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REVIEW

# Sweet sorghum and *Miscanthus*: Two potential dedicated bioenergy crops in China

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**Abstract**

Among the potential non-food energy crops, the sugar-rich $C_4$ grass sweet sorghum and the biomass-rich *Miscanthus* are increasingly considered as two leading candidates. Here, we outline the biological traits of these energy crops for large-scale production in China. We also review recent progress on understanding of plant cell wall composition and wall polymer features of both plant species from large populations that affect both biomass enzymatic digestibility and ethanol conversion rates under various pretreatment conditions. We finally propose genetic approaches to enhance biomass production, enzymatic digestibility and sugar-ethanol conversion efficiency of the energy crops.

**Keywords:** sweet sorghum, *Miscanthus*, bioenergy crops, biofuels, plant cell wall, biomass saccharification, ethanol conversion

## 1. Introduction

Bioenergy is regarded as a sustainable alternative to fossil energy supply (Chen and Peng 2013; Cotton *et al*. 2013). As the second largest energy consumer globally, China has launched several non-fossil energy developing plans, including the 11th Five-Year Plan for Energy Development Planning of China (NDRC 2007a), and the Medium- and Long-Term Developmental Plan for Renewable Energy in China (NDRC 2007b).

To reach the goals outlined in these plans, the selection of bioenergy crops is an important priority to meet the need of biomass production. In general, bioenergy crops can be classified as starch-producing crops, sugar-producing crops and lignocellulose-rich crops for bioethanol production, as well as oilseed crops for biodiesel (Li *et al*. 2010). Starch or sugar-based bioethanol and edible-oil-derived biodiesel may, however, impose challenges for food security if produced on a large scale in China. Nevertheless, conversion of lignocellulosic residues from food crops is a potential alternative (Xie and Peng 2011). Despite those approximately 0.7–0.9 billion tons of crop residues are produced each year, almost half of the residues are burnt to ash or directly discarded around the field (Chen *et al*. 2009). In addition, approximately 0.1 billion ha of marginal lands not suitable for food crops can be applied to grow energy

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crops to meet the large demand of biomass feedstock in China (Yan *et al*. 2008). We argue that sweet sorghum and *Miscanthus* should be considered as major candidates of non-food energy crops for marginal lands.

## 2. Biological characteristics of sweet sorghum and *Miscanthus*

With the advances of biofinery technologies of converting biomass into biofuels, efforts have been made to grow dedicated biomass crops in China. Sweet sorghum and *Miscanthus*, which are respectively originated in Africa and East Asia, are the candidate crops with extremely high biomass yields. Moreover, as these two species are evolutionary related, research advances in each of the crops will expedite improvement in the other crops (Van der Weijde *et al*. 2013).

Sweet sorghum grows rapidly (a life-cycle is around 120–150 days), and has high biomass yield (6.0–7.5 t dry matter (DM) $ha^{-1}$ $yr^{-1}$). Sweet sorghum is, furthermore, highly water-usage efficient, and needs typically only one third of water compared to sugarcane and half of that of corn (Li J *et al.* 2013). It is also drought, salt and cold tolerant as compared to conventional bioenergy crops (e.g., sugarcane and corn). As sweet sorghum can adapt to various environments with low fertilizer requirements, it is extensively grown globally, and is particularly well suited for agriculture in the north of China (Li and Chan-Halbrendt 2009; Xie and Su 2012). Li *et al*. (2014a) and Wu *et al*. (2015) examined over 200 sweet sorghum germplasm accessions stored in the National Plant Germplasm System of China. These accessions were collected from across the world and displayed clear differences in agronomic trait, such as plant height, stem diameter, pitch numbers, lodging resistance, soluble sugar levels and seed yield. From such germplasm collections, it may therefore be possible to find dedicated sweet sorghum accessions that are rich in soluble sugars and that have high digestible lignocellulosic bagasse suitable for bioenergy purposes (Byrt *et al*. 2011; Zegada-Lizarazu and Monti 2012; Li *et al*. 2014a).

*Miscanthus* is also a typical $C_4$ plant that grows rapidly with low fertilizer requirement and high tolerance/resistance to drought, salt and cold conditions. It has wide geographic distributions and high biomass yields ranged from 37.5 to 60.8 t DM $ha^{-1}$ $yr^{-1}$. For instance, the natural distribution of *Miscanthus sinensis* in China is 100.45–127.55°E, 18.34–43.70°N, alititude –12–1 900 m across 23 provinces (Table 1). So far, eleven species of *Miscanthus* have been identified (Jakob *et al*. 2009), and over 1 400 natural *Miscanthus* accessions, including four different species (*M. sacchariflorus*, *Miscanthus lutarioriparius*, *Miscanthus sinensis*, and *Miscanthus floridulua*) have been collected in China (Xie and Peng 2011).

Regardless of the relatively low soluble sugars in the stalks compared with sweet sorghum, *Miscanthus* is considered as a leading lignocellulosic bioenergy crop in China, and across the world (Lewandowski *et al*. 2003; Angelini *et al*. 2009; Xie and Peng 2011). While *Miscanthus* is mainly exploited for lignocellulosic biomass, sweet sorghum, maize, and sugarcane are dual-purpose crops for foods and biofuels (Table 1).

## 3. Bioethanol production from lignocellulosic residues of sweet sorghum and *Miscanthus*

Various technologies have been applied to enhance biomass enzymatic saccharification and ethanol conversion efficiency. Sweet sorghum contains approximately 160–180 g $L^{-1}$ fermentable sugars, including sucrose, glucose and fructose, in the stalk juice (Laopaiboon *et al*. 2009), which can be readily converted into ethanol by yeast fermentation (Sipos *et al*. 2009; Ratnavathi *et al*. 2010). It is also an ideal substrate for fuel gas production, such as hydrogen, by biomass gasification (Antonopoulou *et al*. 2008). A two-step membrane separation process has been developed to increase sugar concentrations and thus ethanol productivity from the stalk juice (Sasaki *et al*. 2014). The remaining bagasse of sweet sorghum is lignocellulose-rich which can also be processed to ethanol. To enhance the enzymatic digestibility of sweet sorghum bagasse, various pretreatment methods have been examined. Dilute NaOH solution autoclaving and $H_2O_2$ immersing pretreatment significantly increased cellulose hydrolysis yield, total sugar yield and ethanol concentration by approximately 6-, 10- and 20-folds, respectively, compared with the control (Cao *et al*. 2012). Integrating hydrothermal pretreatment and alkaline post-treatment significantly increased the saccharification ratio of sweet sorghum bagasse (Sun *et al*. 2015). Steam-pretreatment also resulted in efficient enzymatic hydrolysis of bagasse and conversion of 85 to 90% of the bagasse into ethanol (Sipos *et al*. 2009). Integration of solid-state fermentation technology and alkaline pretreatment has been shown to be a cost-effective process for the production of the ethanol from the sweet sorghum bagasse (Li J *et al*. 2013). In addition, sweet sorghum stalk has been examined as the feedstock for methane (Matsakas *et al*. 2014) and hydrogen production (Antonopoulou *et al*. 2008). It has also been used for heat production (Sipos *et al*. 2009). Sweet sorghum produces grains at a yield of about 2.2–4.5 t DM $ha^{-1}$ $yr^{-1}$, which can be used as food as well as the feedstock for bioethanol and pigment production (Gao *et al*. 2010).

Unlike sweet sorghum, *Miscanthus* is a dedicated