiotic stress tolerance in sugarcane production systems[6,7]. At the same time, rising consumer demand for high-quality sugar products, together with national strategic imperatives to improve self-sufficiency and ensure supply chain security, converge on a central conclusion: The development of a new generation of sugarcane cultivars capable of systemically addressing these multifaceted industry challenges must be driven by sustained scientific and technological innovation[8,9].

Responding to these strategic demands, in alignment with national priorities for the seed industry's revitalization and agricultural modernization, has successfully developed the Zhongtang (ZT) and Zhongfu (ZF) series of novel sugarcane cultivars through the integrated application of two complementary breeding strategies: Inter-varietal hybridization and space radiation mutagenesis[10] (the relevant methods are provided in the supplementary materials). Rather than representing incremental improvements in isolated traits, these cultivars embody a coordinated breeding philosophy aimed at the simultaneous enhancement of multiple key characteristics, including high yield potential, elevated sucrose content, improved stress tolerance, and strong compatibility with mechanized harvesting and cultivation systems (Table 1). Designed to meet the diverse ecological conditions and production models of major sugarcane-growing regions in China, the ZT and ZF cultivar series provide differentiated, region-specific solutions that strengthen the foundation of national sugar security, support farmers in achieving stable yield increases and income growth, and promote the long-term transition of the sugarcane industry toward greater efficiency, environmental sustainability, and resilience.

Parentage and key characteristics of Zhongtang 3 and Zhongfu 1

Within the ZT and ZF series of newly developed sugarcane cultivars, Zhongtang 3 (ZT3) and Zhongfu 1 (ZF1) represent two

Table 1. Parentage and key traits of the Zhongtang and Zhongfu series of sugarcane cultivars

Cultivars	Parentage	Key characteristics
ZT1	YT99-66 × NJ03-218	High sucrose content, strong ratooning ability, and mechanical adaptability
ZT2	RY1 × ROC22	High smut resistance and excellent suitability for mechanical harvesting
ZT3	YT99-66 × ROC28	High yield, high sucrose content, strong ratooning ability, and mechanical adaptability
ZT4	K86-110 × HoCP95-988	High yield and high sucrose content
ZT5	YT00-319 × ROC10	High sucrose content, strong ratooning ability, and mechanical adaptability
ZT6	YL3 × GT02-761	High sucrose content, high yield, and very early maturity
ZT7	GT02-761 × ROC22	Early maturity, high yield, and high sucrose content
ZT8	ZZ50 × YL3	High sucrose content and strong ratooning ability
ZF1	K5 × CT89-103	High yield, high sucrose content, and strong ratooning ability
ZF2	YT00-319 × ROC22	High yield, high sucrose content, and strong ratooning ability
ZF3	GT02-901 × K5	High yield, high sucrose content, and strong ratooning ability

ZF1, ZF2 and ZF3 are all space radiation mutagenesis; that is, the hybrid seeds have been carried aboard in spacecraft.

complementary strategic directions in modern sugarcane breeding pursued by national-level research institutions: (a) high yield and high efficiency, and (a) stress-resilient specialization (Fig. 1).

ZT3 was developed from a cross between YT99-66 (female parent) and ROC28 (Xintaitang28) (male parent). YT99-66 was bred by the Nanfan Seed Industry Research Institute of the Guangdong Academy of Sciences (formerly the Guangzhou Sugarcane Industry Research Institute) through hybridization between YN73-204 and the introduced cultivar CP72-1210. Owing to its stable performance, YT99-66 has been widely cultivated as a commercial variety and extensively used as a crossing parent in Guangdong Province. ROC28, developed by the Taiwan Sugar Research Institute, was introduced into the major sugarcane-growing regions of Guangxi and Guangdong in 2005. This cultivar is characterized by an erect plant architecture, strong lodging tolerance, solid stalks, excellent ratooning ability, and high compatibility with mechanical harvesting systems[11]. The parental lines YT99-66 and ROC28 exhibit complementary agronomic and physiological traits, providing a robust genetic foundation for the development of ZT3.

ZT3 is a mid- to late-maturing cultivar distinguished by its high yield potential and elevated sucrose content. It exhibits a high germination rate, rapid and uniform seedling emergence, strong tillering capacity, and the production of abundant and uniform stalks, resulting in a high number of millable canes per stool. The cultivar demonstrates excellent ratooning performance and shows tolerance to smut, moderate tolerance to sugarcane mosaic virus, and strong tolerance to both low-temperature and drought stress. Its stalks are blue in color, erect, uniform, and solid, conferring enhanced tolerance to lodging and wind damage. In addition, ZT3 exhibits favorable defoliation characteristics, low cane loss and trash rates during harvesting, and strong overall suitability for mechanized cultivation and harvesting operations.

In contrast, ZF1 exemplifies the substantial potential of space radiation mutagenesis as an alternative and innovative breeding pathway[12]. ZF1 was derived from a cross between K5 (female parent) and CT89-103 (male parent). The hybrid seeds were carried aboard the Shenzhou-10 spacecraft in 2013, where they were exposed to a unique space environment characterized by cosmic radiation, microgravity, and other extreme conditions. Subsequently, long-term, systematic ground-based selection enabled the

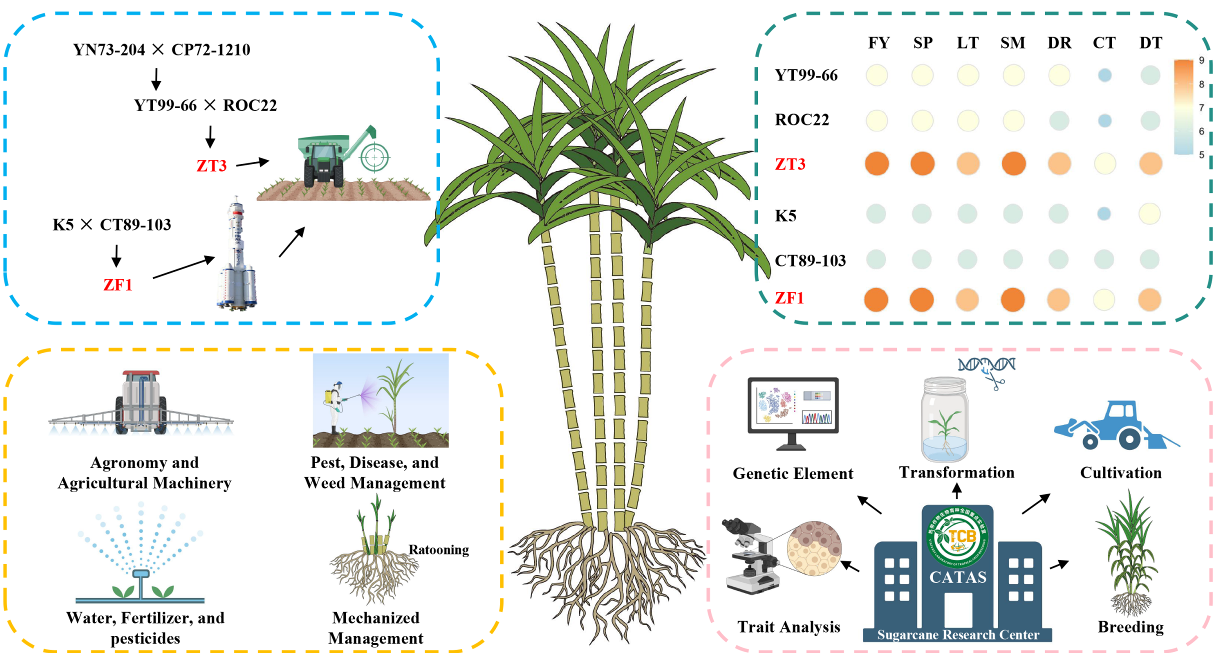

Fig. 1 Zhongtang 3 and Zhongfu 1 as strategically technology-empowered cultivars driving the transformation of the sugarcane industry. This schematic summarizes the integrated innovation framework underlying the development of ZT3 and ZF1. The blue panel depicts the parental origins and distinct breeding pathways of ZT3 and ZF1. The green panel presents comparative trait evaluations of the four parental lines and the two derived cultivars, including field yield (FY), sugar production (SP), lodging tolerance (LT), suitability for mechanization (SM), disease resistance (DR), cold tolerance (CT), and drought tolerance (DT). The yellow panel illustrates the four-component integrated technology system designed to enhance sugarcane's quality and production efficiency. The pink panel highlights the five specialized research teams, whose coordinated efforts collectively support the breeding, deployment, and industrial impact of these landmark cultivars.

identification and stabilization of valuable mutant lines. This approach generated novel mutant germplasm resources that are difficult or impossible to obtain through conventional breeding methods, thereby providing new genetic variation for improving stress resilience and specialized traits in sugarcane.

Dual-path innovation in sugarcane breeding and precision targeting of industry challenges

The breeding strategy underlying the ZT and ZF sugarcane series is rooted in a systematic analysis of the major bottlenecks constraining contemporary sugarcane production. In response to persistent challenges—including poor compatibility with mechanized operations, shortened ratooning cycles, and the high economic and environmental costs associated with pest, disease, and weed management—the research team formulated integrated breeding objectives encompassing high yield potential and sucrose content, enhanced biotic and abiotic stress tolerance, strong ratooning ability, and suitability for mechanized cultivation and harvesting. To achieve these goals, modern breeding technologies were strategically combined, including rational parental configuration, high-throughput phenotypic screening, marker-assisted selection, and whole-genome-based design approaches. These methodologies were further complemented by the targeted improvement of key functional traits, such as insect tolerance and herbicide tolerance, resulting in a substantial increase in overall breeding efficiency.

Across three consecutive years of varietal comparison trials, ZT3 consistently outperformed the widely cultivated control cultivar ROC22 (Xintaitang22). ZT3 exhibited significantly higher ratoon tillering capacity, greater plant height, and increased stalk number, leading to a 6.62% increase in yield per unit of area relative to ROC22. The average sucrose content of ZT3 across the growing season reached 15.14% in the plant cane crop, exceeding that of ROC22 (14.79%) by 0.35 percentage points. This advantage was further amplified in the ratoon crop, where ZT3 achieved a sucrose content of 15.28% (from November to the next February), surpassing ROC22 by 2.42 percentage points (12.86%), thereby confirming its combined high-yield and high-sugar characteristics[11]. ZT3 also exhibited a fiber content of 10.85%, which was 1.12 percentage points higher than that of ROC22 (9.73%). This elevated fiber content, together with strong tolerance to lodging and wind damage and favorable leaf-shedding behavior, resulted in a 19.48% reduction in stalk loss and a 14.17% reduction in trash content during mechanical harvesting compared with ROC22[11], highlighting its superior compatibility with mechanized harvesting systems. In addition, ZT3 demonstrated strong tolerance to smut and moderate tolerance to mosaic disease, providing a robust phytosanitary foundation for large-scale industrial application.

Regional multisite trials also demonstrated the outstanding performance of ZF1. Across one plant cane crop and two successive ratoon crops, ZF1 achieved an average cane yield of 8,854 kg per mu and a sugar yield of 1,243 kg per mu, representing increases of 29% in cane yield and 27% in sugar yield relative to the dominant commercial cultivar, ROC22. ZF1 is characterized by an erect plant architecture, efficient leaf shedding, tolerance to smut, and high tolerance to mosaic disease, traits that collectively contribute to its excellent suitability for mechanized harvesting and low-input cultivation systems. Notably, both ZT3 and ZF1 exhibited substantial improvements in yield performance and stress-tolerance traits compared with their respective parental lines (Fig. 1), underscoring the effectiveness of the dual-path breeding strategy in addressing the complex and interrelated challenges facing the modern sugarcane industry.

Technology-integrated, lightened, simplified, and high-efficiency sugarcane cultivation

The agronomic performance of elite sugarcane cultivars can only be fully realized when the genetic advantages are matched with appropriately designed production technologies. The favorable plant architecture (erect growth habit and moderate stalk diameter) and key agronomic traits (efficient leaf-shedding and strong ratooning capacity) of ZT3 and ZF1 provide a robust biological foundation for the development of an integrated, lightweight, and high-efficiency cultivation system.

To promote the deep integration of agronomy and mechanization, a full-process mechanized production system has been established, encompassing precision planting, intertillage and field management, and high-efficiency harvesting operations. The optimized growth architecture of ZT3 and ZF1 enables seamless mechanized operations throughout the entire production cycle. Variety-specific technical protocols for precision sowing, intertillage management, and whole-stalk or chopper harvesting have been developed, substantially reducing trash content and harvest losses. These advances effectively address long-standing constraints in mechanized sugarcane production and have reduced trash inclusion rates to below 7%, thereby improving harvesting efficiency and processing quality.

From the perspective of green and sustainable production, ZT3 and ZF1 contribute through distinct yet complementary mechanisms. The relatively high fiber content of ZT3 enhances tolerance to insect pests, leading to a direct reduction in the need for chemical pesticide inputs[11]. In contrast, ZF1 exhibits strong tolerance to smut and high tolerance to mosaic disease, as well as improved drought tolerance, which together substantially reduce dependence on plant protection interventions. Collectively, these traits support the establishment of a green cultivation model centered on intrinsic varietal tolerance within an integrated pest, disease, and weed management framework.

This varietal–technological integration is further reinforced by a smart, integrated water–fertilizer–pest management system based on Internet of Things (IoT) monitoring. By enabling real-time sensing and precision regulation of field conditions, this system reduces irrigation water consumption by 30%–40% and increases nitrogen use efficiency to 45.6%. In addition, an innovative mechanized ratoon management technique, namely the "three early and three deep" method, was specifically developed to enhance ratooning performance in these cultivars. This approach extends the stable high-yield ratoon cycle to 4–5 years, thereby substantially reducing the average annual planting costs.

The resulting four-component integrated technology package for improving sugarcan'se quality and production efficiency has been successfully implemented at the "Sweet Light" Modern Sugarcane Industrial Park in Fusui County, Nanning, Guangxi. The system has since been scaled up for application in major sugarcane-growing regions, including Guangxi, Guangxi and Hainan, where it has demonstrated strong environmental adaptability and received widespread recognition by both sugarcane growers and sugar mills (Fig. 1).

Systematic support from national strategic, scientific, and technological capabilities

The successful development of ZT3 and ZF1 is underpinned by a strong national-level scientific and technological innovation platform: The Sugarcane Research Center of the Chinese Academy of Tropical Agricultural Sciences. Anchored by major research infrastructures, including the State Key Laboratory of Tropical Crop Breeding, the center has established a comprehensive, fully integrated research and development system that spans the entire innovation chain from germplasm creation to industrial application.

This system operates through coordinated collaboration among five specialized innovation teams. First, the Efficient Breeding Technology Team accelerates cultivar development through the integrated use of inter-varietal hybridization, space radiation mutagenesis, and genomic-assisted selection strategies. Second, the Green and Simplified Cultivation Team focuses on designing and optimizing integrated agronomic technologies aimed at improving production efficiency, resource use efficiency, and environmental sustainability. Third, the Key Trait Analysis Team is dedicated to elucidating the genetic, physiological, and molecular mechanisms underlying the core agronomic traits, including high yield potential, elevated sucrose content, stress tolerance, and suitability for mechanized production. Complementing this effort, the Genetic Element Discovery Team systematically mines elite germplasm resources to identify and clone key functional genes and regulatory elements that are directly relevant to the breeding objectives. Finally, the Biotechnology Transformation Platform Team applies advanced genetic transformation and gene editing technologies to enable precise, targeted improvement of the priority traits.

Together, these interconnected teams form a full-chain, systematically organized innovation framework that integrates fundamental research, applied breeding, and technology transfer. This structure ensures the efficient conversion of scientific discoveries into deployable cultivars and production technologies, providing strong institutional support for the modernization and sustainable development of the Chinese sugarcane industry (Fig. 1).

Industrial impact and future perspectives

The large-scale promotion of ZT3 has already generated significant economic and industrial benefits. Owing to its combined high-yield and high-sucrose characteristics, ZT3 provides a stable and high-quality raw material base for the sugar processing industry. By the end of 2023, the cumulative cultivation area of ZT3 exceeded 85,000 ha, resulting in an average yield increase of 1.2 t ha^{-1} and an additional sugar output of approximately 81,600 t, which can be attributed to its elevated sucrose content. These performance gains translated into an increase in net income of CNY 500–800 ha^{-1} for sugarcane growers[11]. Beyond conventional breeding gains, further enhancement of ZT3 has been achieved through an *Agrobacterium*-mediated genetic transformation platform, whereas the overexpression of insect- and herbicide-tolerance genes has markedly improved its field adaptability and production stability[13]. Its strong compatibility with mechanized operations and simplified management systems facilitates large-scale production, while reduced reliance on chemical pesticides and fertilizers confers substantial ecological benefits.

In parallel, ZF1 has demonstrated distinct industrial value through its deployment in the selenium-rich soils in Lingao, Hainan. Under these conditions, ZF1 exhibits the capacity to accumulate beneficial trace elements, including selenium and iron, enabling the development of functional, value-added products such as "space sugarcane brown sugar". This innovation represents a transition from primary agricultural production toward higher-value processing and branding, and attracted considerable attention at the 2023 Hainan Winter Trade Fair.

Looking forward, the inherent limitations associated with cultivars developed via conventional hybridization or space radiation mutagenesis will be progressively addressed through advanced biotechnological approaches, including genetic transformation and gene editing technologies[14,15]. These innovations will be further integrated with smart agriculture management platforms, enabling data-driven decision-making and precision control across the production system[16−18]. As representative outcomes of deep, long-term collaboration among industry, academia, and research institutions, the ZT and ZF cultivar series not only constitute a central driving force for the transformation and upgrading of the Chinese sugarcane industry, but also provide a replicable and scalable model for safeguarding national sugar security and advancing the development of green, sustainable agriculture.

Author contributions

The authors confirm their contributions to the paper as follows: conceptualization: Wang P, Wu Q, Que Y; data curation: Wang P, Cai W, Wu Q; investigation: Wu Q, Gan Y, Cao Z; writing original draft preparation: Wang P, Wu Q; review and editing: Wang P, Wu Q, Que Y; resources: Zhang Y, Yang B, Wu Y, Que Y; funding acquisition: Wu Q, Que Y. All authors read and approved the final manuscript.

Data availability

Data availability is not applicable to this perspective, as no new data were created or analyzed in this study.

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Conflict of interest

The authors declare that they have no conflict of interest.

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References

[1] Garsmeur O, Rio S, Pompidor N, Lipzen A, Hervouet C, et al. 2025. The genomic footprints of wild Saccharum species trace domestication,

diversification, and modern breeding of sugarcane. *Cell* 188(25):7252−7266.e15

[2] Huang Y, Zhang Y, Zhang Q, Zhuang G, Li C, et al. 2026. Multiscale pangenome graphs empower the genomic dissection of mixed-ploidy sugarcane species. *Science* 391:eadx1616

[3] Ivan Jo. 2023. Sugarcane industry: modern innovations and sustainable practices. *International Research Journal of Plant Science* 14(3):1−2

[4] Matsuoka S. 2025. Energy cane: a revolutionary clean energy crop for the transition to a sustainable energy system. *Academia Environmental Sciences and Sustainability* 2(2):1−17

[5] Flack-Prain S, Shi L, Zhu P, da Rocha HR, Cabral O, et al. 2021. The impact of climate change and climate extremes on sugarcane production. *GCB Bioenergy* 13(3):408−424

[6] Shang XK, Wei JL, Liu W, Nikpay A, Pan XH, et al. 2025. Integrated pest management of sugarcane insect pests in China: current status and future prospects. *Sugar Tech* 27:299−317

[7] Verma KK, Song, XP, Kumari A, Jagadesh M, Singh SK, et al. 2025. Climate change adaptation: Challenges for agricultural sustainability. *Plant, Cell & Environment* 48(4):2522−2533

[8] Li YR, Zhang BQ, Song XP, Liang Q, Verma KK, et al. 2024. Development of sugar industry in china: R&D priorities for sustainable sugarcane production. *Sugar Tech* 26:972−981

[9] Lu G, Liu P, Wu Q, Zhang S, Zhao P, et al. 2024. Sugarcane breeding: a fantastic past and promising future driven by technology and methods. *Frontiers in Plant Science* 15:1375934

[10] Gan Y, Wu Y, Yang B, Cai W, Zeng J, et al. 2021. Breeding of the new high smut-resistant sugarcane variety 'Zhongtang No. 2'. *Chinese Journal of Tropical Crops* 42(3):816−821 (in Chinese)

[11] Cao Z, Peng L, Cai W, Gan Y, Wu Y, et al. 2023. The breeding and species evaluation of a new sugarcane variety Zhongtang3. *Sugarcane and Canesugar* 52(5):1−7 (in Chinese)

[12] Gan Y, Zhang S, Wu Y, Yang B. 2015. Advance on the mutant characteristics of crops induced by spaceflight. *Guangdong Agricultural Sciences* 42(1):119−123 (in Chinese)

[13] Wang W, Wang D, Zhao W, Zhang Y, Zeng Z, et al. 2025. Highly efficient and genotype-independent genetic transformation system in sugarcane. *Plant biotechnology journal Published online*

[14] Wang D, Gou Y, Yi C, Li Z, Wang W, et al. 2025. ScWRKY2: a key regulator for smut resistance in sugarcane. *Plant Biotechnology Journal* 23(9):3667−3681

[15] Wang P, Si H, Li C, Xu Z, Guo H, et al. 2025. Plant genetic transformation: achievements, current status and future prospects. *Plant biotechnology journal* 23(6):2034−2058

[16] Wang X, Wu Q, Zeng H, Yang X, Yang X, et al. 2024. Digital evolution and twin miracle of sugarcane breeding. *Field Crops Research* 318(1):109588

[17] Wang X, Wu Q, Zeng H, Yang X, Cui H, et al. 2025. Blockchain-empowered H-CPS architecture for smart agriculture. *Advanced Science* 12(27):e2503102

[18] Wang P, Wu Q, Wang W, Wang D, Wang J, et al. 2026. Three-chain empowered sugarcane bio-breeding in China. *The Innovation Life* 4:100207