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Brown and green sugarcane leaves as potential biomass: How they deteriorate under dry and wet storage conditions

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ABSTRACT

The current trends to (1) investigate sugarcane leaves as a sustainable biomass feedstock for the production of biofuels and bioproducts and (2) delivery of more leaves to factories for processing with stalks, have made information on how it deteriorates on storage during dry and wet environmental conditions more important. Brown, dry (BL) and green leaves (GL) were stripped from hand-cut whole-stalks from Louisiana (LA) sugarcane variety LCP 85-384 in two consecutive years. In the first year, BL and GL were separately allowed to deteriorate in a simulated field canopy shade study. One set was watered across 14 days to simulate rain, and the other set was not watered. This 14 day period was repeated three times across the LA harvest season (October to December) to cover varying environmental conditions: 17–31 October (21 °C; 71% mean humidity), 15–29 November (22 °C; 71%), and 13–27 December (15.5 °C; 78%). In the second year, the simulated study was repeated but over a prolonged 28 day period (17 November–15 December) and fresh and deteriorated leaves were also collected from a grower's LCP 85-384 field and analyzed for comparison. Generally, the worst deterioration for both BL and GL occurred in the watered samples, and when the humidity was highest. On deterioration, more soluble impurities were extracted from GL than BL. Only prolonged deterioration of BL caused a reduction of fiber biomass, and the fiber content of GL usually increased on deterioration because of loss of moisture. The nutrient sucrose was often, but not always, preferentially utilized over glucose and fructose. Results from the grower's field were more extreme than from the simulated experiments. Leaf moisture was higher in the deteriorated than non-deteriorated field BL because its shredded state created more surface area to absorb water; this also allowed for more *Leuconostoc mesenteroides* bacteria to grow and form dextran and mannitol. Overall, the total microbe populations were highest on watered GL because of higher available nutrients.

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1. Introduction

Biomass, plant-derived organic matter, currently contributes to over 10% of primary energy to meet world annual demand (Chen et al., 2010) and this is expected to grow further. Attention in the U.S. is now focused on developing sustainable supply chains of biomass feedstocks for new, flexible biorefineries. This includes improved feedstock quality and cost-effective approaches for minimizing feedstock sugar losses during storage. Sugarcane extraneous leafy matter or trash is an agricultural biomass residue that is widely available and, like other biomass sources, could be converted through a wide range of technologies, e.g., biochemical or thermal conversion, into different forms of bioenergy and other marketable coproducts – some of which have been conventionally derived from fossil resources. In such a way, value will be added to an otherwise under-used or improperly used biomass resource. It would also allow rural communities to access local energy supplies or could also bring economic opportunities to many developing countries that grow sugarcane (Chen et al., 2010).

The majority of sugarcane in the US is now harvested into billet stalks (∼22 cm average length) with a combine harvester. With an increasing shift world-wide away from the harvesting of burnt to unburnt (green) sugarcane due to environmental pressures against burning, particularly near urban areas, green harvesting has also

Abbreviations: GL, green leaves; BL, brown, dried leaves; BL_{det}, deteriorated brown leaves; NTU, nephalometer turbidity units; PDA, potato dextrose agar; CFU, total colony forming units; GC, gas chromatography; PSA, particle size analysis; ICUMSA, International Commission for Uniform Methods in Sugar Analysis.

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increased. This has meant a concomitant increase in the amount of harvested sugarcane leaves (leafy trash or extraneous matter). Although combine harvester designs have improved in recent years, considerable trash is still delivered to factories for processing (Eggleston et al., 2012). Some of the leaves remain as a blanket of crop residue on the field and play a vital role in recycling organic matter and minerals back into the soil. The rest are delivered to factories and processed to the detriment of raw sugar quantity and quality (Viator et al., 2005). Even in those areas that still burn, in rainy weather burning is not practical and, therefore, there is a much higher trash load at the factory. Rainy conditions are also more conducive to the deterioration of trash. Furthermore, green harvesting has become an even larger issue in recent years with the move by many countries toward also utilizing green sugarcane as a biomass or bioenergy feedstock crop alongside sugar manufacture. Cogeneration and ethanol plants using sugarcane biomass feedstocks have been built in some countries, e.g., Brazil, which are often situated near the sugarcane factory (Corcodel et al., 2011). Moreover, in recent years that has been considerable research reports (e.g., Rocha et al., 2012; Benjamin et al., 2013; Isaac et al., 2013; Walter et al., 2014) on leafy, sugarcane bagasse for conversion into numerous other coproducts.

The use of sugarcane leaves as a biomass feedstock is heavily dependent on the amount of dry mass available for bioenergy or bioproduct manufacture. Eggleston et al. (2009) reported that on average, 69% of the dry biomass of five Louisiana sugarcane varieties were stalks and 31% green and dried, brown leaves. Dried sugarcane leaf residue is approximately 36% cellulose, 21% hemicelluloses, and 16% lignin (Deepchand, 1986). The quantity and quality of leaves can also vary across the harvesting season in different countries. Donaldson et al. (2008) in South Africa reported that the amounts of green leaves varied with season date while dried, brown leaves changed little with season. Eggleston et al. (2013a,b) in Louisiana, USA, similarly reported a stronger seasonal effect on green than brown leaves, and there was no significant varietal variation in the quantity of brown leaves formed.

Similar to the natural decomposition of sugarcane leaf residue on fields, bacteria and fungi decompose fallen leaves from trees and other plants to humic and water soluble compounds (Lyn et al., 2010). These microbes are saprophytes since they derive nutrients from senescing or dead organic materials. This decomposition or deterioration process for sugarcane leaf residues on the field, however, is a rather slow process because in the field residue blanket there is often more nutrient (crop residue) available than the natural population of microbes can degrade in 1 year (Lyn et al., 2010). If leaves were to be delivered to a biorefinery it would most likely be stored in piles at the biorefinery or could be near the harvest site. How such a pile of leaves would store and for how long is important if a stable and sustainable feedstock supply is to be made available to a biorefinery.

While there are numerous reports on the deterioration of sugarcane whole-stalks or billets (see Van Heerden et al., 2013 for a comprehensive review), there has been very little published reports on the deterioration of sugarcane leaves. Bagasse, the fibrous residue from tandem mill extraction of sugarcane juice in a factory, is sometimes stored in large piles outside a sugarcane factory before it is burned in the boiler house. The following problems, however, have been experienced with stored bagasse piles: (i) anaerobic decomposition and associated bad odors, (ii) spontaneous combustion of the bagasse (constant moving of the pile and water sprinklers helped to alleviate this problem, and (iii) airborne bagasse creating environmental issues (T. Endres, Middle East Sugar, personal communication). It has also been reported that storing large piles of bagasse outside does not require it to be covered and it can be stored for years, however, it does degrade and lose its calorific value (R. Tillett, Royal Swaziland Sugar Corporation, personal communication).

The current trends to investigate the use of sugarcane leaves as biomass for the production of bioenergy and biobased products, and the delivery of even more leaves to factories for processing with stalks, has made information on how leaves deteriorate during storage, under dry and wet environmental conditions, more important. Therefore, this study was undertaken to determine the effects of dry and wet conditions on biomass quality during medium (14 days) and prolonged (28 days) deterioration storage.

2. Materials and methods

2.1. Collection of leaf samples

Commercial sugarcane variety LCP 85-384 whole-stalks were obtained on the first date of each experiment in 2007 and 2008, from Ardoyne farm of the USDA-ARS Sugarcane Research Unit, Schriever, Louisiana (LA) with a soldier harvester. The sugarcane was the second ratoon crop grown on commerce silt loam. Green leaves (GL) and brown, dried leaves (BL) were hand stripped from the stalk and placed into separate piles. Random GL and BL subsamples (~300 g) were shredded by passing through a Jeffco cutter grinder (Jeffress Engineering Pty Ltd., Australia). Approximately 200 g shredded GL or BL were put into separate air-tight, plastic bags (sealed bags) and transported to USDA-ARS Southern Regional Research Center (SRRC) in New Orleans, LA.

2.2. Simulated deterioration of sugarcane leaves in 2007 and 2008

In 2007, a Coleman™ (Golden, CO) 4.3 m × 3.7 m screen house was erected on the grounds of the SRRC to simulate sugarcane canopy shade. Grass inside the screen house was first removed to show bare soil. In the middle of the screen house was placed four 71 cm × 92 cm rectangles marked by pegged string. In the two rectangles in front, whole BL and GL were separately placed with leaves approximately 5.1 cm deep. Similarly, in the two rectangles behind, BL and GL were placed as controls (no water added). Rain (12.7 cm) was simulated on the BL and GL by applying de-ionized water over the length of the experiment with a sprayer. On Days 0 and 14 days samples were removed. One sub-sample of leaves was collected for microbial analyses and another for leaf moisture analysis. The rest of the leaves were used for juice extraction. From Days 0 to 14 the temperature and humidity inside the screen house were recorded with an Oregon Scientific Inc. (Oregon, WA) Deluxe Weather Forecaster with wireless UV sensor. This 14-day leaf deterioration study was repeated three times across the 2007 LA sugarcane processing season in October (17–31), November (15–29), and December (12–27) to cover varying environmental conditions and sugarcane maturation/physiological stages. In October, the temperature range and mean humidity were 11–31 °C and 71%, respectively; in November, 13–31 °C and 71%; and in December 7–24 °C and 78%. In October, Day 0 rain occurred during sampling and the leaves became slightly wet.

In 2008, a similar Coleman™ 4.3 m × 3.7 m screen house was erected on the grounds of the SRRC and prepared the same as in 2007. Four 71 cm × 92 cm rectangles, marked out by string, were placed in the center of the screen house. In first two rectangles, BL and GL were separately placed with leaves approximately 5.1 cm deep. Similarly, in the second two rectangles BL and GL were placed as controls (no water added). One set was wetted with de-ionized water every 3 days for a 14 day period to simulate 12.7 cm of rain, and the other set was not wetted (control). Juice was extracted from the leaves on Days 0, 14, and 28 and analyzed; microbial

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