Fiber Separated from Distillers Dried Grains with Solubles as a Feedstock for Ethanol Production

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ABSTRACT

In the dry-grind process, corn starch is converted into sugars that are fermented into ethanol. The remaining corn components (protein, fiber, fat, and ash) form a coproduct, distillers dried grains with solubles (DDGS). In a previous study, the combination of sieving and elutriation (air classification), known as the elusieve process, was effective in separating fiber from DDGS. In this study, elusieve fiber was evaluated for ethanol production and results were compared with those reported in other studies for fiber from different corn processing techniques. Fiber samples were pretreated using acid hydrolysis followed by enzymatic treatment. The hydrolyzate was fermented using Escherichia coli FBR5 strain. Efficiency of ethanol production from elusieve fiber was 89–91%, similar to that for pericarp fiber from wet-milling and quick fiber processes (86–90%). Ethanol yields from elusieve fiber were 0.23–0.25 L/kg (0.027–0.030 gal/lb); similar to ethanol yields from wet-milling pericarp fiber and quick fiber. Fermentations were completed within 50 hr. Elusieve fiber conversion could result in 1.2–2.7% increase in ethanol production from dry-grind plants. It could be economically feasible to use elusieve fiber along with other feedstock in a plant producing ethanol from cellulosic feedstocks. Due to the small scale of operation and the stage of technology development for cellulosic conversion to ethanol, implementation of elusieve fiber conversion to ethanol within a dry-grind plant may not be currently economically feasible.

MATERIALS AND METHODS

Fiber Separation from DDGS

DDGS material (75 kg) was divided into three batches of 25 kg each. Each batch was sieved using a vibratory sifter (model ZS30-86666, SWECO Vibro-Energy Separator, Florence, KY) using five screens US7 (2800 μm), 24T (869 μm), 34T (582 μm), 48T (389 μm), and 62T (295 μm). Material (2 kg) was sieved on each screen for 1 hr. Material passing through the sieve with a larger opening was collected and placed on the next smaller sieve size. Only one sieve was used at a time.

The four intermediate sieve categories, material retained on 24T (869 μm), 34T (582 μm), 48T (389 μm), and 62T (295 μm) screens, were subjected to elutriation using an apparatus described by Srinivasan et al (2005); elutriation column diameter was 155 mm. Material carried by air to the top of the elutriation column was the lighter fraction, material that settled in the bottom was the heavier fraction. The apparatus consisted of an elutriation column, an air blower for supplying air to the elutriation column, a surge box mechanism for controlling airflow, a vibratory feeder for feeding material into the column, and collection vessels for receiving the lighter and heavier fractions. Due to low fiber content, elutriation was not performed for the largest and the smallest sieve categories. Material was fed into the elutriation column at a rate of 5 g/min.

Elutriation was performed at two air velocities to obtain lighter fraction yields of 15 and 25%. Three passes of elutriation were performed at each individual air velocity by recycling the heavier fraction into the column to ensure complete elutriation. Sample order within each batch was randomized.

Fiber (lighter) fractions, at 15% yield (lower air velocities), from elutriation of four sieve categories were combined into a single fiber sample, F1. Fiber (lighter) fractions, at 25% yield (higher air velocities), from elutriation of four sieve categories were combined into a single fiber sample, F2. From three batches of DDGS, a total of six samples were available for ethanol studies.
Sugar Compositional Analysis

Fiber sugar composition was determined using the procedure described in Dien et al (1997). Fiber samples were hydrolyzed with 2N trifluoroacetic acid (TFA) for 1 hr at 100°C. Sugars were analyzed using high-performance liquid chromatography (HPLC) (Thermo Finnigan Spectra System, San Jose, CA) with an HPX-87C column (300 x 7.8 mm, BioRad, Hercules, CA) at 85°C. The column was eluted with distilled water at a flow rate of 0.6 mL/min. The detector was a 410 differential refractometer (Waters, Milford, MA). Cellulose content was determined using the method outlined in Dien et al (1997). Fiber sugar composition was determined in duplicate for each sample. Moisture content was determined using ASTM method E1756-01 by determining weight loss after drying the sample for 18 hr at 105°C. Moisture content was determined in duplicate for each sample.

Ethanol Production

Two 10-g replicates of each fiber-enriched sample were prepared. Samples were treated with 100 mL of H2SO4 (1% w/v) for 1 hr in an autoclave (121°C, 2 atm). Samples were adjusted to pH 4.5 by adding 2.7N Ca(OH)2. Enzymes (60 filter paper units/g of GC220 Cellulase, Genencor, Rochester, NY, and 40 units/g of Novozyme 188 Cellobiase, Novozymes, Franklin, NC) were added. Samples were saccharified for 18 hr at 50°C. The samples were adjusted to pH 7.0 by adding 2.7N Ca(OH)2 and prepared for fermentation by adding 12.5 mL of 10X buffered basal medium Lysozymy broth (LB) (1M 3-(N-morpholino) propanesulfonic acid (MOPS), pH 7.0, 50 g/L of yeast extract, and 10 g/L of tryptone). The hydrolyzate was inoculated with ethanologenic E. coli strain FBRS (5% v/v) that had been grown overnight (Dien et al 2004). Fermentations incubated six days at 35°C were sampled daily. A control sample with glucose (2.2% w/v), xylose (2.6% w/v), and arabinose (1.1% w/v) in the same basal medium was fermented using test samples. Deionized water (100 mL) was added and the mixture was autoclaved for 15 min at 121°C and 2 atm. Like the hydrolyzates, sugar solutions were supplemented with 12.5 mL of LB and MOPS solution, inoculated with E. coli FBRS, and fermented for six days.

Ethanol Concentration Measurement

Ethanol concentrations were determined using the procedure described by Dien et al (1997). Ethanol concentrations were measured by gas-liquid chromatography using a gas chromatograph (5890A Hewlett Packard, Wilmington, NJ) equipped with an 80/100 Porapak Q column (6 ft x 1.8 in., Supelco, Bellefonte, PA) and a flame-ionization detector (5890 Hewlett Packard, Palo Alto, CA).

Ethanol Yield Calculation

Ethanol yields (L/kg of dry fiber) were calculated as:

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\text{final ethanol concentration (\%) / (0.79 \text{ kg ethanol/L of ethanol})}
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Statistical Analyses

Analysis of variance (ANOVA) and Tukey's test (SAS Institute, Cary, NC) were used to compare means of compositions and yields from elusieve processing of three batches. Statistical significance level was 5% (P < 0.05).

RESULTS AND DISCUSSION

Xylose and arabinose contents were similar for elusieve fiber, wet-milling pericarp, and quick fiber (Table I). Glucose contents were higher for wet-milling pericarp and quick fiber (24.2-28.8%) than for elusieve fiber (17.8-8.4%). Elusieve fiber had lower glucose content probably because starch conversion to ethanol results in low starch content in DDGS. Total carbohydrate content of elusieve fiber was 42.0-48.4%, which was lower than for wet-milling pericarp and quick fiber (51.1 and 58.5%, respectively) because of lower glucose content. Individual carbohydrate content was higher in F1 than in F2 as expected, because F1 (low-yield elusieve fiber) has lower nonfiber content due to lower elutriation air velocities. Repeatability of carbohydrate determination was good (coefficient of variation [COV] ± 5%). F1 and F2 moisture content were 8.0 and 7.5%, respectively (COV ± 5%).

Glucose, xylose, and arabinose concentrations in the saccharified sample and ethanol concentration were higher for F1 than for F2, which corresponded to carbohydrate contents in fiber samples (Tables I and II). Repeatability of sugar and ethanol concentration determination was good (COV ± 5%). The maximum ethanol yield using ethanologenic E. coli strains was 51 g of ethanol/100 g of monosaccharides (Dien et al 2005). Based on total carbohydrate contents in F1 and F2, the efficiency of ethanol production was 89-91%. Dien et al (2004) and Singh et al (2004) reported similar efficiencies (86-91%) for ethanol production from wet-milling pericarp and quick fiber. For elusieve fiber, ethanol production efficiency based on sugars in the saccharified slurry was 100-103% and was similar to efficiency of the control (100%).

Fermentations were completed within 50 hr; final ethanol concentrations for F1 and F2 were 17 and 18 g/L, respectively (Fig. 1). Glucose fermented the quickest; concentrations decreased to zero within 24 hr for all fermentations (Fig. 2). There were decreases in xylose and arabinose concentrations as fermentation progressed (Figs. 3 and 4). An important difference between the control and fiber hydrolyzate fermentations was a small amount...
of residual xylose present following fermentation of fiber hydrolysates. Ethanol yields from elusive fiber were 0.23–0.25 L/kg of dry fiber (0.027–0.030 gal/lb); similar to ethanol yield from quick fiber 0.15–0.27 L/kg (0.018–0.032 gal/lb) (Dien et al 2004) of dry fiber, and ethanol yield from pericarp fiber of 0.19 L/kg (0.023 gal/lb) (Singh et al 2004) of dry fiber.

For every 25.4 kg (1 bu) of corn processed by a dry-grind plant, 10.6 L (2.8 gal) of ethanol is produced and 6.8 kg (15 lb) of DDGS is produced. For every 1 kg of DDGS produced, 0.11 kg of F1 fiber or 0.22 kg of F2 fiber can be separated using the elusive process. Based on ethanol yields of 0.23 L/kg of F1 and 0.25 L/kg of F2 (dry basis), cellulosic ethanol produced from 25.4 kg (1 bu) corn would be 0.16 L (0.03 gal) and 0.34 L (0.07 gal) for F1 and F2, respectively. This would amount to a 1.2–2.7% increase in ethanol production from the dry-grind plants.

Due to the small scale of operation and the stage of technology development for lignocellulosic conversion to ethanol, we expect that implementation of elusive fiber conversion to ethanol within a dry-grind plant may not be currently economically feasible. It could be economically feasible to use elusive fiber along with other feedstock in a plant producing ethanol from cellulosic feedstocks. Revenue obtained by producing ethanol from elusive fiber would be 11¢/kg ($0.009/ton) (based on average moisture content of 8%, conservative ethanol yield of 0.23 L/kg of dry elusive fiber, and ethanol price of 53¢/L ($2.00/gal).

**CONCLUSIONS**

Efficiency of ethanol production from elusive fiber was similar to that for corn fiber from wet-milling and quick fiber processes. The ethanol yield from elusive fiber was similar to ethanol yield from quick fiber.

**Fig. 1. Fermentation profiles for saccharified fiber.**

**Fig. 2. Glucose fermentation profiles for saccharified fiber.**

**Fig. 3. Xylose fermentation profiles for saccharified fiber.**

**Fig. 4. Arabinose fermentation profiles for saccharified fiber.**
Conversion efficiencies to ethanol were 89-91% and fermentations were completed within 50 hr. Elusieve fiber conversion could result in 1.2-2.7% increase in ethanol production from dry-grind plants. Due to the small scale of operation and the stage of technology development for lignocellulosic conversion to ethanol, we expect that implementation of elusieve fiber conversion to ethanol within a dry grind plant may not be currently economically feasible. It could be economically feasible to use elusieve fiber along with other feedstocks in a plant producing ethanol from cellulosic feedstocks.

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LITERATURE CITED


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