Chapter 3

Sugarcane Production in China

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Additional information is available at the end of the chapter

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Abstract

Sugarcane production in China has a prolonged history since fourth century BC. At present, China is the world's third largest sugar producing country after Brazil and India. During the past decade, more than 90% of the sugar production was contributed by sugarcane. Guangxi is the dominant sugarcane and sugar producer, accounting for 65% of sugar production in China. China's sugarcane production faced serious problems in the past several years, especially the rapid increase in the labor cost because of the manual harvest. Now, China requires changing their sugarcane practice from manual to mechanical in order to catch up with the international trends in worldwide industry. Many other challenges and constraints are becoming severe, including abiotic and biotic stress, cost escalation, over fertilization, poor ratooning, and single cultivar. New technologies will be applied to sugarcane production, including omics-based breeding, best management practices, and so on.

Keywords: sugarcane, production, breeding, best management practices, China

1. Overall introduction of sugarcane production in China

China is the world's third largest sugar producing country followed by Brazil and India. About 270 sugar mills were working to meet the basic sugar supply in China, of which 233 mills worked for sugarcane, 37 for sugar beet, and 11 for refinery. The sugar industries contributed to GDP (gross domestic product) of about 6–8 billion RMB, about 0.1% of the gross GDP in China [1]. During the past decades, more than 90% of the sugar production was contributed by sugarcane. Sugarcane is a major crop in southern China, especially in Guangxi, Yunnan and Hainan, and western Guangdong. Guangxi is the dominant sugarcane and sugar producer in China, accounting for 65% of sugar production in China.

2. History of sugarcane production in China

China is one of the original producers of sugarcane. *Saccharum sinense* and *Saccharum spontaneum* are widely distributed, from the North Qinling Mountains to the South Hainan Island. Since the late fourth century BC, sugarcane has been used to produce syrup in China.

Cane production, cane yield, and quality have been improved very quickly in mainland China in the past 60 years. From 1961 to 2013, sugarcane production increased rapidly from 2.643 million to 126.13 million tons; the total area of sugarcane plantation extended from 0.108 million to 1.827 million ha, cane yield from 24.0 to 67.4 tons per ha and total sugar production from 0.15 million to 10.613 million tons (**Figure 1**). The average sucrose content, over this same period, has increased from under 13% to more than 14.5%, with some cultivars now providing an average over 16% (from October to April).

From that on, the sugar industry in China has suffered four consecutive years of operating losses due to high production costs (labor cost), the elimination of government support prices, and import competition [2, 3]. Total sugar production in MY 2016/17 is forecast at 8.2 million metric tons (MMT) raw value, down 200,000 metric tons (MT) from post's revised MY 2015/16 estimate. Estimated total sugar production is lowered from 2.15 to 8.4 MMT for MY 2015/16. Sugarcane production suffered a major shock when Yunnan, Guangdong, and Hainan provinces announced in September 2015 that they would cancel provincial floor prices for MY 2015/16. As of early March 2016, approximately 90% of sugar manufacturers were operating at a loss according to industry reports, and a number of small mills have been closed. However, China's cane sugar production is expected to increase for the second year in a row in MY 2017/18, with production forecast at 9.2 MMT, up 800,000 MT from the revised MY 2016/17 estimate. This increase is due to a significant expansion in acreage, as higher prices have increased farmer returns and encouraged those to plant more cane (**Figure 2**).

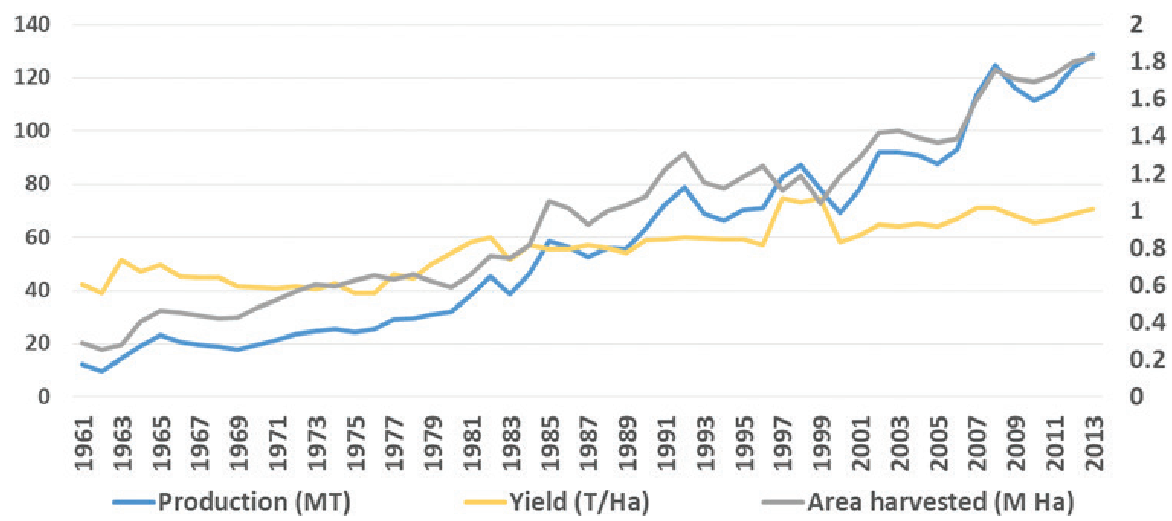

Figure 1. Sugarcane production in China (1961–2013).

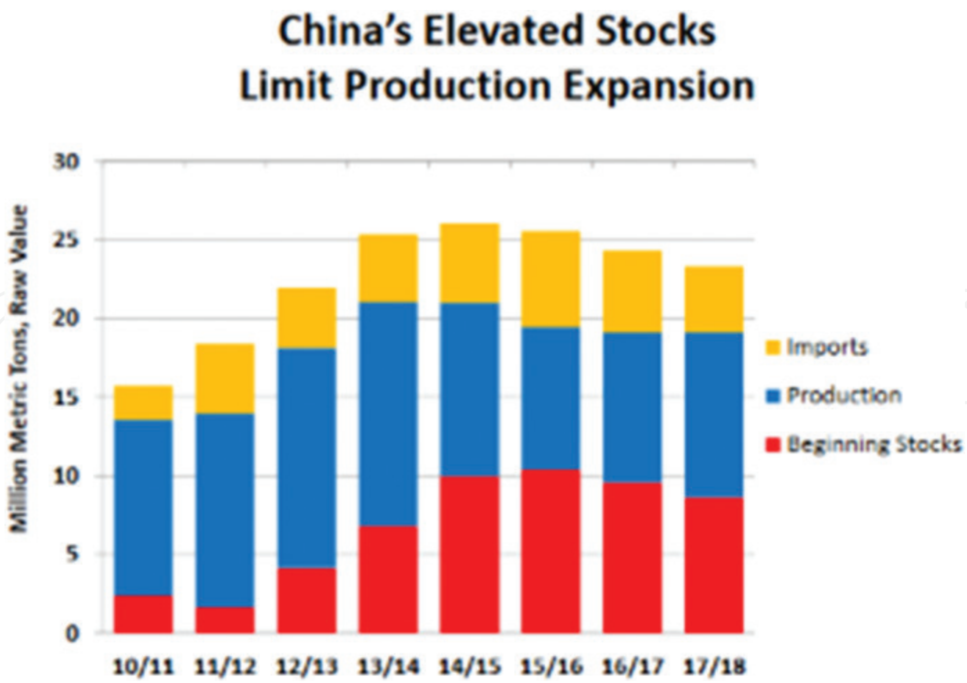

Figure 2. Sugarcane productions in China (from 2010 to 2017).

Sugarcane minimum purchase prices (floor prices) are set by local sugar industry associations and sugarcane processors, in consultation with local governments. In Guangxi Zhuang Autonomous Region, the purchase price has increased to 500 RMB ($72) per metric ton of sugarcane, up from 440 RMB in 2015/16 (**Figure 3**). After many years of declining returns,

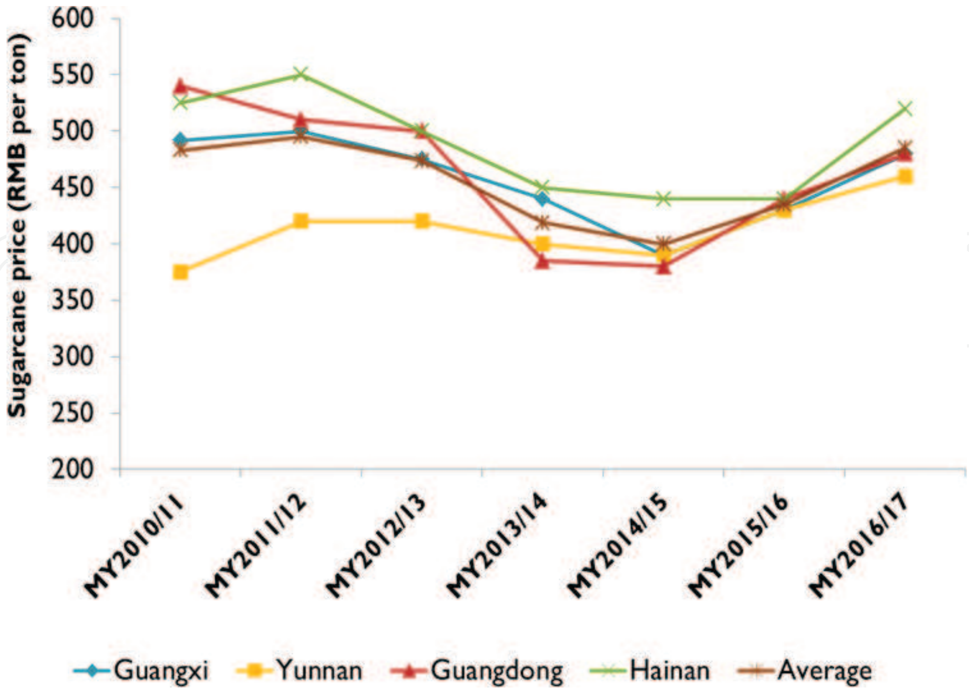

Figure 3. Sugarcane price in China (2010–2017).

sugarcane production has become a little profitable, and farmers are consequently planting more (the planting season is typically February and March). Sugar mill contacts have also confirmed that farmers are keeping more of their cane for seed, highlighting this expected increase in area. These increases are anticipated to be greatest in Guangxi, which accounts for over 65% of the nation's total sugarcane production.

3. China's major sugarcane production areas

The major sugarcane production area in China is located between latitude 18.5°N and 32°N and longitude 92°E and 122°E, including Guangxi, Yunnan, Guangdong, Hainan, Fujian, Taiwan, Zhejiang, Sichuan, Guizhou, Hunan, and Jiangxi provinces (or autonomous regions). Before the late 1980s, coastal areas in southeastern China such as Guangdong and Fujian were the main sugarcane producing areas. Since then, sugarcane production gradually shifted from southeast to southwest. So, the current major production areas include Guangxi, Yunnan, western Guangdong, and Hainan. The combined sugar production from these provinces accounted for over 90% of the total production in China [4]. Dominant production regions in these provinces were central-south in Guangxi, southwest in Yunnan, western in Guangdong, and northern in Hainan (**Figure 4**).

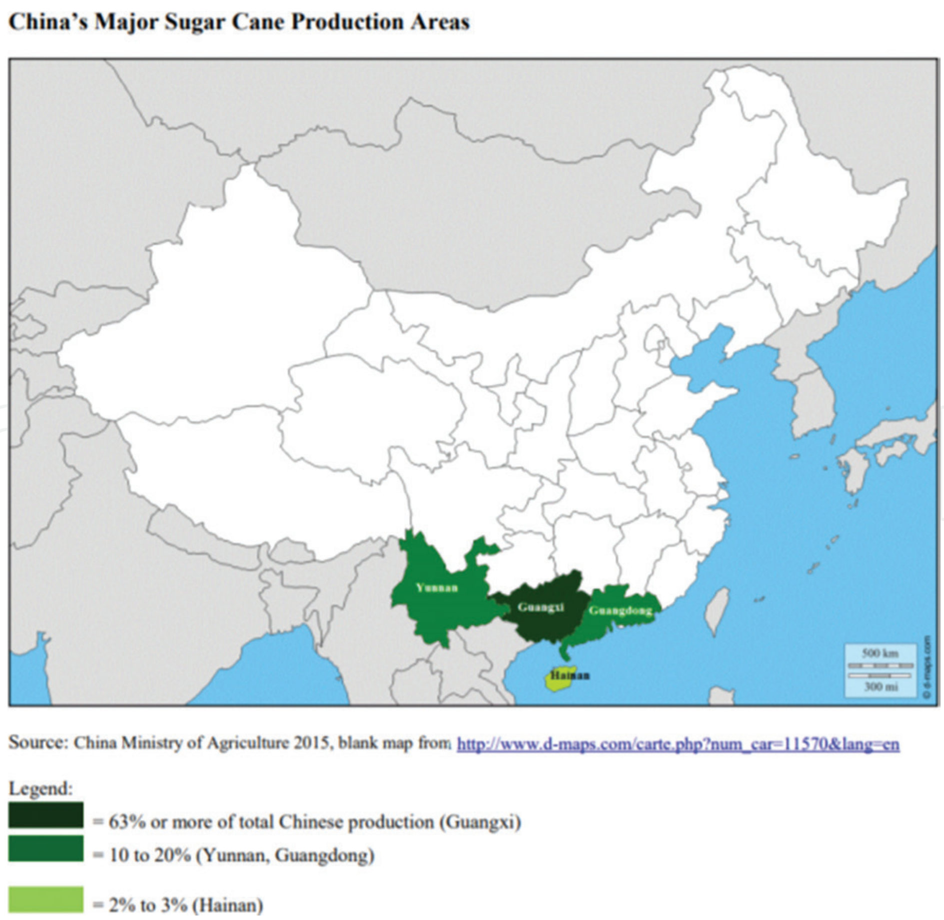

Figure 4. Sugarcane production areas in China.

Despite this increase in area, there are a number of obstacles to continue future acreage expansion. Although a few years ago sugarcane area in China was much more than it is now, this land was planted with fruit trees and eucalyptus trees with a very long production cycle. As a result, even with higher prices, it will not be possible to easily bring this land back into cane production. Mechanization levels are still low in China for sugarcane, and the hilly terrain in much of the production area makes mechanization adoption for harvesting difficult. Production costs continue to be very high. In fact, the price of labor for harvesting sugarcane can make up more than a third of the total cane purchase price [5]. Among major sugar producing countries, China has the highest production costs, with these as much as double those in neighboring Thailand. High production costs and inefficiencies have made Chinese sugar production uncompetitive with other countries, and also it is one of the reasons why the sugar industry approached the Chinese government to request a safeguard investigation into sugar imports for next 3 years (2017–2020).

4. Sugarcane breeding in China

The improved varieties are becoming more important for sugarcane production worldwide [6, 7]. New varieties are continuously released in Guangxi, Guangdong, Yunnan, Fujian, and Hainan by sugarcane breeding institutes, agricultural universities, and sugarcane research and development centers in China (**Table 1**). It would be therefore worthwhile for the growers to manipulate the environment in such a way as to bring out the maximum expression of the yield potential possessed by these varieties.

4.1. Sugarcane varieties bred in mainland China

Sugarcane breeding program in China started in 1953 when the first sugarcane breeding station was established in Yachen, Hainan (formerly known as Yaxian county, 18°27′N and 109°50′E), where sugarcane can flower in the field. Sugarcane fuzzes from this station were sent to sugarcane research institutes in different provinces (**Table 1**). In general, this station can make 1200 crosses from 1600 flowers every year. Besides this station, Ruili hybrid station (Ruili, Yunnan) can provide about 500 crosses. The number of seedlings is about 0.8 million over the country each year. More than 100 sugarcane varieties have been bred and released for commercial sugarcane production in mainland China from 1953 to 2000 [8]. Of these, GT11 (CP49-50 × Co419), YT57-423 (F108 × F134), YT63-237 (Co419 × CP33-310), and MT70-611 (CP49-50 × F134) have become dominant varieties for a period in different provinces. The combinations and seedling numbers were very limited in China, and the breeding efficiency was very low from 1953 to 2000. For example, less than 50 crosses and 30,000 seedlings were evaluated in the sugarcane breeding program in Guangxi Sugarcane Research Institute before 2001. There were no more new dominant sugarcane varieties bred in mainland China since 1980s when GT11, MT70-611, and YT57-423 were released.

From 2000 to 2016, more than 120 new sugarcane varieties have been released for commercial sugarcane production. Of these, LC05-136 (CP81-1254 × ROC22), GT42 (ROC22 × GT2-66), YT93-159 (YN73-204 × CP72-1210), YZ89-151 (GZ64-137 × NJ57-416), YT00-236 (YN73-204 × CP72-1210), FN41 (ROC20 × YT91-976), GT29 (YC94-46 × ROC22), and GT32 (YT91-976 × ROC1)

Institute name	Location	Abbreviated Chinese name and prefix of varieties selected at each location	Breeders
Guangxi Sugarcane Research Institute, Guangxi, Academy of Agricultural Science (GAAS)	Nanning, Guangxi	GuiTang—GT	Yang RZ, Wang LW
Liucheng Sugarcane Research Institute, Guangxi	Liuchen, Guangxi	Liucheng—LC	Lu WX
Guangxi University, Guangxi	Nanning, Guangxi	Zhongzhe—ZZ	Zhang MQ
Guangzhou Sugarcane Industry Research Institute (GSIRI)	Guangzhou, Guangdong	YueGan—YG; Yuetan—YT	Qi YW
Sugarcane Breeding Station, GSIRI	Yacheng, Hainan	YaCheng—YC	Liu SM
Sugarcane Research Institute	Kaiyuan and Ruili	Yunzhe—YZ	Wu CW
Yunnan Academy of Agricultural Science (YAAS)	Yunnan	YunRui—YR	Jing YF
Hainan Sugarcane Research Center, Chinese Academy of Tropical Crop	Haikou, Hainan	Zhongtang—ZT	Yang BP
Sugarcane Synthetic Research Institute, Fujian Agriculture and Forestry University (FAFU)	Fuzhou, Fujian	Funong—FN	Deng ZH
Sugarcane Research Institute, Fujian Academy of Agricultural Science (FAAS)	Zhangzhou, Fujian	Mintang—MT	Pan SM

Table 1. The main sugarcane research institutes in different provinces in mainland China.

was the major cultivars released by Chinese breeding program. These achievements were contributed to the increasing seedling scales and the inputs for breeding program. Substantial financial support from the government for the long term provides an excellent chance for sugarcane improvement. In Guangxi, the cross combination number increased up to 500–1000, and total seedling numbers to 100,000–400,000 since 2002. The highest seedling number reached 600,000 in 2012. In Fujian, Yunnan, and Guangdong, the situations are almost same as Guangxi.

4.2. Introduced sugarcane varieties in mainland China

A large number of overseas sugarcane varieties have been introduced into mainland China since 1930, such as CP series from USA, Q series from Australia, PR series from Puerto Rico, RB series from Brazil, F and ROC series from Taiwan, China, and POJ series from Philippines. After quarantine, most of them have been used as parental clones in the breeding program in China. However, some introduced varieties were suitable for commercial production in some cane growing areas and adopted directly as cultivars. POJ2725, POJ2878, and POJ2883 were firstly introduced from the Philippines, and Badila from Australia, but only POJ2878 and POJ2725 became major varieties for sugar production in China in 1930s. F134 and Co419 (originally from India) were introduced to the mainland from Taiwan in 1947. F134 became the most popular variety in the sugarcane growing areas in mainland China until early 1980.

Since 1980, the CP and ROC series were used most frequently as commercial cultivars or breeding parents [9]. The most popular and widely used cultivars in mainland China include ROC10, ROC16, ROC22, and ROC25 released by Taiwan Sugar Research Institute in China in 1960–2000, HoCP85-384 by Sugarcane Research Unit in Houma, USA in 2010s. The planting area of these four ROC cultivars has expanded continuously due to their high cane yield, high sucrose content, and adaptation to a range of environmental conditions, which accounted for over 70% of the total planting area of mainland China since 1990. The growing areas of new varieties bred in mainland China accounted for less than 30%. Susceptibility to smut, poor ratooning ability as well as adaptability, and yield stability of these newly bred varieties in mainland China are commonly poorer than those of ROC varieties. However, success in the improvement of sucrose content is partly attributed, at least, to the use of introduced varieties with high sucrose, such as CP and ROC varieties, as parents in China. Many of cultivars bred in mainland China have higher sucrose or higher tons cane per hectare (TCH) than the ROC (Taiwan, China) varieties.

4.3. Basic hybridization program in mainland China

China, one of the diversity centers of *Saccharum* complex, is rich in sugarcane germplasm resources. Since 1980s, Chinese sugarcane breeders have collected a large number of wild cane resources from different provinces and overseas and maintained most of these in the National Sugarcane Germplasm Nursery, Kaiyuan City, Yunnan province. Among them, *S. spontaneum* and *Erianthus arundinaceus* are more prominent than other wild species (**Table 2**).

A basic breeding program was established for crossing the local *S. spontaneum* at Yacheng with *Saccharum officinarum* (Badila and other noble cane) in 1953. Several F_1 progenies have been released and widely used in the Chinese breeding program, including YC58-43, YC58-47, Ya71-374, and Ya73-512, which in turn have produced a lot of commercial varieties, respectively. In addition, more attentions were paid to the germplasm innovation by exchanging germplasm with other countries, utilizing local wild germplasm collections, such as *S. spontaneum*, *E. arundinaceus*, and *Narenga porphyrocoma*, which were crossed and backcrossed with commercial sugarcane varieties. Some promising clones have been selected from BC_1 to BC_4 progenies [10].

The genus *Erianthus* is one of the important wild relatives to sugarcane and has attracted considerable interest from sugarcane breeders worldwide for many decades. Within the genus *Erianthus*, most species including *Erianthus arundinaceus*, *Erianthus fulvus*, and *Erianthus rockii* have many superior traits for sugarcane improvement, such as high biomass, vigor, ratooning ability, tolerance to abiotic stresses caused by drought and water logging, and resistance to biotic stresses arising from various pathogens and pests [11]. In order to transfer desirable traits from the genus *Erianthus* into sugarcane, sugarcane has been hybridized with the genus *Erianthus* in China since 1990. In general, *S. officinarum* was usually used as female parent for speeding up the nobilization progress of *Erianthus*, and a series of intergeneric F_1 hybrids between *S. officinarum* and *Erianthus* have been obtained successfully. However, the resulting F_1 progeny could not be backcrossed directly to sugarcane as male parents due to pollen sterility [12]. Hence, the F_1 progeny between *S. officinarum* and *Erianthus* were used as female parents to backcross with sugarcane, and a number of

Genus	Species name	Number
Saccharum officinarum L.	*S. officinarum*	32
	S. barberi	3
	S. sinense	25
	S. robustum	6
	S. spontaneum	690
	Local cultivar and fruit cane	96
	Oversea sugarcane cultivars	665
	Domestic cultivars	686
Erianthus Michaux.	*E. fulvus*	63
	E. rockii	51
	E. arundinaceum	290
Narenga Bor	*N. porphyrocoma*	11
Miscanthus Anderss.	*M. floridulus*	2
	M. sinensis	31
Imperata Cyr.	*I. cylindrica*	23
Pennisetum Rich.	*P. schumach*	6
	Pennisetum spp.	2
	Total	2682

Table 2. Sugarcane germplasms conserved in the National Sugarcane Germplasm Nursery, (Kaiyuan City, Yunnan; 103.23E, 23.70N).

backcrossing lines have been successfully generated in the past 20 years. *S. spontaneum* was used as a bridge species for the introgression of *E. arundinaceus*, due to *S. spontaneum* with a good source of incorporating fertility in order to overcome the pollen sterility of F_1 progeny between *Saccharum* and *Erianthus* [13]. So far, a series of fertility F_1 progeny between *S. spontaneum* and *Erianthus* had been obtained. Verification of the introgression of *E. arundinaceus* lineage into sugarcane is an essential way in sugarcane improvement. Over the past two decades, a number of genuine intergeneric hybrids between *Saccharum* and *E. arundinaceus* have been verified and patented using sequence-tagged microsatellite site (STMS), 5S rDNA sequences, 45S rDNA sequences, and inter-Alu sequences [14, 15]. Genomic in situ hybridization (GISH) has been used to identify genuine intergeneric hybrids between *Saccharum* and *E. arundinaceus* and to track the introgression of *E. arundinaceus* lineage into sugarcane. In addition, to detect the chromosomal rearrangement between *Saccharum* and *Erianthus* in the intergeneric high-generation progeny [9, 16], some promising clones (BC2-BC5) have been bred from the cross between *Erianthus* and *Saccharum*, such as YC04-55, YC05-64, YC05-164, YC06-92, YC06-140, YC06-166, YC07-65, YC07-71, YC07-74, YC06-111, YC06-61, YC06-63, YC06-91, and YC05-150.

4.4. Selection program in mainland China

The selection programs conducted in China are almost the same in all research institutes or universities in mainland China. Clones are first tested in an experiment station at each institute or university for 5–6 years, followed by testing at multiple sites (regional trial) outside the original institute for 4–5 years. In addition to selection schemes operated by each individual institute, China began a new project to evaluate sugarcane varieties in a nationally coordinated series of trials in 1996. The project was named the National Sugarcane Variety Cooperative Regional Test (NSVCRT) and was coordinated by Fujian Agriculture and Forestry University and supported by Crop Variety Examination and Approval Committee, Ministry of Agriculture in China. Till now, a total of 141 sugarcane varieties were tested in the nationwide regional test and 89 were determined for production test in 14 sites from three sugarcane major ecological zones, *viz.* the Southern China Inland Ecological Cultivation Zone, the Southwestern Plateau Ecological Cultivation Zone, and the Southern China Coastal Ecological Cultivation Zone (**Table 3**) [17]. The released cultivars were evaluated on sucrose content, tillering capacity, yield potential, good field appearance, slight thick and long stalks,

Variety name	Female parent	Male parent	Identified by	Released year
GT91-116 (GT19)	ROC1	YC85-55	National	2005
GT93-103 (GT23)	ROC1	YC71-374	National	2005
GT94-116 (GT24)	GT71-5	YC84-153	National	2005
GT96-44 (GT25)	CP72-1210	YC71-374	National	2005
GT96-211 (GT26)	Pindar	GT11	National	2007
GT86-267 (GT16)	YT59-65	Ya72-399	National	1999
GT84-332 (GT15)	HN56-12	Neijian59-782	National	1999
GT89-5 (GT17)	GT11	YC62-40	National	1999
GT94-119 (GT21)	GZ75-65	YC71-374	National	2005
GT90-95 (GT18)	CP65-357	F172	Guangxi	2001
YT89-240 (YT48)	CP72-1210	GT11	National	2005
YT91-976 (YT49)	YN73-204	CP67-412	National	2005
YT91-1102 (YT51)	YN73-204	YT84-3	National	2007
YT93-159	YN73-204	CP72-1210	Guangdong	2001
YT85-177	YT57-423	CP57-614 + CP72-1312	National	1999
YT96-835 (YT49)	Co419	ROC10	National	2007
YT96-86 (YT50)	YT85-177	Zang74-141	National	2007
FN91-3623	CP72-1210	GT11	National	2002
FN91-4621	CP72-1210	Zang74-141	National	2002

Variety name	Female parent	Male parent	Identified by	Released year
FN91-4710	CP72-1210	Ke5	Fujian	2004
FN94-0403	CP72-1210	MT69-263	National	2005
FN98-1103	CP72-1210	Zang74-141	National	2009
FN95-1702	CP72-1210	YN73-204	National	2005
FN83-36	CP49-50	FN57-18	National	1999
FN81-745	YT59-65	CP36-105	National	1999
MT88-103	Co1001	YC82-96	National	1999
MT92-649	ROC1	Co1001	National	2005
MT86-2121	Q641	CP49-50	National	2005
MT92-505	Co1001	CP73-1547	National	2007
MT99-596	Co1001	YC73-226	National	2009
YZ85-151	Gang64-137	Chuang57-416	National	1999
YZ92-19	Gang64-137	CP67-412	National	2005
YZ89-351	YC82-96	GT11	National	2005
YZ94-375	CP72-1210	YC73-512	National	2007
YZ99-596	Co419	YC85-881	National	2009
FN38	YT83-257	YT83-271	National	
FN39	YT91-976	CP84-1198	National	
FN41	ROC20	YT91-976	National	
GT43	YT85-177	GT92-66	Guangxi	
GT44	ROC1	GT92-66	Guangxi	
GT42	ROC22	GT92-66	Guangxi	
GT46	YT85-177	ROC25	Guangxi	
GT47	YT85-177	CP81-1254	Guangxi	
GT49	GZ14	ROC22	Guangxi	

*Variety identified by National means that the variety is approved to plant in main production provinces in order to achieve higher sugar yield. Identified by one province means can only be grown in this province; before extending in other provinces, further testing may need to be done in those provinces.

Table 3. Part of new varieties bred in recent 20 years and their parents.

long internodes, nonlodging, nonflowering or shy flowering, erect growing habit, absence of spines on the leaf sheaths, good ratooning ability, less bud sprouting, absence of splits on the stalks, and resistance to local abiotic and biotic stress [18].

5. Best management practices of sugarcane

5.1. Fertigation and water-saving irrigation practices

The distribution and availability of soil water plays an important role in size and distribution of the root system, and also it induces differences in the capacity of crops to exploit deeper soil reserves. In general, most sugarcane roots are close to the surface and then decline exponentially with depth, which is approximately 50% of root in the top 20 cm of soil and 85% in the top 60 cm. Thus, the moisture extraction pattern from different soil layers follows the root distribution. The percentage of roots in the top 0–20 cm was 62.0%, 23.4% from 20 to 40 cm, 8.8% from 40 to 60 cm, 4.4% from 60 to 80 cm, and less than 1.4% from 80 to 120 cm. Thus, the moisture extraction pattern from different soil layers follows the root distribution.

Sugarcane requires a large amount of water at about 645-738.6 tons per year (**Figure 5**) and fertilizers at 300-330 kg/ha of N, 90-120 kg/ha of P_2O_5 and 300 kg/ha of K_2O (**Table 4**) since it is a long duration crop of 10–14 months in China and since it produces huge amounts of biomass. The water requirement of sugarcane is dependent on its growth phase, 8.3% in the seedling, 21.7% in the tillering, more than 56.9% in the elongation, and 13.0% at the maturity. In southern China, the rainfall is enough for sugarcane growth. However, unbalanced distribution of the rainfalls does not match up with the sugarcane growth stage, so sugarcane always suffers from the drought, especially in the Spring and Autumn. More than 80% of sugarcane requires irrigation in China. In recent years, water-saving irrigation practices are developing fast in China, including spray, microspray, and drip irrigations [19]. The fertigation practices coupled application of this water-saving irrigation with fertilization save a lot of water, fertilizer and labor, and improve fertilizer-use efficiency [20]. The fertilizer concentrations in fertigation practice ranged from 0.1 to 0.2% in the seedling phase and 0.2 to 0.3% in the tillering and elongation phase. No any fertilizer is applied in the maturity phase. Fertigation increased cane productivity by 19.2–56.4% and fertilizer-use efficiency by 90%. It also saved water by 30–60%. In dry upland sugarcane areas, fertigation practices are becoming popular since 2000s.

Compared with the conventional application methods, fertigation practices showed several distinct advantages (**Table 5**), including more even distribution of nutrients in the root area, decrease in the losses of nutrient and water, increase in the uptake of nutrient, less labor, and equipment required.

5.2. Healthy seed cane program

Sugarcane is vegetatively propagated for commercial cultivation. Different kinds of planting materials *viz.*, cane setts, settlings, and bud chips are used for raising sugarcane crop. Generally, two-bud setts are used for planting in China, while in some areas, three-bud setts

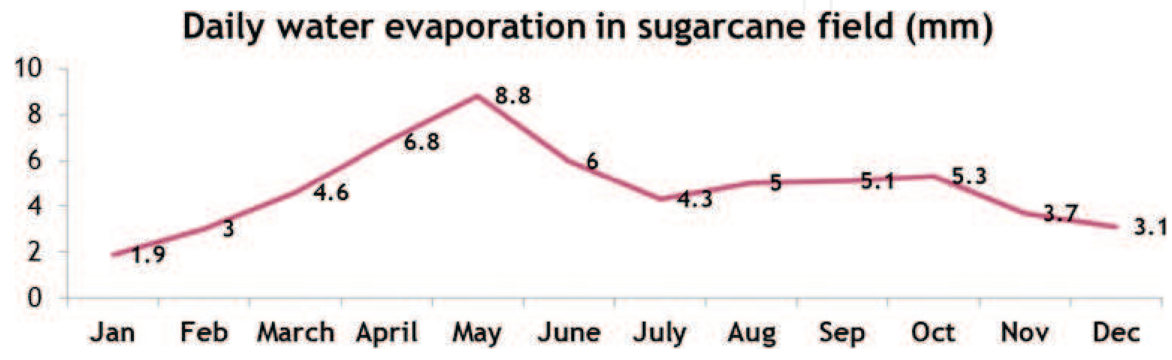

Figure 5. Daily water evaporation in sugarcane field (mm).

Growth phase (d)	Nutrition uptake (g/mu)							Yield (kg/mu)
	0–50	51–100	101–150	151–200	201–250	251–300	301–350	
N	500	765	2625	4750	3950	2250	605	13,463
P	75	201	665	1250	835	205	15	
K	265	535	2035	7265	2503	835	665	

Table 4. Nutrition uptake in different growth phases of sugarcane.

are also used. Germination capacity of single-bud sett is very poor due to loss of moisture and fungal or bacterial infection from cut ends on either side. Furthermore, the plants arising from single-bud setts also lack vigor and yield lower as compared to those from two- or three-bud setts. The ideal seed cane involved is as follows: (1) half-year seed cane, (2) fine and viable buds without damage and aerial root, (3) free pathogens and pest, and (4) pure in quality.

Traditionally, farmers in China obtain the seed cane from their harvested cane and have no any treatments before planting, which results in low plant population per unit area consequently reducing the yield. Since 2000, healthy seed cane program has been developed to protect the sugarcane from soil-borne diseases causing pathogens, which usually gain entry into the setts through the cut ends following planting and cause sett rotting and damage to buds, thus affecting germination. The healthy seed cane was produced by micropropagation, thermos- or chemotherapy.

The healthy seed cane was produced at three stages, i.e., breeder's stock, stock seed cane from micropropagation and commercial seed cane. For micropropagation, no pathogen was detected in the plantlets derived from sugarcane stem tip tissue culture, which is required for mosaic, ratooning stunt, and yellow leaf [21, 22]. Use of pathogen-free healthy seed cane improved cane productivity by 15.1–52.1% and sucrose content by 0.12–1.71% due to control of various diseases such as ratoon stunting disease, mosaic viruses, and yellow leaf disease in the seed cane. However, the application of healthy seed cane (about 2% of total sugarcane plantation) was not satisfactory with respect to the production cost, re-infection in the field, and the small-scale farms in China.

Three kinds of major disease (smut, ratooning, and grassy shoot) were transferred through seed cane, which could be eliminated by heat-treatment at 52°C for 30 min and organo-mercurial treatment to protect the setts from soil-borne diseases to ensure better germination. To control

Efficiencies	Spray	Microspray	Dip irrigation	Control
N	42.33	50.39	51.32	31.46
P	24.33	29.41	30.21	10.19
K	41.37	51.64	52.11	27.34
Water	67.44	89.24	90.01	—

Table 5. Differences of nutrition and water use efficiencies among irrigation ways.

the Pokkah Boeng disease, the setts was treated by carbendazim solution at 0.1% (at 1 g/l) for 15 min. To control termites, early shoot borers, and scale insects, the setts was treated by a systematic insecticide *viz.* malathion 50EC (at 2 ml/l) or dimethoate 30EC (at 3 ml/l) for 15 min.

5.3. Mechanization for field management

With the urbanization in China, labor is becoming scarce, and labor cost is increasing, thereby favoring mechanization for field management in sugarcane production. In the past few years, the labor cost for harvest increased from 30–50 RMB in 2008 to 130–150 RMB per tonnage. Almost 100% mechanization has been attained in soil preparation and in most field operations such as planting, fertilizer application, mulching with trash and plastic film, and weed and pest controls, but very little mechanization is practiced for sugarcane harvesting (**Table 6**).

For higher sugarcane yields, providing optimum soil environment is an essential prerequisite since the crop remains in the field for about 5–6 years due to the practice of raising several ratoon crops [23]. The ideal land should be prepared by the following steps: (i) subsoiling or chiseling to a depth of 50–75 cm, (ii) discing to shatter clods, (iii) plowing the old crop's residues and organic manures, and (iv) constructing the trench or ridge for draining excess water during rainy season. The land preparation also requires 25 cm of furrow depth and 10 cm of the loosened furrow bottom and drainage channels.

It is necessary to harvest sugarcane at a proper time i.e., peak maturity, by adopting right technique in order to realize maximum weight of the millable canes (thus sugar) produced with least possible field losses under the given growing environment. Otherwise, it will cause great losses in cane yield, sugar recovery, poor juice quality, and problems in milling. In China, more than 95% of sugarcane was manually harvested using various types of hand knives or hand axes. Among the several tools, the cutting blade is usually heavier and facilitates easier and efficient cutting of cane. Manual harvesting requires skilled laborers and large amount of labor cost.

In China, harvesting labor is becoming more scarce and costly in view of diversion of labor to other remunerative work in industry, construction, business, etc. (0.5–1 tons per day for one adult). In addition, more and more younger farmers are not interested in the field operations.

Operation	**Power requirement/ha**		**Output (ha/h)**
	kW	**Diesel (l/ha)**	
Prediscing	125	18	2.5
Ripping	165	48	0.5
Plowing	165	24	1.7
Postdiscing	125	18	2.5
Land leveling	125	7	3.5
Ridging	70	16	0.5

Table 6. Power requirement and work output for land preparation of sugarcane.

It is reported that only 5% of younger farmers born in 1990s still worked in the field. Mill stoppages are becoming more common because of nonavailability of canes, which are resulted from the shortage of harvesting labor, especially during Chinese Spring Festival. In addition, most of the new mills are of higher crushing capacity and many old mills are expanding their crushing capacities. Therefore, daily requirement of cane is increasing and hence greater demand for harvesting labor. Mechanization is inevitable and hence, adoption of mechanical harvesting of cane is also inevitable in future.

Compared to the countries, such as Australia, Brazil, USA, South Africa, and Cuba, China has less than 5% of sugarcane harvested by machine. The limitation of mechanical harvesters is use of the large mechanical harvesters in small, irregular and fragmented holdings, diversified cropping patterns, and limited resource capacity of small and marginal farmers in China. In the highly mechanical harvested countries, sugarcane is grown on large plantation scale in large farms owned by either mills or big farmers. The field capacity of mechanical cane harvesters varies with the size (2.5–4 ha per day of 8 h).

5.4. Comprehensive control of diseases, pests, and weeds

Sugarcane is a major commercial crop grown in tropical and subtropical regions of China, which is cultivated in about 1.3 million ha. During the last 100 years, the country has witnessed epidemics of various diseases like smut, pokkah boeng, red rot, wilt, and yellow leaf. The damage caused to sugarcane during each epidemic depends upon the nature of disease and spread of the susceptible varieties [24, 25]. The incidence of diseases is increasing at an alarming rate, and the yield is declining every year. About 10–15% of the national sugar produced is lost due to diseases in China [26]. Many sugarcane varieties were replaced due to their breakdown to a new disease or to a new pathogenic strain, such as mosaic, foliage disease, and yellow leaf.

Smut, pokkah boeng, and red rot remains to be the major fungal diseases of sugarcane in China, and *Phoma sorghina* var. *saccharum*, *Alternaria* sp. are the new fungal pathogens causing twisted leaves and brown leaf streak diseases in China, respectively [27–31]. Among the viral diseases, mosaic and yellow leaf syndrome are prevalent in almost all parts of the country. Bacterial diseases like ratoon stunting disease (RSD) are found to cause considerable yield loss in China, while leaf scald disease (LSD) and chlorotic streak disease are also identified to be caused by *Xanthomonas albilineans* and *Xanthomonas sacchari*, respectively [32].

Sugarcane is infested by 287 species of insect and noninsect pests. Out of them, 25 are major pests of sugarcane in China. Borers are major pests attacking sugarcane throughout the growth period, including *Tetramoera schistaceana*, *Chilo infuscatellus*, *C. venosatus,* and *Sesamia inferens*, in which *Tetramoera schistaceana* was the predominant species in China. The sugarcane borer causes the serious economic losses in China by tunneling that enters into the stalk for secondary invaders including bacterial and fungal diseases. More than 25% of sugarcane was infected in China, in some cases reaching as high as 98% of sugarcane. Severe incidences of shoot borer are noticed during water shortage and high temperatures. The other insects include white grubs, wireworms, and yellow sugarcane aphid and mites, including resistant cultivars, biological control agents, insect control and prevention, cultural practices, and pesticides. A successful integrated pest management (IPM) program helps protect the environment, which also possibly saves money for the growers.

Weeds can reduce sugarcane yields by competing for moisture, nutrients, and light during the growing season. Several weed species also serve as alternate hosts for disease and insect pests. These weed species include Coast cockspur (*Echinochloa walteri*), Goosegrass (*Eleusine indica*), Sorghum-almum (*Sorghum almum*) and *Cyperus rotundus*, etc.

Comprehensive control of diseases, pests, and weeds included resistant sugarcane varieties, pest and pathogen-free healthy seed canes, and green prevention and control practices by integrated managements of physical, chemical, cultural, and biological controls. These green prevention and control practices include as follows: (i) sterilizing seed canes; (ii) removing sources of diseases, pests, and weeds; (iii) using techniques like mechanical trapping in the field; (iv) using pheromone for control of borers, *Trichogramma* and *Cuban flies*; (v) Metarhizium to control termite; (vi) light trapping of borer, longhorn beetle, and scarab; (vii) using herbicide to control pre- and postemergent weed; and (viii) crop rotation for weed control in large scale.

Although chemical and biocontrol methods are effective individually, they are not able to give protection throughout the crop period. If a combination of these agents is available, we can expect a treatment with more efficacy and prolonged protection, such as thiophanate-methyl and carbendazim with bacterial (*Pseudomonas*) for *C. falcatum* [33]. As in other methods of disease control in sugarcane, this approach also works prophylactically. Furthermore, repeated application of the bacterial strains is needed to boost the efficacy.

A network for *Trichogramma* production has been set up in Nanning East Asia Sugar Corporation Ltd., Guangxi. All the cards of *Trichogramma* are provided to all the farmers, which resulted in the decrease of borer incidence by 30% and the increase in sucrose content by 0.5% (absolute value). The best practice program for pest and weed management is becoming a potential and cost-saving approach. Over 70 weed species have developed resistance to the triazine herbicides. These biotypes include several members of the genera *Amaranthus*, *Ambrosia*, *Chenopodium*, *Eleusine*, *Panicum*, and *Solanum*, which are commonly found in China sugarcane fields.

6. New challenges and prospects for sugar industry in China

There were about 5 million farms. The average farm size was about 0.27 ha and produced an average of 18 t cane. Most of planting, weeding, cultivation, fertilizing, spraying, and harvesting were still done by hand. Fertilizer was used excessively, especially nitrogen, at three times over the world average, while the usage efficiency was low. It resulted in soil acidification and degradation as well as in pollution. Most of the sugarcane fields were dry slopes with infertile soil. The average available irrigation was less than 20%. Rainfall distribution was uneven and seasonal natural disasters such as drought and frost happened frequently.

6.1. Mechanization

In China, sugarcane mechanization is one of the greatest challenges due to the small farm holding and the over requirement of the harvested cane. Most of the sugarcane-growing areas are lack of over 160 horse powers tractors for soil preparation. Less than 30 cm of plow results in shallow root system and weak soil water-holding capacity, which leads to suffer from drought and lodging.

6.2. Over-fertilization

Over fertilization not only increases the production cost, but also leads to low fertilizer utilization efficiency. It is reported that applications of N, P, and K are over 70, 50, and 30%, respectively, of sugarcane requirements [34].

6.3. Simplification of commercial cultivar

Cultivars (ROC10, ROC16, and ROC20) from Taiwan Sugar Co-operation were grown in more than 70% of the total sugarcane plantation area, while varieties bred in mainland China were less than 30% in the past 30 years. ROC 22 has been planting more than 50% of sugarcane growing area in China over 20 years. This variety is becoming more susceptible to smut and cold, and poor ratooning ability. Especially, after continuous cultivation of ROC22 in the same fields, the soils have accumulated considerable amounts of smut pathogens. That is why healthy seed cane application for ROC22 does not give expected good results in sugarcane production. Finally, the sugarcane ratooning is limited to 1 or 2 years in China, when compared to Brazil where the production cycle is over 5 years.

6.4. Frequent stresses on sugarcane production

Sugarcane production often suffers from the biotic and abiotic stress in China [35, 36]. For example, the frost in 1998–1999 and the drought in 2005–2006 caused serious damage to sugar production. Sugarcane smut, Pokkah Boeng, ratoon stunting, mosaic, and other diseases caused more than a 20% reduction in production. Borers and soil-borne pests (e.g., *Dorysthenes granulosus*, grub) were found in over 60% of sugarcane plantations, which caused the loss of sugar content of over 0.5%.

6.5. Prospect and solutions of Chinese industry

CY 2016 is the first year of China's governmental five-year plan (2016–2020) to boost sugar production. The plan's target is to raise annual sugar production to 15 MMT by 2020, when consumption is forecast to reach 18 MMT. The plan also implies the government's intention to gradually reduce imports. Sugar production needs to increase more than 10% annually from 2016 to 2020 in order to meet these challenging policy targets. The government has stated that it will provide subsidies and financial support to farmers to increase yields and reverse declines in sugarcane acreage. The Guangxi government has already started providing subsidies of $5625 per hectares for seeds to sugarcane farmers, farm machinery, mulching film, and fertilizer. The goal is to reach 333,300 ha of "double-high" (high in sugar content and yield) sugarcane. "Double-high" production is classified as a yield of at least 120 MT per hectare and sugar content at 14% or more by constructing the sugarcane production base for optimization of cultivars, mechanization of production, modernization of water conservancy, and operation at large scale [37]. Currently, in Guangxi province, sugarcane production is under 75 MT per hectare and sugar content is 12%. So, there is a long way and urgent issue to go for sugarcane production in China, including breeding cultivars for mechanical harvest and planting sugarcane at economical and efficient production.

To date, no complete sugarcane genome sequence has been reported, which restricts the development of functional genomics and modern breeding. Omics-based sugarcane breeding will benefit sugarcane production by shortening breeding duration and increasing selection efficiency, including transgene, genomic edit, and marker-assisted selection [38–40]. They have created much enthusiasm to identify genetic components of traits, particularly quantitative traits, in Mendelian factors, and to monitor or direct their changes during breeding through omics-based selection.

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