AIMS Bioengineering, 8(3): 221–234.
DOI: 10.3934/bioeng.2021019
Received: 26 May 2021
Accepted: 25 July 2021
Published: 03 August 2021

http://www.aimspress.com/journal/Bioengineering

Research article

Dilute acid hydrolysis of wastes of fruits from Amazon for ethanol production

Flávia Fernandes[1], Amanda Farias[2], Livia Carneiro[4], Ralyvan Santos[2], Daiana Torres[4], João Silva[4], João Souza[3,*] and Érica Souza[2]

[1] Post-Graduate Program in Biotechnology and Natural Resources of the Amazon, Amazonas State University, Manaus, Amazonas, Brazil
[2] School of Technology, Amazonas State University, Manaus, Amazonas, Brazil
[3] Mycology Laboratory, National Institute of Amazonian Research – INPA, Manaus, Amazonas, Brazil
4 Department of Chemical Engineering, Engineering College of Lorena, University of São Paulo, Lorena, São Paulo, Brazil

* **Correspondence:** Email: joao.souza@inpa.gov.br; Tel: +5592991147815.

Abstract: This study carried out the screening of wastes from Amazon plants to produce hydrolysates with a high monosaccharides content for ethanol production. Initially, we hydrolyzed (diluted acid) Amazon wastes (peel from the fruit of *Astrocaryum aculeatum* Meyer, peel from the fruit of *Bactris gasipaes* Kunth, straw obtained from endocarp of the fruit of *Euterpe oleracea* Mart., peel from the fruit of *Theobroma grandiflorum* Schumann and peel from the root of *Manihot esculenta* Crant) to obtain hydrolysates with the high content of fermentable sugars. Then, we investigated by 2^3 factorial design the influence of the factors: a) hydrolysis time (min); b) H_2SO_4-to-waste ratio (g/g) and c) solid-to-liquid ratio (g/mL) in the variables reducing sugars and furans. The hydrolysis of the peel of the fruit of *Bactris gasipaes* resulted in the highest concentration of reducing sugars (23.7 g/L). After detoxification and concentration process, the *Bactris gasipaes* hydrolysate results in 96.7 g/L of reducing sugars largely fermentable (90%) by *Saccharomyces cerevisiae* PE-2. The experimental design demonstrated that the factors H_2SO_4-to-waste ratio (g/g) and solid-to-liquid ratio (g/mL) were the most significant affecting the final content of reducing sugars and furans in the hydrolysate of the peel of *Bactris gasipaes*. Hydrolysis time of 4.4 min, H_2SO_4-to-waste ratio of 0.63 g/g, and the solid-to-liquid ratio of 0.17 g/mL resulted in the concentration of reducing sugars of 49 g/L. This study shows the potential of peels from the fruit of *Bactris gasipaes* to produce ethanol.

Keywords: *lignocellulosic biomass waste; saccharification; acid hydrolysis optimization; bactris gasipaes*

1. Introduction

The policy of reducing gas emissions and the oil price are essential issues from the fuel industry. Besides, the world population is estimated to increase to 9.6 billion people by 2050, and ethanol production is projected to increase 3.4-fold by 2035. Therefore, the search for renewable sources of biomass will become increasingly essential [1,2]. The USA and Brazil are the world's largest ethanol producers. Nowadays, bioethanol is the major source of renewable biofuel with about 29,000 (Mil. Gal.) produced in 2019 [3]. Brazil produces 33.8 billion liters of ethanol through sugarcane fermentation, 10.2 billion liters of anhydrous ethanol, and 23.6 billion liters of hydrous ethanol [4].

Last decade studies have investigated the improvement of the sector producing ethanol from lignocellulosic biomass, especially agro-industrial waste [5–8]. Usually, conventional acid hydrolysis or/and enzymatic hydrolysis are the possible ways to be undertaken to achieve bioethanol production from biomass. [9] The acid hydrolysis processes require severe conditions such as high temperatures and low pH. The advantages of this process are that the acid can penetrate lignin without pretreatment, and the acid hydrolysis is faster and cheaper than enzyme hydrolysis [10,11]. Therefore, the investigation of biomass for acid hydrolysis has been carried out worldwide. Acid hydrolysates with high fermentability were obtained with potato peel, wood chips, rice straw, maple wood, wood, sugar cane bagasse, and Paja brava [8,12–19].

Open markets from city of Manaus (Amazonas State- Brazil) produce 95.4 tons of vegetal waste per day. Carbohydrates, such as cellulose, starch and other polysaccharides can be found in fruits and processed waste in ethanol [20]. The present study was the first to screen vegetal wastes to produce acid hydrolysate suitable for ethanol fermentation. In addition, we investigated the influence of hydrolysis factors in the final concentration of fermentable sugars and furfural.

2. Materials and methods

2.1. Wastes

The wastes investigated were a) peel from the fruit of *Astrocaryum aculeatum* Meyer, b) peel from the fruit of *Bactris gasipaes* Kunth, c) straw obtained from endocarp of the fruit of *Euterpe oleracea* Mart., d) peel from the fruit of *Theobroma grandiflorum* Schumann, and e) peel from the root of *Manihot esculenta* Crant. These wastes were obtained from open markets from the city of Manaus in January and April 2015. Wastes were washed with distillate water, grounded (< 3 mm) in a Skymsen Blender, 1.5 L, dried (80 °C for 6 h), and stored at −20 ℃.

2.2. Microorganism

Saccharomyces cerevisiae PE-2 (Strain 2) was provided by the Sugar Cane Technology Center, from the Junqueira factory (São Paulo, Brazil). This strain tolerates industrial conditions, such as ethanol tolerance and temperature changes [13,14]. We maintained this strain in Sabouraud agar (dextrose 40 g/L, peptone 10 g/L, and agar 20 g/L).

2.3. Acid hydrolysis

Acid hydrolysis was performed as described previously [21] with some modifications: the residue (5 g) and 50 mL of 3.7% w/w sulfuric acid were transferred to Erlenmeyer flasks (150 mL). The mixture was incubated in an autoclave (Autoclave Vertical Class B, FANEM, São Paulo, Brazil) with heating from room temperature 25 to 121 ℃ (9 min) and after reaching the 121 ℃ (15 psi) the hydrolysis was carried out for 15 min and we wait to the autoclave to reach room temperature (30 min). The hydrolysate neutralized (pH 7.0, NaOH) and filtrated 0.11 μm (Whatman® qualitative filter paper, grade 1, United States of America). The acid hydrolysates were characterized (sugars and furfural) before and after a detoxification step filtration through activated charcoal.

The detoxification step was carried out by mixing the hydrolysate with 1% activated carbon (Merck KGaA, Darmstadt, Germany) followed by orbital agitation (100 rpm at 60 ℃ for 30 min). At the end of each, the resulting precipitate was removed by 11 μm filtration (Whatman® qualitative filter paper, grade 1, United States of America) to remove precipitate formed [22].

2.4. Fermentation assays

Fermentation tests were carried out in 125 mL Erlenmeyer Flasks with airlock [9]. Hydrolysates without any nutrient correction (50 mL) were inoculated with *Saccharomyces cerevisiae* PE-2 at 1×10^7 cells/mL and incubated under orbital agitation (100 rpm) at room temperature (25 ℃). Samples were taken after 0, 6, 12, 16, 24, 36, 48, 56, and 72 h and analyzed for cell biomass, reducing sugars, and ethanol. Acid hydrolysates were concentrated about five times (thermal oven at 80 ℃) to kinetics studies on fermentation and again passed through the neutralization (NaOH, pH 7.0) and detoxification steps.

2.5. Influence of factors in acid hydrolysis

The assays were carried out according to the experimental design 2^3 with 3 central points (Table 1) (de Barros Neto et al. 1995) evaluating the influence of the a) hydrolysis time (min); b) H_2SO_4-to-waste ratio (w/w) and c) solid-to-liquid ratio (w/v). The response variables were reducing sugars (g/L) and furans (g/L).

Table 1. Levels that were used to determine the influence of the concentrations of H_2SO_4-to-waste ratio (g/g), solid-to-liquid ratio (g/mL) and time (min) in acid hydrolysis according to 2^3 factorial design.

	Levels		
Factors	−1	0	1
H_2SO_4 to liquid ratio peel (g/g)	0.11	0.37	0.63
Solid to liquid ratio (g/mL)	0.03	0.10	0.17
Time (min)	4.4	15	25.6

2.6. Analytical testing

2.6.1. Chemical composition of acid hydrolysates

Acid hydrolysates were characterized for their monosaccharides by high-performance liquid chromatography (HPLC). The analysis was carried out on a Waters instrument, equipped with a refractive index detector and a BIO-RAD Aminex column HPX 87H (300 7.8 mm; Bio-Rad, Hercules, CA, USA), coupled to a refractive index detector (RID-6A). Sulfuric acid 0.005 mol/L was used as eluent at a flow rate of 0.6 mL/min, column temperature of 45◦C, and injected volume of 20 µL. The samples were previously filtered through a Sep-Pak C18 filter (Sigma Aldrich, USA). Concentrations of furfural and hydroxymethylfurfural (HMF) were also determined by High-Performance Liquid Chromatography Performance (HPLC) on a Waters machine with UV/Vis detector and HP-RP18 (200 × 4.6 mm), coupled to an ultraviolet detector SPD-10A UV–VIS in a wavelength of 276 nm, with eluent acetonitrile: water (1 : 9), and 1% of acetic acid. The used flow was 0.8 mL/min, the column temperature was 25 ℃, and the volume injected was 20 µL.

Sugars and furans of analytical standard were used for the construction of the quantitative standard curves used. Sugar concentration ranged from 0.02 g/L to 4.0 g/L. Furans concentration ranged from 1.0 mg/L to 150 mg/L.

2.6.2. Reducing sugars

The concentration of reducing sugars (RS) was determined by the 3,5-Dinitrosalicylic acid dinitro method –DNS. Samples were centrifuged at 3,500 rpm for 5 min, diluted with distilled water, and added 1 mL of the DNS reagent, and we incubated the mixture in a boiling water bath for 5 min. After cooling to room temperature, we measured the absorbance of the supernatant at 540 nm (Spectrophotometer 600 plus, Fenton, São Paulo). The absorbance values for the substrate and enzyme blanks were subtracted from the absorbance value for the sampled sample. The observed absorbance was correlated to the concentration of reducing sugar using a standard glucose curve [23].

2.6.3. Total Furans

The formation of inhibitory products mainly containing furfural and 5-hydroxymethyl furfural (HMF) after acid hydrolysis stage was monitored as total furans in mg/L as estimated by applying the methodology described by Martinez et al. [24]. Aliquots of the filtrates were previously centrifuged (15 min at 10,500 g); the pH adjusted to 7.0 with 0.1 M phosphate buffer, and absorbance (Spectrophotometer 600 plus, Fenton, São Paulo) was measure at 284 nm and 320 nm. The formula developed by Martinez et al. [24] was used to estimate the total furans in mg/L: Total Furans = (A284 − A320 − 0.056) / 0.127.

2.6.4. Yeast biomass

S. cerevisiae cell growth was determined by measuring the optical density at 600 nm (Spectrophotometer 600 plus, Fenton, São Paulo) of the fermentation broth without centrifugation. Biomass (g/L) was determined using a calibration curve relating biomass (dry weight) to optical density.

2.6.5. Ethanol

Fermented media samples were steam-distilled in a Tecnal model Te-012 micro still before ethanol concentration determination. Ethanol concentration was determined by spectrophotometer (Spectrophotometer 600 plus, Fenton, São Paulo) at 600 nm using the potassium dichromate method [25]. Ethanol yield was calculated as produced ethanol amount divided by the theoretical amount (calculated based on the quantity of sugar in the must) and expressed as a percentage w/w.

2.7. Statistical analysis of results

All the experiments were carried out in triplicates and the data presented are the mean of the results and the standard deviation calculated for each analysis. The influence of the variables using the factorial design was performed using STATGRAPHICS PLUS software (version 4. 1).

3. Results and discussion

We carried out the hydrolysis of the wastes obtaining the hydrolysates. Then we submitted the hydrolysates to the analysis of the composition of their monomers and fermentation inhibitors by HPLC (Table 2). Among the wastes studied, hydrolysates of the peel of *Bactris gasipaes* and the peel of *Manihot esculenta* root had the highest concentrations of the monomers, with total monomers mass of 40.6 and 18.0 g/L, respectively.

Table 2. Concentration of carbohydrate monomers (glucose, xylose and arabinose) and furans (furfural and HMF) in hydrolysates obtained by acid hydrolysis of plant residues obtained from open markets in the city of Manaus (state of Amazonas, Brazil).

Biomass	*Hydrolysates chemical constituents*				
	Glucose (g/L)	Arabinose (g/L)	Xylose (g/L)	Furfural (mg/L)	HMF (mg/L)
Peel of *Bactris gasipaes*	33 ±2	1.0 ±0.1	7.1±0.7	22 ±1	189 ±17
Peel of *Manihot esculenta*	16.3 ±0.07	0.32 ±0.01	1.42 ±0.04	9 ±1	69 ±3
Peel of *Theobroma grandiflorum*	0.2 ±0.1	0.2 ±0.1	2.5 ±0.3	37 ±3	17 ±6
Peel of *Astrocaryum aculeatum*	1.04 ±0.07	2.5 ±0.2	5.5 ±0.5	8 ±2	19 ±4
Straw of *Euterpe oleracea*	0.45 ±0.05	0.59 ±0.07	11.1 ±0.3	71 ±7	32 ±2

We observed that the peels of *Bactris gasipaes* and *Manihot esculenta* were suitable to be converted into substrates rich in fermentable sugars. These two residues also had the highest concentration of starch [26,27]. This result agrees with previous works that demonstrate the better potential of starchy products to produce acid hydrolysates rich in sugars [9].

The sugar content observed in the hydrolysates of *Bactris gasipaes* peel hydrolysate was satisfactory in comparison with results proposed in previous works reported in the literature [8,13,16,28–30]. Oberoi et al. [31] obtained 50.8 g/L of sugar concentration in acid hydrolyzed orange peel. In another study, Chandel et al. [32] got maximum of the release of sugars of 30.29 g/L for acid hydrolysis of sugarcane bagasse.

We did detoxification of the hydrolysate with activated coal. We have done this detoxification to remove fermentation inhibitors as Furfural and Hydroxymethylfurfural (HMF). These inhibitory compounds hinder the growth and metabolism of the microbes during the fermentation process and the severity of their effect on the cell increases with their concentration [33]. The detoxification treatment provided a complete furfural removal. In addition, the detoxification caused a reduction of 71% and 92% of HMF from *Manihot esculenta* and *Bactris gasipaes*, respectively. We also observed a reduction in the concentration of fermentable sugars (glucose, xylose, and arabinose), reaching losses between 17–30% (Table 3).

Table 3. Monomer concentration, furfural, and hydroxymethylfurfural Amazon waste after detoxification by activated carbon.

Biomass	*Hydrolysates chemical constituents*				
	Glucose (g/L)	Arabinose (g/L)	Xylose (g/L)	Furfural (mg/L)	HMF (mg/L)
Peel of *Manihot esculenta*	13.48 ±0.07	0.27 ±0.01	1.19 ±0.05	-	20 ±4
Peel of *Bactris gasipaes*	24 ±2	0.8 ±0.1	5.5 ±0.7	-	14.9 ±0.2
Peel of *Theobroma grandiflorum*	0.2 ±0.1	0.2 ±0.2	1.7 ±0.2	-	-
Peel of *Astrocaryum aculeatum*	0.81 ±0.08	1.9 ±0.2	4.7 ±0.5	-	-
Straw of *Euterpe oleracea*	0.30 ±0.05	0.44 ±0.08	8.2 ±0.3	-	-

**Note:* - Not detected by chromatography.

We obtained concentrations of inhibitors lower than those described in the literature as impeding yeast fermentation. According to Ask et al. [34] the maximum concentrations of HMF and furfural that allow the growth of Saccharomyces cerevisiae strain VTT C-10883 is 1.30 g/L of HMF and 0.40 g/L of furfural. Thus, the concentrations (maximum of 30 mg/L of HMF and free of furfural) of furans present in the detoxified hydrolysates of this study can be considered low enough not to interfere with the production of ethanol. Similar results of detoxification with activated carbon were previous described. Arruda et al. [35] treatment with activated carbon reduced phenols in sugarcane bagasse hydrolysate to 88.5%. Sarawan [36] demonstrated a 98% and 88% removal efficiency for furfural and 5-hydroxymethylfurfural (HMF) respectively, with a 7% reducing sugar loss from acid-pretreated sorghum leaf (SL) wastes.

To investigate the fermentability of the hydrolysates obtained after the detoxification, we concentrated and evaluated the conversion of sugars of the hydrolysates in ethanol in a fermentation assay with *Saccharomyces cerevisiae*. In the assays, the initial sugar concentration in the hydrolysates of *Manihot esculenta* and *Bactris gasipaes* peels were 65.75 g/L and 96.68 g/L, respectively. Sugars were consumed during de fermentation with high fermentability (Figure 1). The yeast produced 29 g/L (2.9% w/w), and 44 g/L (4.4% w/w), of ethanol in 72 h for the cultures conducted in *Manihot esculenta* and *Bactris gasipaes* hydrolysates, respectively (Figure 1). As for the concentration of ethanol achieved, Oberoi et al. [31] report a 1.2% (w/w) of ethanol from acid hydrolyzed orange peel. In another study, Manikandan et al. [37] obtained ethanol production of 9.8% (w/w) from banana peel acid hydrolysate after 120 h fermentation with mutant strains of Saccharomyces cerevisiae.

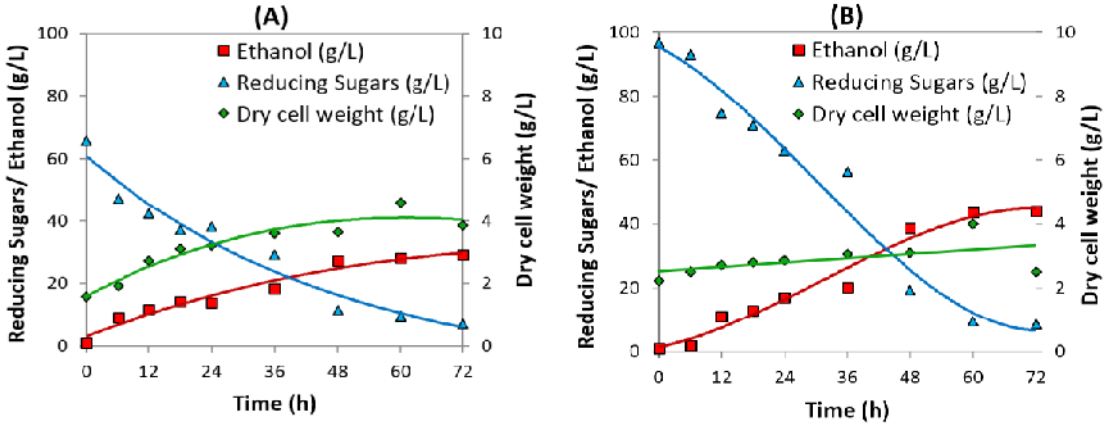

Figure 1. The concentration of reducing sugars (g/L), ethanol yield (g/L), and cell (dry weight, g/L) during alcoholic fermentation of the acid hydrolysate of the peel of *Bactris gasipaes* (A) and peel of the root of *Manihot esculenta* (B).

The peel of *Bactris gasipaes* due to the high content of fermentable sugars in the hydrolysates was selected to investigate the influence of hydrolysis factors in the variables reducing sugars and furans, we carried out hydrolysis experiments according to a factorial design 2^3 investigating the influence of time, H_2SO_4 to waste ratio and liquid to solid ratio. The peel of *Bactris gasipaes* was the residue selected for these experiments. Table 4 shows the levels of factors used and the results of the response variables. The reducing sugar concentration ranged from 1.6 to 48.9 g/L, demonstrating the high effect of the factors investigated.

Table 4. Influence of the factors H_2SO_4-to-residue ratio (g/g), solid-to-liquid ratio (g/mL), and time (min) in the response variables reducing sugars and total furans experiments performed according to a factorial design 2^3 + midpoints.

Exp.	Variables (real values)			Responses	
	H_2SO_4-to-residue ratio (g/g)	Solid-to-liquid ratio (g/mL)	Time (min)	Reducing Sugars (g/L)	Furans (mg/L)
1	0.37	0.10	15.0	25.9	8.8
2	0.63	0.17	4.4	48.9	21.6
3	0.11	0.17	25.6	16.6	12.0
4	0.63	0.03	4.4	6.4	10.0
5	0.11	0.17	4.4	21.7	4.4
6	0.63	0.17	25.6	37.1	22.0
7	0.11	0.03	4.4	1.6	0.6
8	0.63	0.03	25.6	6.1	4.2
9	0.37	0.10	15.0	27.1	6.5
10	0.37	0.10	15.0	23.5	7.4
11	0.11	0.03	25.6	3.0	0.7

The main effects and their interactions calculated from the data in Table 4 are presented in Table 5.

Table 5. Effect of variables H_2SO_4 to residue ratio (A), solid to liquid ratio (B), and their second order interactions (AB; AC; BC) on to produce reducing sugars and furans calculated from the data presented in Table 4.

Effect estimated	Reducing sugars (g/L)	Furans (mg/L)
Average	19.80 ±0.55*	8.92 ±0.35*
A: H_2SO_4-to-residue ratio (g/g)	13.92 ±1.30*	10.02 ±0.82*
B: solid-to-liquid ratio (g/mL)	26.82 ±1.30*	11.12 ±0.82*
C: Time (min)	−3.93 ±1.30	0.57 ±0.82
AB	9.94 ±1.30*	3.57 ±0.82
AC	−2.09 ±1.30	−3.27 ±0.82
BC	−4.47 ±1.30	3.42 ±0.82

***Note:** Standard errors in a pure error with 2 degrees of freedom, *: Effects statistically significant at 95% confidence.

In the statistical analysis, the significant effects in reducing sugars ($p < 0.05$) were: H_2SO_4 to residue ratio (A), solid to liquid ratio (B), and their interaction (AB). The significant factors in furans were: H_2SO_4 to residue ratio (A), solid to liquid ratio (B).

Based on the significant effects, models predicted the sugar and furans content in the hydrolysate as a function of the hydrolysis condition. (Equations 1 and 2).

Reducing sugars (g/L) = 0.94 + 0.27 * A + 90.23 * B + 268.92 * A * B (1)

Furans (mg/L) = 0.94 + 0.27 * A + 90.23 * B + 268.92 * A * B (2)

The analysis of variance (ANOVA) of the mathematical models described by Equations 1 and 2 are presented in Tables 6 and 7, respectively. Both models were significant at 95% confidence, no lack of adjustment, and reaching determination coefficients higher than 80%. Thus, both models were considered suitable for representation as response surfaces.

Table 6. Analysis of variance of the response reducing sugars in the hydrolysates of *Bactris gasipaes* peel under different ratios of H_2SO_4-to-residue ratio (g/g) and solid-to-liquid ratio (g/mL).

Source	Sum of squares	DF	Mean Square	F-Value	*p*- value
Model	2025.3	3	675.1	21.2	0.0007
A: H_2SO_4-to-residue (g/g)	388.0	1	388.0	12.2	0.0102
B: solid-to-liquid ratio (g/mL)	1439.4	1	1439.4	45.1	0.0003
AB	197.9	1	197.9	6.2	0.0415
Residual	223.2	7	31.9		
Lack of Fit	216.5	5	43.3	12.8	0.0739
Pure error	6.8	2	3.4		
Total	2248.5	10			
Coefficient of determination (R^2)		90.1%			
Adjusted coefficient of determination (Adj-R^2)		85.8%			

*Note: *Significant at 95% confidence: $p < 0.05$.

Table 7. Analysis of variance of the response "total furans" in the hydrolysates of *Bactris gasipaes* peels under different ratios of H_2SO_4-to-residue ratio (g/g) and solid-to-liquid ratio (g/mL).

Source	Sum of squares	DF	Mean Square	F-Value	*p*- value
Model	448.5	2	224.3	22.0	0.0006
A: H_2SO_4-to-residue (g/g)	201.0	1	201.0	19.7	0.0022
B: solid-to-liquid ratio (g/mL)	247.5	1	247.5	24.2	0.0012
Residual	81.7	8	10.2		
Lack of Fit	79.0	6	13.2	9.8	0.0955
Pure Error	2.7	2	1.3		
Total	530.2	10			
Coefficient of determination (R^2)		84.6%			
Adjusted coefficient of determination (Adj-^{2})		80.7%			

*Note: **Significant at 95% confidence: $p < 0.05$.

Response surfaces (Figures 2 and 3) describe the behavior of total sugar and furan concentrations as a function of hydrolysis conditions, as predicted by the models (Equations 1 and 2). The responses surface graphs showed that the increase in the H_2SO_4 to waste ratio (g/g) and solid to liquid ratio (g/L) favored the release of sugars in the hydrolysate and the formation of furans (Figures 2 and 3).

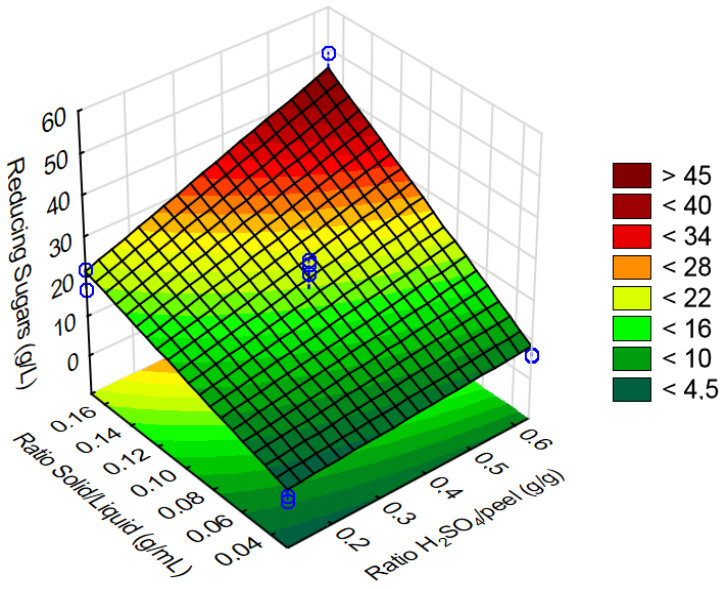

Figure 2. Response surface demonstrating the effect of the ratio solid-to-liquid ratio (g/g) and H_2SO_4-to-waste ratio (g/mL) in the concentration of reducing sugars (g/mL) in the acid hydrolysate of the peel of *Bactris gasipaes*.

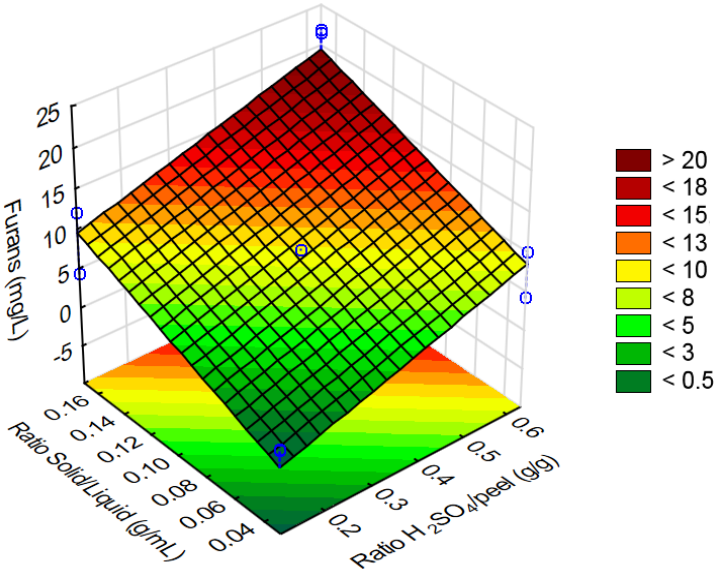

Figure 3. Response surface demonstrating the effect of the solid-to-liquid ratio (g/g) and H_2SO_4-to-waste ratio (g/mL) in the concentration of Furans (mg/L) in the acid hydrolysate of the peel of *Bactris gasipaes.*

The maximum sugar content, approximately 49 g/L of total reducing sugars, was, obtained in hydrolysis using 0.17 solid to liquid ratio (g/mL) and 0.63 H_2SO_4 to waste ratio (g/g) and 4.4-minute reaction times. The total amount of sugars achieved in *Bactris gasipaes* peel hydrolysis, about 49 g/L, was high compared to the literature in studies reporting hydrolysates from various lignocellulosic materials, which generally reached values between 6.9 and 36.5 g/L of total sugars (Table 8). This result shows the great potential of *Bactris gasipaes* peel, as a residue to produce high content of monosaccharide hydrolysates, which can be used as a substrate in bioprocesses such as ethanol production.

Table 8. Optimal parameters for obtaining hydrolysates from various agro-industrial wastes, determined by previous works.

Waste	Concentration of H_2SO_4 w/v (%)	Temperature (℃)	Duration (min)	Total sugar (g/L)	References
Bactris gasipaes	7.4	121	4.4	48.9	Present study
Sugar cane bagasse	7.0	121	45	6.9	Morais and Broetto *et al.*[38]
Brewery waste	2.0	121	15	26.3	Carvalheiro *et al.*[39]
Spent coffee grounds	1.0	162	45	33.5	Mussatto *et al.*[40]
Corn Stover	1.5	120	15	17.8	Kabir *et al.*[19]
Rice Straw	1.5	120	20	15.4	Kabir *et al.*[19]
Wheat Straw	1.5	120	20	20.6	Kabir *et al.*[19]

This study is important since we are presenting the literature wastes from the Amazon biomass able to be used in ethanol production. Open markets from the city of Manaus produce about 35 tons of vegetal residue daily including tons of the peel from the fruit of *Bactris gasipaes* and peel of *Manihot esculenta* root. Instead of their abundance, few studies investigated these vegetal wastes as substrates for biotechnological uses [41]. The results obtained in the present study are auspicious, and this residue of *Bactris gasipaes* of Amazon regional agriculture presents potential as a substrate for acid hydrolysis and ethanol fermentation.

4. Conclusions

Waste management is a huge field and improving methods of collecting, distributing, reusing, transforming, and disposing of wastes is an important work to help protect the interests of the environment and sustain our growing population. Among the wastes studied, hydrolysates of the peel of *Bactris gasipaes* had the highest concentrations of the monomers. After the detoxification treatment provided a complete furfural removal. The reducing sugars generated by the acid hydrolysis of cassava and peach palm peel could be fermented by ethanol. We produced information about the influence of acid/residue ratio, the ratio of solid/liquid, and time in the hydrolysate of the peel of *Bactris gasipaes*. The maximum sugar content, approximately 49 g/L of total reducing sugars, was, obtained in hydrolysis using 0.17 solid to liquid ratio (g/mL) and 0.63 H_2SO_4 to waste ratio (g/g) and 4.4-minute reaction times. This is the first study to submit residues from the Amazon Forest to acid hydrolysis, resulting in important information for discussion of the second-generation biofuel.

Acknowledgments

The authors would like to recognize funding received from Fundação de Amparo à Pesquisa do Estado do Amazonas (FAPEAM); Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES - Pró-Amazônia 2012, N.47); Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq, and Escola de Engenharia de Lorena (EEL-USP) (Analytical assays).

Conflict of interest

The authors have declared no conflict of interest.

Author contributions

The research was designed by João Souza, Érica Souza and Flávia Fernandes; experiments were conducted by Flávia Fernandes, Amanda Farias, Ralyvan Santos, Daiana Torres; analytical tools were provided by João Silva and Livia Carneiro; data were analyzed and interpreted by João Souza, João Silva, Livia Carneiro; and the manuscript was written by João Souza, Flávia Fernandes, João Silva and Érica Souza and then read and approved by all authors.

References

1. Junginger M, van Dam J, Zarrilli S, et al. (2011) Opportunities and barriers for international bioenergy trade. *Energy Policy* 39: 2028–2042.
2. Khatib H (2012) IEA world energy outlook 2011—a comment. *Energy Policy* 48: 737–743.
3. Renewable Fuel Association (RFA), Annual World Fuel Ethanol Production, 2020. Available from: https://ethanolrfa.org/wp-content/uploads/2019/02/RFA2019Outlook.pdf.
4. CONAB (2019) Acompanhamento da safra Brasileira de Cana-de-açúcar - Safra 2019/2020. Monit Agrícola - Cana-de-açúcar 6: 58. Available from: https://www.conab.gov.br/info-agro/safras/cana/boletim-da-safra-de-cana-de-acucar/item/download/31590_6cfbbc41aa04783c69113c50fa499cba.
5. Kovalski G, Herrmann HW, Gallina A, et al. (2014) Ethanol production from fermentation of industrial waste. *Rev Tecnológica* 2014: 13–21
6. Khawla BJ, Sameh M, Imen G, et al. (2014) Potato peel as feedstock for bioethanol production: A comparison of acidic and enzymatic hydrolysis. *Ind Crops Prod* 52: 144–149.
7. Castro YA, Ellis JT, Miller CD, et al. (2015) Optimization of wastewater microalgae saccharification using dilute acid hydrolysis for acetone, butanol, and ethanol fermentation. *Appl Energy* 140: 14–19.
8. Lenihan P, Orozco A, O'Neill E, et al. (2010) Dilute acid hydrolysis of lignocellulosic biomass. *Chem Eng J* 156: 395–403.
9. Arapoglou D, Varzakas T, Vlyssides A, et al. (2010) Ethanol production from potato peel waste (PPW). *Waste Manag* 30: 1898–1902.
10. Cheung SW and Anderson BC (1996) Ethanol production from wastewater solids. *Water Environ Technol* 8: 263142.
11. Taherzadeh MJ, Niklasson C, Lidén G (1997) Acetic acid—friend or foe in anaerobic batch conversion of glucose to ethanol by *Saccharomyces cerevisiae*? *Chem Eng Sc*i 52: 2653–2659.
12. Iranmahboob J, Nadim F, Monemi S (2002) Optimizing acid-hydrolysis: A critical step for production of ethanol from mixed wood chips. *Biomass Bioenergy* 22: 401–404.
13. Karimi K, Kheradmandinia S, Taherzadeh MJ (2006) Conversion of rice straw to sugars by dilute-acid hydrolysis. *Biomass Bioenergy* 30: 247–253.
14. Hu R, Lin L, Liu T, et al. (2010) Dilute sulfuric acid hydrolysis of sugar maple wood extract at atmospheric pressure. *Bioresour Technol* 101: 3586–3594.
15. Canettieri EV, Rocha GJ de M, de Carvalho JA, et al. (2007) Optimization of acid hydrolysis from the hemicellulosic fraction of *Eucalyptus grandis* residue using response surface methodology. *Bioresour Technol* 98: 422–428.
16. Aguilar R, Ramírez JA, Garrote G, et al. (2002) Kinetic study of the acid hydrolysis of sugar cane bagasse. *J Food Eng* 55: 309–318.
17. Sanchez G, Pilcher L, Roslander C, et al. (2004) Dilute-acid hydrolysis for fermentation of the Bolivian straw material Paja Brava. *Bioresour Technol* 93: 249–256.
18. Hsu TC, Guo GL, Chen WH, et al. (2010) Effect of dilute acid pretreatment of rice straw on structural properties and enzymatic hydrolysis. *Bioresour Technol* 101: 4907–4913.
19. Kabir F, Gulfraz M, Raja GK, et al. (2019) Comparative study on the usability of lignocellulosic and algal biomass for production of alcoholic fuels. *BioResources* 14: 8135–8154.
20. Souza O, Schulz MA, Fischer GAA, et al. (2012) Alternative biomass energy: bioethanol from banana peel and pulp. *Braz J Agric Env Eng* 16: 915–921.

21. Oberoi HS, Vadlani P V, Saida L, et al. (2011) Ethanol production from banana peels using statistically optimized simultaneous saccharification and fermentation process. *Waste Manag* 31: 1576–1584.
22. Marton JM, Felipe MGA, Almeida e Silva JB, et al. (2006) Evaluation of the activated charcoals and adsorption conditions used in the treatment of sugarcane bagasse hydrolysate for xylitol production. *Brazilian J Chem Eng* 23: 9–21.
23. Wood IP, Elliston A, Ryden P, et al. (2012) Rapid quantification of reducing sugars in biomass hydrolysates: Improving the speed and precision of the dinitrosalicylic acid assay. *Biomass Bioenergy* 44: 117–121.
24. Martinez A, Rodriguez ME, York SW, et al. (2000) Use of UV absorbance to monitor furans in dilute acid hydrolysates of biomass. *Biotechnol Prog* 16: 637–641.
25. Zimmermann HW (1963) Studies on the dichromate method of alcohol determination. *Am J Enol Vitic* 14: 205–213.
26. Nuwamanya E, Chiwona-Karltun L, Kawuki RS, et al. (2012) Bio-ethanol production from non-food parts of cassava (*Manihot esculenta* Crantz). *Ambio* 41: 262–270.
27. Sanches MA, dos Santos RA, Cortez ACA, et al. (2018) Biosurfactant production by *Fusarium oxysporum* LM 5634 using peels from the fruit of *Bactris gasipaes* (Kunth) as substrate. *Biotechnol J Int* 21: 1–9.
28. Moraes E de JC, Silva DDV, Dussán KJ, et al. (2020) Xylitol-sweetener production from barley straw: optimization of acid hydrolysis condition with the energy consumption simulation. *Waste Biomass Valori* 11: 1837–1849.
29. Jr AP, de Mancilha IM, Sato S (1997) Evaluation of sugar cane hemicellulose hydrolyzate for cultivation of yeasts and filamentous fungi. *J Ind Microbiol Biotechnol* 18: 360–363.
30. Bujang N, Rodhi MNM, Musa M, et al. (2013) Effect of dilute sulfuric acid hydrolysis of coconut dregs on chemical and thermal properties. *Procedia Eng* 68: 372–378.
31. Oberoi HS, Vadlani PV, Madl RL, et al. (2010) Ethanol production from orange peels: two-stage hydrolysis and fermentation studies using optimized parameters through experimental design. *J Agric Food Chem* 58: 3422–3429.
32. Chandel AK, Kapoor RK, Singh A, et al. (2007) Detoxification of sugarcane bagasse hydrolysate improves ethanol production by *Candida shehatae* NCIM 3501. *Bioresour Technol* 98: 1947–1950.
33. Jönsson LJ and Martín C (2016) Pretreatment of lignocellulose: Formation of inhibitory by-products and strategies for minimizing their effects. *Bioresour Technol* 199: 103–112.
34. Ask M, Bettiga M, Mapelli V, et al. (2013) The influence of HMF and furfural on redox-balance and energy-state of xylose-utilizing *Saccharomyces cerevisiae*. *Biotechnol Biofuels* 6: 22.
35. Arruda PV, Chaud LCS, Felipe M das GA, et al. (2008) Effect of the cane bagasse hydrolysate detoxification on the phenols removal, sugars loss and xylose-to-xylitol bioconversion. *Nucleus* 5: 1–17.
36. Sarawan C, Suinyuy TN, Sewsynker-Sukai Y, et al. (2019) Optimized activated charcoal detoxification of acid-pretreated lignocellulosic substrate and assessment for bioethanol production. *Bioresour Technol* 286: 121403.
37. Manikandan K, Saravanan V, Viruthagiri T (2008) Kinetics studies on ethanol production from banana peel waste using mutant strain of *Saccharomyces cerevisiae*. *Indian J Biotechnol* 7: 83–88.

38. Morais APDS and Broetto F (2012) Pre-acid hydrolysis of sugarcane bagasse and its physicochemical characteristics. *Energ Na Agric* 27: 01.
39. Carvalheiro F, Duarte LC, Lopes S, et al. (2005) Evaluation of the detoxification of brewery's spent grain hydrolysate for xylitol production by *Debaryomyces hansenii* CCMI 941. *Process Biochem* 40: 1215–1223.
40. Mussatto SI, Carneiro LM, Silva JPA, et al. (2011) A study on chemical constituents and sugars extraction from spent coffee grounds. *Carbohydr Polym* 83: 368–374.
41. Didonet AA and Ferraz IDK (2014) Fruit trade of tucuma (*Astrocaryum aculeatum* G. Mey-Arecaceae) at local market-places in Manaus (Amazonas, Brazil). *Rev Bras Frutic* 36: 353–362.

AIMS Press

© 2021 the Author(s), licensee AIMS Press. This is an open access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0)