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# Wheat as a Feedstock for Fuel Ethanol

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## ABSTRACT

Canadian Prairie Spring and Soft White Spring wheats, which contained high levels of starch, gave higher concentrations of ethanol after fermentation than was obtained with high-protein Hard Red Spring wheat. Dry milling to remove fiber and to concentrate the starch in the flour resulted in even greater increases in ethanol content of the beer, although final ethanol yields were reduced on a per ton of wheat basis. However, preprocessing of the grain would increase the throughput rate and capacity of ethanol plants. It was estimated that bran removal could increase plant capacity by 20.3–26.4%, based on the three market classes evaluated in this study. The bran fraction separated from grain during preprocessing could increase revenue from sale of coproducts, thus improving the ratio of grain cost to revenue.

**Index Entries:** Fuel ethanol; wheat feedstock; grain preprocessing; ethanol yield, coproducts composition.

## INTRODUCTION

The fuel ethanol plants in the United States operate almost exclusively on corn feedstock. Corn is not available, though, in Western Canada, and fuel ethanol plants here utilize wheat and barley. Both grains are 10–15% lower in starch content than corn, which results in reduced concentrations of ethanol in the beer and substantially lower ethanol yields per unit weight of grain.

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The feedstock cost is the most substantial component of ethanol production costs and, even at the low price of $100 Can. per ton (metric) of wheat, accounts for over 60% of the total production cost. Also, wheat bran, germ, and outer endosperm proteins, which do not contribute to the ethanol yield, are carried through the process, further increasing the production cost. Combined, the latter components constitute over 40% of the original weight.

New cultivars of Canadian Prairie Spring wheats have been developed with more starch and less protein than durum and bread wheats, to provide a better industrial feedstock for ethanol plants. Also, grain preprocessing techniques have the potential to enhance starch concentration of wheat feedstock and, thus, make it more comparable to corn. An increase in starch content in feedstock for ethanol production is expected to improve the economics of ethanol production.

The objectives of the present investigations were to evaluate the high-starch wheats and their preprocessed flours as feedstocks for ethanol production. Ethanol concentrations in the beer, ethanol yields, and mass balance and composition of products were determined and compared to those from bread wheat. Also, the influence of processing of high-starch feedstocks on plant throughput and plant profitability was evaluated.

## MATERIALS AND METHODS

Cultivars selected for the study included the most common bread wheat grown in Western Canada, Katepwa Hard Red Spring (HRS), and the most popular soft wheat, Fielder Soft White Spring (SWS). A new market class of high-yielding, medium-protein wheats is now grown widely in Western Canada, and a sample of Biggar Canadian Prairie Spring (CPS) wheat was used for the present study. The three cultivars were harvested in the 1992 growing season from replicated plots on the University of Saskatchewan farm. Samples of wheat were ground on a Wiley Mill, and passed through a 60-mesh screen to prepare samples for analyses and for fermentation studies.

A three-stage experimental Allis Chalmers Mill, equipped with three sets of smooth and corrugated rolls, was used to evaluate the preprocessing of wheat samples. After each pass through the sets of rolls, the product was separated on screens to separate the germ and bran progressively from endosperm and maximize the yield of high-starch flour.

Ground wheat or preprocessed flours (Fig. 1) were dispersed in water, ratio of grain or flour to water being 1:2.7. The α-amylase enzyme, Maxalic (International Bio-Synthetics, Inc., Charlotte, NC), was added at an enzyme concentration of 0.15% (v/w enzyme to grain/flour), with stirring. The temperature was increased to 95°C and held constant for 2 h and 45 min.

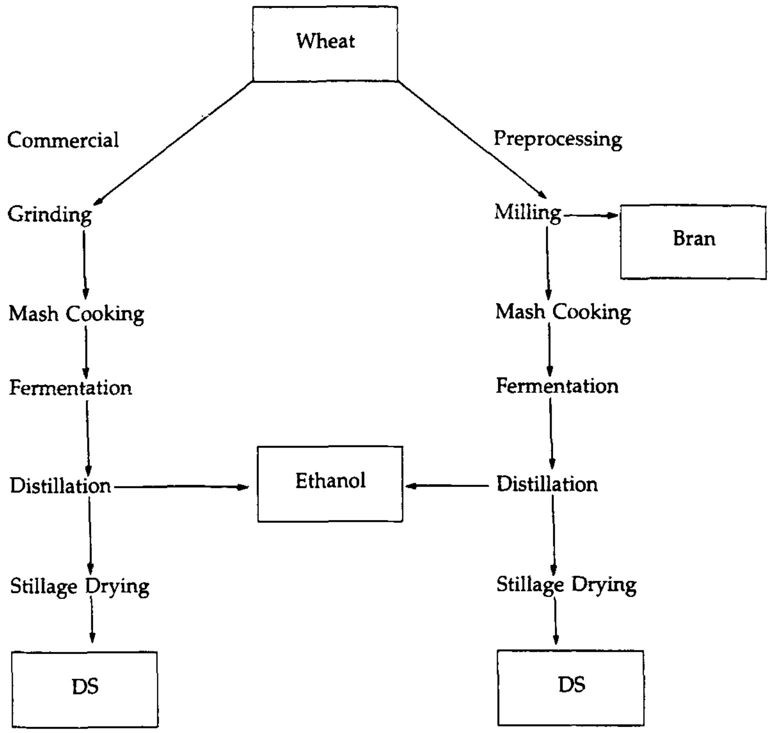


Fig. 1. Ethanol production process.

Following mash cooking, the temperature was decreased to 55°C, and the glucoamylase enzyme, Amigase (International Bio-Synthetics, Inc., Charlotte, NC) was added to mash at an enzyme concentration of 0.25% (v/w enzyme to grain/flour). Saccharification at 55°C was carried out for 2 h, after which the mash temperature was lowered to 30°C. Mashed ground wheat or flour samples were transferred into Wheaton Biostir 6 fermenters (Wheaton Instruments, Millville, NJ). Inoculum (1.6 × $10^7$ cells/mL) of *Saccharomyces cerevisiae* yeast (Alltech, Inc., Nicholasville, KY) was added to the cooled mash (*1*). Fermentations were carried out at 30° C for 72 h.

Ethanol and residual glucose were determined in beer using the Ethanol Kit #332-A (Sigma Chemical Co., St. Louis, MO) and the Glucose Reagent Kit (Reagents Applications, Inc. San Diego, CA, respectively. Ethanol was evaporated from the beer by distillation on the Buchi rotavaporator (Brinkman Instruments Canada, Mississauga, ON), and the stillage was dried in a forced-air oven at 60°C overnight.

Samples of grain, preprocessed flours, bran, and dried stillage (DS) were analyzed by standard AACC (*2*) procedures for moisture (Method 44-15A), crude protein (Method 46-13), and crude fat (Method 30-25). Protein contents of samples were calculated using the nitrogen-to-protein conversion factor of 5.7, based on the recommendation of Sosulski and

Table 1
The Influence of Wheat Class and Grain Preprocessing on Ethanol Concentration in the Beer

| Wheat class and product | Protein | Starch | Ethanol concentration in the beer* | |
|---|---|---|---|---|
| | —% as is— | | % w/v | % v/v |
| Grain | | | | |
| HRS-Katepwa | 15.09 | 53.63 | 10.14 | 12.68 |
| CPS-Biggar | 12.54 | 57.05 | 10.71 | 13.38 |
| SWS-Fielder | 13.02 | 57.02 | 11.01 | 13.77 |
| Flour | | | | |
| HRS-Katepwa | 14.89 | 64.24 | 12.15 | 15.18 |
| CPS-Biggar | 11.88 | 66.82 | 12.32 | 15.41 |
| SWS-Fielder | 12.14 | 68.20 | 12.69 | 15.89 |

*Ratio of grain/flour to water 1:2.7.

Imafidon (3). Starch was measured as glucose on a YSI Model 27 Industrial Analyzer (Yellow Springs Instrument Co., Yellow Springs, OH) after hydrolysis with α-amylase and amyloglucosidase (4). Total dietary fiber (TDF) was quantitated by the enzymatic gravimetric method of Prosky et al. (5).

## RESULTS AND DISCUSSION

The commercial process for ethanol production from starchy grain consists of grinding to reduce particle size, starch gelatinization with steam, liquefaction of gelatinized starch to dextrin with amylolytic enzymes, and subsequently, saccharification of dextrin with glucoamylase enzyme and fermentation of released glucose with yeast to alcohol (Fig. 1). The ethanol is distilled from the beer, and the resulting stillage is dried or fed wet to animals. The preprocessing of grain removed the outer kernel layers, thus reducing the fiber and protein in the feedstock for fermentation. The preprocessed flours were hydrolyzed and fermented under the same experimental conditions.

The highest protein content was determined in HRS wheat (Table 1). The CPS and SWS wheats were 2.5–3% lower in protein, but correspondingly over 3% higher in starch than HRS wheat. Since ethanol concentration in the beer depended directly on the starch content in the feedstock, high-starch wheats yielded more ethanol than HRS. However, the differences in ethanol concentration were only 0.6–0.9%, w/v.

Preprocessing of grain reduced protein and increased starch contents in flour (Table 1). The increased concentrations of starch, from 54–57% in grains to 64–68% in flours, increased the concentrations of ethanol in beer

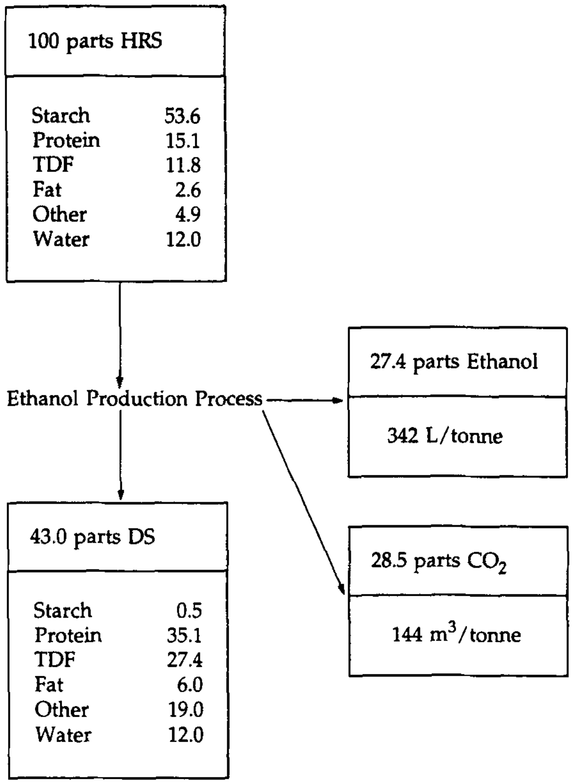


Fig. 2. Mass balance, ethanol yield, and dried stillage composition for Katepwa HRS wheat after commercial processing.

from an average of 10.6% (w/v) to 12.4% (w/v), respectively. For comparison with literature values, ethanol concentrations in Table 1 are also presented in %, v/v.

The volumes of ethanol produced from the wheats by commerical procedures ranged from 342 L/ton for HRS (Fig. 2) to over 362 L/ton for CPS and SWS (Figs. 3 and 4). Ethanol represented only 27.4–29.1% of total product yields. At the same time, $CO_2$, which is not utilized in small ethanol plants, accounted for 28.5–30.4% of total products. Dried stillage (DS) represented 40–43% of products obtained from ethanol production (Figs. 1–3). More DS was produced from HRS than from CPS or SWS wheats. Also, the stillage from HRS contained the highest levels of protein and fiber.

In addition to protein (31.5–35.1%), TDF (24.9–27.4%), and fat (5.3–6.3%), DS contained 19.0–23.5% of other constituents, including ash, phytate, and fermentation byproducts, such as glycerol and organic acids (Figs. 1–3). The residual, "resistant" starch was under 1% of the DS samples, and no free glucose was detected.

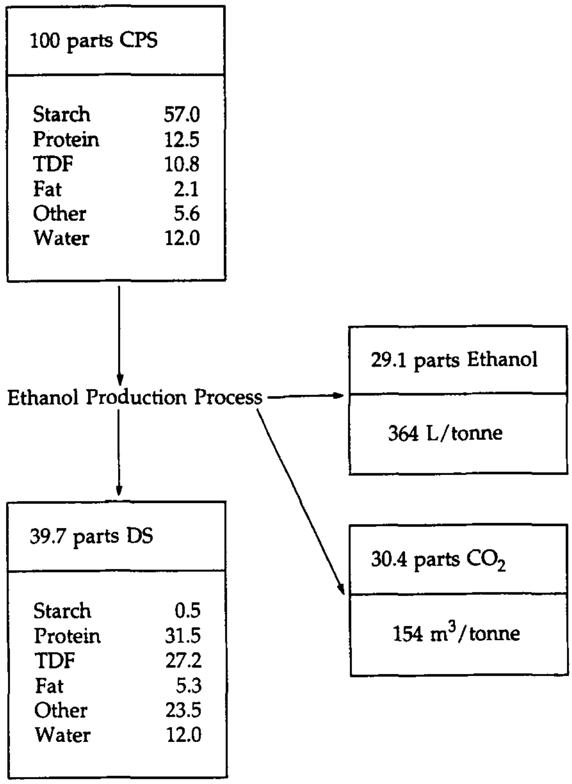


Fig. 3. Mass balance, ethanol yield, and dried stillage composition for Biggar CPS wheat after commercial processing.

Preprocessing of grain removed 22.0–24.2% of grain weight into the bran fractions (Figs. 5–7). TDF was the major constituent of bran that indicated a successful removal of fiber from the outer kernel layers. However, bran contained 18.7–22.2% of starch, which represented a 7.5–9.2% loss of the total grain starch into bran. Less starch was lost from SWS than from HRS or CPS wheat. Starch lost to bran was not available for ethanol production.

The flours represented 75.8–78.0% of grain weights and contained 64.2–68.2% starch (Figs. 5–7). Preprocessing enriched starch contents in flours by 10–11% as compared to grain. When these flours were processed under the same conditions as grain, the increased starch contents in flours yielded greater concentrations of ethanol in the beer (Table 1).

Preprocessing of grain only slightly decreased protein contents in flour fractions, but substantially reduced TDF contents (Figs. 5–7). Reduction of TDF in flours, which became the feedstocks for ethanol fermentation, reduced TDF in DS with corresponding increases in protein content, as compared to DS from grain (Figs. 2–4). The DS from fermentation of

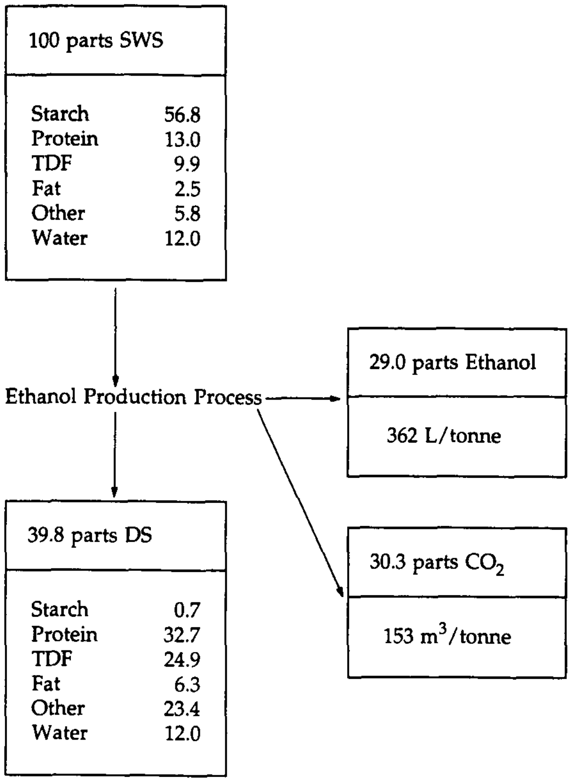


Fig. 4. Mass balance, ethanol yield, and dried stillage composition for Fielder SWS wheat after commercial processing.

flours was lightly colored and probably more suitable for other uses than ruminant feed.

As determined before for DS from grain (Figs. 2–4), the DS from fermentation of preprocessed flours was free of glucose and contained < 1% of unhydrolyzed starch. Therefore, it appeared that high-starch flours could be successfully mashed and fermented into ethanol. The results of the experimental laboratory fermentations of wheat grain and preprocessed flours were used to extrapolate and evaluate the benefits of grain-preprocessing in a theoretical 10 million L/yr ethanol plant.

The volumes of ethanol produced from flours, when calculated on a per ton of original grain basis, were lower (312–333 L/ton) (Figs. 5–7), as compared to those produced from grain (342–364 L/ton) (Figs. 2–4). The differences in ethanol yield reflected differences in starch losses to the bran fractions during grain preprocessing. On a constant throughput basis for the fermenters, however, preprocessing increased the capacities by 20.3–26.4%, depending on market class of wheat (Tables 2–4). Preprocessing also had a much greater influence on increase in plant capacity

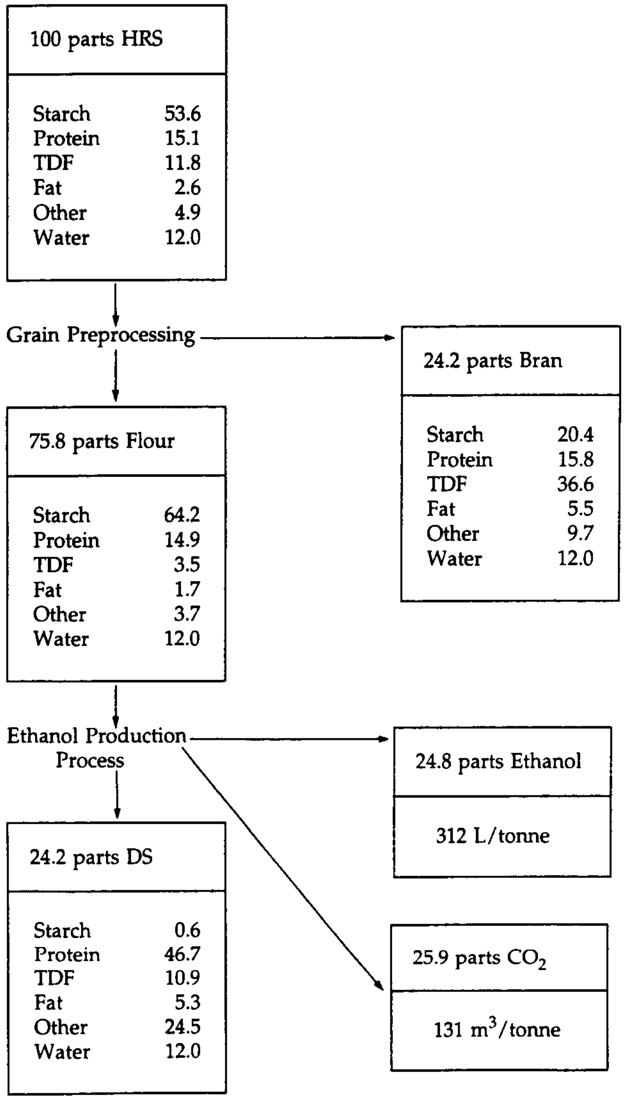


Fig. 5. Mass balance, ethanol yield, and product compositions for preprocessed Katepwa HRS wheat.

than variety of wheat. Commercial ethanol plants obtain their revenue from sales of ethanol and DS. It appeared that, at a low-ethanol price of $0.22/L, plants might earn more revenue processing a low-starch feedstock, like HRS, that will yield more DS than CPS or SWS wheat (Tables 2-4). However, the additional revenue from increased production of DS could only be realized by a few plants. If the supply of DS increased sub-

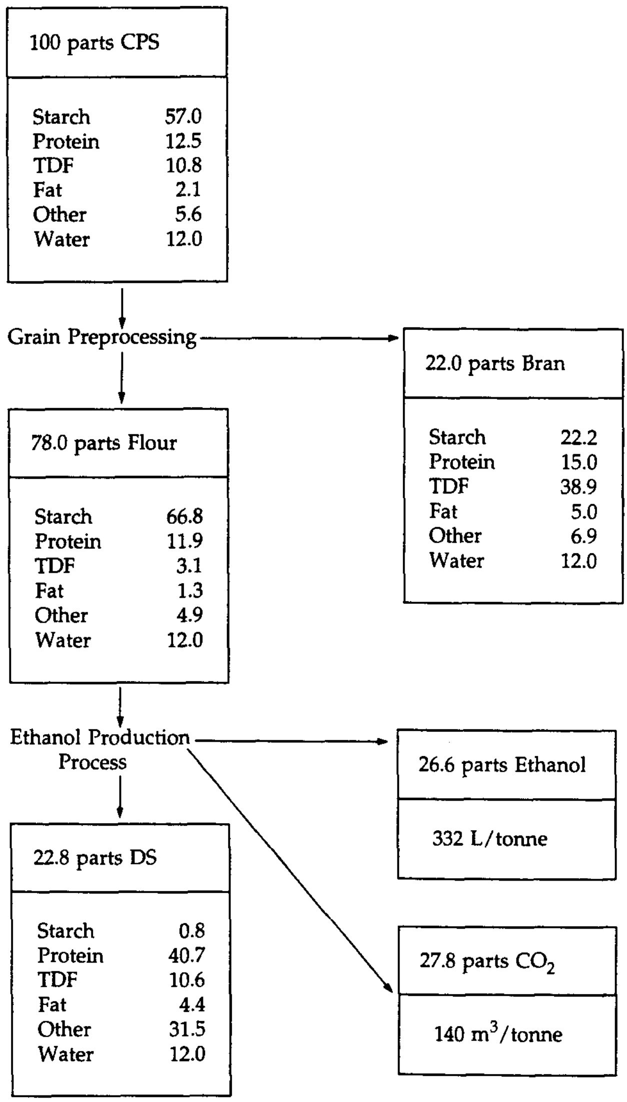


Fig. 6. Mass balance, ethanol yield, and product compositions for preprocessed Biggar CPS wheat.

stantially, the price for DS would be lowered, and there would be no economical benefit from processing of low-starch grain.

Preprocessing of grain generated a new coproduct, the bran fraction, that would have a substantially higher value than ethanol or DS (Tables 2-4). Therefore, the ethanol plant would receive more revenue than when whole grain is converted directly to ethanol and DS. Also, plants that preprocessed grain had a much better ratio of grain cost to revenue.

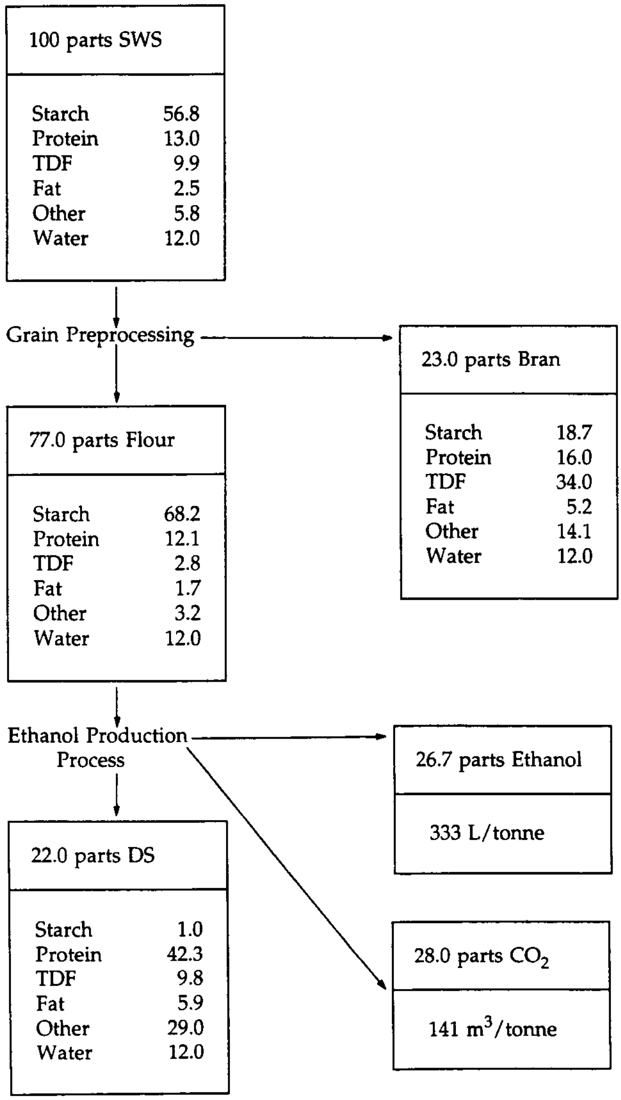


Fig. 7. Mass balance, ethanol yield, and product compositions for preprocessed Fielder SWS wheat.

## CONCLUSIONS

1. The new high-yielding, medium-protein CPS wheat and soft SWS wheat yielded beer with increased concentrations of ethanol as compared to bread-quality HRS wheat.
2. Preprocessing of wheat reduced fiber and increased starch contents in feedstock for ethanol production, yielding beers containing 2.0–2.5% w/v higher concentrations of ethanol than those from grain.

Table 2
Effect of Preprocess on Product Yields and Revenue from Wheat Fermentation, Based on a 10 Million-L Ethanol Plant Processing Katepwa HRS Wheat

| | | Katepwa HRS | |
|---|---|---|---|
| | | Whole grain | Preprocessed |
| Grain processed | (tons) | 29,240 | 38,575 |
| Flour | (tons) | — | 29,240 |
| Bran | (tons) | — | 9336 |
| DS | (tons) | 12,573 | 9336 |
| Ethanol | (million L) | 10.00 | 12.03 |
| Ethanol production increase (%) | | — | 20.3 |
| Grain cost ($100/ton) | | 2,924,000 | 3,857,500 |
| Revenue: | | | |
| Stabilized bran ($250/ton) | | — | 2,334,000 |
| DS ($180/ton) | | 2,263,140 | 1,680,480 |
| Ethanol ($0.22/L)* | | 2,200,000 | 2,647,788 |
| Total ($) | | 4,463,140 | 6,662,268 |
| Grain cost: revenue | | 1:1.53 | 1:1.73 |

*Subsidies and cost of grain preprocessing are not included.

Table 3
Effect of Preprocess on Product Yields and Revenue from Wheat Fermentation, Based on a 10 Million-L Ethanol Plant Processing Biggar CPS Wheat

| | | Biggar CPS | |
|---|---|---|---|
| | | Whole grain | Preprocessed |
| Grain processed | (tons) | 29,240 | 37,487 |
| Flour | (tons) | — | 29,240 |
| Bran | (tons) | — | 8247 |
| DS | (tons) | 11,608 | 8547 |
| Ethanol | (million L) | 10.64 | 12.44 |
| Ethanol production increase (%) | | 6.4 | 24.4 |
| Grain cost ($100/ton) | | 2,924,000 | 3,748,700 |
| Revenue: | | | |
| Stabilized bran ($250/ton) | | — | 2,061,785 |
| DS ($180/ton) | | 2,089,440 | 1,538,466 |
| Ethanol ($0.22/L)* | | 2,341,539 | 2,738,050 |
| Total ($) | | 4,430,979 | 6,338,301 |
| Grain cost: revenue | | 1:1.52 | 1:1.69 |

*Subsidies and cost of grain preprocessing are not included.

Table 4
Effect of Preprocess on Product Yields and Revenue from Wheat Fermentation, Based on a 10 Million-L Ethanol Plant Processing Fielder SWS Wheat

| | | Fielder SWS | |
|---|---|---|---|
| | | Whole grain | Preprocessed |
| Grain processed | (tons) | 29,240 | 37,974 |
| Flour | (tons) | — | 29,240 |
| Bran | (tons) | — | 8734 |
| DS | (tons) | 11,637 | 8354 |
| Ethanol | (million L) | 10.58 | 12.64 |
| Ethanol production increase (%) | | 5.8 | 26.4 |
| Grain cost ($100/ton) | | 2,924,000 | 3,797,400 |
| Revenue: | | | |
| Stabilized bran ($250/ton) | | — | 2,183,505 |
| DS ($180/ton) | | 2,094,660 | 1,503,770 |
| Ethanol ($0.22/L)* | | 2,328,673 | 2,781,975 |
| Total ($) | | 4,423,333 | 6,469,250 |
| Grain cost: revenue | | 1:1.51 | 1:1.70 |

*Subsidies and cost of grain preprocessing are not included.

3. Grain preprocessing would increase the capacity of an ethanol plant, since more starch is processed in the same volume of feedstock. The increase in plant capacity would be in the range of 20.3–26.4%, depending on market class of wheat.

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