



Sugar Industry in China : R & D and Policy Initiatives to Meet Sugar and Biofuel Demand of Future

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ABSTRACT

The sugar industry in China is becoming increasingly important both domestically and internationally because of its rapid development. Significant progress has been achieved not only in sugar production, but also in the integrated utilization, developments such as productions of sugar-based products and cane by-products, and environment-friendly management of vinasse. Production of liquid fuel (ethanol) from sugarcane is also gaining much importance by the Chinese sugar industry. These developments are the result of the combined impact of governmental policies, management creativity and technological innovations. The innovations in both technologies and management strategies have improved the Chinese sugar industry dramatically in the past 15 years. The opportunities and new challenges for further progress of the Chinese sugar industry require further emphasis on developing creative managements and innovative technologies in the new era.

Keywords: China, sugar, sugar industry, sustainable development

INTRODUCTION

The sugar industry in China is changing rapidly to meet global challenges of dwindling productivity, increasing cost of cultivation, socio-economic drift due to WTO regulations and emerging environmental concerns. From its condition in 1980, when China adopted an affirmative policy of "Opening up", the industry has grown more than 300%, with the promise of more growth to come. At the same time, the industry faces formidable challenges as result of the country's entry into the World Trade Organization (WTO) and the changes that agreement portends for the sugar market, both domestically and internationally. In addition, the government is committed to streamline the policy positions for "sustainable development" that were designed to bring greater stability to the domestic market, greater equity in profits to the farmers and the manufacturers, and greater protection to the environment, upon which all else depends.

These issues and factors, policy initiatives, new management approaches, and technological developments, environmental issues have been discussed in this article. These will shape the destiny of Chinese sugar industry in times to come.

Recent history, current status and future directions

In the past three years, sugar consumption in China has increased at an average of 7% annually, nearly twice the 4% annual average seen over the past decade taken as a whole. It should also be noted that the domestic per capita consumption of sugar is less than 8 kg per year, which contrasts with the roughly 50 to 60 kg per year in some high sugar consumption countries. The per capita sugar consumption in China is well below the worldwide average of 22 kg per year and even significantly below the Asia average of 13 kg per year (Li, 2004a). These figures indicate that there is still room for considerable growth in the domestic Chinese market.

The sugar industry in China is mainly concentrated in the southern provinces which have sub-tropical climate aptly suited for the growth and sugar accumulation. These provinces

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are Guangxi, Yunnan, Guangong, Hainan and Fujian provinces. In fact, about 60% of all of the sugar in China originates in Guangxi (Li, 2005). In the year 2003-2004 season Guangxi produced 5.88 MT of sugar, with an average sugar recovery of 12.6%. This industry contributed 16.8 billion RMB Yuan to the Gross Domestic Product (GDP), making sugar a "Pillar Industry" of the province. In 2004-05 season, however, the total sugar production decreased to 5.32 million because of the severe drought that had not been seen in the past 50 years. Still, the sugar output in Guangxi remained 62.2% of the total cane sugar and 58.1% of the total sugar in the country. According to the recent estimation, because the rainfall conditions in most Guangxi sugarcane growing areas are much better in 2005 than in 2004, the total sugar output in Guangxi for the year 2005-06 is estimated to be around 6.0 million tons.

Progress of sugar industry: Technical indicators

The current technology and economic indices of sugar factories in China are shown in Table 1. As compared to the other advanced sugar-producing countries, China still has much potential for improvement both in field and factory especially improvement in sucrose content in sugarcane, average recovery percent cane and energy conservation and co-products utilization.

Table 1. Technical indicators of progress of Chinese sugar industry

| | |
|--|-----------|
| Sucrose % cane | 12-14.3% |
| Steam (energy) consumption per ton of cane | 40-50* |
| Boiling house recovery (%) | 89-92.6 |
| Sugar in cane recovery % total sugar | 86.6-88.5 |
| Average sugar recovery (% cane) | 11.5-12.5 |

*Author's estimate on records from some major sugar factory in China

Based on the current status of sugar industry the industry and the Government have a set the following goals for the sustainable development of industry in future.

(a) Sustainable development

Sustainable development is a term applied to industrial processes (including the sugar industry) in which the growth and operation of the industry is conducted in such manner that the production is in balance with the input of renewable resources, including energy. This thrust puts an emphasis on reducing the significant environmental impacts associated with the production of sugar in China and throughout the world. As a part of this future direction, there will be an emphasis on the environmentally sound utilization of downstream products i.e. by-products and co-products often referred as "wastes". In nut shell an "in-depth" consideration of the entire sugar production process i.e. Planting-Processing-Production cycle.

(b) Increasing quality

The sugar produced in China usually suffers from a lower

quality due to color and sulphur content and therefore does not conform to ICUMSA standards. Much emphasis is now being given to introduce better and improved processing techniques and expand capacity of mills.

(c) Decreasing cost and increasing efficiency

While significant cost reductions have been achieved in the past 15 years, there is still an opportunity for additional savings through the use of creative management and innovative technology. All of these activities will be played out against a backdrop dominated by agreements of the World Trade Organization (WTO). Over the next few years, the Chinese sugar industry will experience an influx of competition and capital from overseas. How the industry adapts to these challenges and opportunities remains to be seen.

Policy initiatives: Cane price fixation

The "Opening up" of China in the 1980s was accompanied by changes in the economic system of the country that provided for modified markets in many sectors. As a result, consumer demand more directly affected the supply of commodities, such as sugar. By the early 1990s, the government had relaxed its controls on the sugar market to such an extent that a generally "laissez-faire" (or "hands off") situation existed, ideally subject only to control of the "invisible hand" of market forces.

However, in the early 1990s, a series of dramatic swings occurred in the market as a result of oscillations between supply and demand brought on, in part, by conditions in the international sugar markets abroad and bad weather conditions at home. These sudden changes had a negative effect on everyone: farmers, producers, and consumers. In addition, it became clear that certain persistent problems were not going away and, in fact, were becoming more serious; e.g., the uncertain financial rewards for farmers and producers and the significant negative impacts that an unrestrained sugar industry could impose on the environment.

These factors combined to illustrate the need for some level of government economic policies in order to provide for an orderly sugar market in which mutually desirable ends could be reached, such as, greater equity in rewards and greater protection for the environment. To achieve these ends, the government adopted and implemented policies in a variety of areas. For example, the government declared its policy to help the farmers make a decent profit from their labors. No longer would farmers receive the equivalent of "IOUs". Instead, they would sell their crop for a reasonable price, at the time of sale. Further, action would be taken to link the economic interests of the farmers and the producers so that they would see benefit in their working together; e.g., profit sharing arrangements.

For example, sugarcane farmers now receive a set base

price for their product; e.g. 160 RMB Yuan per ton of cane vs. 2400 RMB Yuan per ton sugar or lower price, no matter what the price of sugar on the international market might be at harvest time. If, at the time of sale of the sugar produced from the purchased cane, the price exceeds the threshold level, e.g., 2400 RMB Yuan per ton of sugar, the farmer will receive a second payment of 5RMB Yuan per ton of cane for every 100 RMB Yuan per ton of sugar above the threshold, as his share of the increased profit. For example, if the final sale price of the sugar was 2600 RMB Yuan per ton, the farmer's second payment would be an additional 10 RMB per ton of cane. If the price of sugar falls below the threshold level, the mills will absorb the loss, not the farmers.

Additional steps taken by the government to achieve these policy goals include the following:

- (i) Government reduced the number of factories making artificial sweeteners and set production limits on their overall output. This action was based, in part, on health concerns that had been raised in other parts of the world. In addition, the positive economic impact on the sugar industry was also a consideration.
- (ii) A major restructuring of the Chinese sugar industry was undertaken in which generally smaller, older mills were closed and/or combined to build units of greater efficiency and profitability. As a result, the 539 mills that existed in China in the early 1990s were reduced, by 2003, to 323 belonging to 200 different companies, a condition which should lead to greater efficiency while leaving a sufficient number of players for meaningful competition.
- (iii) Government provided encouragement and incentives to update plant operations and acquire new technology.
- (iv) The foreign investors were encouraged to enter the Chinese sugar industry, bringing with them their innovative management approaches (including replacing the onerous system of "IOUs") and their updated equipment and new technology.

Achieving policy goals

Achieving the policy goals listed in the previous section will require a combination of management and technology solutions.

Creative Management

The industry in China is on a steep "learning curve" as it seeks to adapt to and adopt economic markets and market practices that have long been dominated by the West. As a result, there are significant changes taking place in long-held attitudes towards and culturally-embedded ways of doing business. The sugar industry is no exception. While substantial challenges remain, there have also been signs of significant progress. For example, it is well-known that the

sucrose % cane begins to decrease as soon as the cane is cut in the field. Therefore, there is a premium placed on processing of the cane as soon as possible following harvest. In the past, an excess of cane would be brought to the mill and would have to be stored in the "cane yard" for an average of 36 hours or more, until there was available capacity in the processors. Today, most mills are orchestrating a "managed harvest" in which cane is harvested and brought to the mill based upon variety, maturity, etc., rather than all of it being brought at one time. The result is that the cane is generally in the cane yard for less than 24 hours. However, the goal is to improve this performance even more so as to replicate the "just-in-time" inventory approaches that have been so successfully employed in other sugar-producing countries, such as Australia and Brazil.

Another example of management creativity to achieve the policy goals relates to the optimal size of a sugar mill. As noted above, there has been considerable consolidation in the sugar industry in China. Larger and more cost-effective operations have been the result. As the leading producer of sugar in the country, Guangxi Province has led the way in these efforts. Guangxi has 38 factories milling more than 4000 tons of millable cane per day, 53 factories milling 1000 to 4000 tons per day, only five factories milling less than 1000 tons per day, and the average milling ability is 3438 tons/day. Estimates have been made that suggest that the optimal size of milling ability – before the law of diminishing return really takes effect – would be about 10,000 tons/day. Therefore, there are still management gains to be made in this area.

Innovative technologies in cane production

Economically successful sugar production increasingly relies upon innovative technology in the areas of production and processing. Methods that have served people well for many years — even generations — will not survive in a market driven by high quality and low cost. We now discuss just a few of the many technological changes that are occurring in China and are being reproduced in many instances by competitors in other nations. Undoubtedly, this internationalization of an ever-changing "means of production" will increase.

New R & D methods to improve quality and quantum of raw material

(a) Drought management strategies

Drought is one of the most important abiotic stress limiting sugar productivity in China, especially in Guangxi Province because about 90% of sugarcane is grown in the upland areas where irrigation facilities are negligible. Drought occurs very often in the major sugarcane growing areas, especially in the spring and autumn, which affects cane yield and sugar productivity seriously. Based on the statistical records from the Guangxi Statistical Department, in 2002-03, the cane

productivity was as high as 79.95 tons/ha in Guangxi, and there was no significant drought in this year. In 2003/2004, however, the cane productivity decreased to 67.17 tons/ha which was 19.03% lower than the previous year because of the long spell of severe drought since early September. The severe drought in autumn also affects the normal process of sugar accumulation in cane stalks. In fact, the sugarcane in considerable parts of Guangxi, Yunnan and Hainan provinces suffered severe drought in both 2004-05 and 2005-06.

(b) Introduction of drip irrigation system in upland areas

The annual precipitation in most of the sugarcane growing areas hovers between 1,200-1,600 mm, which is enough for the normal growth of sugarcane crop. But in southern China, entire rainfall is experienced during June to August and there is practically no rains during the subsequent months. Therefore, spring and/or autumn drought are referred to the biggest limitation for sugarcane production, especially for the upland crop which occupies almost 90% of the total growing area in this country. Usually, severe drought occurs every two to three years that causes serious loss of cane yield and sucrose content (Yang and Li, 1995; Li and Yang, 1999).

Under the upland condition, drip irrigation system is considered more economic and effective than spray/ sprinkler and furrow irrigation (Li and Yang, 1999). In recent years, some sugarcane farms such as Jinguang Farm in the suburb of Nanning City, has established drip irrigation system for sugarcane production, and they have obtained very good gain from this system. Drip irrigation is now developing fast in the upland sugarcane growing areas, especially in Guangxi Province. Recent trials done in many farms have shown the techno-economic feasibility of drip irrigation in upland areas where cane tonnage up to 120-150 tons/ha, has been recorded, its indeed a very encouraging technology for the farmers and Government is seriously considering to popularize it on a larger scale. Besides, it will boost the ratoon productivity and minimize fertilizer consumption leading to a considerable reduction in the cost of sugarcane production.

(c) Efficient and specialized cane husbandry practices under drought conditions

As the investment on the irrigation system construction for upland areas is too expensive for most sugarcane farmers at present, scientific and adoptable measures such as planting of drought resistant sugarcane varieties (Li *et al.*, 1993), deep tillage and planting in furrows (Ye *et al.*, 1995), planting after rains when the soil moisture is appropriate (Li, 1997), selecting appropriate length of seed cane setts (setts with multiple buds for upland and dry weather conditions) (Li, 1997; Li and Yang, 1999; Ye *et al.*, 2001, 2002), covering with plastic film after planting and irrigation or at the time of good soil moisture (Li, 1997), trash mulching (Li, 1997), furrow blocking for water

storage design (Li, 1997), chemical regulation of sprouting and drought tolerance (Li and Yang, 1999, Li *et al.*, 2004), etc. have been recommended to increase the productivity and quality of cane. Some of these methods singly or in combination have been proven very effective and there have been many high productivity examples in the rainfed sugarcane upland areas, but adequate training to farmers and more demonstration experiments are still needed to realize the full potential of these new technologies.

(d) Sugarcane varietal improvement program

Sugarcane varieties are very important for improving sugar productivity in upland drought prone areas of Guangxi. Replacement of old and introduction of improved sugarcane varieties have played an important role in the development of Chinese sugar industry (Tan and He, 2004). However, the efficiency of sugarcane breeding is very low in conventional breeding program. In recent years, several new approaches have been studied with the purpose to improve sugarcane breeding efficiency, which are as follows:

- (i) *Breeding with distant parents*: As the distant parent *E. arundinaceus* has been used to provide *S. officinarum* with the gene of smut resistance to produce highly resistant progenies. However, *E. arundinaceus* is male sterile, and there is barrenness after two generations posterity of *E. arundinaceus*. Recently, the key problems have been solved and derivatives with *E. arundinaceus* germplasm have been obtained, which showed good prospects to create excellent clones by crossing *S. officinarum* with *E. arundinaceus* (Yang *et al.*, 2004). For further broadening the germplasm base of the breeding program, genes of high sugar content and resistance from exotic germplasm have been used. The accumulation of multiple germplasm would increase heterogeneity in the hybrids. Wild germplasm such as *S. spontaneum*, *Erianthus*, *Narenga* distribute in various locations in China. *S. runderinaceus* would be continuously accumulated in *S. officinarum*, and their posterities would be utilized to cross with *S. spontaneum* and *E. arundinaceus*.
- (ii) *Improvement through molecular biology*: Advancement in molecular biology knowledge and tools is one of the emerging possibilities for the improvement of cane varieties for specific purpose. It is believed that molecular technology would be efficient for improving sugarcane varieties in the future. It was reported that some sugarcane varieties are difficult to be identified by agronomic and morphologic characters due to isomorphism and paramorphism but they have been distinguished successfully with AFLP molecular markers (Li *et al.*, 2004). The fingerprinting maps and their dendrogram of 24 sugarcane germplasm entries preserved in Guangxi Sugarcane Research Institute have been

finished recently, and the F1 and F2 progenies of *E. arundinaceu* from distant hybridization have been identified with RAPD molecular markers (Yang *et al.*, 2004; Liao *et al.*, 2003). Molecular markers, such as RAPD, ISSR and ITS, were used to assess genetic diversity of *Erianthus* and *S. spontaneum*, to clarify the molecular classification of related *Saccharum* species and to characterize the genuine hybrid from *Saccharum* and *Erianthus* in our program (Zhang *et al.*, 2004). For testing RSD pathogen, several hundreds of sugarcane samples from different areas in Guangxi were detected by PCR method with the specific *Clavibacter xyli* Subsp. *xyli* primers, and the results indicated that almost all the varieties in the commercial production had the pathogen of *Clavibacter xyli* Subsp. *xyli* (Deng *et al.*, 2003). PCR method is also used to test the pathogen-free effect of meristem culture after heat water treatment (Wang *et al.*, 2002). Xu *et al.* (2004) reported that the genetic diversity and differentiation of sugarcane smut fungus *Ustilago scitaminea* Syd. detected by random amplified polymorphic DNA or RAPD were associated in some degree with geographical origin, but not suitable to all isolates, and not related to the host origin. Pan *et al.* (2001) detected nematode-resistant gene in chewing cane varieties by PCR-Southern blotting, and found that 6 chewing cane cultivars had a sequence between 460bp special fragment and nematode resistant gene in sweet potato and there was a great homogeneous sequence between 690bp special fragment and nematode resistant gene in sweet potato, but no sequence of root-knot nematode resistant gene was found in Badila.

Genetic transformation technology

It is used as a supplemental tool of sugarcane breeding. Clones of transformation plants with *S. spontaneum*, *E. arundinaceus* and bar gene have been cultured through gene gun and *Agrobacterium* mediated genetic transformation (Li *et al.*, 2000). Some of the major breakthrough in this field are:

- Genetic transformation of sugarcane *Saccharum officinarum* mediated by *Agrobacterium tumefaciens* was reported successful (Wang, Z.Z. *et al.*, 2002).
- It was reported that trehalose synthase gene transfer mediated by *Agrobacterium tumefaciens* enhanced resistance to osmotic stress in sugarcane plants (Wang, Z.Z. *et al.*, 2005).
- Isolation, sequencing, cloning and expression the ACC oxidase and ACC synthetase in sugarcane has been done successfully (Wang, Z.Z. *et al.*, 2003; Wang A.Q. *et al.*, 2004, 2005a, 2005b, 2006).
- Cloning and expression of gene encoded betaine aldehyde dehydrogenase in *Erianthus arundinaceus* were

reported by Yu *et al.* (2004).

- Transgenic sugarcane plants with ScMV-CP gene were obtained by Yao *et al.* (2004).

These studies indicated that gene cloning and genetic transformation technologies will play important roles in sugarcane variety improvement in the imminent future.

Healthy seed-cane production

Healthy seed cane propagation system establishment. The trial results indicated that production with pathogen-free seed canes increased cane improve yield significantly by 30%-68.7% higher for chewing cane (Pan *et al.*, 2001, Wang, L.W. *et al.*, 2002; Ye *et al.*, 2003), and 38.5%-48.3% higher for the millable cane variety GT11 (You *et al.*, 2005) as compared with the conventional seed canes. The investigations showed that the incidence of sugarcane mosaic virus disease was zero in virus-free healthy seed cane treatment. The Yield, Fv/Fm and Fv/F0 of PS II in virus-free healthy seed cane treatment were all lower than those in the conventional seed cane treatment. The mean leaf angle, penetration coefficient, radiation penetration coefficient, extinction coefficient and leaf distribution of the colony canopy in virus-free healthy seed-cane treatment at elongating stage were better than those in the conventional seed cane treatment, which suggested a more rational canopy architecture was formed by the plant population from virus-free seed-canes (Wu *et al.*, 2005). Therefore, the virus-free seed cane propagation system of would be important for sugarcane production.

For propagating virus-free seed cane, the cane setts are treated in 52 hot water for 30 minutes, and planted in a nursery for propagation, and the harvested cane will be used as the seed cane of commercial sugarcane production. If the virus-free seed cane is produced by tissue culture schedule, the meristem treated with hot water could get rid of the pathogen perfectly. The cane of the second generation of the tissue-cultured plants from field nursery will be used for commercial production (Huang *et al.*, 2005; Wang, L.W. *et al.*, 2002, 2005).

Judicious utilization of distillery waste to conserve moisture conservation and increase cane yield

Alcohol is one of the major by-products of distilleries, and more than 8 million tons of vinasse (liquid waste also known as spent wash /vinasse or dunder) is produced during alcohol production from all the sugarcane mills in China. The disposal of effluent on land results in obnoxious condition of the region and is a serious threat to flora, fauna and groundwater resources of the neighboring environment. If soil is porous, the effluent may also affect ground water quality and cause human health associated problems. Thus, the discharge of untreated vinasse into ponds and rivers make the environment unsafe for aquatic life. The traditional disposal method of this toxic waste is to store it in the ponds for natural oxidation or

lagooning, which takes a long time and big open spaces, this process of natural treatment leads to severe environmental pollution as well as pollute water reservoirs and rivers. Studies carried out by the Soil and Fertilizer Research Institute, Guangxi Academy of Agricultural Sciences, vinasse from China sugar distilleries contains 0.645% total nitrogen, 0.017% total phosphorus, 1.088% total potassium and 8.391% organic matter with pH 4-5, COD 10-13x10⁴mg/L and BOD 5.7-6.7x10⁴mg/L. The best strategy for utilization of this effluent is its agri-recycling and this precious nutrient rich liquid should not be wasted under any circumstances.

Previous experiments conducted in China and other places have shown that direct application of vinasse in sugarcane fields increased cane yield by 3%-37%, and sucrose % cane by 0.3% - 1.0% (absolute value) as compared with the traditional fertilization (Bashkar *et al.*, 2004; Jin, 2000; Li *et al.*, 2004; Tang *et al.*, 2004) in up land areas. It has been very successful to apply vinasse in large scale of sugarcane plantation (mostly in ratoon crop) in Brazil (Lee, 2004; Leme and Orlando, 2005). Agri-recycling of vinasse especially in the cane plantation not only saves chemical fertilizers and increases sugar productivity, but also improves soil fertility and minimizes environmental pollution. At the same time, negative and adverse effects of vinasse application were also reported from some places in China. This was primarily due to flood irrigation of cane fields using vinasse, which probably interfered with normal plant-soil oxygen exchange. Professor TSG Lee speaking in a seminar at the Guangxi Academy of Agricultural Sciences in October 1998 pointed out that rate of application is very important to ensure the success for direct application of vinasse in sugarcane fields. However, successful large scale experiments were carried out in Shang Si County, Guangxi, China (Li *et al.*, 2004). The vinasse was applied to the cane fields by mobile pipe irrigation connected to a tank transported by truck. The application area reached about 2,000 hectares in 2005, increase in cane yield ranged between 23.4%-36.2%, and cane quality was also improved.

Based on the various experiments carried out in China and elsewhere in the world, Guangxi Academy of Agricultural Sciences has developed a novel technology for direct application of vinasse in sugarcane fields. This technology combines direct application of rational amount of diluted vinasse in the cane fields followed by the covering of setts with a plastic film to ensure proper sprouting and early growth. The experiment conducted at six different agro-ecological zones of Guangxi province showed that this method showed improvement in tillering, elongating and sugar productivity, however the response varied with the rate of vinasse application. Application of vinasse at 45t/ha, 75t/ha and 105t/ha improved cane yield as compared to non-fertilizer control by 13.24%, 17.55% and 14.92%, respectively. As compared to conventional fertilization control it was 7.66%, 11.75% and 9.25% higher. Sucrose % cane showed 0.06%, 0.25% and 0.23%

improvement than that of non-fertilization control and 0.11%, 0.30% and 0.28% increase over conventional fertilization. As vinasse has excellent nutritional qualities and is a very good complete organic fertilizer for sugarcane. It produces significant increases in cane tonnage and sucrose % cane and the benefit-cost analysis favours its large scale of application. Recent studies have shown that the application of 75 t/ha vinasse showed the best economic benefit. The direct rational application of fresh vinasse in sugarcane fields is practically possible through a set of technical measures.

Emphasis on biological nitrogen fixation in sugarcane

Nitrogen is a key nutritional element for sugarcane growth, and very high levels of nitrogen fertilizer are used in commercial sugarcane production in countries such as Mexico, Venezuela, India and China (>200 kg/ha). Whereas, nitrogen fertilizer application is not more than 50kg per hectare for sugarcane production in Brazil (Reis *et al.*, 1994) despite neither cane yield nor soil N reserves seem to diminish after decades of continuous cane planting. The nitrogen level applied in Brazil is only as high as about 10 percent of that in Guangxi, but the cane yield is higher in Brazil. The experiments carried out in Guangxi (Wang L.W. *et al.*, 2002; Liang, 2004) have produced similar result to that done in Brazil. Many reports from Brazil indicate that the contribution of biological nitrogen fixation to sugarcane cultivars ranged from 50 to 80% of the total nitrogen required by the cane plant (Boddey *et al.*, 1991). Since the agricultural sustainable progress was proposed, much attention has been paid to the biological nitrogen fixation. Many nitrogen fixing bacteria have been found to be associated with sugarcane, such as *Azospirillum*, *Azotobacter*, *Bacillus*, *Derxia*, *Enterobacter*, *Erwinia*, *Herbaspirillum seropedicae* and *Acetobacter diazotrophicus*.

Recently, several endophytic nitrogen-fixing bacteria with high nitrogenase activity were isolated from different sugarcane varieties grown in Guangxi, China. They were identified on the base of phenotypic, physiological, biochemical characteristics and 16S rRNA gene sequences, and position of phylogenetic development and the biological traits of these bacteria were studied (Xing, 2006). It showed that the strain B9LA could be classified as a member of *Sphingomonas* sp. The complete 16S rDNA of the strain B9LA was 1339 bp in length and a phylogenetic tree was constructed by the 16S sequences homology. The strain B16SA belonged to *Ochrobactrum* sp. and the complement sequence in length was 4100bp; the strain B16SH was identified as *Microbacterium* sp, and the complement sequence in length was 1346bp; the strain B8I belonged to *Achromobacter xylosoxidans*, the strains B8R, 25R, B11S and B17SH belonged to *Stenotrophomonas maltophilia*; and the strains B8S and B8LH belonged to *Agrobacterium tumefaciens*, and their 16S RNA sequence in length were 1403b and 1339bp,

respectively. The accession numbers of these bacteria in GenBank were DQ466571, DQ466569, DQ466572, DQ466568, Q466570, DQ466574, DQ141193, AY850392 and DQ466575, respectively. The complete information of the train B8S has already been published (Xiang *et al.*, 2006).

This is very encouraging and it is believed the biological nitrogen fixation will play an important role in the commercial sugarcane production in the near future.

Chemical ripening to improve cane quality

Sugar productivity in major cane growing areas of China hovers between 7 to 8 tons/ha/years, which is low as compared to other progressive cane growing countries. Extensive efforts are being made to improve sucrose content in cane varieties. Economic feasibility of non-conventional technologies such as “chemical ripening” is also being explored in commercial sugarcane plantation, especially during early season.

The global progress and recent development in China Chemical ripening of sugarcane were reviewed by Solomon and Li (2004). In China, Lin *et al.* (1990) conducted during early October 1989 proved that the foliar spray of 400 mg/L ethephon could significantly increase sucrose content in cane and improved the juice quality of three sugarcane varieties one month after the treatment. The cane yield was also increased when the crop was harvested in next February. In several experiments, the 300 mg/L glyphosate treatment also produced good ripening result (Wu, Wen, Ye, 1987; Pang, 1987; Lin *et al.*, 1990; Liao *et al.*, 1997). Ethephon was highly effective in promoting sugar accumulation and increasing sucrose content in the immature internodes but not in the mature internodes of sugarcane (Yao *et al.*, 2000; Li and Solomon, 2003, 2005; Li, 2004b).

Li *et al.* (2000) developed a chemical mixture consist of 300 mg/L glyphosate+400 mg/L boric acid, and was named sucrose-cane promoter. After confirming its good effect in speeding up the ripening and increasing sucrose % cane, cane quality cane yield and growth of next ratoon crop (Li *et al.*, 1992, 1993, 2000; Liao *et al.*, 1997), the sucrose-cane promoter was popularized in large scale of sugarcane plantations in Guangxi Province (Li, 1994c), and the total application area reached 20,000 ha., and very good results were obtained. However, the extension was limited by the difficulty of spraying based on hand operation.

Most recent studies were conducted in Shangsi County, China during 2003-2004 season (Li *et al.*, 2004) to advance cane maturity and improve sucrose content during early milling phase. The above mentioned ripener complex (300 mg/L glyphosate+400 mg/L boric acid) was sprayed by airplane over 2000 hectares of sugarcane during 4th week of October, 2003 on cane varieties ROC10, ROC16 and ROC22. The increase in sucrose % cane in these varieties sprayed with glyphosate-borate showed average increase to the extent of

1.18%, 1.30% and 0.78%, respectively, in 30, 45 and 60 days as compared to untreated control. The purity of juice was also increased indicating that the artificial ripening using the above ripener complex was very effective and profitable for sugarcane crop of this area. Sugarcane grown near irrigated paddy fields showed better results 40 days after ripener's treatment. The highest value of sucrose in cane i.e. 19.83% following ripeners treatment was recorded in this experiment which is never observed in general commercial sugarcane fields in Guangxi area. The artificial ripening using small airplane which was convenient and economical was recommended for commercial sugarcane plantation of Guangxi areas as the milling generally commences in early November (sometimes in late October) when the sucrose content in cane is rather low and recoveries are poor. This combination ripener treatment was also effective under drought conditions. In 2005, chemical ripening of sugarcane was again experimented in 1000 hectares in Shangsi County operated by truck tank with high pressure injector, and good results were obtained (unpublished data). It is concluded that application of appropriate chemical ripener would improve the sugar productivity from sugarcane. Studies are now underway to develop chemical formulation (s) which could be applied as granules to advance cane maturity and improve sucrose content in sugarcane.

Besides, biological pest control is strongly recommended for safe and non chemical pollutant sugarcane production.

Efficient planting and harvesting methods

As described above, innovations are underway to a) reduce the time for millable cane transportation to the mills after the cane being cut and, b) encourage farmers to adopt more productive varieties of cane.

China has a long history of agriculture being conducted on small plots of land, often times in remote areas, marked by limited accessibility. As a result, much of the sugar crop in China is not amenable to current labor-saving machine harvesting. At the present time, China's population structure can support the labor-intensive hand harvesting that is performed in many areas. There are some advantages to the hand-harvest approach, including a cleaner and more properly-trimmed product. However, as the population structure changes, as farmers enjoy increased rewards from their labor, and as technology seeks new ways to harvest sugarcane on even smaller plots, the situation is likely to change.

The cane payment system goes to the core of the way in which farmers are compensated for their product. In the past, the price was determined by a simple measurement of the mass (i.e., total weight) of the crop, thereby providing an incentive for the farmer to produce “heavy” cane. In fact, it is the sucrose content that is the more important, more desirable measure of crop “worth”. A few plants now adopt the quick near infrared (NIR) measurement of sucrose content to purchase the cane (Lu *et al.*, 2004).

Pretreatment and Juice extraction

New techniques are being used to shred the cane prior to the extraction process. In some cases, shredding percentages in the neighborhood of 90% have been achieved.

In China, milling trains are the most common method to extract juice from the sugar cane. Recent technological improvements in some milling factories include installation of forced-feed rollers, six-rollers mill, highly-efficient lotus rollers, and automation systems to monitor and control many aspects of the milling train, such as feed rate, torque and lubrication (Lu *et al.*, 2004).

Decoloration and Clarification Techniques

In contrast to much of the rest of the world, China has committed to sulphitation as its decoloration technology in the production of cane sugar. While 320 sugarcane mills use sulphitation, only 10 use carbonation (All 30-40 of China's beet sugar factories use the carbonation method.) Most cane mills employ a double sulphitation approach, in which both the raw juice and the condensed syrup are treated.

The major advantages of sulphitation in China are the low capital costs, the easy scaling up to large capacities, and that the filter mud (residue from treatment) can be directly applied to farm fields as fertilizer without significant deleterious effects on the soil, in contrast to that from carbonation. The major disadvantages are that sulphitation resulted in less optimal decoloration and purification as compared to carbonation, thereby leaving impurities that can lead to additional colored products as time goes by.

These disadvantages are being addressed through process and technology changes. For example, attempts are being made throughout the process to prevent precursors and colored products from entering or being produced in the material by adjusting pH and adding various adsorbents, flocculants, and chemical assistants in order to obtain a syrup of higher quality. Another goal is to eliminate the need for the second sulphitation (of the syrup) step in the process and replace it with a syrup floatation technology. An even more basic technological change seeks to replace the double sulphitation approach with one based on membrane filtration. In order to pursue this avenue, research is being conducted to produce cheaper, longer-lasting membranes (Lu *et al.*, 2004).

Environmental Protection and socio-economic concerns

In its rapid economic growth phase, China has been slower to respond to the environmental impacts of development than some observers might consider to be desirable. Therefore, increasing attention is being focused on how creative management and innovative technology can address problems in this important area.

Water recycling and conservation in sugar factory

Sugar production is a water-intensive process. At present, on average, 20-30 tons of water are needed in order to process one ton of sugar in China. In the developed countries, processes have been developed to recycle the water so that the same water is used two or more times before being treated and released back into the environment. In China, much of the water is used only once before it is discharged as wastewater, too often with a resulting negative impact on the receiving streams. Although there is some progress being made in this area, there is much to be done to develop and implement a pollution prevention ethic of "reduce, reuse, and recycle" (Wei *et al.*, 2004).

Treatment of wastewater and vinasse

The large volumes and significant contaminant content of effluent from sugar mills and from the often-associated molasses-based alcohol distilleries pose a significant challenge to the Chinese sugar industry. The long-used lagoon, store-and-release treatments are being replaced by more effective and "in-depth" approaches that result in recoverable, marketable, downstream products. For example, land application of wastewater — both with and without added nutrients — has been an effective strategy for making profitable use of something that was once simply discarded. In a related approach to enriching the land, vinasse (the effluent from distilleries) has been used directly or with additional nutrients — as a compost fertilizer for future crops. In an alternative approach, anaerobic digestion of vinasse has been used to generate methane to help fuel the operation of the plant, while leaving a residue that is amenable to land application. More directly, the vinasse can be concentrated and fed directly into boilers as an energy source for the plant (Wei *et al.*, 2004).

Centralization of distilleries

Studies suggest that a significant management step could be made by consolidating some of the smaller distilleries attached to some of the sugar plants. By taking the molasses to larger, centralized facilities, producers could take advantage of economies of scale to generate a higher quality product, at a lower overall cost, and a reduced net negative impact on the environment (Wei *et al.*, 2004).

Development and implementation of technical indicators for cleaner production in the cane sugar industry

Researchers have investigated science-based management tools that can be used to signify the level of performance of a sugar factory in six different areas:

a. Utilization of resources and energy

Indicators for this aspect of the industry include resources and energy used in the production of the cane itself,

the manufacture of the sugar, and the treatment of the waste.

b. Product quality

Indicators in this category signal adherence to sanitary standards for the product, and also its adherence to standards for environmental controls in packaging, and downstream uses

c. Pollutant generation

For this aspect, conventional indicators were chosen, such as wastewater volume, chemical oxidation demand (COD), and suspended particulates (SP) per mass of product.

d. Process and equipment features

Indicators for this aspect are related to a particular plant's adoption of key technological developments in areas such as automation control, water saving, energy saving, and pollution prevention/reduction techniques.

e. Waste reclamation

Here, indicators convey an overall picture of a plant's disposition of all of the various plant wastes, from filter mud to slag.

f. Environmental management

For this area, indicators address four aspects:

1) applicable laws/regulations of the environment, 2) environmental audit procedures, 3) environmental controls in place, and 4) overall environmental management procedures.

A given factory's indicators can then be compared against indicators from a) the international sugar industry, b) the exemplary facilities in the domestic market, and c) average facilities in the domestic market. Such comparisons can provide managers and the government with an objective measure of the conditions at the factory (Zhong *et al.*, 2004).

Green chemistry approach to sugar production: Recycling of agro-industrial residues of sugar industry

The Governments, especially the local governments of the cane growing areas, have encouraged the sugar industry to develop so-called "Green Chemistry" (a.k.a. "environmentally friendly") approaches. As a result, sugar productions and businesses in China are giving special attention to new ways to utilize the by-products from the sugar mill and to get the highest value from the cane resource, by developing new products and sucrose-based in-depth (value-added) processing to enhance competitiveness and to support sustainable development in the industry.

For example, in addition to the traditional use of bagasse as a fuel for generation of plant energy, in some cases the energy is used to generate electricity that is then sold to the national electrical grid for use throughout the country. In

addition, a substantial business has arisen from the use of bagasse in the manufacture of paper. In fact, in some parts of China, the majority of newsprint and tissue paper originated as sugar cane. Other downstream uses of bagasse include particle board, degradable dishware, and cellular package material (Wei *et al.*, 2004).

While most of the molasses (about 90%) from the sugar industry has traditionally been used for the manufacture of alcohol, alternative value-added products are emerging from the laboratory and entering the marketplace. These include production of single cell proteins (SCP) and yeast products, as well as animal feed (Wei and Xu, 2004).

As noted above, in recent years the filter mud from the sulphitation process has been combined with organic matter and phosphates to manufacture a very marketable organic complex fertilizer (Wei and Xu, 2004).

At the output end of the sugar product stream, technology is leading to innovative value-added products. For example, esters of sucrose are well-known, environmentally friendly (i.e., biodegradable) surfactants with a wide range of uses. Techniques are being developed to improve the production efficiency and purity of these esters. Some of these techniques involve biotechnology approaches (e.g., enzyme synthesis methods) that overcome many of the problems posed by chemical approaches (Wei *et al.*, 2004).

Another new use of sucrose involves its hydrolysis to form fructose and glucose, which are then hydrogenated to generate mannitol and sorbitol. These products are now produced at a rate 10,000 tons/year at a single plant. Other sucrose-based products include fructo-oligosaccharides (FOS) which are used as functional sweeteners in health foods and which utilize innovative technologies, such as immobilized enzymes, in their manufacture. Finally, a novel sucrose-based polymer has been synthesized that shows promise as a non-toxic, biodegradable material that could be useful in fruit and vegetable modified-atmosphere storage and in plant growth regulation (Wei and Xu, 2004).

All of these developments illustrate the future potential that awaits the further exploration and exploitation of "sucrochemistry".

Biofuels from sugar cane

The energy consumption in China is increasing at a faster rate due to the rapid economic growth. In 2004, the economic growth increased by 9.5% but the energy increased by 15.1% over the previous year. Now the energy consumption has reached 13.6% of the total energy consumption in the world. China has become a net petroleum importing country. In 2004, its total petroleum consumption and imported petroleum listed No.2 in the world, just behind the USA, and its import dependence reached 35. In 2004, China imported 123 million

tons of crude oil and 37.88 million tons of refined oil, which spent foreign currency of USD \$54.2 billion based on the price of USD \$60/barrel. If the international oil price increases USD\$1.00/barrel, China will spend RMB4600 million yuan (USA\$567.2 million) more for importing petroleum each year. By the year of 2020, the energy consumption in China will reach 3100 million tons of standard coal which covers 13.2% of the total energy consumption in the world. If the yearly average GDP growth keeps at 7% or higher, the energy consumption will have to increase about 4% each year. It is imperative that new and renewable energy sources should be explored to meet the growing demand of fuel and in this respect use of bio-fuels have made significant. In addition to this, China energy program also includes bio-energy, nuclear energy, solar energy, sea energy, hydrogen energy, etc (Wang, 2005).

Bio-fuels are renewable liquid fuels coming from biological materials (sugar crops, grains, cellulosic residues) and have been proven to be good substitutes or blend for oil in the energy sector. These biofuels such as bio-ethanol or bio-diesel are gaining worldwide acceptance as solution to many emerging problems such as:

- Energy security
- Environmental pollution
- Reducing dependence on crude saving of foreign exchange
- Rural employment and agricultural economy
- Utilization of waste or unproductive lands
- Providing new and economic outlet of sugar crops and substantiation of farmers economy by way of better price for sugar crops

Sugarcane is a highly productive crop and its productivity could reach 448-538 t/ha. In the commercial production record, the productivity of sugarcane reached 250.5 t/ha in Hawaii and Australia (1967), 322.3 t/ha (1974) and 366t/ha (1975) in Hainan, China, respectively (Editor Group for *Sugarcane Cultivation in Guangxi*, 1991).

Comparison of ethanol yield for different crops

Sugarcane has significant advantage for ethanol production because of its highest biomass productivity and ethanol yield and commercial profitability, which has been proven by China, India, Hawaii, Australia and especially Brazil (Li *et al.*, 2003; Rao, 1997).

Sugarcane based bio-fuel program in China: Initiatives & Incentives

- ❖ The bio-energy program started in 2000.
- ❖ On 2 April 2001, the national standards for denatured ethanol and gasoline with ethanol for automobile were published.

Table 2. Yearly ethanol yield per hectare for several crops

| Crop | Productivity (ton/ha/year) | Ethanol yield per ton harvested crop | Annual yield of ethanol per hectare |
|--------------|----------------------------|--------------------------------------|-------------------------------------|
| Sugarcane | 40-120 | 70 | 2800-8400 |
| Cassava | 10-40 | 180 | 1800-7200 |
| Sweet potato | 10-40 | 125 | 1250-5000 |
| Sugar beet | 10-40 | 120 | 1200-4800 |
| Sorgo | 20-60 | 55 | 1100-3300 |
| Corn | 1-4 | 400 | 400-1600 |

- ❖ Experiments on automobile gasoline with ethanol were conducted since June 2002, and they were very successful.
- ❖ Government stopped selling of common 90# and 93# gasoline but promoted sale of E90# and E93# gasoline instead, in Jinlin Province since 21 August 2003.
- ❖ On 10 February 2004, the State Committee for Development and Reformation decided to extend the E-gasoline experiments to Liaoning, Hebei, Shandong and Jiangsu Provinces.
- ❖ On April 2001, A production line for 200,000 t/year of denatured fuel ethanol at Henan Tianguan Group Ltd. began to work. The line was enlarged to 300,000 t/y in November 2002.
- ❖ At the end of year 2003, a production line for 300,000 t/year of fuel ethanol began to operate in Jilin Fuel Ethanol Company Ltd.
- ❖ At the end of 2003, one more production line for 320,000 t/y was established on the basis of two lines for 60,000 t/year of fuel ethanol in Anhui Fengyuan Fuel Ethanol Company Ltd.

Sugarcane based energy program: R& D scenario Chinese Government is supporting the commercial trials for bio-energy production with sugarcane and cassava, including breeding of the energy crop varieties and the processing technology for ethanol production.

- (a) **Breeding of energy cane varieties:** Two sugarcane varieties, FN91-4710 and FN94-0403, were released by the Sugarcane Research Institute of Fujian Agriculture and Forestry University in 2003 for both sugar and energy, which have the productivity 128.3 and 129.5 tons of cane per hectare for plant and ratoon crops, and they contain 46.18 and 46.69 tons of total fermentable sugar, respectively.

A sugarcane variety, GT22, was released by Guangxi Sugarcane Research Institute in 2005 for bi-purposes of sugar and energy, which showed the average productivity of 121 tons of millable cane per hectare.

- (b) Trial on ethanol production from sugarcane: In recent years, China produced about 85 million tons of millable cane which resulted in more than 500,000 tons of potable

ethanol with the byproduct molasses, but ethanol production with pure cane juice is still in commercial trial. A production line for 100,000 t/y of ethanol production with cane juice was supported by the State Government in 2002, and established in Suixi Super Quality Ethanol Company, Guangdong Province.

Futuristic research on cane based bio-fuels

- (i) **Area for cane energy cropping:** China is the third biggest sugar producer in the world, and more than 90% of total sugar is from sugarcane. Besides, there are more than 2.5 million hectares of other land found suitable for sugarcane production in 9 provinces of southern China, and sugarcane production is highly competitive. The productivity is rather high for energy cane which could reach 280 t/ha/year. The ethanol production with sugarcane is profitable because of its low processing cost and high additive value of the byproducts.
- (ii) **Innovation of energy cane varieties:** High biomass and high fermentable sugar producing cane varieties. As compared with sugar cane, the sucrose % cane could be lower, 13% to 14% would be good enough for energy cane, but it requests higher cane tonnage and better adoptability, ratoon ability and resistances. The plant type should be good for machine harvest and easily managed. Besides, conventional hybrid breeding, new local wild germplasm should be used to produce new parents and materials. Molecular genetic technique assistant breeding might be necessary for improving the breeding efficiency.
- (ii) **Processing technology for energy cane:** Brazil is the most advanced in mastering the commercial processing technology for ethanol production from sugarcane (Chen, 2003). The sugar fermentation efficiency could be improved by transformation of the yeast through biotechnology and gene engineering, raising the suitable temperature for the yeast and increasing the maximum ethanol concentration for fermentation. If the fiber in bagasse can be hydrolyzed effectively by enzymes such as cellulase, the ethanol production efficiency will be increased significantly. The Government and research institutions are focusing on the following technology to

augment biofuel productivity:

- ❖ Exploitation of marginal/sub-marginal land to produce cane or cellulosic biomass round the year for the production of ethanol. It is visualized to produce high biomass or fermentable sugars/unit area/unit time to increase bioethanol productivity. It is feasible to integrate artificial ripening technology to advance maturity *vis a vis* increase sugar content in cane for high ethanol productivity (Solomon and Li, 2006).
- ❖ Improvement in fermentation and distillation efficiency.
- ❖ Microbial or chemical saccharification of cellulosic biomass and its subsequent fermentation (SSF) to ethanol will give boost to bio fuel program.
- ❖ Introduction of "Oil crops" as inter crop in sugarcane and *Jatropha* to produce biodiesel in problematic areas such as water deficit conditions, saline/alkaline soils, etc.

The Biofuel program based on sugar crops is a new and burning topic for Chinese scientists and engineers. There are many challenges in breeding, agronomy and industrial development (Zhang and Chen, 2002). Research must be advance and should be strongly supported by the government. A co-operative movement where farmers participation to supply raw material for biofuel production to refining-cum-processing unit will be more successful for the developing countries, such as China (Solomon and Li, 2006). Beside, a pragmatic Government policy to protect farmers and processing industry, quality control standard, sale and purchase of raw material, price, tax, export policy and other laws should be streamlined to boost this important sector of economy.

CONCLUSION

The sugar industry in China is heading for a big change and has a very bright future as it is transforming itself from sugar to agro-industrial complexes. The opportunities that are coming as a result of creative management and innovative technology are coming at a time when new challenges are emerging on the rapid changing international scene. There is a large untapped potential for Chinese sugar industry and therefore, the industry will have to work hard to compete with the global industry. The prospects to produce biofuels from sugarcane are bright and better.

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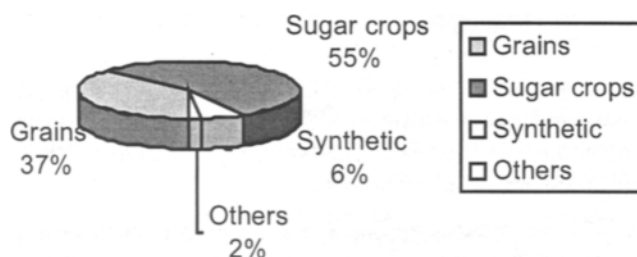


Fig. 1. World ethanol production by feed stock (year 2001)

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