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Organosolv fractionation of palm tree residues

Iwona Cybulska[a]*, Grzegorz Brudecki[a], Jens Ejbye Schmidt[a], Mette H. Tomsen[a]

[a]Masdar Institute of Science and Technology, Abu Dhabi, UAE

Abstract

Palm tree trimmings represent primary landscaping residue in the United Arab Emirates, making it an easily accessible feedstock for bio-based products generation. This study examines organosolv treatment of the palm fronds as a method of delignification and fractionation of this lignocellulosic biomass. The results revealed that treating palm fronds with ethanol-water mixture at elevated temperature (200°C) results in up to 43% lignin recovery with no catalyst added. This corresponds to production of 13g lignin per 100g raw dry biomass. Over 90% glucan was found to be retained in the solid fiber fraction after the treatment, producing cellulose-rich pulp.

Keywords: Organosolv treatment, palm tree, lignin, bio-fuels

1. Introduction

Current energy needs and increasing crude oil prices are the driving force for exploring new energy resources. Lignocellulosic biomass is considered very attractive as a feedstock for valorization by generation of bio-fuel (including bioethanol), and products due to its complex structure and natural abundance [1]. One of the most common biofuel feedstocks groups is represented by agricultural, gardening and municipal residues. Palm trimmings, including palm fronds (leaves and branches) and trunks, are the most common landscaping residue found in the United Arab Emirates.

Organosolv treatment is a method that can be used as simultaneous biomass pretreatment and fractionation, since it removes lignin from the lignocellulose, and makes the cellulose more digestible at the same time [1]. The principle of organosolv treatment is dissolving the lignin component in an organic solvent (e.g. ethanol, acetic acid, acetone, methyl isobutyl ketone), while the cellulose fraction remains in

* Corresponding author. Tel.: +971 2810 9241;
E-mail address: icybulska@masdar.ac.ae

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the solid [2]. In some processes, water is added to the solution in order to extract hemicellulose components and by-products, and to obtain higher purity of the desired cellulose and lignin streams [3,4]. Organosolv lignin is easily recoverable and relatively pure (i.e., low in ash and carbohydrate contamination), which makes it an attractive source of phenolic compounds which can be used to produce resins, chemicals, or pharmaceuticals [5-7].

Due to relatively high lignin content (30%DM) in the palm fronds fraction of the landscaping residues of Abu Dhabi, a study was performed to examine suitability of this feedstock to produce pure streams of lignin and sugars. Organosolv treatment was used as the fractionation method using relatively low overall toxicity of the process.

Nomenclature

DM – dry matter

SA – sulfuric acid

OST – organosolv treatment

2. Materials and methods

2.1. Palm fronds

The feedstock material has been collected from a local farm, air-dried and milled to produce 1mm particle size powder.

2.2. Raw material characterization

Milled palm fronds have been subjected to a typical 2-step chemical characterization for lignocellulosic materials including:

- Analysis of extractives (via Soxhlet extraction) [8]
- Analysis of carbohydrates and lignin (via strong acid hydrolysis) [9]

2.3. Organosolv treatment (OST)

The treatment was performed in a high-pressure reactor (Parr Instrument Company, Moline, IL) with a capacity of 1 L. Biomass loading was 10% and the digesting solvent was an aqueous solution of ethanol in varying concentration. The treatment was performed at different temperatures and catalyst (sulfuric acid) was added to some of the runs. The experimental plan has been presented in Table 1. Time of the treatment was maintained constant at 60 min. All of the runs were performed in duplicates. The experimental plan was generated using a full central component design for 3 factors.

Table 1. Experimental plan of the OST

Run number	Temperature [^oC]	Ethanol content in the solvent [% w/w]	SA concentration in the solvent [% w/w]
1	140	60	0
2	200	60	0
3	140	60	1.5
4	200	60	1.5
5	140	80	0
6	200	80	0
7	140	80	1.5
8	200	80	1.5

After the treatment, solid (cellulose-rich fibers) were separated from the liquid, and lignin was precipitated from the liquid fraction. Cellulose fibers were then characterized for carbohydrate content to determine their recovery after the OST [9]. Hemicellulose recovery in the pulp was calculated based on the sum of xylan and arabinan remaining in the pulp after the organosolv treatment.

3. Results

3.1. Raw material characterization

Palm fronds were found to be rich in both carbohydrates and lignin, making them an interesting typical lignocellulosic substrate (Figure 1). Lignin content of 30% DM suggests that low severity, simple pretreatment such as hydrothermal pretreatment could not be suitable for this biomass, and thus extracting lignin prior to further processing might be advantageous. Glucan content of about 20% suggests that this biomass can be suitable for bioethanol fermentation.

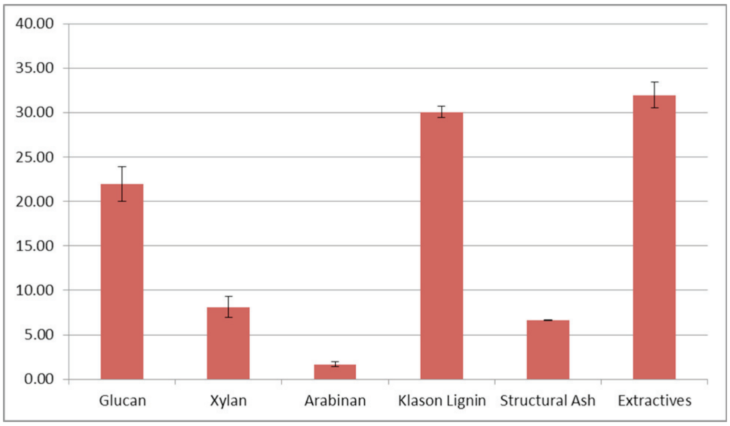


Fig. 1. Palm fronds composition [g/100gDM]

3.2. OST mass balance

Mass balance of the OST process showed low overall biomass losses (3-9%), with high solids recovery (Figure 2a). Lignin extraction was effective in 14-43%, and the highest lignin recovery was found in the sample treated at 200^{o}C, with digesting solvent containing 80% ethanol and no catalyst (Figure 2b). High temperature and high organic content in the digesting solvent seems to promote lignin extraction from the biomass, regardless of the catalyst addition. Generally, higher organic content in the digesting solvent is advantageous, as it promotes fresh water conservation.

Avoiding catalyst use is also an advantage, lowering the toxicity of the process and costs of the chemical recovery. Lignin is considered an interesting bio-substrate for production of value-added chemicals and biopolymers, which makes it a desired fractionation output stream. Due to high lignin content in the raw biomass this result gives a value of 13g lignin/100g dry raw biomass.

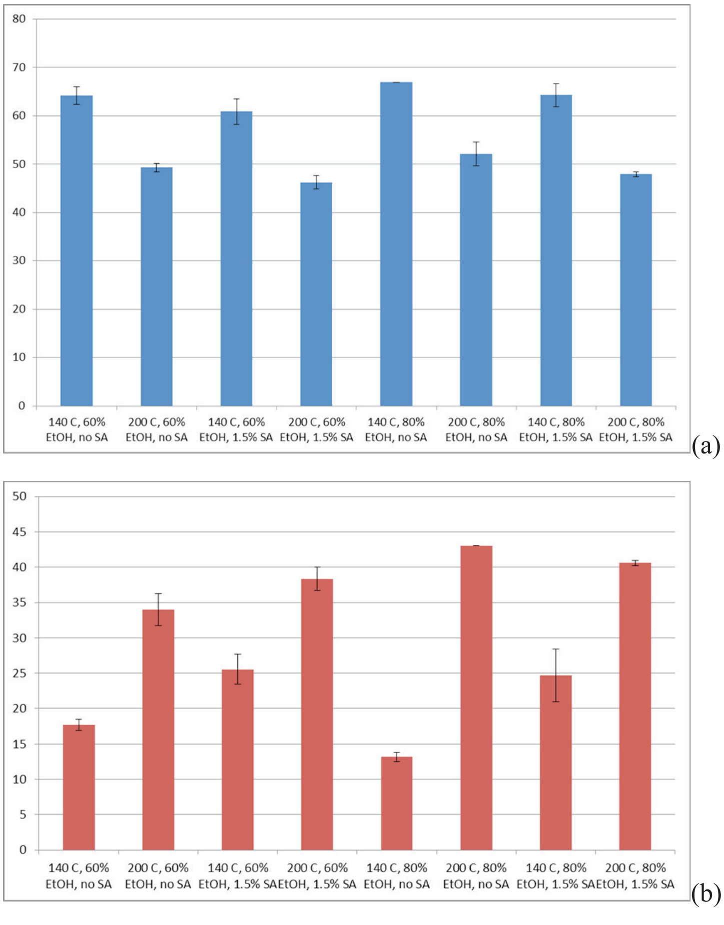
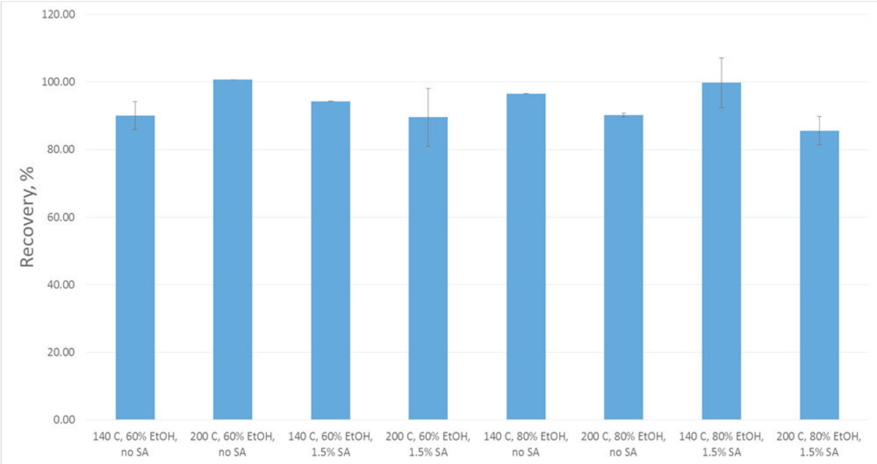
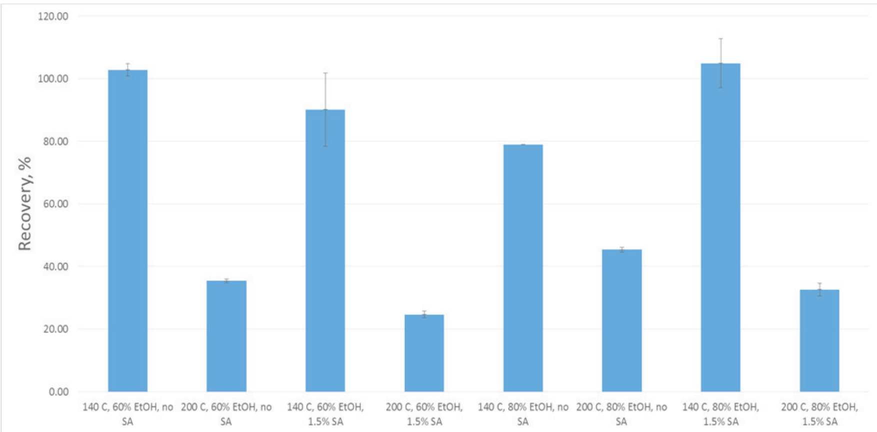


Fig. 2. (a) Solid recovery after the OST [%]; (b) Lignin recovery from the liquid fraction after the OST [%]

Glucan was mainly retained in the solid fraction (up to over 90%), suggesting suitability of the pulp as a substrate for obtaining glucose (Figure 3a). High glucan recovery in the solid shows a good fractionation efficiency and applicability of the solid fibers as a feedstock in generation of glucose. Hemicellulose recovery was dependent on temperature, being removed from the solid more efficiently at higher temperature (200^{o}C) (Figure 3b). However, statistical analysis of the data will be performed to prove significance of the influence of the factors. Recovery exceeding 100% in this case is most probably caused by underestimated xylan amount in the original raw biomass due to the fact that less than 100% of xylan was hydrolyzed by the strong acid hydrolysis.



(a)



(b)

Fig. 3. (a) Glucan recovery in the solid after the OST; (b) Hemicellulose recovery in the solid after the OST

4. Conclusion

The results of the palm fronds fractionation using a relatively mild organosolv treatment revealed that the biomass can be efficiently delignified at 200^{o}C, using high organic content in the digesting solvent (80% w/w) and with no catalyst added. Lignin can be recovered in the amount of 13g lignin/100g dry raw biomass, which is comparable with typical lignocellulosic materials (e.g. switchgrass), pretreated with higher toxicity conditions [10]. Most of the glucan present in the raw biomass was retained in the solid fiber fraction, making it a cellulose-rich output stream, which is also a desirable substrate for e.g. bioethanol production or pulp and paper.

5. Acknowledgement

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Biography

Dr. Iwona Cybulska is a Post Doctoral Researcher at Masdar Institute of Science and Technology in Abu Dhabi. Her research focuses on the halophytic plant species and waste utilization for bioenergy and bioproducts. She is an author and co-author of several peer-reviewed publications, book chapters and conference contributions on the biofuels production.