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EFFECTS OF COMPRESSIVE FORCES ON THE EXTRACTION OF JUICE FROM SWEET SORGUM AND SWEET PEARL MILLET FOR EVENTUAL BIOETHANOL PRODUCTION

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ABSTRACT

Sweet sorghum and sweet pearl millet contain a high concentration of readily fermentable sugars. Many studies have been carried on the harvesting and pressing processes of sweet sorghum for bioethanol production. However, few research studies have been done on sweet pearl millet. Juice of these crops can be extracted with a press and then fermented to produce bioethanol. Forage residues obtained after pressing could be fed to cattle. Trials on the pressing process of sweet pearl millet and sweet sorghum were carried out in the province of Quebec, Canada, at two different experimental sites. A specific screw press was used to investigate the effects of compressive forces on juice extraction. Three compressive forces (35, 45, and 55 psi) were tested and the optimum pressure for juice extraction was found between 45 and 55 psi. Average rates of extracted juice were 0.475 and 0.595 litre per kilogram of biomass for sweet pearl millet and sweet sorghum, respectively. However, compressive forces had no effect on juice sugar concentration for both crops. Further experiments are required to optimize the harvesting and pressing processes of sweet pearl millet and sweet sorghum to optimize the juice extraction for an eventual bioethanol production.

Keywords: *Bioethanol, sweet pearl millet, sweet sorghum, press, juice extraction.*

INTRODUCTION

Sweet sorghum and sweet pearl millet contain a high concentration of readily fermentable sugars that can be used for bioethanol production. Lots of studies have been done on the pressing process of sweet sorghum, but almost none on sweet pearl millet. Mask and Morris [1] showed, with a roller press, that about 50 to 60% of the initial weight of sweet sorghum biomass could be extracted as juice. They showed that the extraction ratio depends on press speed, moisture of biomass, and multiple press adjustments. Cosgrove et al. [2] indicated that even though some presses allowed 70 to 80% juice extraction from sweet sorghum, in-field press resulted in relatively low performance, usually between 30 to 50%. Process created by Badalov [3] using two screw presses is supposed to remove 95% of the sugar from sweet sorghum. However, results from experiments using one screw press showed only between 54 and 70% juice extraction [4]. Monroe et al. [5] tried two roller presses and showed that more than half of the sugar remained in the plant after the pressing process. A roller belt press was also tested but less than 20% of juice was extracted [6]. Roller presses tested during many years allowed an extraction rate between 35 and 58% [7].

Preliminary investigation into the pressing process of sweet sorghum and sweet pearl millet using a screw press was carried out in 2009 [8]. Results showed a moisture extraction of 52 and 63%, for both crops respectively, but lots of unwanted biomass residues were found in the juice. During the same investigation, a vertical hydraulic press was also used, and a moisture extraction rate of about 35% for sweet pearl millet and 42% for sweet sorghum was obtained. The main objective of this experiment study was to investigate the effects of compressive forces applied with a specific screw press on juice and sugar extraction of chopped biomass of sweet pearl millet and sweet sorghum.

MATERIALS AND METHODS

The experiment was replicated in two sites: McGill University experimental farm in Sainte-Anne-de-Bellevue near Montreal (2900-3100 CHU) and Université Laval research station in Saint-Augustin-de-Desmaures near Quebec City (2300-2500 CHU). Three independent factors were considered during the experimentation: harvesting time (AM vs. PM), crop species (sweet pearl millet vs. sweet sorghum), and compressive force (35, 45, and 55 psi). The effects of compressive forces will be mainly discussed in this paper. The experiments were carried out following a randomized complete block design where the 12 treatments were applied in the same day and repeated over three days (blocks).

Harvesting was carried out on August 30-31 and September 1st 2010 in Sainte-Anne-de-Bellevue and on September 17 and 20, 2010 in Saint-Augustin-de-Desmaures. Crops were harvested by hand with sickles and then chopped finely, at about 0.5 to 1.5 cm long, with a crop chopper. About 13.2 kg of biomass were then weighted and compressed with a screw press, model CP-6, from Vincent Corporation. The selection of this press was made based on the results of the preliminary investigation of 2009 [8]. Three compressive forces were tested: 35, 45, and 55 psi.

All the juice extracted from the biomass was weighted, and the volume measured. The rate of juice extraction was then calculated in L of juice on kg of biomass compressed. However, the rate of juice extraction was not enough to measure the efficiency of juice extraction since it does not take into consideration the moisture content of the biomass. Samples of biomass before and after compression were also taken and dried for at least three days at 55^{o}C. These samples were weighted before and after drying in order to determine the rate of water extracted from the samples (RWEs). The rate of water extracted from the entire biomass (RWE) was determined using equations 1, 2 and 3.

$$W_1 = B_1 \times RWE_S \quad (1)$$
$$W_2 = B_2 \times RWE_S \quad (2)$$
$$RWE = (W_1 - W_2) / W_1 \times 100 \quad (3)$$

Where:
B_1 = Weight of biomass before compression, (kg);
B_2 = Weight of biomass after compression, (kg);
W_1 = Weight of water before compressing the biomass, (kg);
W_2 = Weight of water after compressing the biomass, (kg);
RWE_s= Rate of water extracted from the samples, (%);
RWE= Rate of water extracted from the entire biomass, (%).

The brix degree was determined using a refractometer. Since lots of residues were found in the juice during the preliminary investigation of 2009 using a similar press, the juice was centrifuged for 30 minutes at 12 000 rpm using a Sorval RC-5B in order to determine the weight of unwanted residues. The water was drain and the wet residues were weighted.

ANOVA of the data were performed using the proc mixed of the SAS system (version 9.2), Test of simple effects was done using the command /slice when a significant difference was found ($\alpha = 0.05$).

RESULTS AND DISCUSSIONS

As expected, an impact of the compressive force on the extraction of juice was found (Table 1). When the compressive force is higher, more juice is extracted. However, a plateau was reached in Sainte-Anne-de-Bellevue since the amount of juice extracted at 45 psi was comparable to that extracted at 55 psi. More juice was extracted from sweet sorghum than from sweet pearl millet; between 0.555 and 0.632 L/kg for sweet sorghum and between 0.442 and 0.509 L/kg for sweet pearl millet at Saint-Augustin-de-Desmaures and Sainte-Anne-de-Bellevue, respectively. At the highest pressure, about 0.584 and 0.532 L of juice per kg of biomass were extracted at Sainte-Anne-de-Bellevue and Saint-Augustin-de-Desmaures, respectively.

Table 1: Effects of crop species and compressive forces on the juice extraction rates (L juice extracted/kg of forage biomass)

Crop species	**Sainte-Anne-de-Bellevue**	**Saint-Augustin-de-Desmaures**
Sweet pearl millet	0.509 b	0.442 b
Sweet sorghum	0.632 a	0.555 a
Compressive forces		
35 psi	0.551 b	0.464 c
45 psi	0.577 a	0.500 b
55 psi	0.584 a	0.532 a

A lower rate of water extracted from the entire biomass was found in Saint-Augustin-de-Desmaures (Table 2). Even if no statistical analysis was done to compare sites, it seems that it was harder to extract the water from the biomass in Saint-Augustin-de-Desmaures than from that in Sainte-Anne-de-Bellevue. In the field, it was clear that the stems were drier and brittle in Saint-Augustin-de-Desmaures while they were moist and juicy in Sainte-Anne-de-Bellevue. Moister stems could be easier to compress and extract juice; however, more research needs to be done to investigate this phenomenon.

Results of water extraction indicated that a “plateau” was reached between 45 and 55 psi, in both sites (Table 2). In Sainte-Anne-de-Bellevue, about 63.3 and 74.9% of water was extracted from sweet pearl millet and sweet sorghum, respectively, which can be considered as a good extraction compared to other studies. However, lots of unwanted residues were found in the juice. The juice was unclear and opaque.

Table 2: Rate of water extracted from the entire biomass (%)

Crop species	**Sainte-Anne-de-Bellevue**	**Saint-Augustin-de-Desmaures**
Sweet pearl millet	63.3 b	54.1 b
Sweet sorghum	74.9 a	65.5 a
Compressive forces		
35 psi	66.1 b	56.6 b
45 psi	69.3 a	60.0 a
55 psi	71.9 a	62.7 a

Results of the centrifugation of juice samples surprisingly indicated no effect of the compressive forces on the amount of residues. More residues were found in sweet pearl millet juice than in sweet sorghum juice (Table 3). Since sweet pearl millet has a greater leaf to stem ratio than sweet sorghum, this might explain why more residues were found in its juice.

Table 3: Forage residues present in the juice after extraction by pressing (g residue/mL of juice)

Crop species	**Sainte-Anne-de-Bellevue**	**Saint-Augustin-de-Desmaures**
Sweet pearl millet	0.065 a	0.036 a
Sweet sorghum	0.040 b	0.023 b

On the other hand, no effect of compressive forces was found on sugar extraction (Table 4). Only a difference between sugar concentrations in the juice of sweet pearl millet and sweet sorghum was found, as expected.

Table 4: ANOVA results for sugar concentration of the extracted juice (Brix)

	Site A	***Site B***
Crop species	<. 0001	<. 0001
Compressive forces	0.924	0.1357
Crop species × compressive forces	0.774	0.1822

Significantly different when lower than 0.05

CONCLUSIONS AND RECOMMENDATION

Results showed that the compressive force had a positive impact on juice extraction but not on the sugar concentration of the juice. Based on this study, it is recommended to use, with this specific press, a compressive force between 45 and 55 psi to extract the juice from sweet pearl millet and sweet sorghum. Moreover, the compressive force had no effect on the amount of unwanted residues found in the juice. Juice was easier to extract from sweet sorghum than from sweet pearl millet. It seems easier to extract the juice when the crops are moister. More work needs to be done on the mechanization of the harvest and pressing processes of sweet pearl millet and sweet sorghum.

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