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Changes in stem composition and harvested produce of sweet sorghum during the period from maturity to a sequence of delayed harvest dates

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ABSTRACT

Four cultivars of sweet sorghum (*Sorghum biocolor* (L.) Moench) were investigated to analyze the effects of delayed harvesting on the changes in stem composition and the related end-use quality for bioethanol. During the delayed harvest periods of 2006-2007 and 2007-2008, the early (Zaoshu-1) and middle (Chuntian-2) maturity cultivars showed that the main component contents were in the order of sugar > cellulose > hemicellulose > starch in the sweet sorghum stems. There was a slight increase in stem dry weight, soluble sugar content, soluble sugar yield and CEY from the physiological maturity date to the first killing frost date. After the frost date, soluble sugar content and yield decreased significantly ($p < 0.05$) for all cultivars, whereas cellulose, hemicellulose, and CEY from cellulosic materials were relatively consistent or slightly decreased during the two delayed harvest periods for the middle and late (Lvneng-3 and M-81E) cultivars. Taking cellulosic ethanol into account, the total CEY (4723–10,803 L ha^{-1}) decreased by 2–12% for the middle and late cultivars, when the harvest dates were delayed from physiological maturity to December. The findings indicate that harvest date for the middle and late maturity cultivars, rather than the early type showing considerably lower stem dry weight and CEY, could be delayed to December for biofuel production in North China.

1. Introduction

Biomass is one of the most promising renewable energy sources that can be used for production of biofuels, since it is an abundant resource, has low CO_2 emission and low cost [1–4]. Sweet sorghum (*Sorghum biocolor* (L.) Moench) showed high radiation use efficiency [5], high biomass and sugar yields [6,7], low N fertilizer rate and irrigation water use [8], wide adaptability, and tolerance to drought and salinity [9]. It was found to be rich in sugars [1,10–12], cellulose and hemicellulose in the stems [1,6,13,14]. Fuel ethanol is now produced on an industrial scale from sugar and starch. Lignocellulose materials will be used as feedstock for ethanol production in the very near future [15]. Various studies have recently been carried out on the energy potential of sweet sorghum and recognized the crop as one

Abbreviations: ZS1, Zaoshu-1; CT2, Chuntian-2; LN3, Lvneng-3; CEY, calculated ethanol yield; PMD, physiological maturity date.

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of the most potential feedstocks for biofuels in Northern China [6,9,14,16,17].

It is important that sweet sorghum has a long enough harvest period for bioprocessing of carbohydrates to biofuel. In a previous study, we found that sweet sorghum grown in North China permitted a harvest-window beginning at 20 days after anthesis for the early maturity cultivars and ending at the grain physiological maturity stage of the late cultivars [14]. However, sucrose, the main sugar form in the sweet sorghum stems, could be converted into acids after harvest, leading to considerable sugar loss [18]. Meanwhile, it cannot be processed within a short period due to limitations in the processing capacity of the mill. The crucial issue that needs to be resolved is how to harvest and store sweet sorghum stalks or juice in order to maximize its end-use quality as a feedstock for industrial fuel production. Therefore, it is of importance to minimize sugar loss, prolong the processing period and improve the handling efficiency of bioethanol mills.

Methods of wet storage, freezing storage, cold storage, antiseptic storage [19], tectorial storage with sulfur dioxide [20], enzyme storage [19], and condensing stalk juice [17] have been investigated for preserving sugars in sweet sorghum stalks or juice. However, these methods have the disadvantages of extra energy use and a short storage period. Delayed harvest (winter or spring following the growing season) was found to be a low cost and widely studied method for storage of energy crops [21–26]. However, little is known about whether delayed harvest is advisable for sweet sorghum production. In this study, we carried out a delayed harvest field experiment with four different sweet sorghum cultivars which had physiological maturity dates (PMD) between late August and middle October in the temperate zone of North China. The objectives of the study were (1) to identify the effects of delayed harvest on changes in biomass and carbohydrates in the stems of early-, middle-, and late-maturity cultivars of sweet sorghum; (2) and to investigate the changes in calculated ethanol yields from sugar, starch, cellulose and hemicellulose in the stems with delayed harvest for biofuel production in North China. We hypothesized that: (1) the stem dry weight would change with time after PMD; (2) the soluble sugar content would change with time after PMD; (3) the insoluble carbohydrates would be consistent with time after PMD; and (4) Sweet sorghum cultivars with different crop cycling length exhibited a different suitability for delayed harvest based on the calculated ethanol yield (CEY).

2. Materials and methods

2.1. Study site, experiment design, and crop cultivation

A field study was conducted from 2006 to 2008 at the Shangzhuang Experimental Station (39°56′ N, 116°20′ E) of China Agricultural University in Beijing, China. The data on daily minimal and maximal temperature and monthly precipitation during the study periods were collected from a weather station adjacent to the experimental field and are presented in Fig. 1 and Fig. 2, respectively. The first killing frost dates were October 23 in 2006 and October 19 in 2007. Sweet sorghum hybrid Zaoshu-1 (ZS1) and Chuntian-2 (CT2), and inbred Lvneng-3 (LN3) and M-81E were tested with a completely randomized block design of four replications. More details of the crop management were presented in our previous paper [14]. The physiological maturity dates (PMD) of each variety was determined according to Lu [27]. On the PMD, panicles with seeds were harvested and stalks were left in the field until the following spring.

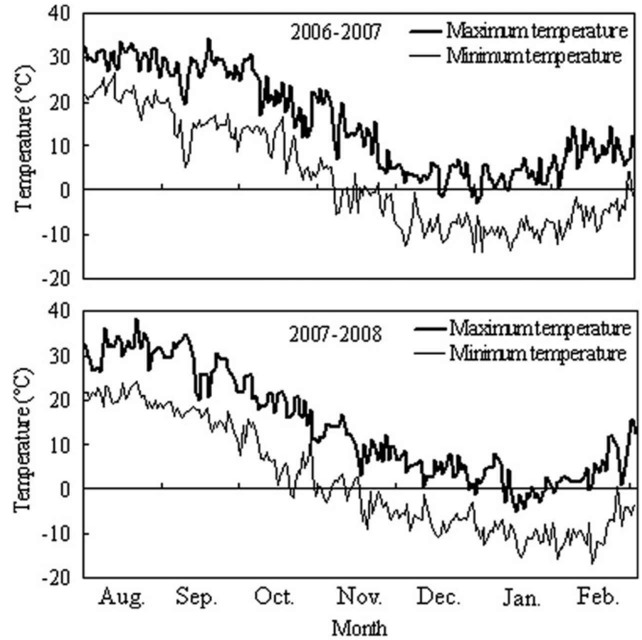

Fig. 1 – Variations in daily minimum and maximum temperature during the 2006-2007 and 2007-2008 study periods at the site Shangzhuang, Beijing.

2.2. Sampling and measurements

Sampling of each sweet sorghum cultivar was undertaken in the autumn and winter during the 2006-2007 and 2007-2008 study periods. The harvest date and its thermal time of each sample are presented in Table 1. Ten (10) aboveground plants

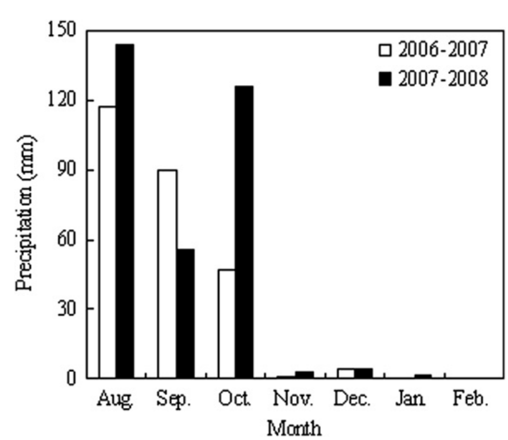

Fig. 2 – Monthly precipitation during the 2006-2007 and 2007-2008 study periods at the site Shangzhuang, Beijing.