Dry Grind Corn Processing – New Technologies

Vijay Singh
Associate Professor
Department of Agricultural & Biological Engineering
University of Illinois at Urbana-Champaign, Urbana, IL

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Presentation Outline

- Corn Kernel Composition
- Corn Processing Terminology
- Conventional Dry Grind Process
- New Technologies
Composition of Corn Kernel

- Pericarp
- Endosperm
- Germ
- Tip Cap

Corn Milling Processes

1. Wet Milling

Corn Wet Milling Facility

- 2.5 gal (9.46 L) of Ethanol
- 1.5 lb (0.68 kg) of Corn Oil
- 12.4 lb (5.62 kg) of Gluten Feed
- 3 lb (1.36) of Gluten Meal

Ruminant Food

Poultry Food

One bushel of Corn (25 kg or 56 lb)
Corn Milling Processes (Cont.)

2. Dry Milling

- One bushel of Corn (25 kg or 56 lb)
  - Corn Dry Milling Facility
  - Flaking Grits
  - Corn Meal
  - Hominy Feed (Germ + Bran + Flour)
  - Breakfast Cereals
  - Hominy Feed
  - Ruminant Food

Corn Milling Processes (Cont.)

3. Dry Grind

- One bushel of Corn (25 kg or 56 lb)
  - Corn Dry Grind Facility
  - 2.7 gal (10.2 L) of Ethanol
  - 15 lb (6.8 kg) of DDGS
  - Ruminant Food
Conventional Dry Grind Process

New Technologies in Dry Grind Ethanol Production:
Feedstock Development
Conventional Corn
High Fermentable Corn (HFC) Hybrids

- Typically Dry Grind Ethanol yield
  - 2.7 gallons/bushel
- Range
  - 2.65 to 2.75 gallons/bushel
  - 3-4% difference in ethanol yield

Correlation between Starch and Ethanol


Starch Yield and Ethanol Conc.  
*(Singh and Graeber 2005)*

\[ R^2 = 0.0038 \]


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

\[ R^2 = 0.25 \]

Why Poor Correlation Between Starch and Ethanol?

- Starch is very broad term
  - Amylose
  - Amylopectin
    - Are both amylose and amylopectin equally digestible?
  - Resistant Starch
    - Resistant starch (RS) is part of starch that is resistant to enzymatic hydrolysis
    - RS acts as fiber and is not hydrolyzed
- Corn contains other micronutrients that affect dry grind fermentation process

Effect of Amylose and Amylopectin Content in Starch on Ethanol Yield

Effect of Amylose and Amylopectin Content in Corn on Ethanol Yield


Feedstock Development: Conventional Corn

- Variation in ethanol potential among yellow dent corn hybrids
  - 3 to 4% variation between a high performing and low performing corn hybrids
- Ethanol potential cannot be predicted based on starch content alone
- Determination for ethanol potential of corn hybrids should be done based on fermentation assay
Emerging Technologies in Dry Grind Ethanol Production:
Feedstock Development of New Corn

Transgenic Corn for Dry Grind Process

**15 L Fermentations**  
Control vs 3% amylase corn addition

![Graph showing ethanol concentration over fermentation time](image)

**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

### Dry 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>+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 (Small Grits)</td>
<td>29.88</td>
<td>28.91</td>
<td>31.79</td>
<td>31.46</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>

Feedstock Development: Transgenic Corn

- Reduces requirement of exogenous alpha amylase
- Only 3% amylase corn addition is required with dent corn for complete liquefaction
- No differences in DDGS composition between 3% amylase corn treatment and conventional treatment

New Technologies that Affect Dry Grind Ethanol Fermentation
Conventional Dry Grind Process

Corn → Grinding (Hammermill)

Water → Blending → Liquefaction

Alpha-Amylase → Saccharification & Fermentation

CO₂ → Overhead product (Recycled back)

Ethanol → Dehydration column

Yeast & Glucoamylase → Stripping/Rectifying Column

Centrifuge → Thin Stillage → Evaporator

Wet Grains → Syrup → DDGS

Fermentation Profile

Ethanol Concentration (% v/v) vs. SSF (hr)

% Ethanol Produced vs. SSF (hr)
**Fermentation Profile**

**Plant 1**
- Mash Solids: 32.0%

- Graph showing sugars, ethanol, glycerol, and other concentrations over fermentation time (hr).

**Plant 2**
- Mash Solids: 34.0%

- Graph showing sugars, ethanol, glycerol, and other concentrations over fermentation time (hr).
New Technology: Granular Starch Hydrolyzing Enzymes

Granular Starch Hydrolyzing (GSH) Enzymes

- These enzymes have high granular starch (raw starch or native starch) hydrolyzing activity
  - Blend of alpha and glucoamylases
- Can liquefy and saccharify starch into glucose at low temperature (< 48°C)
  - Stargen 001, Genencor International
  - BPX, Novozymes NA
- These enzymes can be used for all cereal grains
**Corn Starch Treated with Granular Starch Hydrolyzing Alpha and Glucoamylase**  
**pH 4.5, 32°C**

Granular Starch Incubated with GSHE, 2 hr

Granular Starch Incubated with GSHE, 4 hr

Granular Starch Incubated with GSHE, 8 hr

Source: USDA/ARS/ERRC and Genencor International

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**Granular Starch Hydrolyzing Enzymes**

Results: Ethanol Concentration


Fermentation Profiles with GSH Enzymes

Mash Solids 32.0%
Granular Starch Hydrolyzing Enzymes

- Final ethanol yield with GSH enzymes is comparable to conventional enzymes
- Glucose, maltose and maltotriose concentrations are consistently low with GSH enzymes throughout fermentation
- GSH enzymes work at same temperature conditions as conventional SSF
  - With GSH enzymes simultaneous liquefaction, saccharification and fermentation can be conducted
- GSH enzymes are commercially being used
  - Corn ethanol production in US
  - Rye, wheat, broken rice ethanol production in Europe and Asia

New Technology: Corn Fractionation
Corn Wet Fractionation

- Involves soaking of corn or other cereal grains (wheat, sorghum) in water and separation of coproducts in aqueous medium
- Uses wet grinding mills, hydrocyclones and screens for separation
  - Quick Germ Process, Univ. of Illinois (UIUC)
  - Quick Germ Quick Fiber Process, UIUC (Licensed to MPI Inc.)
  - Enzymatic Dry Grind Process, UIUC & US Dept. of Ag.
  - Hydromilling Process, CVP, LLC (Joint venture between AMG Inc, Centrisys Corporation and QTI)

Wet Fractionation Equipment

- Wet Degermination Mill
- Hydrocyclones
- Screens
**Corn Dry Fractionation**

- Involves tempering of corn or other cereal grains (wheat, sorghum) with steam or hot water and dry separation of coproducts
- Uses dry degeminators, gravity tables and sifters for separation
  - Dry Degerm Defiber Process (3D process), UIUC
  - FWS Process, FWS Technologies, Winnipeg, MB, Canada
  - BFrac Process, Poet
  - CTP Process, Cereal Process Technologies, LLC
  - Extrax Process, Renessen LLC
  - Mor Technology Inc.
  - DTS, Delta-T Corporation
  - Applied Milling System, ICM Inc.

**Dry Fractionation Equipment**

- Satake Degerminator
- Beall Degerminator
- Dry Degermination Mills
  (Duensing et al. 2003, Corn Dry Milling, Corn Chemistry and Technology Book)
Dry Fractionation Process (3D Process)


Comparison of Wet and Dry Fractionation: Fermentation Profiles

Corn Fractionation Processes

- Corn fractionation (wet or dry) prior to fermentation
  - Reduces volume of DDGS produced
  - Recovers germ and fiber as valuable coproducts
  - Increases final ethanol concentration
- Wet fractionation process compared to dry fractionation process
  - Has higher rate of fermentation
  - Has higher final ethanol concentration

New Technology:
Simultaneous Liquefaction, Saccharification, Fermentation and Distillation (SLSFD)
New Technology:
Optimal Control of SSF Process

Conventional Controller Schematic
SSF Model: Input and Output

**INPUT**
- Mash composition after liquefaction
- Enzyme dosage
- Enzyme activity
- Yeast dosage
- Temperature, pH of fermentor

**OUTPUT**
- Consumption rate of glucose
- Production rates of ethanol, yeast cell mass, acetic acid, lactic acid and glycerol


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Overall Control System Architecture

- Dynamic controller
- Theoretical model (SSF process)
- Fermentor system
- Set point controller
- System state information
- Control action (Activation of pumps, valves)
- Set point values for temperature, pH and glucoamylase
- Temperature, pH and HPLC measurements

Optimal Controller: Lab Results

- 50% reduction in glucoamylase dose in a conventional dry grind ethanol plant with optimal controller

Optimal Controller: Lab Results

- No difference in ethanol profile between baseline and optimal controller

Optimal Controller: Plant Results

- 35% reduction in glucoamylase dose in a conventional dry grind ethanol plant

Optimal Controller for SSF

- Lower concentration of glucose during SSF
- Less glucoamylase requirement during SSF
- Similar or higher final ethanol concentration

New Technologies that Affect DDGS Volume and/or Composition and Allow Recovery of Other Coproducts
Conventional Dry Grind Process

One bushel of Corn (25 kg or 56 lb)

Corn Dry Grind Facility

2.7 gal (10.2 L) of Ethanol

15 lb (6.8 kg) of DDGS

Ruminant Food

DDGS Utilization

% Used

2002 2003 2004 2005 2006 2007

Dairy Beef Poultry Swine

University of Illinois at Urbana-Champaign

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

Beef Cows

Milk Cows
New Technology: Corn Fractionation

**Corn Wet Fractionation: Enzymatic Dry Grind Corn Process (E-Mill)**

Bushele of Corn (25 kg or 56 lb)

- Density Separation
- Density Separation
- Size Separation

Corn Dry Grind Facility

- 2.6 gal (9.84 L) Ethanol
- 3.7 lb (1.68 kg) Residual DDGS

Ruminant Food

Nonruminant Food

**DDGS Composition: Corn Wet Fractionation (E-Mill Process)**

<table>
<thead>
<tr>
<th></th>
<th>Conv.</th>
<th>E-Mill</th>
<th>Soy Meal</th>
<th>CGM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Prot. (%)</td>
<td>28.50</td>
<td>58.50</td>
<td>53.90</td>
<td>66.70</td>
</tr>
<tr>
<td>Crude Fat (%)</td>
<td>12.70</td>
<td>4.53</td>
<td>1.11</td>
<td>2.77</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>3.61</td>
<td>3.24</td>
<td>---</td>
<td>----</td>
</tr>
<tr>
<td>Acid Det. Fiber (%)</td>
<td>10.8</td>
<td>2.03</td>
<td>5.95</td>
<td>6.88</td>
</tr>
</tbody>
</table>

Corn Dry Fractionation:
Dry Degerm Defiber Process (3D Process)


Comparison of Wet and Dry Fractionation:
DDGS Nutrient Content

<table>
<thead>
<tr>
<th>Component</th>
<th>Conventional Dry grind</th>
<th>Dry Fractionation</th>
<th>Wet Fractionation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein (%)</td>
<td>21</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>14</td>
<td>9</td>
<td>5.4</td>
</tr>
<tr>
<td>Fiber (TDF) (%)</td>
<td>36</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>Lysine (%)</td>
<td>0.73</td>
<td>0.63</td>
<td>0.91</td>
</tr>
<tr>
<td>Lys, % of CP</td>
<td>3.4</td>
<td>2.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Phosphorus (%)</td>
<td>0.78</td>
<td>0.47</td>
<td>1.12</td>
</tr>
</tbody>
</table>

Corn Fractionation Processes: Effect on DDGS

- Corn fractionation (wet or dry) prior to fermentation
  - Reduces volume of DDGS produced
  - Increased protein and reduces fiber content of DDG
- Wet fractionation process compared to dry fractionation process
  - Better nutritional quality of DDGS

Other Benefits of Fractionation Processes: Recovery of Valuable Coproducts

- Recovery of germ, pericarp and endosperm fiber as valuable coproducts
  - Germ
    - Corn Germ Oil
  - Pericarp and Endosperm Fiber
    - Corn Fiber Oil
    - Corn Fiber Gum
    - Ethanol


Comparison of Wet and Dry Fractionation:
Germ Composition

<table>
<thead>
<tr>
<th>Milling Process</th>
<th>Oil (%)</th>
<th>Protein (%)</th>
<th>Starch (%)</th>
<th>Ash (%)</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Wet Milling A</td>
<td>40.89</td>
<td>14.03</td>
<td>8.00</td>
<td>2.20</td>
<td>7.50</td>
</tr>
<tr>
<td>Commercial Wet Milling B</td>
<td>36.39</td>
<td>13.09</td>
<td>6.90</td>
<td>1.43</td>
<td>7.50</td>
</tr>
<tr>
<td>Laboratory Wet Milling</td>
<td>38.77</td>
<td>18.38</td>
<td>11.60</td>
<td>2.30</td>
<td>7.51</td>
</tr>
<tr>
<td>Wet Fractionation</td>
<td>36.43</td>
<td>21.36</td>
<td>6.20</td>
<td>ND</td>
<td>6.50</td>
</tr>
<tr>
<td>Commercial Dry Milled</td>
<td>23.00</td>
<td>15.35</td>
<td>19.81</td>
<td>ND</td>
<td>12.00</td>
</tr>
<tr>
<td>Dry Fractionation</td>
<td>18.06</td>
<td>17.46</td>
<td>21.20</td>
<td>ND</td>
<td>13.86</td>
</tr>
</tbody>
</table>


Lipids in Refined Vegetable Oils

- Saponifiables (>99%)
  - Acyl Lipids
  - Triacylglycerols (TAG)
- Nonsaponifiables
  - Phytosterols
    - Free
    - Acyl esters
    - OH-cinnamate esters
  - Tocols
    - Tocopherols (Vitamin E)
    - Tocotrienols
  - Carotenoids
- Others (squalene, phospholipids, glycolipids)
Why are Phytosterols Valuable

- When consumed, Phytosterols can lower LDL-Cholesterol levels by 15-20% without the use of “statin” drugs
- This is estimated to reduce the risk of heart disease by 20-40%
- Recent NIH guidelines regarding the need to lower LDL-Cholesterol levels points to increasing demand for phytosterols

Corn Fractionation Processes: Recovery of Additional Coproducts

- Corn fractionation (wet or dry) prior to fermentation
  - Recover germ, pericarp fiber and endosperm fiber as additional coproducts
  - Fibers can be used as feedstock for recovery of other valuable coproducts
    - Corn fiber oil
    - Corn fiber gum
- Wet fractionation process compared to dry fractionation process
  - Recovers germ with better composition
New Technology: DDGS Fractionation

DDGS Fractionation: Elusieve (ES) Process

Modified Dry Grind Process: Elusieve (ES) Process

Corn → Grinding (Hammermill) → Water

Saccharification & Fermentation → CO₂

Mash → Blending → Alpha Amylase

Liquefaction → Yeast & Glucoamylase

Overhead product (Recycled back) → Ethanol

(10. 2 L or 2.7 gal)

(6.8 kg or 15 lb)

DDGS

Stripping/Rectifying Column → Centrifuge

Thin Stillage → Syrup

Dehydration column → Wet Grains

Ethanol

Thin Stillage

Wet Grains

DDGS

Syrup


Sieving Results

<table>
<thead>
<tr>
<th>Size Category</th>
<th>Nominal Particle Size (Microns)</th>
<th>% Retained on Screen</th>
<th>Protein %</th>
<th>Fat %</th>
<th>NDF %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Material</td>
<td>All</td>
<td>100</td>
<td>33.6</td>
<td>12.5</td>
<td>32.5</td>
</tr>
<tr>
<td>24T</td>
<td>&gt; 869</td>
<td>27</td>
<td>29.3</td>
<td>12.5</td>
<td>33.4</td>
</tr>
<tr>
<td>34T</td>
<td>582 to 869</td>
<td>19.4</td>
<td>26.9</td>
<td>11.3</td>
<td>37.8</td>
</tr>
<tr>
<td>35M</td>
<td>447 to 582</td>
<td>13.3</td>
<td>31.2</td>
<td>10.9</td>
<td>33.6</td>
</tr>
<tr>
<td>60M</td>
<td>234 to 447</td>
<td>20.1</td>
<td>37.5</td>
<td>11.3</td>
<td>29.3</td>
</tr>
<tr>
<td>Pan</td>
<td>&lt; 234</td>
<td>20.2</td>
<td>42.2</td>
<td>12.9</td>
<td>19.0</td>
</tr>
</tbody>
</table>

NDF – Neutral Detergent Fiber

### Elutriation Results

<table>
<thead>
<tr>
<th>Fraction</th>
<th>NDF %</th>
<th>Protein %</th>
<th>Fat %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighter</td>
<td>53.3</td>
<td>19.3</td>
<td>7.05</td>
</tr>
<tr>
<td>Bulk</td>
<td>33.4</td>
<td>29.3</td>
<td>12.5</td>
</tr>
<tr>
<td>Heavier</td>
<td>32.6</td>
<td>35.6</td>
<td>14.2</td>
</tr>
</tbody>
</table>

**24T, Air Velocity = 3.35 m/s, Yield (Lighter) = 27.8%**

<table>
<thead>
<tr>
<th>Fraction</th>
<th>NDF %</th>
<th>Protein %</th>
<th>Fat %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighter</td>
<td>58.7</td>
<td>15.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Bulk</td>
<td>37.8</td>
<td>26.9</td>
<td>11.3</td>
</tr>
<tr>
<td>Heavier</td>
<td>32.4</td>
<td>33.1</td>
<td>13.8</td>
</tr>
</tbody>
</table>

**34T, Air Velocity = 2.55 m/s, Yield (Lighter) = 33.4%**

<table>
<thead>
<tr>
<th>Fraction</th>
<th>NDF %</th>
<th>Protein %</th>
<th>Fat %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighter</td>
<td>56.0</td>
<td>16.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Bulk</td>
<td>33.6</td>
<td>31.2</td>
<td>10.9</td>
</tr>
<tr>
<td>Heavier</td>
<td>27.6</td>
<td>35.4</td>
<td>13.1</td>
</tr>
</tbody>
</table>

**35M, Air Velocity = 1.84 m/s, Yield (Lighter) = 19.3%**

<table>
<thead>
<tr>
<th>Fraction</th>
<th>NDF %</th>
<th>Protein %</th>
<th>Fat %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighter</td>
<td>55.3</td>
<td>16.5</td>
<td>8.5</td>
</tr>
<tr>
<td>Bulk</td>
<td>33.6</td>
<td>31.2</td>
<td>10.9</td>
</tr>
<tr>
<td>Heavier</td>
<td>27.6</td>
<td>35.4</td>
<td>13.1</td>
</tr>
</tbody>
</table>


### DDGS Fractionation Process

- DDGS fractionation
  - Modified DDGS with high protein, high fat and low fiber content compared to conventional DDGS
  - Depending upon separation parameters DDGS can be produced with
    - Protein content, 42%
    - NDF, 19%
  - Cost of retrofitting a 45 Mil gallon/yr is less than $1.0 M
  - Payback period is less than 2 years