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Fuel ethanol production from sweet sorghum bagasse using microwave irradiation

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ABSTRACT

Sweet sorghum is a hardy crop that can be grown on marginal land and can provide both food and energy in an integrated food and energy system. Lignocellulose rich sweet sorghum bagasse (solid left over after starch and juice extraction) can be converted to bio-ethanol using a variety of technologies. The largest barrier to commercial production of fuel ethanol from lignocellulosic material remains the high processing costs associated with enzymatic hydrolysis and the use of acids and bases in the pretreatment step. In this paper, sweet sorghum bagasse was pretreated and hydrolysed in a single step using microwave irradiation. A total sugar yield of 820 g kg^{-1} was obtained in a 50 g kg^{-1} sulphuric acid solution in water, with a power input of 43.2 kJ g^{-1} of dry biomass (i.e. 20 min at 180 W power setting). An ethanol yield based on total sugar of 480 g kg^{-1} was obtained after 24 h of fermentation using a mixed culture of organisms. These results show the potential for producing as much as 0.252 m^3 $tonne^{-1}$ or 33 m^3 ha^{-1} ethanol using only the lignocellulose part of the stalks, which is high enough to make the process economically attractive.

1. Introduction

Biomass still remains the best carbon source to replace fuels and chemicals currently produced from crude oil and coal [1,2]. Although a number of second generation technologies for the production of fuel ethanol have been proposed and tested [3–6] the use of large amounts of harsh chemicals and enzymes necessary to liberate sugars from the plant materials have made most of the technologies very expensive. The concept of a bio-refinery was developed in an effort to produce a wide variety of products from a single biomass feedstock [7–11] which would help to make the production facility economically feasible. A bio-refinery in itself does not contribute toward alleviating fears regarding food security, even if second generation feedstock such as grass or agricultural waste is used, because the energy crop still needs to be planted and for that land and water is required. A more elegant solution is the use of a bio-refinery feedstock that can produce both food (in the form of grain) and fuel (from bagasse) in a single crop.

Sweet sorghum (*Sorghum Bicolor L Moench*) is a hardy crop that can be grown very successfully on marginal land [12,13]. A single crop can be grown in six months to produce grain with a high starch content as well as stalks that is rich in sugar syrup and lignocellulose materials. In this study, a single step method for the pretreatment and hydrolysis of sweet sorghum bagasse (solids left after syrup has been pressed from stalks) is presented and discussed. The short pretreatment and hydrolysis time as well as the fact that no enzymes are required for sugar liberation makes the proposed method

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economically attractive for large scale production of bio-ethanol from grass type biomass.

2. Materials and methods

2.1. Sweet sorghum feedstock

Sweet sorghum bagasse (Hunni green) was obtained from sweet sorghum harvested after six months growth by the Agricol Research Company in Potchefstroom, North West province, South Africa (26°41′36″S, 27°05′35″E). The sweet sorghum plants (whole plants) were transported on the same day of harvest to a roller press and pressed to remove the sugar rich juice from the stalks until no more liquid was obtained. The plant material left after pressing was sun dried to 10% moisture content, milled and screened to a particle size of ±1.5 mm. The dried plant material, referred to in this study as sweet sorghum bagasse, was packed in air-tight bags and then stored at room temperature until used in the experiments.

An initial compositional analysis of the sweet sorghum bagasse used for experiments was done by the Agricultural Research Council (ARC) – Analytical Services (Pretoria, RSA) and the results are presented in Table 1.

2.2. Micro-organisms

Zymomonas mobilis ATCC 31821 was obtained from the American Type Culture Collection (ATCC) and maintained as freeze dried at −80 °C till further use. The freeze dried organism was re-hydrated with sterile water and inoculated on sucrose broth medium and was grown for two days at 30 °C, 120 rpm. Stock cultures were either made up in 15% glycerol for long term storage at 4 °C; or it was sub-cultured on nutrient agar plates for 72 h at 32 °C, from which inoculums were prepared.

Commercial *Saccharomyces cerevisiae* was used for fermentation of 6-carbon sugars. The dried yeast cells were revived from the inactive state by using a broth containing nutrients as shown in Table 2. Prior to fermentation, the broth was incubated at 32 °C, for 24 h, to reduce lag time.

2.3. Experimental method

The experimental procedure followed for the pretreatment, hydrolysis and fermentation of sweet sorghum bagasse is illustrated in Fig. 1.

Table 1 – Compositional analysis of raw sweet sorghum bagasse used in this study.

Content	Mass fraction
Cellulose	36.60
Hemicellulose	22.96
Acid determined fibre	42.50
Neutral determined fibre	65.46
Acid determined lignin	5.90
Moisture	10.85
Ash	3.07
Residual sugars	25.00

Table 2 – Medium for *Z. mobilis* and *S. cerevisiae*.

Nutrient ($g.L^{-1}$)	*Z. mobilis*	*S. cerevisiae*
Yeast extract	10	–
Peptone	5	0.5
$(NH_4)SO_4$	1	1
K_2HPO_4	2	0.1
$MgSO_4 \cdot 7H_2O$	0.5	0.5

Dried and milled bagasse was pretreated and hydrolysed in a single step. Sulphuric acid (H_2SO_4) (10–70 g kg^{-1}) in a water solution was used during pretreatment and hydrolysis of the bagasse. The appropriate mixture was made up to a total volume of 100 cm^3 containing 5 g kg^{-1} bagasse and then subjected to irradiation in a standard domestic microwave oven at different power inputs of 18–72 kJ g^{-1} of dry biomass. The temperature of the mixture was measured before and after treatment and was found to remain constant at 82 ± 1 °C throughout the duration of each experiment. After pretreatment and hydrolysis, the hydrolysate was filtered and the solid fraction was analysed using scanning electron microscopy (SEM) and Fourier Transform Infrared (FT-IR) to determine the effectiveness of pretreatment and hydrolysis on the liberation of cellulose and hemicellulose from the bagasse plant material. The liquid fraction was analysed for total as well as 5 and 6 carbon sugar content using high performance liquid chromatography (HPLC) with a Shodex SP0810 column and a refractive index detector. The cell count of the broth was monitored during fermentation using ultraviolet spectrometry (UV). Fermentation of liquid hydrolysates was done in 250 cm^3 Duran bottles in an incubator at 32 °C and pH of 4.8 for 24 h. *Z. mobilis* (5 g dry weight per litre of hydrolysate) and *S. cerevisiae* (10 g dry weight per litre of hydrolysate) were added to the hydrolysates to convert both 5- and 6-carbon sugars in the hydrolysate to ethanol.

3. Results and discussion

3.1. Sugar release

Sweet sorghum bagasse was pretreated with dilute sulphuric acid in a domestic microwave oven. The influence of acid concentration and power input on total sugar yield (g sugar per g bagasse) is shown in Fig. 2. The experimental error associated with this set of experiments was determined to be 4.03% at a 95% confidence level.

The amount of hexose and pentose sugars liberated from the plant material at the different power inputs and a constant sulphuric acid concentration of 50 g kg^{-1} in water is shown in Fig. 3. The results in Fig. 3 do not include the residual hexose sugars that were initially present in the bagasse. The experimental error associated with this set of experiments was determined to be 4% at a 95% confidence level.

Low concentrations of sulphuric acid (10 and 30 g kg^{-1}) did not significantly increase the total sugar yield above that of the control sample. Treatment time is limited to the boiling point of the sugar broth and thus the microwave irradiation cannot be continued indefinitely without loss of liquid at atmospheric pressure. The power input (through

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