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REVIEW ARTICLE

Research and Development Priorities for Sugar Industry of China: Recent Research Highlights

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Abstract The major purpose of sugarcane production is for sugar in China. The major limits for sugar productivity include abiotic and biotic factors. Drought is the most important abiotic limit while smut and borer are the most important biotic constraints. In practice, high nitrogen fertilizer input causes high production cost and agricultural environment pollution, which also has been paid high attention to research and development priorities for sugar industry of China include breeding highly productive, high sugar, strongly resistant and nitrogen efficient sugarcane cultivars by conventional and biotechnological approaches, developing low cost and efficient cultivation technologies for sugarcane production, crossing parents innovation by utilizing wild germplasm. Whole sugarcane genome sequencing, proteome analysis and biological nitrogen fixation research are also under way.

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Introduction

Sugarcane contributes 90 % or more to the total sugar output in China. Sugarcane is primarily grown in the subtropical areas mainly in Guangxi, Yunnan, Guangdong, and Hainan provinces. Guangxi is the dominant sugar producer in China, and it produced 7.95 million tons of sugar in 2012/2013 milling year, which occupied 66.05 % of the cane sugar output and 60.57 % of the total sugar in the country. However, the sugarcane productivity is usually lower than 70 t/ha in normal conditions. That is because 90 % of sugarcane in Guangxi is grown in rain-fed upland fields, and easily affected by drought. Another challenge for Chinese sugar industry is rapid cost increase for sugarcane production because of the fast increase in labor payment and fertilizers and chemical. The third is the dominance of a single sugarcane variety. At present, ROC22 occupied 68 % of the total sugarcane growing area, and even more than 95 % in certain areas. The breeding and propagation of new sugarcane varieties are inefficient. In commercial sugarcane production, the nitrogen application rate reaches 600–800 kg/ha, which is about five to six times as high as that in Brazil. The high nitrogen application rate not only makes high production cost, but also reduces sugar content in cane, and even pollutes environments (Li 2010). Based on the major existing problems, we have set up the research and development priorities for sugar industry of China.

Sugarcane Germplasm Innovation

Wild germplasm such as *Saccharum spontaneum* , *Erianthus*, *Narenga* naturally exist in various locations of China. To enrich the genetic variation of the crossing sugarcane parents, we have tried for many years to incorporate wild germplasm such as *S. spontaneum* L, *Erianthus arundinaceus* (Retz.) Jesws. and *Narenga porphyrocoma* (Hance) Bor. into the commercial breeding parents for sugarcane improvement. A hybrid of *Erianthus arundinacius* (Retz.) Jesws. × *Saccharum spontaneum* L., GXAS07-6-1, was obtained. This AC complex was used as a male parent to cross and backcross with *Saccharum* hybrids, and the posterities of GXASF1 and GXASBC1 were obtained. After identification of the real genetic background with SSR, SRAP (Liu et al. 2012; Gao et al. 2013) and in situ hybridization, the posterities are further used for parent innovation, especially for improvement of smut resistance and drought tolerance. We are also using sugarcane × *Narenga porphyrocoma* (Hance) for germplasm innovation (Liu et al. 2012).

Germplasm exchanges with different countries are also our priority. We hope to improve the genetic variation of sugarcane crossing parents through utilizing the germplasm from different countries.

The accumulation of multiple germplasm would increase heterogeneous in the hybrids.

Sugarcane Breeding and New Variety Propagation

Producing high productivity, high sugar, strongly resistant and nitrogen efficient sugarcane cultivars is one of our major priority in our sugarcane breeding program. Based on the biological nitrogen fixation characteristic, we select the parents with high nitrogen fixation potential to make combinations with other parents with high sugar and high productivity, and strong resistance (to drought, cold or disease, etc.). The hybrid offspring selection is being conducted under low nitrogen pressure in upland field. Ratoon ability is also one of the important aims for sugarcane improvement in China.

We are also working on establishing an efficient new sugarcane propagation system through operating by variety breeding institutions, enterprises and farmers in the propagation bases, studying on new technologies to increase propagation coefficients and to ensure the health of seedcane for commercial production, and new management mechanisms, and finally to form a standardized efficient new sugarcane propagation system so to accelerate the velocity of new sugarcane variety extension.

Development of Low Cost Drought Resistant Cultivation Technologies

Drought is the most important limitation for sugarcane productivity in China because about 90 % of sugarcane is grown in the upland areas where irrigation is not available. Drought occurs very often in the major sugarcane growing areas, especially in the spring and autumn, which affected cane yield seriously. The severe drought in autumn also affects the normal process of sugar accumulation in cane stalks. As the investment for irrigation system construction is too expensive for most sugarcane farmers at present, so comprehensive measures including selecting and applying drought resistant sugarcane varieties, deep tillage and planting furrow preparation, planting after raining when the soil moisture is appropriate, selecting appropriate length of seedcane setts (setts with multiple buds for upland and dry weather conditions), covering with plastic film after planting and irrigating or being in good soil moisture, field covering with sugarcane trash, furrow blocking for water storage design, chemical regulation, and so on, were recommended to increase the productivity and quality of cane. These have been proven very effective and there have been many high productivity examples in the rain-fed sugarcane upland areas, but more training on farmers and more demonstration experiments are still needed. At the same time, investment to improve the irrigation condition has been strongly recommended. Under the upland condition, drip irrigation system is considered more economic and effective than spray and furrow irrigation (Li and Yang 1999).

Vinasse Application as a Liquid Fertilizer or for Making Granule Fertilizer

There are more than eight million tons of vinasse produced during alcohol production using molasses from sugarcane mills in China. Among the various industries, distilleries of sugar industry play a major role in polluting the water sources. But the components of vinasse are from sugarcane, and there are no additional substances that are toxic to human being. This polluting distillery waste or vinasse contains exceptionally high level of organic carbon and other essential macro and micro elements such as K (10,000–13,000 mg as K_2O l^{-1}), Ca (2,100–3,000 mg l^{-1}), Mg (2,000–3,300 mg l^{-1}), S (4,000–5,000 mg l^{-1}) and moderate amount of N (1,200–1,500 mg l^{-1}), Fe (65 mg l^{-1}), Zn (10.5 mg l^{-1}), Mn (5.5 mg l^{-1}), sulphate (4–8 g l^{-1}) chloride (5–6 g l^{-1}) required for the growth of plants. After many years experiments carried out in Guangxi, 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. It produces significant increases in cane tonnage and sucrose

% cane and the benefit-cost analysis favors its large scale of application (Li et al. 2007). The direct rational application of fresh vinasse in sugarcane fields is practically feasible through a set of technical measures. In recent years, we have successfully used vinasse for making granule fertilizer, which is good for storage, transportation and application. Combining popularization of the two technologies will completely avoid vanasse from pollution, and recycle the nutrient into agricultural fields, which is good for environmental protection and developing low cost and nutrient saving sugar economy.

Healthy Seedcane Production and Application

The trial results indicated that production with pathogen–free seed canes increased cane yield significantly by 30–68.7 % higher for chewing cane, and 38.5–48.3 % higher for the millable cane (Li 2010) as compared with the conventional seed canes. The investigations showed that the incidence of sugarcane mosaic virus disease was zero in pathogen-free healthy seed cane treatment. Therefore, the pathogen-free seed cane propagation system of would be important for sugarcane production. Extension of healthy seedcane in commercial sugarcane production has become a priority in recent years. However, this technology application should be combined with new sugarcane variety multiplication.

Comprehensive Control of Diseases, Insect Pests, Weeds and Rats

For disease control, the first priority is to breed resistant varieties for controlling smut, mosaic and yellow leaf syndrome. Producing and applying healthy seedcane for commercial production is very good for controlling ratoon stunting disease, mosaic and other diseases. It is strongly recommended to use fungicide and other chemical treatment on seedcane before planting. Agricultural measures such as artificial removing of smut whips, limiting nitrogen fertilizer over-application, cleaning environment, etc., are proven effective.

Breeding is also first consideration for insect pest control. Biological pest control is strongly recommended for safe and non chemical pollutant sugarcane production, and now our focus is on borer control with natural enemies such as trichogramma and Cuban fly etc., for longhorn beetles control with *Metarhizium anisopliae* and so on. Physical measures are highly recommended for pest control, for example, applying frequency light shows very good control effect for several important insect pests such as borers, scarabs, longhorn beetles, and so on. Agricultural measures, for example, gigging pits around sugarcane fields to trap longhorn beetles are very effective, and applying vinasse plus covering plastic film is also effective to reduce soil pests in the planting furrows, and so on. Sex attractant is also effective for borer control.

Herbicides application, intertillage and rational intercropping are recommended for effective weed control. Artificial trapping and chemical control are combined for rat control.

Machine Harvest

As the labor wages for harvesting sugarcane has been increasing rapidly in recent years, machine harvest is now become one of the research priorities to reduce the production cost as the harvest expense has occupied about one-fourth of the total sugarcane production cost.

Biological Nitrogen Fixation in Sugarcane

It is essential to reduce N fertilizer input and cultivation cost while achieving high yield and high sugar for of the sustainable and environmentally benign sugarcane production. Sugarcane plants can obtain nitrogen from biological nitrogen fixation via diazotrophs (Taulé et al. 2012; Li et al. 2013). However, little is known about the major N_2-fixers and their N_2-fixing locations in sugarcane plants. So we are trying to develop methods for detecting the bacterial *nif*H gene expression in sugarcane stems based on the established associative sugarcane-diazotroph systems, use qRT-PCR to measure the *nif*H expression activity in sugarcane stems from 25 cultivars grown under conditions suitable for associative N_2 fixation, and use RT-PCR to amplify the nifH transcriptomes from cultivars showed high nifH expression activity. Moreover, based on the phylogenetic congruence between the nifH gene and the 16S rRNA gene, we will use high-throughput sequencing and bioinformatics to analyze the diversity of the functional diazotrophs and to determine the major functional diazotrophs in sugarcane plants. Furthermore, we will isolate the major functional diazotrophs from sugarcane plants or select ones from the available culture collection for diazotrophs in China, use the major functional diazotrophs to inoculate the sugarcane cultivars shown high nifH expression activity, and then use qRT-PCR and ^{15}N isotope dilution methods to determine the efficient sugarcane N_2-fixing systems, and use in situ hybridization assay to find the N_2-fixing location in sugarcane plants. Together, this study will lay a biological foundation for development of low nitrogen input, efficient and sustainable sugarcane production in China. At the same time, we are trying to detect the effects of soil pH, nitrogen and phosphorus levels, and microbes on nitrogen fixation efficiency in sugarcane.

Genome and Proteome Research

Although sugarcane genomes are very complex and the genome research progresses very slowly, it is important to sequence the whole genome. After years of preparation, Sugarcane Research Center, Chinese Academy of Agricultural Sciences/Guangxi Academy of Agricultural Sciences decided to begin the whole sugarcane genome sequencing program in China. This is being conducted with a local collection of *Saccharum spontaneum*, GXS87-16 ($2n = 64$) with the cooperation of Beijing Genome Institute (BGI)–Shenzhen. This project includes two terms. The first term is planning to be completed in 3 years since July 2013. In the first term of the project, 100× (100 Gb) of WGS sequencing will be done, 10 × BAC clones will be constructed and 1× (about 10,000 clones) will be selected for BAC library construction and sequencing. These data will be used to estimate complexity of sugarcane genome, and the primary sequence map will be obtained.

For sugarcane proteome analysis, we are focusing on the differential proteins in different genotypes and/or under stress of drought, cold, and diseases such as smut, ratoon stunting and yellow leaf.

Gene cloning and function analyses are being done for those related to sugar metabolism, resistance to drought, cold, and diseases such as smut, ratoon stunting mosaic and yellow leaf. Genetic transformation technology is used as a supplemental tool of sugarcane breeding. Resistance improvement especially resistance to borer and drought is the priority. The gene cloning and genetic transformation technologies might play important roles in sugarcane variety improvement in the future.

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