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Towards integrated biorefinery from dried distillers grains: Selective extraction of pentoses using dilute acid hydrolysis

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ABSTRACT

The abundant availability and high level of hemicellulose content make dried distillers grains (DDG) an attractive feedstock for production of pentoses (C5) and conversion of C5 to bioproducts. One target of this work was to produce a C5 extract (hydrolyzate) with high yield and purity with a low concentration of C5 degradation products. A high selectivity towards pentoses was achieved using dilute acid hydrolysis of DDG in a percolation reactor with liquid recirculation. Pretreatment of starting material using screening and ultrasonication resulted in fractional increase of the pentose yield by 42%. A 94% yield of pentoses on the DDG (280.9 g kg^{-1}) was obtained. Selective extraction of individual pentoses has been achieved by using a 2-stage hydrolysis process, resulting in arabinose-rich (arabinose 81.5%) and xylose-rich (xylose 85.2%) streams. A broader impact of this work is towards an *Integrated Bio-Refinery based on DDG* – for production of biofuels, biochemical intermediates, and other bioproducts.

1. Introduction

In recent years, significant research effort has been dedicated to the development of economically viable methods for conversion of lignocellulosic biomass, one of the most abundant and largely unused renewable resource on our planet, into bioproducts such as fuels and chemicals [1–3].

The biomass can be residue from farming, byproducts from agricultural and industrial processing, or from crops grown solely for the purpose of energy production. However, biomass inherently has some drawbacks for use as starting material for fuels, chemicals, and other biomaterials [4,5]. The drawbacks include: low bulk density, leading to high storage and transportation costs; lower shelf life compared to petroleum (the biomass is dried to improve shelf life, thus adding to its cost); and its processing to sugars leaves residue, which needs to be handled. All these add to the overall cost of biomass processing, as shown in Fig. 1. In order to reduce the impact of the cost of feedstock on the overall production cost,

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Zhang [5] suggested some of the top priorities of biomaterials R&D to be: 1) cost-effective release of sugars from lignocellulose and 2) co-utilization of lignocellulose components for the production of value-added compounds that subsidize whole biorefineries.

Our goal is to develop an integrated approach for making bioproducts from biomass in order to contain the impact of the high feedstock cost on the overall process economics (Fig. 2). In this approach, we chose dried distillers grains (DDG) as our low cost renewable raw material. With an increasing demand for ethanol-based fuels, DDG – which is the major by-product of dry grind corn ethanol production – is a highly desirable biomass starting material. For an estimate, about 7% by weight of corn is seed hull (pericarp) fiber biomass. The amount of corn seed hulls available in the US is estimated to be about 20 million tons and growing – *a low cost and large volume opportunity*. The DDG are commercially available and are used in animal feed applications [6]. Their shipping, storage, and other logistics costs are more effectively manageable compared to other traditional biomass feedstocks, such as corn stover. In addition, corn fiber has a unique composition – higher hemicellulose compared to cellulose and lower lignin [7,8] which makes this feedstock particularly attractive for pentose extraction.

As shown in Table 1, corn fiber has about 4 times the amount of hemicellulose compared to that of cellulose. In addition, the lignin is only 3 %–6 % (all the % values in this work will refer to mass fraction). Such a composition of corn fibers will allow us to develop a process with higher selectivity, fewer process steps, and more importantly with lower cost. The described approach can co-exist with existing grain processing operations with a minimal economic impact on food and feed markets. The appropriate utilization of DDG to biofuels, biochemicals, and carbon fibers using an integrated approach will not only make the existing processing facilities cost efficient, but will also create new business and employment opportunities. This will also promote new opportunities for local agriculture and agricultural products.

As shown in Fig. 2, our approach consists of the following steps: 1) Corn fiber from DDG is used to produce a pentose-rich hydrolyzate, 2) The pentose-rich hydrolyzate is used to produce biofuels and biochemicals, and 3) The residual fiber after acid hydrolysis is used in animal feed application or high value applications such as to produce carbon fibers. Pentoses (e.g., xylose and arabinose) can be biologically converted to liquid fuels, such as ethanol and butanol [9,10]. Alternatively, pentoses can be a platform for synthesis of a variety of industrially important chemicals (e.g., cyclopentadiene, cyclopentane, etc.), which are currently derived from petroleum [11]. Pentoses were identified by the US Department of Energy in 2004 among the top candidates of valuable chemical precursors which could be produced from biomass [11]. Many studies have been performed to develop processes for extraction of pentoses from a wide range of feedstocks [12–14]. Dilute acid hydrolysis is considered to be the most efficient method for selective extraction of pentoses, because hemicellulose is more easily hydrolyzed than cellulose due to amorphous structure and lack of hydrogen bonding.

The primary goal of this study and the first step in our DDG biorefinery approach is to develop a process for pentose extraction from DDG that will meet several requirements: (1) high yield of pentoses, (2) high selectivity towards pentoses (maximized percent of pentoses in total monomeric sugars), (3) minimized sugar degradation, and (4) minimized acid and energy consumption. A thorough analysis of the past work by several researchers suggests that this goal can be achieved through several process steps:

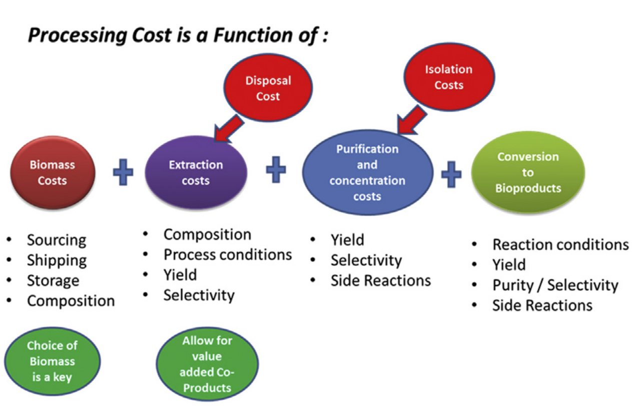

Fig. 1 – Factors contributing to high processing cost for bioproducts from biomass.

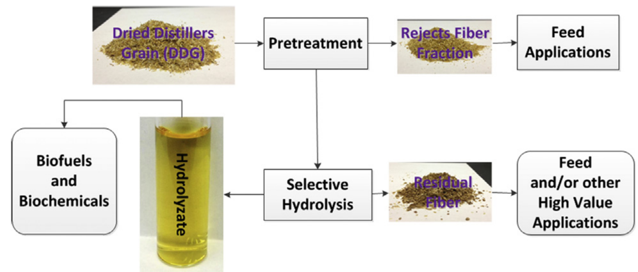

Fig. 2 – An integrated bio-refinery based on dried distillers grains (DDG).

1.1. *Increase of fiber content in starting material via mechanical pretreatment*

Increasing the fiber content of DDG is typically accomplished by reducing its proteins and oil content. In the past studies reported in the literature, screening or air aspiration were

Table 1 – The composition analysis of fiber from various types of biomass.[a]

Composition	Corn fiber from Kernels	Softwood	Hardwood
Hemicellulose	39–40	25–29	25–35
% Cellulose	11–13	40–44	43–47
% Lignin	3–6	25–31	16–24
% Ash	<1	<1	<1

[a] [7,8].