Copyright © 2004 by Humana Press Inc.
All rights of any nature whatsoever reserved.
0273-2289/04/115/0837–0842/$25.00

Effect of Germ and Fiber Removal on Production of Ethanol from Corn

Elankovan Ponnampalam,* D. Bernie Steele, Deborah Burgdorf, and Darold McCalla

MBI International, 3900 Collins Road, Lansing, MI 48910, E-mail: ponnam@mbi.org

Abstract

Ethanol fermentations were conducted using both whole corn, and corn with 100% of the germ, and a portion (~74%) of the fiber removed. Ethanol production increased 11% in the germ and fiber-removed corn vs the whole corn. The protein content of distiller's dried grains and solubles increased from 30 to 36%, and phosphate levels were 60% lower in corn with germ and fiber removed vs whole corn. Removal of germ and fiber prior to fermentation allows higher starch loading and results in increased ethanol production. The integration of germ and fiber removal in the dry-grind ethanol industry could increase capacity and add valuable coproducts, resulting in increased productivity and profits.

Index Entries: Ethanol; germ; fiber oil; distiller's dried grains and solubles; fermentation.

Introduction

Of the current corn-to-ethanol processes, wet milling and dry grind, the dry grind has lower capital investment and produces more ethanol per bushel of corn, when compared with the wet-milling process *(1)*. Current wet-milling facilities utilize the corn germ and other nonfermentables as valuable coproducts that increase the profitability of their operations. Removal of the germ and hull during the dry-grind process would be expected to offer the same benefits to the dry-grind industry. Removal of these nonfermentables prior to fermentation is expected to increase ethanol production capacity in dry-milling operations. The increase in capacity and the production of germ and fiber byproducts, such as corn oil and corn fiber oil, could increase profit margins and reduce reliance on a single product.

*Author to whom all correspondence and reprint requests should be addressed.

There are currently several methods for the removal of the germ and fiber during dry-grind operations. The "Quick Germ" and "Quick Fiber" separations, developed at the University of Illinois, are examples of relatively inexpensive and simple methods for germ and fiber removal *(1,2)*.

Original assumptions by Singh and Eckhoff *(2)* predicted approx 7–10% increase in fermentation capacity using the Quick Germ process. The relative economics of using whole corn vs corn with the germ removed has been discussed previously *(2,3)*. Taylor et al. *(3)* estimated that the savings from the sale of germ (for production of corn oil) would be approx $0.094/gal of ethanol. This assumes a sale price of $0.25/lb for corn oil (current market price) and includes utility costs as well as capital-related costs for production. Wahjudi et al. *(1)* estimated an additional $0.04/gal from removal of the fiber.

The current study compared the fermentation of whole corn (as currently practiced in the dry-grind industry) with the high-density fermentation of corn with 100% of the germ and approx 74% of the fiber removed.

Materials and Methods

Feedstocks

Two corn samples (70 lb each) were received from Bunge Milling (Danville, IL) and stored in plastic bags at –20°C. The whole ground corn comprised of yellow dent corn kernels that had been reduced to a coarse meal granulation by passage through a Romer Mill, which is a laboratory-scale, burr-type mill. The proximate composition of this ground corn was essentially the same as the composition of the starting whole corn, since the entire stream was collected during the grinding process. The granulation profile for this ground corn sample was very broad but could be generally described as "minus 10/plus 50" with about 15% through the 50 sieve. The second sample was yellow dent corn with 100% of the germ and approx 74% of the fiber removed and henceforth referred to as "germ and fiber-removed corn" (G/F minus corn). This sample was prepared by physically blending a degermed corn grits product with a degermed corn meal product. This product also exhibited a "minus 10/plus 50" granulation profile with about 10% through the 50 sieve, although this granulation was not quite as broad as the whole ground corn sample.

Fermentations

Five pairs of ethanol fermentations (5 L) were completed. Each fermentor was loaded with 27.9% (w/w) dry mash. The pH was adjusted to 5.8 with NaOH. Amylase (Enzyme Biosystems, Beloit, WI) in the amount of 1367.4 U was added to the fermentors. The temperature was held at 85°C for 3 h with mixing. The temperature was then reduced to 60°C and the pH adjusted to 4.4 with H_2SO_4. Glucoamylase (Enzyme Biosystems) was then added in the amount of 274 U and the temperature maintained at 60°C for 2 h. The temperature was then lowered to 35°C, and a nitrogen

source was added to the fermentors (1.5 g/L of ammonium chloride). The fermentors were inoculated with 5% active yeast culture (*Saccharomyces cerevisiae* ATCC 4126). During the fermentations, the pH was maintained at 4.0 with 10% NaOH, and temperature was controlled at 35°C. Condensers were used on fermentor gas outlets to reduce the amount of ethanol loss owing to evaporation. Ten-milliliter samples were taken periodically during the process to monitor ethanol production and acid production, as well as glucose concentration, and to microscopically observe yeast cells. Samples were collected and stored at –20°C for further analysis. The initial samples were treated with enzyme for complete hydrolysis of the starch to obtain the glucose numbers necessary for yield calculations. The average initial glucose concentration after complete hydrolysis for the whole corn batches was 211.4 g/L and for the degermed corn batches was 248 g/L.

Fermentations were run until glucose concentrations were <1 g/L or the glucose concentration stopped decreasing. On completion of the fermentations, the whole broth was dried at 50°C and a coffee grinder was used to homogenize the dried samples. Samples from each of the fermentations (10 total) were sent to a commercial laboratory (Servi-Tech, Hastings, NE) for analysis of standard nutritional parameters and minerals for cattle feed.

Analytical Procedures

In all experiments, amyloglucosidase (A-3042; Sigma, St. Louis, MO) was used to convert starch to glucose. A biochemistry analyzer (YSI model 2700; Yellow Springs, OH) was used to measure glucose concentrations. A five-point external calibration curve was used for dextrose (0.5–100 g/L). Starch was determined using a standard protocol from the National Renewable Energy Laboratory (NREL) (Golden, CO), NREL LAP-016, 1996. Ethanol was measured by high-perfromance liquid chromatography. This assay used a Waters 600 Multisolvent Delivery System with a Waters 410 Differential Refractometer detector and an internal detector temperature of 35°C. The separation was performed on an Aminex HPX-87H column with a Cation H guard column maintained between 45 and 55°C using a Waters Column Heater Module with a mobile phase of 0.021 *N* H_2SO_4 and a flow rate of 0.5 mL/min. The mobile phase was prepared using 18.2 Mohm deionized water obtained from a Milli-Q system, and all samples were filtered through a 0.45-mm filter prior to injection using an Alcott 728 autosampler. Data werecollected by a TurboChrome 4 data acquisition package using a PE Nelson 900 series Interface. A five-point external calibration curve was used for ethanol (0.25–100 g/L).

Results

The fermentation profile shown in Fig. 1 is the average of five fermentations of whole corn and five fermentations with G/F minus corn.

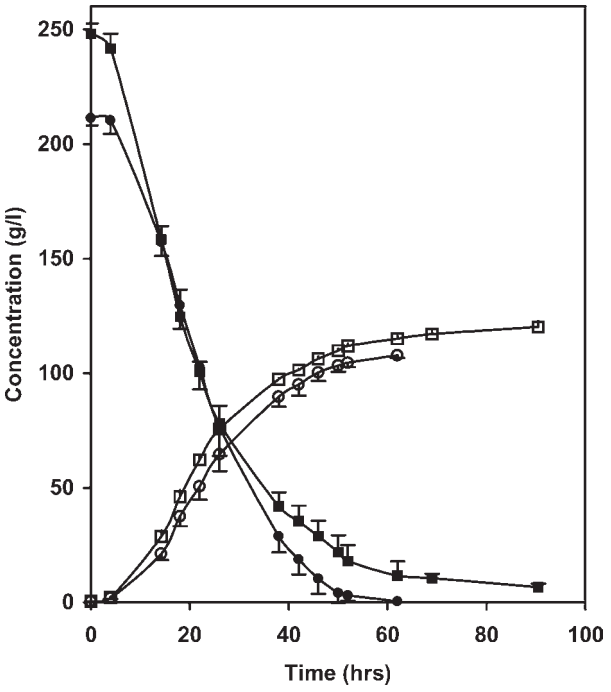

Fig. 1. Comparison of ethanol production from whole corn and G/F minus corn. (●) Whole-corn dextrose; (■) G/F minus corn dextrose; (○) whole-corn ethanol; (□) G/F minus corn ethanol.

The average ethanol concentration derived from whole corn fermentations was 106.8 g/L. The average ethanol concentration from G/F minus corn was 118.7 g/L, an 11% increase. While the whole-corn fermentations finished (residual glucose of <1 g/L), the G/F minus corn fermentations did not finish (residual glucose average of 6 g/L). The best G/F minus corn fermentation reached a peak ethanol production of 123.2 g/L with a residual glucose of 4.9 g/L. It is expected that yeast strains more tolerant to high-density fermentations could achieve ethanol concentrations of approx 125 g/L.

Table 1 shows the nutritional and mineral analysis of distiller's dried grains and solubles (DDs) from both whole-corn and G/F minus corn fermentations. Most significant are a 23% increase in protein concentration, a 58.5% decrease in neutral detergent fiber, a 45.5% decrease in fat, overall increases in net energy, and a 60.7% decrease in phosphorus.

Discussion

As the data have shown, the removal of the germ and fiber does allow higher starch loading, which results in an increase in ethanol production.

Table 1
Analysis of DDGs from Whole Corn and G/F Minus Corn

Parameter	G/F minus corn	Whole corn
Crude protein (%)	36.7 ± 4.50	29.8 ± 1.00
Neutral detergent fiber (%)	13.74 ± 1.57	33.14 ± 5.05
TDN[1] (%)	83.7 ± 2.20	78.3 ± 1.90
Net energy, main. (Mcal/lb)	0.97 ± 0.03	0.90 ± 0.02
Net energy, gain (Mcal/lb)	0.65 ± 0.03	0.58 ± 0.02
Phosphorus (%P)	0.33 ± 0.04	0.84 ± 0.04
Fat (% by acid hydrolysis)	9.63 ± 0.75	17.68 ± 1.63
Swine D.E. (Mcal/lb)	1.46 ± 0.08	1.27 ± 0.07
Swine M.E. (Mcal/lb)	1.29 ± 0.07	1.15 ± 0.06

This type of fermentation is generally limited by high suspended solids; however, removal of the germ results in lower suspended solids *(3)*. Taylor and colleages *(3,4)* also predicted that combining germ removal with continuous high-gravity fermentation with stripping could further improve economics. The estimated savings by combining continuous high-density fermentation with stripping with germ removal is approx 6–10 ¢/gal of ethanol *(3)*. Complete removal of the fiber could enhance the cost savings even further. Corn fiber oil contains phytosterols and other compounds shown to reduce cholesterol levels *(5,6)*. Extraction of this oil from corn fiber could offer a high-value coproduct that would result in even greater cost savings for an ethanol production facility.

The removal of the germ and fiber prior to fermentation results in significant changes to the DDGs produced during fermentation. Protein and digestible nutrients are increased while fat and fiber are reduced, although the increase in digestible nutrients and net energy could be attributed to residual glucose in the fermentation broth. A robust yeast strain capable of tolerating higher ethanol concentrations will be necessary to fully utilize the glucose in a high-density fermentation. The 60% reduction in phosphorus is significant in light of more stringent regulation of phosphate wastes in the livestock industry. The increased protein, lower fat and fiber, as well as the reduction in phosphate may offer a more valuable livestock feed.

In summary, removal of germ and fiber prior to fermentation allows higher starch loading and results in increased ethanol production. The integration of germ and fiber removal in the dry-grind ethanol industry could increase capacity and add valuable coproducts, resulting in increased productivity and profits. A more complete economic study of integrating germ and fiber removal into a dry mill ethanol plant is needed to determine the feasibility of such a strategy.

Acknowledgments

We wish to thank Heartland Grain Fuels, LLP and the Illinois Corn Marketing Board for supplying materials. This work was supported by US Department of Energy (DOE) Cooperative Agreement No. DE-FC36-02G012001 (DOE support does not constitute an endorsement by DOE of the views expressed in this article).

References

1 Wahjudi, J., Xu, Li., Wang, P., Singh, V., Buriak, P., Rausch, K. D., McAloon, A. J., Tumbleson, M. E., and Eckhoff, S. R. (2000), *Cereal Chem.* **77(5),** 640–644.
2 Singh, V. and Eckhoff, S. R. (1997), *Cereal Chem.* **74,** 462–466.
3 Taylor, F., Mcaloon, A. J., Craig, Jr., J. C., Yang, P., Wahjudi, J., and Eckhoff S. R. (2001), *Appl. Biochem. Biotechnol.* **94,** 41–49.
4 Taylor, F., Kurantz, M. J., Goldberg, N., McAloon, A. J., and Craig, Jr., J. C. (2000), *Biotechnol. Prog.* **16(4),** 541–547.
5 Moreau, R. A., Powell, M. J., and Hicks, K. B. (1996), *J. Agric. Food Chem.* **44(8),** 2149–2154.
6 Wilson, T. A., DeSimone, A. P., Romano, C. A., and Nicolosi, R. J. (2000), *J. Nutri. Biochem.* **11(9),** 443–449.