

Expedited extraction of xylan from corncob by power ultrasound

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Abstract: Some lignocellulosic biomass like corncob contains a large amount of xylan, a valuable material for applications in food, chemical and pharmaceutical industries. Conventional extraction of xylan is a time consuming process, requiring 12 to 24 hours to complete. In this study, the efficacy of power ultrasound for reducing the extraction time and increasing the xylan yield was investigated. Two acoustic energy densities (0.18 W/mL and 0.45 W/mL) of the power ultrasound were applied to corncob for 10, 20, 30, and 60 min. The treated samples were steamed at 110, 118 and 121 °C for 30 min. At 0.45 W/mL acoustic energy density and 121 °C steaming temperature, ultrasonic treatment was able to extract 39% of xylan in 43 min. In contrast, the conventional treatment was able to extract only 34% of xylan in 24 h. Power ultrasound assisted extraction reduced the processing time by 97% in addition to yield increase by 14.7%. Power ultrasound can be a potential technology for enhanced xylan extraction from corncob to result in significant processing time savings.

Keywords: Power ultrasound, sonication, lignocellulosic biomass, xylan, extraction, corncob, steaming

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1 Introduction

As global climate change, air quality, and volatility in the fossil fuel market intensify the concerns about renewed interest in alternative fuels, biomass has resurfaced as a source of renewable energy. Use of

lignocellulosic biomass such as corncobs as a biomass feedstock offers promising possibilities for renewable energy production. The United States produces 30–50 million metric tons of corncob annually^[1,2]. Corncob, a major agricultural waste, is abundant in xylan-type hemicelluloses^[3]. Xylan has a wide application in food, medical and chemical industries.

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Researchers have used various conventional and non-conventional technologies to extract xylan. If xylan could be extracted from the lignocellulosic biomass – corncob before it is destined for ethanol production, this would add a great value to the biomass fuel economy.

Xylan in corncob is covalently bonded with lignin and other carbohydrates, thus restricting it from undergoing any chemical changes and enzymatic degradation. Therefore, the raw material should be pretreated to break this bond to expose the polysaccharide components to further enzymatic and chemical reactions. Several pretreatment methods have been developed to break the covalent bonds which exist between xylan and other carbohydrates in corncob. Conventional extraction of xylan is a time consuming process and produces several undesirable products such as reducing sugars and furfural.

Garrote et al.^[4] extracted 28% of xylan from corncob at 170°C by hydro-thermal mixing of water and corncobs using six blade turbine impellers. Yang et al.^[5] developed a dilute sulfuric acid pretreatment to enhance xylan extraction. They have obtained extraction rates of 19.9%, 39.4% and 52.9% at 135, 140 and 150°C steaming temperatures, respectively. Their results indicate that the increase in steaming temperature results in higher extraction rate. However, the increase in steaming temperature also results in an increased concentration of reducing sugars.

The efficacy of high concentration alkaline extraction^[6], low concentration alkaline treatment^[7], and acidic pretreatment^[8] were also investigated for extraction of xylan. Some of these methods are successfully used for xylose, xylitol or butanediol production. However, alkaline extraction and acidic extraction are not suitable for the production of xylo-oligosaccharides, because the former causes serious corrosion and alkali pollution, while the later produces a large amount of xylose in the hydrolysate.

Due to the limitations of the conventional pretreatment methods, there is a need for a better pretreatment method which can effectively break the bonds in a short duration and maximize the xylan

production. Power ultrasound has demonstrated a promising trend to achieve this goal^[9-12],

Ultrasonication is the application of high-intensity, high frequency sound waves (normally in the range of 20-100 kHz) to liquid or gaseous media. The propagation and interaction of sound waves alter the physical and chemical properties of materials that are subjected to ultrasonication due to its cavitation effect^[13]. Cavitation induces localized high temperature and pressure and results in the production of highly reactive free radicals, such as OH[•], H⁺, H₂O₂, and H₂O₂, thus enhancing chemical reactions. The sonomechanical effect of ultrasound enhances the penetration of the solvent and heat into cellular material and thus improves the mass transfer. The use of ultrasound also results in disruption of biological cell walls to facilitate the release of cellular contents^[14].

Power ultrasound has been proven to significantly enhance the extraction rate of proteins, medicinal compounds and other agricultural food products. The application of ultrasound has also significantly improved the pectin production and the industrial productivity of medicinal tinctures from herbs^[15]. Extraction of polysaccharides from plants has also been enhanced by the application of ultrasound^[11]. Hromadkova et al.^[10] reported that 36% of xylan was extracted from corncob with 5% NaOH solution at 60°C for 10 min of ultrasonication. The xylan extracted by these researchers was in turn used in immunogenic tests, and results showed that the immunogenic property of xylan was affected by ultrasonication, but there was no significant decrease in the biological response at the tested conditions^[9].

Wang and Zhang^[12] also studied the effect of ultrasonication on the extraction of xylan from corncob. In this study, different molar solutions of NaOH at a corncob to solution ratio of 1:25 (w/w) was used for the extraction, with sonication conducted at 200 W power level for 30 min at 60°C. The study suggested that as the sonication time increased, the extraction rate increased until 30 min treatment and no significant increase observed thereafter. The extraction rate was also

increased as the power of ultrasound increased.

As the literature review substantiates, application of ultrasound has potential to improve the extraction of xylan from agricultural wastes. Conventional process of dilute acid treatment developed by Yang et al.^[5] also produced a higher extraction rate with acceptable levels of reducing sugars. Therefore, this study investigates the efficacy of combined dilute acid and ultrasound treatment for enhanced xylan extraction.

2 Materials and methods

2.1 Materials

The lignocellulosic biomass used in this study was corncob in a powder form. The corncob powder was produced by the Mt. Pulaski Products Inc, IL, USA in a hammer mill with a 0.8 mm (1/32") screen. As per the supplier, the original xylan content of this corncob was 32.6% on average, which was measured following an HPLC procedure.

2.2 Ultrasound equipment and acoustic energy density determination

Two probe-type ultrasound processors: i) Model S3000 ultrasonic processor (Misonix Inc., NY) with a 350 W power rating at an output frequency of 20 kHz, and ii) Ultrasonic IL 1000-6/2 unit (Ultrasonic Technique – Inlab Ltd., Saint-Petersburg, Russia), working at frequency 22 kHz with power rating of 1000 W, were used in this study.

Sonation power density or acoustic energy density (AED) was examined for both ultrasound units used in this study. The power density of the unit depends upon mass or volume of the sample taken for sonication. For the sample subjected to sonication, the temperature (T) was recorded with a thermometer as a function of time. The rate of temperature rise ($\Delta T/\Delta t$) was calculated for 30 s time interval. The average AED for each unit was calculated as the average power divided by the volume of water used in the test. The resultant AEDs for both units are summarized in Table 1.

2.3 Corncob pretreatments by conventional methods

A 10-g corncob sample was soaked in dilute sulfuric acid (2% H_2SO_4 , 1:10 w/v ratio) at 50°C for 24 h (Figure 1). The extract was separated by filtration. The residue

Table 1 Determination of acoustic energy density (AED) levels

	Unit 1 (Ultrasonic Technique, Inlab Ltd, St. Petersburg, Russia)	Unit 2 (Misonix Model S3000 ultrasonic liquid processor)
Change in temperature (ΔT)/°C	16	6.5
Duration of time (Δt)/s	30	30
AED/W · mL ⁻¹	0.45	0.18

was washed with water before being subjected to steaming. This pretreatment helps in breaking the covalent bonds between lignin and xylan present in the corncob, thus releasing xylan.

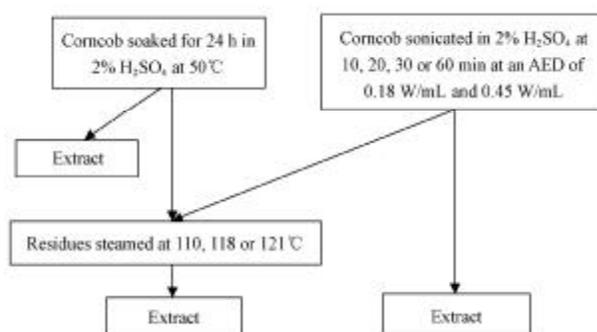


Figure 1 Flow diagram of the experimental setup

2.4 Corncob pretreatments with sonication

Corncob (10 g) was placed in dilute sulfuric acid (2% H_2SO_4 , 1:10 solid to liquid ratio) and subjected to sonication for 10, 20, 30 or 60 min at AEDs of 0.45 W/mL and 0.18 W/mL. The sonicated sample was filtered and washed with tap water before subjected to steaming (Figure 1).

2.5 Steaming of pretreated samples

The pretreated samples were placed in a stainless steel vessel and subjected to steaming in an autoclave (Market Forge Industries, Inc., MA). This process was carried out for 30 min at 110, 118, or 121°C (Figure 1). These temperatures were selected with reference to Yang et al.^[1,5] and consideration of maximizing xylan extraction and minimizing the production of reducing sugars and other undesirable products. After steaming, the steamed sample was blended with 100 mL of water at 16000 r/min for 2 min (G-value \approx 15000). For chemical analysis, the slurry obtained after the extraction was filtered by gauze. The filtered sample was chemically tested for the presence of xylan.

2.6 Chemical analysis of the extracts

The amount of xylan present in the extracts following pretreatments and steaming could be determined through measuring the total soluble sugar content. This is because the total soluble sugar present in the extract consists of the soluble xylan and xylooligosaccharides^[1,5], but since the content of xylooligosaccharides is very low in the extract according Yang et al.^[5] and the solubilization of cellulose in the corncob is negligible under the pretreatment and extraction conditions used in this work, the total soluble sugar would be a close indication of the amount of xylan present in the sample. On the other hand, xylooligosaccharides are also favorable products of the extraction process, because after enzymatic conversion of xylan, the target products are xylooligosaccharides. It is therefore equally good to obtain xylan or xylooligosaccharides during the extraction process. Because of this, in this study the small quantity of xylooligosaccharides was counted into xylan extraction for simplicity purpose.

Therefore, xylan content was estimated by measuring the total soluble sugar content in the filtrate, as expressed below^[5]:

$$\text{Percentage xylan in the extract} = \left(\frac{\text{Total soluble sugar (xylan) in the extract}}{\text{Xylan in the raw material}} \right) \times 100 \quad (1)$$

Analysis of the total soluble sugars followed the standard Anthrone method^[16,17]. Absorbance of the extracted samples at 630 nm were determined using an UV-Visible Spectrophotometer (Genesys 6, Thermo Electron Corporation, Waltham, MA). According to the Anthrone method^[16], a standard curve is developed using glucose (Sigma chemicals, St. Louis, MO), and a pre-determined factor was considered when plotting the absorbance values at concentrations of 0.01, 0.02, 0.03, 0.04, and 0.05 mg/mL to yield the standard curve. Anthrone reagent used in the measurement was prepared by dissolving 2 g of Anthrone in 1 liter of cold 95% sulfuric acid.

2.7 Kinetic modeling for ultrasound enhanced extraction of xylan

Three reaction kinetic models (Equations (2) to (4)) were used in this study. Equation 2 is a 1st order model,

Equation 3 a 2nd order model, and Equation 4 a Michaelis-Mention type mixed order model^[1]. The models were applied to determine the kinetic correlation between xylan concentration and sonication time. The data under the three steaming temperatures were combined into one grand set of data for development of an overall kinetic model. The model parameters such as k , a and b , were determined using linear regression with Excel (Version 2003, Microsoft corporation, Redmond, VA).

$$\ln \left(1 - \frac{C}{C_0} \right) = -kt \quad (2)$$

$$\frac{C}{C_0(C_0 - C)} = kt \quad (3)$$

$$\frac{1}{C} = a \frac{1}{t} + b \quad (4)$$

where, C — xylan concentration in the supernatant, g/L; k , a , b — kinetic rate constants; C_0 — initial concentration of xylan in the raw corncob sample (32.6 g/L); t — time, min.

2.8 Statistical analysis

Experimental results were analyzed by analysis of variance (ANOVA) using SAS (Version 9.0, SAS corporation, Raleigh, NC). Means of xylan extraction were compared using Tukey's Studentized range test at 5% level of significance. Linear curve-fitting (regression) was conducted on the Excel (Version 2003, Microsoft Corporation, Richmond, VA). The goodness-of-fit of the models was judged by both the coefficient of determination (R^2) and the coefficient of variation (c.v.%), which was calculated as the grand average of the relative percent difference between the model estimated values and the measured data.

3 Results and discussion

3.1 Xylan extraction rates by the conventional method

The total extraction rate of the sample was calculated using:

$$\text{Extraction percentage} = \frac{\text{Total soluble sugar in the extracted sample}}{\text{Initial xylan concentration in the corncob}} \times 100 \quad (6)$$

where the initial concentration of xylan in corncob was set at 32.6 g/L.

The xylan extraction rates immediately after conventional pretreatment (24 h) and steaming (30 min), as well as the total xylan extraction rates at different steaming temperatures (110, 118, and 121°C) are listed in Table 2. Approximately, 29.1% of the initial xylan content in the corncob was extracted by the conventional pretreatment used in this study (Table 2). Steaming resulted in more extraction of xylan, for instance, 7.3%, 8.2%, and 8.8% extraction of xylan at 110, 118, and 121°C steaming, respectively. This indicates that steaming enhanced xylan extraction, possibly because of the following two reasons: 1) more covalent bonds with lignin and other carbohydrates were broken during steaming, thus releasing more xylan; 2) although corncob was washed with water before steaming, there was still some H₂SO₄ remaining in the corncob and acid hydrolysis could still take place at an elevated temperature. However, the former might have played a bigger role in increased xylan extraction.

Table 2 Extraction of xylan by conventional pretreatment and steaming

Extraction due to 24 h pretreatment	Steaming temperature °C	Extraction due to 30 min steaming	Total extraction
29.1±0.5%	110	7.3±0.3% ^{a*}	36.4±0.3 ^a
29.1±0.5%	118	8.2±0.3% ^b	37.3±0.3 ^b
29.1±0.5%	121	8.8±0.2% ^b	37.9±0.2 ^b
Average			37.2

* Values with same superscripts in column are not significantly different ($p \leq 0.05$).

Tukey's Studentized range tests indicated that the extraction rates due to steaming at 118 and 121°C were significantly different from the extraction rate at 110°C ($p < 0.05$). However, there was no statistical difference between extraction rates at 118 and 121°C. Similarly, the total extraction rates (extraction due to pretreatment + extraction due to steaming) for the conventional treatment at 118 and 121°C steaming temperatures were significantly different from that corresponding to 110°C steaming temperature ($p < 0.05$), and no significant

difference was found in total extraction rates between 118 and 121°C steaming temperatures. The temperature difference has to be large enough to have the additional energy required to break the bonds and increase xylan extraction. The average total extraction rate for conventional pretreatment and steaming was 37.2% (Table 2). This value was used for comparison of total extraction rates by ultrasonication.

As discussed earlier, Yang et al.^[5] studied the effect of steaming temperature on the extraction rate of xylan from corncob using 1% H₂SO₄ as soaking solvent. The soaking was conducted at a water bath temperature of 60°C for 12 h, resulting in a total extraction rate of 20% at 135°C of steaming temperature. In the present study, the extraction was significantly increased by using 2% H₂SO₄ as soaking solvent at water bath temperature of 50°C for 24 h. For instance, an extraction rate of about 38% was obtained at 121°C of steaming temperature (Table 2). Therefore, the use of higher concentration of H₂SO₄ for longer duration may result in further breakdown of the covalent bonds and release of more xylan. However, the overuse of acidic solvents may produce a large amount of xylose in the hydrolysate which is undesirable for the subsequent production of xylooligosaccharides.

3.2 Xylan extraction rates by ultrasonication

The extraction rates by ultrasound pretreatment and steaming are given in Table 3. Results show that ultrasonication resulted in increased extraction of xylan at 0.45 W/mL AED level. For instance, the total extraction rates at 110, 118, and 121°C were 36.4%, 37.3%, 37.9% for the conventional pretreatment for 24 h, while they were 39.3%, 39.9%, and 40.7% for sonication at 0.45 W/mL AED level for 60 min. Also, the total extraction rates increased with increased sonication durations. For example, extraction rates of 10.0%, 14.6%, 22.2%, and 29.1% were obtained after 10, 20, 30, and 60 min sonication at 0.18 W/mL AED level (Table 3). Longer ultrasonication would increase accumulated cavitation effect, which would possibly lead to increased breakage of covalent bonds between xylan and lignin, thereby releasing more xylan to the solution.

Table 3 Extraction of xylan by ultrasound pretreatment and steaming

Sonication duration /min	AED: 0.18 W/mL			AED: 0.45 W/mL		
	Temperature /°C					
	110	118	121	110	118	121
10	^A 10.0 ± 0.9 ^{a*}	^{AB} 11.6 ± 1.4 ^a	^B 12.3 ± 1.6 ^a	^A 14.7 ± 0.6 ^{a*}	^{AB} 16.7 ± 1.4 ^a	^B 17.4 ± 2.0 ^a
20	^A 14.6 ± 1.1 ^b	^{AB} 15.5 ± 1.0 ^b	^B 16.5 ± 0.7 ^b	^A 22.0 ± 1.5 ^b	^{AB} 23.0 ± 1.4 ^b	^B 23.6 ± 1.9 ^b
30	^A 22.2 ± 0.7 ^c	^{AB} 22.5 ± 0.7 ^c	^B 23.6 ± 0.9 ^c	^A 29.9 ± 1.5 ^c	^{AB} 30.3 ± 1.4 ^c	^B 31.0 ± 2.2 ^c
60	^A 29.1 ± 0.5 ^d	^{AB} 30.0 ± 0.6 ^d	^B 30.3 ± 1.6 ^d	^A 39.3 ± 0.8 ^d	^{AB} 39.9 ± 0.5 ^d	^B 40.7 ± 0.5 ^d

*Values not preceded by the same upper case letters in the same column are significantly different from each other ($p \leq 0.05$). Values not followed by the same lower case letters in superscript in the same row are significantly different from each other ($p \leq 0.05$).

However, extended application of sonication may reduce the degree of polymerization and produce oligomers and even monomers (e.g., xylose). For example, it may result in rupture of xylan structure itself, making it not suitable for further chemical or enzymatic reactions^[9]. Therefore, there is a trade-off with respect to sonication duration.

Increase in the AED level resulted in increased extraction of xylan. Higher AED levels induced more cavitation effects, and as a result led possibly to more effective bond breakage, enabling extraction of more xylan. This is evident from the extraction rates of 30.3% and 40.7% obtained with AED levels of 0.18 and 0.45 W/mL, respectively at 121°C after 60 min of sonication. At all the tested conditions, AED level of 0.45 W/mL resulted in higher extraction than AED level of 0.18 W/mL. Increasing AED levels beyond 0.45 W/mL, may lead to further increase in the extraction.

A similar study was conducted by Hromadkova et al.^[10] using 250 mL of 1% and 5% NaOH as the solvent at acoustic power levels of 100, 200 and 270 W. The extraction rate achieved in their study was 37% using 5% NaOH sonicated for 10 min. In our study, a 10-min sonication yielded extraction rates of 10%, 11.6% and 12.3% at 110°C, 118°C and 121°C steam temperatures, respectively. Even after a 60-min sonication at 0.18 W/mL AED, only about 30% extraction rate was achieved. The lower extraction rate obtained as compared to the results of Hromadkova et al.^[10] was due to the lower acoustic energy density used in the study. Hromadkova et al.^[10] used AED levels of 0.4 to 1.08 W/mL as opposed to 0.18 W/mL and 0.45 W/mL used in this study. However, extraction rate of 40.7%

was obtained at an AED level of 0.45 W/mL after steaming at 121°C for 60 min. Therefore, the modified pretreatment method used in this study (i.e., sulfuric acid pretreatment at 0.45 W/mL AED) could enhance the xylan extraction rate, although a longer application time of sonication was necessary to compare to Hromadkova et al.^[10].

The total extraction rates at 0.18 W/mL AED were less than that by the conventional method for the sonication durations tested in this study. For example, at 121°C steaming temperature and 60 min sonication duration, the total extraction rate was 30.3% (Table 3), which was less than the average extraction value (37.2%) by the conventional method. However, there was a different picture in this regard for 0.45 W/mL AED level.

Steaming had a significant effect on xylan extraction rates. Increased steaming temperature resulted in increased extraction of xylan for both AED levels. For instance, extraction rates of 14.6%, 16.7%, and 17.4% were obtained at 110, 118, and 121°C, respectively, for samples treated with ultrasound for 10 min at 0.45 W/mL AED. Similarly, the extraction rates of 10.0%, 11.6%, and 12.3% were achieved after a 10 min ultrasound treatment at 0.18 W/mL at 110, 118, and 121°C, respectively.

The effect of steaming temperature for the ultrasound pre-treated corncob samples is given in Table 4. Statistical results show that there was no significant difference in the extraction rates between 110°C and 118°C, and between 118°C and 121°C steaming temperatures. However, a significant statistical difference existed between the steaming temperatures of 110°C and 121°C in the extraction rates at both AEDs.

This indicates that the temperature gradient has to be large enough to provide the necessary energy available for bond breakage in order to have a significant effect.

Table 4 Effect of 30 min steaming on xylan extraction rates

AED/W · mL ⁻¹	Steaming Temperature /°C		
	110	118	121
0.18	4.4 ± 0.7 ^a	5.4 ± 1.0 ^{ab}	6.1 ± 1.2 ^b
0.45	4.0 ± 0.9 ^a	5.0 ± 1.2 ^{ab}	5.9 ± 1.5 ^c

* Means were separated using the Tukey's Studentized test ($p \leq 0.05$).

3.3 Kinetic modeling

Three kinetic models (Equations (2) to (4)) were used to fit the experimental data using Excel. During the regression, data sets at the three steaming temperatures at each AED were combined to develop a grand kinetic model. The resultant model constants (i.e., k , a , and b) as well as the coefficient of determination (R^2) are listed in Table 5.

Table 5 Constant values for the kinetic models for extraction of xylan

Kinetic Models	Model Constants			
	k	a	b	R^2
1 st order kinetic	0.0097	NA	NA	0.70
2 nd order kinetic	0.0004	NA	NA	0.86
Michaelis-Menton	NA	1.3511	0.0581	0.93

From the R^2 values, it can be seen that the Michaelis-Menton kinetic model outperformed both the first and second order kinetic models in representing the ultrasound assisted xylan extraction process at all the steaming temperatures (Table 5). The research results also agreed with those obtained by Yang et al.^[1] in terms of xylan hydrolysis (extraction) in their study. They had concluded that neither first-order nor second-order reaction kinetics were suitable for their kinetic data of xylan extraction; however, the mix-order kinetic model, i.e., the Michaelis-Menton equation, well represented the data. Nevertheless, in some other studies of xylan extraction such as Garrote et al.^[4] and Nabarlatz et al.^[18], xylan hydrolysis was reported to follow a first-order reaction kinetic model.

Figure 2 shows the goodness-of-fit of the three kinetic models tested in this study to the measured data. The calculated c.v.% for the first-order kinetic,

second-order kinetic and Michaelis-Menton models were 23%, 14% and 6%, respectively. The low c.v.% for the Michaelis-Menton model indicates that the model represented the xylan extraction kinetics reasonably well.

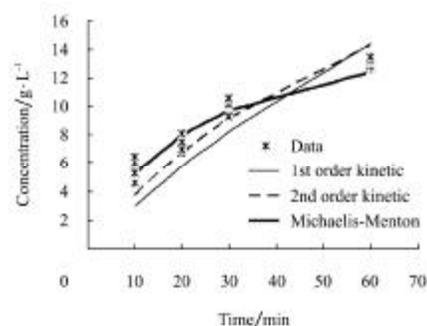


Figure 2 Kinetic models for power ultrasound enhanced extraction of xylan from corncob

3.4 Significant processing time reduction by power ultrasound

To determine the magnitude of processing time saving when power ultrasound was used to enhance xylan extraction, the data under 121°C steaming temperature and 60 min sonication duration in Table 3 were chosen to exemplify the calculation. Interpolation was taken on the extraction rates for the sonication durations between 30 min (31.0%) and 60 min (40.7%) in order to determine the sonication time when the extraction rate was 37.2% (i.e., the mean extraction rate by the conventional method). This resulted in a sonication duration of about 49.2 min. This was the ultrasound enhanced processing time as opposed to the conventional processing time used in this study (24 h). Therefore, power ultrasound at 0.45 W/mL AED level could reduce the xylan extraction processing time by approximately 97% in the 2% sulfuric acid solution.

How did the conventional extraction rate at 49.2 min compare to that of sonication (i.e., 37.2%) at the same treatment time? Although in this study the conventional extract rate was not measured at other durations than 24 h, an estimate of it could be obtained from Fig. 1a in Yang et al.^[1] that measured the conventional extraction rates from 0 to 360 min in similar conditions (i.e., 1% sulfuric acid solution at 60°C, 125°C steaming temperature as opposed to 2% sulfuric acid solution at 50°C, 121°C steaming temperature in this study). The

conventional extraction rate for 49.2 min turned out to be around 12.5%, which was much lower than that by sonication (i.e., 37.2%).

4 Conclusions

Power ultrasound can be effectively used to enhance xylan extraction from the lignocellulosic biomass-corn cob. The steaming temperatures (in the range of 110 to 121 °C as tested in this study) and ultrasonic power densities (0.18 and 0.45 W/mL) had a significant effect on xylan extraction rates. Kinetic studies indicated that the mix-order kinetic model (Michaelis-Menton model) could represent the kinetic data of ultrasound assisted extraction of xylan from corn cob better than either the 1st-order or the 2nd-order kinetic models. It was found that power ultrasound greatly enhanced xylan extraction rates. Use of power ultrasound at the acoustic energy level of 0.45 W/mL significantly reduced the xylan extraction time from 24 h in the conventional process to about 49 min in the sonication process, accounting for approximately 97% reduction in the processing time. Power ultrasound can be potentially used to reduce the processing time and increase the yield of xylan in the industry.

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