Developments of Corn for Dry Grind Corn Processing

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Presentation Outline

- Conventional Dry Grind Process
- Ethanol Production Capacity and Growth in Dry Grind Corn Processing Industry in US
- Development of Corn in Dry Grind Corn Processing
  - Effect of hybrid variability on dry grind corn process
  - High fermentable corn hybrids
  - Correlation between extractable starch and fermentable starch
  - Granular starch hydrolyzing enzymes
  - Corn hybrids with endogenous liquefaction enzymes
  - Corn hybrids for modified dry grind corn processes
- Conclusions
Dry Grind Process

One bushel of Corn (25.4 kg) → Corn Dry Grind Facility → 2.5-2.7 gal of Ethanol

15-17 lbs of DDGS → Ruminant Feed
Dry Grind Process

- Corn
- Water
- Enzymes
- Liquefaction
- Mash
- Blending
- Grinding (Hammermill)
- Saccharification & Fermentation
- Yeast & Enzymes
- CO₂
- Overhead product (Recycled back)
- Ethanol
- Dehydration column
- DDGS
- Stripping/Rectifying column
- Ethanol
- Mars
Ethanol Production in the US

- Currently 4.3 billion gal of ethanol is produced in the US every year.
- Estimates indicate that ethanol production in the US will increase to 6.0 billion gals/yr by 2006.
- Most of the increase in the ethanol capacity will come from new dry grind ethanol plants:
  - Low capital cost for dry grind corn plants
  - Tax incentives from federal and state governments
  - Farmer co-ops
Developments of Corn for Dry Grind Process

- Hybrid Variability
- High fermentable corn hybrids
- Correlation between extractable starch and fermentable starch
- Corn hybrids with endogenous liquefaction enzymes
- Corn hybrids for modified dry grind corn processes
Hybrid Variability

- Hybrid variability in a dry grind corn facility is generally defined by two factors:
  1. Differences in fermentability
  2. Variation in the composition of DDGS
Effect of Hybrid Variability on Dry Grind Corn Process

- Final ethanol concentration in beer
- Coproduct quality
- Capital and Operating Cost
  - Process fluctuations
  - Maintenance
Extent of Hybrid Variability for Ethanol Production

**Ethanol Conc. % (v/v)**

- 3.26%
Hybrid Specific Processing

- Limited number of elite line hybrids
  - good producer yields but with good ethanol yield, too
Identifying of Hybrids with High Fermentability

Dry-Grind Ethanol

2004 Pioneer. Brand and hybrids for

This is the North America HFT List of Pioneer brand hybrids. Please check with your local Pioneer sales professional for availability of a more specific localized list of Pioneer HFT hybrids. The HFT designation is assigned to elite Pioneer brand hybrids that are above the mean based on data from over 15,000 Pioneer progeny entries over the past three years.
Identifying of Hybrids with High Fermentability

Monsanto’s research has proven there is a wide range of variability in ethanol production between different grain samples and hybrids.

Only a select group of hybrids meet the Processor Preferred criteria.

Source: http://www.monsanto.com/monsanto/us_ag/content/enhanced_value/pro_per/pro_per_corn/brochure.pdf
What Causes Hybrid Variability

- Variability due to genetics
  - Starch?
  - Protein?
  - Other constituents?

- Variability due to environment (phenotype)
  - Effect of location
  - Effect of crop year
Correlation between Starch and Ethanol
Starch Yield and Ethanol
(Dien et al 2002)

Starch Yield and Sugars

(Pruiett 2002)

**Extractable Starch Yield (%db)**

**Sugars (%db)**

- **R² = 0.048**

Starch Content and Ethanol Yield (Haefele et al 2004)

Starch Yield and Ethanol Conc. (Zhan et al, 2005)

Variability Due to Environment
Effect of Planting Location

Significant Interaction between Hybrids and Years
Comparison of Ethanol Conc. for 5 Hybrids Over 3 Years

- Ethanol Conc. Deviation from Average (%v/v)

- N33-V5
- N35-B8
- N32-K3
- N32-L9
- N25-J7

Year:
- 2002
- 2003
- 2004
Comparison of Ethanol Conc. for 4 Hybrids Over 3 Years

![Graph showing the comparison of ethanol concentration for 4 hybrids over 3 years. The graph includes data points for N43-M9, N45-A6, N46-J7, and N50-P5 across the years 2002, 2003, and 2004. The x-axis represents the hybrids, and the y-axis represents the ethanol concentration deviation from the average (%/v/v).]
Granular Starch Hydrolyzing (GSH) Enzymes
Starch Granule Hydrolyzed by GSH Enzyme
Dry Grind Process

With GSH enzyme hybrid variability was only approximately 11% compared to 23% with conventional dry grind enzymes.
Development of New Transgenic Corn Specifically for Dry Grind Process
Dry-grind Process

- Corn
- Water
- Enzymes
- Grinding (Hammermill)
- Blending
- Mash
- Liquefaction
- Yeast & Enzymes
- Saccharification & Fermentation
- CO₂
- Overhead product (Recycled back)
- Ethanol
- Dehydration column
- DDGS
- Stripping/Rectifying column
A new transgenic corn with endogenous liquefaction enzymes has been developed that is activated in presence of water at high temperature.
Amylase Expressing Corn
500 ml Fermentations
Control vs 3, 5 and 10% amylase corn addition

500 ml Fermentations
Control vs 1, 2 and 3% amylase corn addition

# DDGS Composition

<table>
<thead>
<tr>
<th>Components</th>
<th>3% amylase corn addition</th>
<th>Control Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Protein (%)</td>
<td>26.1 ± 0.2</td>
<td>25.8 ± 0.1</td>
</tr>
<tr>
<td>Crude Fat (%)</td>
<td>14.1 ± 0.1</td>
<td>13.6 ± 0.2</td>
</tr>
<tr>
<td>Crude Fiber (%)</td>
<td>6.6 ± 0.1</td>
<td>6.8 ± 0.1</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>3.78 ± 0.1</td>
<td>3.35 ± 0.1</td>
</tr>
</tbody>
</table>

No significant difference in composition of DDGS for 3% amylase corn addition and control treatment

<table>
<thead>
<tr>
<th>Fractions</th>
<th>Control</th>
<th>0.1% Amy</th>
<th>1.0% Amy</th>
<th>10% Amy</th>
</tr>
</thead>
<tbody>
<tr>
<td>+5(Large Grits)</td>
<td>31.42</td>
<td>33.23</td>
<td>30.59</td>
<td>28.73</td>
</tr>
<tr>
<td>-10+24</td>
<td>29.88</td>
<td>28.91</td>
<td>31.79</td>
<td>31.46</td>
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<tr>
<td>(Small Grits)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-24(Fines)</td>
<td>18.01</td>
<td>17.47</td>
<td>16.65</td>
<td>18.18</td>
</tr>
<tr>
<td>Germ</td>
<td>13.02</td>
<td>12.88</td>
<td>13.32</td>
<td>13.79</td>
</tr>
<tr>
<td>Pericarp</td>
<td>7.45</td>
<td>7.57</td>
<td>7.64</td>
<td>7.60</td>
</tr>
<tr>
<td>Total</td>
<td>99.78</td>
<td>100.06</td>
<td>99.98</td>
<td>99.76</td>
</tr>
</tbody>
</table>

### Wet Milling (1 kg Procedure)

<table>
<thead>
<tr>
<th>Fractions</th>
<th>Control</th>
<th>0.1% Amy</th>
<th>1.0% Amy</th>
<th>10% Amy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solubles (%)</td>
<td>4.52</td>
<td>4.40</td>
<td>4.38</td>
<td>4.82</td>
</tr>
<tr>
<td>Germ (%)</td>
<td>6.21</td>
<td>6.35</td>
<td>6.43</td>
<td>6.74</td>
</tr>
<tr>
<td>Fiber (%)</td>
<td>12.36</td>
<td>11.72</td>
<td>11.98</td>
<td>11.90</td>
</tr>
<tr>
<td>Starch (%)</td>
<td>67.24</td>
<td>67.66</td>
<td>67.33</td>
<td>66.19</td>
</tr>
<tr>
<td>Gluten (%)</td>
<td>10.25</td>
<td>10.18</td>
<td>10.16</td>
<td>10.65</td>
</tr>
<tr>
<td>Total (%)</td>
<td>100.59</td>
<td>100.31</td>
<td>100.29</td>
<td>100.30</td>
</tr>
</tbody>
</table>

Corn for Modified Dry Grind Processes
Modified Dry Grind Ethanol Processes

- Wet fractionation technology: similar to wet milling
  - Enzymatic dry grind process (E-Mill process)
  - Recovers germ, pericarp fiber and endosperm fiber at front end of dry grind ethanol plant

- Dry fractionation technology: similar to dry milling
  - Dry degerm defiber process (3D process)
  - Recovers germ and pericarp fiber at front end of dry grind ethanol plant

These modified dry grind processes, recover valuable coproducts, improve efficiency of dry grind process and reduce volume of DDGS produced.
DDGS Utilization (2005)

- Dairy: 46%
- Beef: 39%
- Swine: 11%
- Poultry: 4%
Coproduct values

Coproduct Value ($/ton)

corn
DDGS

Cattle and Calves Inventory
Source: USDA-NASS 2002 Census of Agriculture

Beef Cows

Milk Cows
Poultry and Swine Inventory
Source: USDA-NASS 2002 Census of Agriculture

Pigs

Broiler and Other Meat
Type Chicken
Wet Fractionation Technology: Enzymatic Dry Grind Process (E-Mill)

One bushel Corn

Corn Dry Grind Facility

2.6 gal Ethanol

2.6 gal Ethanol

E-Mill

3.7 lb Residual DDGS

Nonruminant Food

Ruminant Food

Quick Germ

Quick Fiber

3.3 lb Germ

4 lb Pericarp Fiber

4 lb Endosperm Fiber

4 lb Fiber
Dry Fractionation Technology: Dry Degerm Defiber Process (3D Process)

One bushel Corn

- Dry Degerm Defiber Process
  - 4 lb Germ
  - + 4 lb Pericarp Fiber

Corn Dry Grind Facility

- 7.0 lb Residual DDGS

- Ruminant Food
  - 2.6 gal Ethanol

- Nonruminant Food

- Nonruminant Food
Effect of Hybrid Variability on Enzymatic Dry Grind Corn Process

5 Hybrids
N36-R6
N22-T8
NX2603
N34-F1

x

2 Locations
Waupun, WI
Brookings, SD

Enzymatic Dry Grind Process

Coproducts and Ethanol Yield
### Coproducts and Ethanol Yield for Waupun, WI

<table>
<thead>
<tr>
<th>Fraction (% db)</th>
<th>N36-R6</th>
<th>N22-T8</th>
<th>NX2603</th>
<th>N34-F1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germ</td>
<td>9.18</td>
<td>9.22</td>
<td>9.41</td>
<td>8.85</td>
</tr>
<tr>
<td>Pericarp Fiber</td>
<td>8.62</td>
<td>7.79</td>
<td>8.61</td>
<td>6.04</td>
</tr>
<tr>
<td>Endosperm Fiber</td>
<td>3.89</td>
<td>5.46</td>
<td>5.04</td>
<td>3.93</td>
</tr>
<tr>
<td>DDGS</td>
<td>7.38</td>
<td>8.14</td>
<td>8.29</td>
<td>8.31</td>
</tr>
<tr>
<td>Ethanol Conc. (% v/v)</td>
<td>13.41</td>
<td>14.60</td>
<td>14.34</td>
<td>13.35</td>
</tr>
</tbody>
</table>
## Coproducts and Ethanol Yield for Brooking, SD

<table>
<thead>
<tr>
<th>Fraction (% db)</th>
<th>N36-R6</th>
<th>N22-T8</th>
<th>NX2603</th>
<th>N34-F1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germ</td>
<td>8.87</td>
<td>9.21</td>
<td>9.54</td>
<td>8.89</td>
</tr>
<tr>
<td>Pericarp Fiber</td>
<td>10.45</td>
<td>7.51</td>
<td>9.37</td>
<td>8.05</td>
</tr>
<tr>
<td>Endosperm Fiber</td>
<td>5.60</td>
<td>6.50</td>
<td>5.53</td>
<td>6.56</td>
</tr>
<tr>
<td>DDGS</td>
<td>8.01</td>
<td>10.83</td>
<td>9.34</td>
<td>8.63</td>
</tr>
<tr>
<td>Ethanol Conc. (% v/v)</td>
<td>13.40</td>
<td>12.93</td>
<td><strong>13.56</strong></td>
<td>13.38</td>
</tr>
</tbody>
</table>
Conclusions

- New Developments in Dry Grind Corn Processing
  - Significant variability in corn hybrids for dry grind ethanol production
    - 23% total variability
    - 75% of this variability is due to genetics and 25% is due to environment
    - Variability can be reduced with hybrid specific processing or by using GSH enzyme
  - Negligible or weak correlation between starch content or extractability and starch fermentability
  - Corn with endogenous liquefaction enzymes
  - Hybrid specific processing for conventional and modified dry grind processes to increase ethanol yield and coproduct quality