PRODUCTIVE DIVERSIFICATION FROM SUGARCANE LIGNOCELLULOSIC BYPRODUCTS

By

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Abstract

THE ACTUAL PROCESS of sugar and ethanol production in Mexico only uses the carbohydrates in the sugarcane juice and molasses. The remaining material, trash, bagasse and pith, constitutes the lignicellulosic byproducts (biomass) of this industry. In this work, three production alternatives were investigated: edible mushroom *Pleurotus ostreatus*, pulp and paper and fermentable sugar productions from sugarcane biomass. The characterisation of byproducts was carried out according to AOAC test. For the case of mushroom production, sugarcane trash and a 50:50 mixture of trash and bagasse showed the highest yields (biological efficiencies) of 106% and 103% respectively. For acid hydrolysis, trash samples generated in the local industry were used. Several tests were performed to obtain the maximum production of fermentable sugars using diluted H_2SO_4 at concentration level of 1.0%, temperatures (80–160°C) and hydrolysis times (0 to 330 minutes). A pseudo first-order kinetic model was developed to explain the hydrolysis from sugarcane trash using sulfuric acid. In the last alternative, bagasse pulping and ECF Bleaching (elementary chlorine free) were analysed in detail using TAPPI standards to establish the optimum pulping conditions for this lignocellulosic material.

Introduction

Sugarcane (*Saccharum officinarum*) is a grass that is harvested for its sucrose content. Sugarcane residue is composed of green cane leaves, tops and what is known as cane residue or trash. After the extraction of sugar from the sugarcane in the mill, the plant material that remains is termed bagasse (Castellan, 1999).

Composition of sugarcane biomass

The chemical characterisation was done according to the TAPPI (2000) and AOAC (1995) methods (Tables 1 and 2).

Table 1—Chemical composition (dry weight) of sugarcane biomass.

Components (%)	Trash	Depithed bagasse	Whole bagasse (fibre and pith)	TAPPI test
Extractives ETOH-Toluene	3.4	3.8	4.6	T222 om-93
Extractives H_2O	3.7	4.2	1.3	T207 om-71
Lignin	24.5	20.7	20.3	T222 om-88
Holocellulose	78.7	76	74.7	T203 om-93
α cellulose	47	46.5	45.7	T203 om-93
Pentoses	25.6	25.2	22.4	T223 om-84

Table 2—Chemical analysis of sugarcane biomass.

Components (%)	Ash	Lipids and fat	Crude fibre	Protein	Carbohydrates
Depithed bagasse	13.33	0.98	34.11	6.69	33.40
Sugarcane trash	2.40	0.28	45.00	2.69	38.05
Whole bagasse (fibre and pith)	7.58	1.24	38.51	1.75	25.82

Production of bagasse pulp

Soda Pulping was performed according to a batch cooking (semi-pilot scale) on depithed bagasse samples (87% fibre and 13% pith) from a sugar mill at Cordoba Veracruz. Four liquor compositions were used as a charge in aqueous caustic soda (NaOH) (19, 17, 15 and 13% as Na_2O on weight percent on a dry basis bagasse and liquid/solid relation 1:7) cooking time (165°C) for 30 min to obtain the lowest kappa number (The Kappa number is determination of relative bleachability or degree of delignification of pulp) (Table 3).

Table 3—Cooking parameters.

Liquor composition	Kappa number	Residual lignin (%)	Yield (%)	Shives %
19% Na_2O	13	1.95	51.6	1.1
17% Na_2O	13.5	2.03	51.3	1.8
15% Na_2O	16.8	2.52	52	2.5
13% Na_2O	18.1	2.72	54.5	4.2

The bagasse unbleached pulp (kappa number 18) was subjected to ODP Bleaching (Oxygen delignification, chlorine dioxide and hydrogen peroxide bleaching). Bleaching parameters are presented (Table 4) and strength properties of bagasse pulps to brightness of 90% ISO for this sequence and CEH pulp (conventional bleaching) (Table 5).

Table 4—Bleaching parameters.

Bleaching parameters	Bleaching stages		
	O	D	P
Kappa No.	18.1	5.4	2.4
Pulp consistency (%)[1]	10	10	10
Temperature (°C)	100	70	70
Treatment time (min)	60	180	180
pH	13.2	6.3	11.6
O_2 (kg/cm^2)	4	–	–
NaOH (%)	2	–	1
Na_2SiO_3 (%)	–	–	1
H_2O_2 (%)	–	–	1.7
ClO_2 (%)	–	0.825	–
$MgSO_4$ (%)	0.05	–	0.05
Degree of delignification (%)	70	55.5	
Stage yield (%)	90.9	97.2	98.3
Overall bleach yield (%)	87		

[1] The term used to describe solid content of pulp during pulp processing. For pulp and paper making, this is the most important process parameter. All equipments are designed to handle pulp at and up to certain consistency. Pulp consistency is roughly divided into three ranges: low Consistency: <5%, Medium Consistency: 5 – 15% , High Consistency: >15% .

Table 5. Strength properties of bagasse pulps (TAPPI, 2000)

Properties / pulp	TAPPI Test	Unbleached pulp	ECF bleached pulp	CEH bleached pulp
Shopper Riegler (° S.R.)	T-227	14	20	21
Freeness (mL C.S.F.)	T-227	653	592	574
Drainage Time, (Sec)	T-205-sp-95	4.55	5.18	5.09
Breaking Length, (Metres)	T 404-om-87	5617	5070	4030
Burst Index, ($kPa.m^2$ / g)	T-403 om - 91	3.59	4.17	2.75
Tear Index ($mN.m^2$ / g)	T-414 om - 88	7.85	8.50	7.52
Folding endurance (#)	T - 423	213	127	34
Air resistance (Seg. / mL)	T 460 om-02	6.0	11.3	11.07
Viscosity (Pa.s)	T-230-om-94	0.0365	0.01112	0.017
Brightness (% ISO)	T-218 om - 91	48.2	89.9	81.2

Pleurotus ostreatus cultivation in sugarcane biomass

Pleurotus ostreatus has been cultivated on different substrates: sawdust, corncobs, waste paper, straw, bagasse and others byproducts (Mandeel *et al*., 2005; Contreras *et al*., 2004).

The substrates, waste wheat straw (control treatment) (T_1), sugarcane trash (RAC) (T_2), depithed bagasse (BD) (T_3), sugar mill bagasse (BI) (T_4) and a 50:50 RAC and sugar mill bagasse (T_5) were evaluated using a randomised experimental design with five different treatments.

Each substrate was ground, soaked and pasteurised at 85ºC by hot water, cooled and packaged in 40 x 60 cm polyethylene bags and inoculated by hand with the spawn (*Pleurotus ostreatus*) in a 5% w/w proportion of fresh substrate weight per test.

The average temperature was 25ºC and relative humidity was > 60%. The production was determined according to the biological efficiency (BE). (BE is defined as the weight of fresh mushrooms harvested divided by dry weight substrate at spawning expressed as a percent for each experiment).

Yield of edible mushroom.

The highest biological efficiencies were attained by the RAC (T_3) substrate and the trash/bagasse mixture (T_5). The lowest BE was for sugar mill bagasse (T_4). (Table 6).

Table 6—Biological efficiency (BE).

Treatments	Substrates	Biological efficiency (%) (kg/100 kg substrate)
T_1	Wheat straw	114.89
T_2	Depithed bagasse	66.64
T_3	Trash	106.64
T_4	Bagasse	70.09
T_5	Trash/bagasse mixture	103.50

The mushrooms from the sugarcane substrates and wheat straw could be dried with direct solar radiation. This processing technology also permits an increase in the value added to mushrooms, to standardise mushroom quality and taste, to highlight properties of mushrooms (Table 7).

Table 7—Chemical analysis of edible mushroom *Pleurotus ostreatus* (% dry weight).

	Components (%)	Ash	Fat	Crude fibre	Protein	Carbohydrates
Substrates	Wheat straw	8.3	2.2	12.08	20.56	40.96
	Depithed bagasse	6.28	1.48	12.83	17.18	44.78
	Sugarcane trash	7.82	1.79	12.39	19.68	41.2
	Bagasse from mills	5.81	1.94	12.89	15.81	45.14
	Mixture	6.64	1.85	12.65	21.25	40.41

Fermentable sugar from sugarcane trash

Hydrolysis of sugarcane trash was carried out using dilute sulfuric acid solutions (0.5, 1.0 and 1.5%, w/w) in a batch reactor. Operating conditions of the reactor were hydrolysis time (60 to 120 min), temperature (100 to 160°C) and mass ratio of solid to liquid 1:10 on a dry basis.

The determination of the Fermentable Sugars or Recovered acid hydrolysates (%) was evaluated by the Saeman Method (Canizales and Aguilar, 2004) through a 3^3 factorial design with two replications with respect to the interactions of acid concentration (AC), temperature (TEMP) and time (T). Variance analysis was performed with THE SAS SISTEMS® (Table 8)

Table 8—Total sugar yields of glucose and xylose (AFT %) in acid hydrolysis.

H_2SO_4 (%)	Temp. (°C)	Hydrolysis time (min)	Fermentable sugars (%)	H_2SO_4 (%)	Temp. (°C)	Hydrolysis time (min)	AFT (%)
0.5	100	60	3.38	1	130	120	13.8200
0.5	100	90	3.5067	1	160	60	16.9133
0.5	100	120	5.4200	1	160	90	15.2800
0.5	130	60	8.8233	1	160	120	14.9467
0.5	130	90	8.1133	1.5	100	60	16.2500
0.5	130	120	7.0967	1.5	100	90	15.9967
0.5	160	60	14.1333	1.5	100	120	16.0433
0.5	160	90	12.4767	1.5	130	60	14.9433
0.5	160	120	11.8800	1.5	130	90	16.9600
1	100	60	11.7300	1.5	130	120	16.2467
1	100	90	12.3767	1.5	160	60	16.4767
1	100	120	11.6000	1.5	160	90	18.3467
1	130	60	16.5033	1.5	160	120	16.3767
1	130	90	14.0933				

The results were statistically significant for interaction AC*TEMP (R^2 = 0.938491), and indicated the possibility to obtain a considerable amount of fermentable sugars from sugarcane trash.

Kinetic models

The hydrolysis reactions in dilute-acid medium are very complex (Zheng, 2007, Canizales and Aguilar, 2004; Bustos *et al*., 2003; Pessoa *et al*., 1997); based on the Saeman model and the two-fraction model, kinetic parameters for predicting these compounds in the hydrolysates were: k1= 0.00702631 and k2=0.0003951; and the hydrolysis model was $Y = -10.830114 + 22.3378444(X_1) + 0.07505037(X_2) - 7.1239111 (X^2_1)$ (Y: AFT mol/L, X_1: sulfuric acid %, X_2

Temperature °C). The optimal conditions selected were 160°C, 1.5% H_2SO_4, and 38.52 min (2311.2 seg) (Table 9).

Table 9—Kinetic parameters in the hydrolysis of sugarcane trash with sulfuric acid.

Hydrolysis time Sec.	Holocelullose Mol/m^3	AFT Mol/m^3	Degradation products Mol/m^3	raA	raB	raC
2278.8	1.00497127	1.0149045	0.54412423	–0.000412138	5.2514E-06	0.000406886
2289.6	1.00052018	1.01496122	0.5485186	–0.000410312	3.3887E-06	0.000406924
2300.4	0.9960888	1.01499782	0.55291338	–0.000408495	1.55E-06	0.000406945
2311.2	0.99167706	1.01501456	0.55730839	–0.000406686	–2.6481E–07	0.000406951
2322	0.98728485	1.0150117	0.56170346	–0.000404885	–2.0559E–06	0.000406941
2332.8	0.98291209	1.01498949	0.56609841	–0.000403091	–3.8238E–06	0.000406915
2343.6	0.97855871	1.0149482	0.5704931	–0.000401306	–5.5684E–06	0.000406874

The results emphasise the remarkable potential of sugarcane biomass for applications for the extractive, chemical, food and biochemical industry with sustainable technologies for sugarcane farmers, sugar mills or by products industries. The diversification is a complement to sugar production, improving the exploitation of sugarcane and contributing in this way to the sustainability of the Mexican sugar economy.

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DIVERSIFICATION PRODUCTIVE DE SOUS-PRODUITS LIGNOCELLULOSIQUE DE LA CANNE A SUCRE

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MOTS-CLÉS: Biomasse de Canne à Sucre,
Diversification, Champignons, Pâtes et Papiers,
Sucres Fermentescibles.

Résumé

LE PROCESSUS RÉEL de la production de sucre et d'éthanol au Mexique utilise uniquement les carbohydrates dans le jus de la canne et de la mélasse. Les autres matières, paille, bagasse de canne à sucre de par leur caractère, constituent les sous-produits lignicellulosiques (biomasse) de cette industrie. Trois axes de production ont été étudiées: production du champignon comestible *Pleurotus ostreatus*, pâtes et papiers et sucres fermentescibles à partir de la biomasse de la canne. La caractérisation des sous-produits a été effectuée conformément au protocol AOAC. Dans le cas de la production de champignons, la paille de canne et un mélange 50/50 de paille et de bagasse ont demontré des rendements plus élevés (efficacité biologique) de 106% et 103% respectivement. Pour l'hydrolyse acide, des échantillons de paille générés dans l'industrie locale ont été utilisés. Plusieurs tests ont été réalisés pour obtenir la production maximale de sucres fermentescibles à l'aide de l'acide sulfurique diluée à unde concentration de 1.0%, des températures de 80 à 160°C et la duree de l'hydrolyse (0 à 330 minutes). Un modèle de cinétique de premier ordre a été développé pour expliquer l'hydrolyse de la paille de canne à l'aide d'acide sulfurique. Dans la dernière alternative, la bagasse et l'ECF blanchi (sans chlore) ont été analysés en détail à l'aide des normes TAPPI pour établir le melange optimal pour produire de la pulpe à partir de ce matériau lignocellulosique.

DIVERSIFICACIÓN PRODUCTIVA A PARTIR DE LOS SUBPRODUCTOS LIGNOCELULÓSICOS DE LA CAÑA DE AZÚCAR.

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PALABRAS CLAVE: Biomasa de la Caña de Azúcar, Diversificación, Hongos Comestibles, Pulpa y Papel.

Resumen

EL PROCESO de producción de azúcar y alcohol en México actualmente emplea solamente los carbohidratos de los jugos de la caña y las melazas. Los restantes materiales, paja de caña, bagazo y meollo, constituyen los subproductos lignocelulósicos (biomasa) de la industria. En este trabajo se investigaron tres alternativas de producción: hongos comestibles, pulpa y papel y la producción de azúcares fermentables a partir de la biomasa de la caña de azúcar. La caracterización de los subproductos se realizó de acuerdo a las pruebas AOAC. Para el caso de producción de hongos comestibles, la paja de la caña y una mezcla 50:50 de paja y bagazo presentaron los mayores rendimientos (eficiencias biológicas) de 106% a 103% respectivamente. Para la hidrólisis ácida se emplearon muestras de paja de caña generadas en la industria local. Se realizaron varias pruebas para obtener la máxima producción de azúcares fermentables, empleando ácido sulfúrico diluido a una concentración de 1.0%, temperatura de 80-160ºC y tiempo de hidrólisis entre 0 y 330 minutos. Se desarrolló un modelo cinético de pseudo-primer orden para explicar la hidrólisis de la paja de caña empleando ácido sulfúrico. En la última opción se desarrollaron en detalles pulpeo de bagazo y blanqueado ECF (elementary chlorine fase) utilizando estándares TAPPI para establecer las condiciones óptimas de pulpeo para este material lignocelulósico.