The Ninth International Starch Technology Conference

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Edited by

Kent Rausch
Vijay Singh
Mike Tumbleson
The Conference

The International Starch Technology Conference (ISTC) has been offered every two years since 1999. The conference is designed to facilitate interaction among international representatives from the starch processing industry, government research agencies and allied industries. Speakers from industry, research agencies and occasional academia are invited from around the world to speak and present a paper. While there are many trade expos and conferences that promote entrepreneurial efforts, and quite a few scientific conferences that focus on carbohydrate chemistry, ISTC is unique in that it focuses on research and advances in processing of cereal grains and other starch bearing crops.

For the first time this year, ISTC was held in conjunction with the Corn Wet Milling and the New Technologies in Ethanol Production short courses. The aim was to provide more information to the starch processing industry within a compact schedule.

The International Starch Technology Conference is an entirely self supported endeavour. As such, it does not receive funding from the University of Illinois other than to support faculty efforts in organizing the conference and editing the proceedings. Speakers and organizers do not receive reimbursement or honoraria for their contributions. There is no overarching support or project funding; conference expenses are met primarily by registration fees.

As a result, we are deeply appreciative of the speakers who participated in our conference.
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*indicates presenter
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Agenda

Tuesday, February 3
Participants registered for the wet milling short course will be shuttled to the Hawthorn from campus

4:00 Opening Remarks for ISTC
4:15 Pauline Teunissen, DuPont Industrial Biosciences
“A novel method for producing maltose rich syrup”
5:15 Dell Hummel, Alfa Laval
“Centrifuges for a green future”
6:15 **Reception** at Hawthorn, hot hors d’oeuvres (included in ISTC registration)
Poster viewing with the authors

Wednesday, February 4

8:00 Opening remarks
8:15 Jeremy Saunders, Novozymes
“Maximizing starch conversion to ethanol”
9:15 Steve Hughes, National Center for Agricultural Utilization Research, ARS, USDA
“Development of synthetic chromosomes and improved microbial strains to utilize cellulosic feedstocks and express valuable coproducts for sustainable production of biofuels from corn”

**Break**
10:15 Eric Shinsato, Ingredion
“The latest trends in high potency sweeteners”
11:15 Jeroen Poldervaart, Andritz Gouda
“Andritz separation in starch industry”

**Lunch**, Hawthorn Suites (included with registration)
12:45 Participants registered for New Technologies in Ethanol Production short course will shuttle to ACES Library

6:00 **Reception** at Hawthorn, hot hors d’oeuvres (included in ISTC registration)
Poster viewing with the authors

*indicates presenter
Poster Presentations
THIN STILLAGE FOULING IN MULTIPLE EFFECT EVAPORATORS

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In a corn dry grind plant, evaporator fouling occurs during thin stillage concentration using multiple effect evaporators. Evaporator fouling is caused by deposit formation from thin stillage components such as carbohydrates, protein, fiber, fat and minerals. Deposit formation on evaporator surfaces increases costs for energy consumption, maintenance, labor and cleaning chemicals (Epstein, 1981). Falling film evaporators are used widely in the food industry due to higher heat transfer coefficients at low evaporating temperatures and short residence times. One operating parameter that affects heat transfer in a falling film evaporator is solids concentration (Chen and Jebson, 1997). Total solids content in thin stillage increases as it is concentrated in a multiple effect evaporator. During final stages of thin stillage concentration, oil is recovered by centrifugation to generate additional revenue. Effects of oil separation on evaporator fouling are largely unknown.

Long chain carbohydrates, such as starch, were found to foul heat transfer surfaces (Challa et al., 2015). In addition to carbohydrates, components such as postfermentation corn oil may influence thin stillage fouling tendencies. In an earlier study, Singh et al (1999) used refined corn oil to evaluate the effects of on thin stillage fouling. However, refined corn oil characteristics are thought to be different from postfermentation corn oil present in thin stillage. An annular fouling probe was used to study fouling tendencies of thin stillage collected from various stages of a multiple effect evaporator. Compared to thin stillage, thin stillage concentrates had higher fouling resistances. Postfermentation corn oil addition to thin stillage increased fouling resistances but decreased at 1.5% w/w addition.

LITERATURE CITED
Objectives

- Investigate fouling rates of thin stillage and evaporator concentrates.
- Determine effects of post fermentation corn oil and glycerol addition to thin stillage (TS) on fouling rates.

Introduction

- More than 200 biorefineries use multiple effect evaporators to remove water from thin stillage.
- For a 40 mgy ethanol plant, 240 to 280 mmyg TS is produced.
- TS forms deposits on evaporator surfaces which reduce efficiency, consuming more energy per unit water evaporated.
- During corn processing, fouling deposits increase over time and require periodic evaporator shutdowns for cleaning [1,2].
- Costs associated with fouling include increased labor and cleaning equipment, capital and environmental impact from cleaning chemical disposal [3].
- Proteins, carbohydrates, fats and fiber may increase evaporator fouling rates; studies published in corn processing have been limited [1,2,4,5,6].
- Thin stillage recycling (approximately 50%) during ethanol production increases composition variability [1,2].
- The effects of heat treatment as indicated by evaporator stage and post fermentation oil need to be determined.

Methods

- An annular probe was used to measure fouling tendencies of synthetic thin stillage [1,2,4,5,6].
- \( R_f = \frac{1}{U_{fouled}} - \frac{1}{U_{unfouled}} \) (m²K/kW).
- TS (7% solids) and evaporator concentrates (8 to 11% solids) were collected from four evaporator stages.
- Test mixtures prepared by adding corn oil or glycerol to TS.
- Batch temperature was 75 ± 2°C; power (410 ± 10W) was supplied to fouling probe to adjust initial probe temperature (120 ± 2°C) (Fig. 1).
- As fouling occurred, temperature increased with time; tests were terminated after 5 hr or at T = 200°C.
- Determine effects of post fermentation corn oil and glycerol addition to thin stillage (TS) on fouling rates.
- Investigate fouling rates of thin stillage and evaporator concentrates.
- Batch evaporator fouling rates; studies published in corn processing have been limited [1,2,4,5,6].
- Thin stillage had linear fouling; some sloughing was apparent for evaporator concentrates (Fig. 2).
- Evaporator concentrates from stages 1 and 2 were similar within the 5 hr test period.
- Evaporator concentrate from stage 4 had final \( R_f = 0.505 \) m²K/kW.

Results

Fouling of evaporator concentrates

- Thin stillage had linear fouling; some sloughing was apparent for evaporator concentrates (Fig. 2).
- Evaporator concentrates from stages 1 and 2 were similar within the 5 hr test period.
- Evaporator concentrate from stage 4 had final \( R_f = 0.505 \) m²K/kW.

Corn oil effects

- Thin stillage had a final \( R_f = 0.15 \) m²K/kW during 5 hr test period (Fig. 3).
- At 0.5% (w/w) post fermentation corn oil addition, final \( R_f \) increased to 0.34 m²K/kW but decreased to 0.21 m²K/kW at 1.5% (w/w) addition (Fig. 3).

Glycerol addition to thin stillage at 1% w/w concentration decreased TS fouling rates (Fig. 4).

Conclusions

- Concentrates had higher fouling resistances compared to thin stillage before evaporation.
- Deposit sloughing was observed for concentrates collected from stages 3 and 4.
- Post fermentation corn oil addition to TS in 0.5% w/w increments increased fouling followed by decrease at 1.5% w/w addition.
- TS fouling rates were lower than those with added post fermentation corn oil.
- Glycerol addition to thin stillage at 1% w/w concentration increased fouling resistance.

References

HYDROTHERMOLYTIC PRODUCTION OF XYLOOLIGOSACCHARIDES FROM MISCANTHUS X GIGANTEUS: CHARACTERISTICS, PURIFICATION AND FUNCTIONAL TESTS

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Miscanthus x giganteus (MxG), a perennial grass, is a leading candidate energy crop for fuel conversion. Xylooligosaccharides (XOS) are sugar oligomers made of xylose units. Due to their prebiotic functionality and other health promoting effects, XOS can a value added coproduct for the cellulosic ethanol industry. There is lack of information on production of XOS in conjunction with cellulosic ethanol processes, especially with MxG. The objective of this study was to produce and recover XOS from the liquid phase of pretreated MxG and optimize subsequent enzyme hydrolysis to release fermentable sugars for ethanol fermentation.

XOS could be produced from autohydrolysis at 160, 180 and 200°C for 60, 20 and 5 min, respectively. The maximum XOS yield was 13.5% (w/w) of initial biomass and 69.2% (w/w) of xylan. The degrees of polymerization (DP) were similar for each of the conditions as measured using HAPEC-PAD. Soluble XOS were recovered using activated carbon adsorption coupled with ethanol/water elution; the highest recovery of 47.9% (w/w) XOS was recovered by using 10% activated carbon (w/v) and eluted with 5, 30, 50, 70 and 95% ethanol/water solution. Chromatographic analyses were indicative that higher ethanol solutions could recover higher DP molecules. Recoveries of 91.8% xylobiose, 86.9% xylotriose, 66.3% xylotetrose, 56.2% xylopentaose and 48.9% xylohexaose were observed in XOS. During enzyme hydrolysis of pretreated material, yield of 85.0% theoretical sugars was observed in pretreated MxG. Purities of XOS fractions were increased to 76.2% (w/w) by prior hot water/ethanol extraction. Larger scale autohydrolyses were performed in 500 mL pipe reactors. Recovered XOS were utilized by Bifidobacterium sp. and consumption of each DP oligomer was monitored during culture growth. XOS have the potential to be developed into prebiotic products and a coproduct for cellulosic ethanol plants.

LITERATURE CITED
Introduction

Hydrothermolytic Production of Xylooligosaccharides from Miscanthus x giganteus: Characteristic, Purification and Functional Test

Material and Methods

Acknowledgement

Results and Discussion

Conclusions

Table 1. Recovery of XOS from activated carbon adsorption.

Table 2. Glucose production from pretreated MxG.

Fig. 1. Study flow chart.

Fig. 2. Reactor, sand bath and temperatures

Fig. 3. Autohydrolysis of MxG

Fig. 4. Property of XOS from three conditions.

Fig. 5. Recovering of XOS using 10 and 20% (w/v) activated carbon.

Fig. 6. Growth of Bifidobacterium aldolescentis in vitro

Fig. 7. Recovery and purification of XOS

Fig. 8. Trehalose, galactose and inositol.
POSTHARVEST GRAIN LOSS ASSESSMENT METHODS

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Brazil, a country endowed with vast agricultural resources, is a leader in the production of dry beans (ranked 1st in both value and production), soybeans (ranked 2nd in both value and production) and corn (ranked 3rd in both value and production) (FAOStat, 2011). Soybean and corn production, concentrated in the states of Mato Grosso, Goiás, Paraná and Minas Gerais, increased in the last three decades as a result of research efforts by Embrapa, producers, industry, university and private research centers. The wide range in scale in crop production, large farms, vast pastures and big grain production coexisting with subsistence family farms involving more than 4.5 M people, presents a range of postharvest loss challenges throughout the supply chain. A team of faculty and students from the University of Illinois, Federal University of Mato Grosso, Federal University of Viçosa and Federal University of Goiás are collaborating on measuring and documenting postharvest losses at different stages of the supply chain. We will develop measurement protocols and technologies that can be applied to other regions in the world where agronomic practices, climate and challenges are similar to Brazil. Data collected and protocols developed will provide important baselines for measuring improvements in grain quality during harvest, transport and storage once improvements in infrastructure are realized. We will provide an overview of our recent efforts in documenting postharvest grain losses during soybean and corn harvest (Paulsen et al., 2014), soybean transportation (Olsen et al., 2013, Wilhelmi et al., 2014) and hermetic storage of corn (Taffarel et al., 2013).

LITERATURE CITED


Wilhelmi, C.R., Danao, M.G.C., Gates, R.S., Zandonadi, R.S. and Hansen, A.C. 2014. Assessment of fleet used for soybean transportation in Mato Grosso, Brazil. ASABE Paper No. 141905584. Montreal, Quebec, Canada.
Postharvest grain loss assessment methods
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Acknowledgments. These activities were partially funded by the ADM Institute for the Prevention of Postharvest Loss, Lemann Institute for Brazilian Studies, Aprosoja, and generous in-kind support by the faculty, staff, and students at the Federal University of Mato Grosso. The authors are grateful to the producers and storage facility workers who have contributed greatly to this project.

Typical Agronomic Practice in North-Central Brazil

Figure 1. Mean temperatures in Cuiabá, MatoGrosso and corresponding agronomic practices in the state.

Grain Monitoring Probe Used in Transportation Loss Assessment

Figure 2. A grain monitoring probe was designed to have five chambers (C1 to C5), each containing a Model K33-BLG sensor package (CO2Meter Inc., Ormond Beach, FL, USA). The probe was equipped with a global positioning system (GPS) antenna and receiver which was used to determine location of the sensor and key points in grain handling: loading, transit, and unloading periods.

Figure 3. Example temperature, relative humidity, carbon dioxide, speed and distance data collected from two probes during one trip. In general, temperatures inside grain trailer were uniform and remained constant throughout trip. All relative humidity and carbon dioxide sensors responded to presence of grain. Carbon dioxide built up once the trailer began to move. Monitoring period is the time when trailer is transporting grains from 10 farms to 12 storage facilities.

During the 2014 soybean harvest season, we were able to implement the probes in 43 trips by 22 trucks transporting grains from 10 farms to 12 storage facilities.

Previous Work: Assessing Combine Losses and Efficacy of Silo Bags as Temporary Storage of Grain in the Tropics

Figure 5. Procedures for measuring soybean and corn harvest losses were developed (full details are available in DOI 10.1093/ajx/aaa30.109630). During the 2012 soybean harvest, estimated yields at 15% moisture ranged from 26.61 to 46.66 kg ha⁻¹. Preharvest losses ranged from 1.0 to 13.5 kg ha⁻¹; total combine losses ranged from 47.4 to 56.5 kg ha⁻¹. Headers were the largest contributors to losses at 31 to 47 kg ha⁻¹.

Figure 6. Corn (60 kg x 65% moisture) harvested in July 2012 was stored in a silo bag for 5 m in Sinop, Mato Grosso. While silo bags are used extensively in Argentina and Paraná (state), their use in the tropics and Mato Grosso are not well documented. Grain temperature inside the bag remained between 30 and 36 °C. No significant differences in corn quality parameters were observed over 5 mo and when compared to grain stored in a metal silo at the same location.

Grain Monitoring Probe Used in Transportation Loss Assessment

Figure 2. A grain monitoring probe was designed to have five chambers (C1 to C5), each containing a Model K33-BLG sensor package (CO2Meter Inc., Ormond Beach, FL, USA). The probe was equipped with a global positioning system (GPS) antenna and receiver which was used to determine location of the sensor and key points in grain handling: loading, transit, and unloading periods.

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Figure 4 (left). From Fig. 3, loading period began as soon as a C1 relative humidity sensor responded to presence of grain. Transit period is the time when trailer was moving from farm to storage. Unloading period was marked with a sudden drop in relative humidity and carbon dioxide sensor responses in an unloading trailer.

During the 2014 soybean harvest season, we were able to implement the probes in 43 trips by 22 trucks transporting grains from 10 farms to 12 storage facilities.
TECHNOECONOMIC ANALYSIS OF BIODIESEL AND ETHANOL COPRODUCTION FROM LIPID PRODUCING SUGARCANE

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Biodiesel production from vegetable oils and animal fats has increased progressively over the past two decades. However, the limited supply of animal fats and low amounts of oil produced per hectare from temperate seed oil crops, opportunities for further increases in North America are limited. Genetically modified lipid producing sugarcane (lipid cane) provides a potential to produce biodiesel as an alternative feedstock, due to its much higher productivity vs soybean and canola.

Technoeconomic analysis models were developed for biodiesel and ethanol coproduction from lipid cane assuming 2, 5, 10 and 20% lipid concentrations in the harvested stem (dry mass basis). The models were compared to the conventional soybean biodiesel process model to assess market competitiveness. Using SuperPro Designer software, we incorporated compositions of raw materials and products, sizing of unit operations, utility consumption and estimation of capital and operating costs. Parameterization used data from current soybean and corn oil extraction facilities, sugarcane mill operations, and previous studies.

With the increase of the lipid content in lipid cane from 2 to 20%, biodiesel production costs decreased from $1.05 to 0.72/L ($3.96 to 2.73/gal), which are lower than the production cost from soybean at $1.07/L ($4.03/gal). Byproducts (ie, surplus electricity for cane process and soymeal for soybean process) can reduce biodiesel production costs for both cane and soybean processes. Due to its high productivity, lipid cane with 20% lipid content can produce 6,700 L of biodiesel from each hectare of land, while soybean can produce only about 500 L of biodiesel from each hectare of land.
**TECHNOECONOMIC ANALYSIS OF BIODIESEL AND ETHANOL CO-PRODUCTION FROM LIPID PRODUCING SUGARCANE**

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**MOTIVATION**

- Currently, biodiesel is produced from soybean, corn and animal fats.
- Shortage in food-based feedstock and high production cost of biodiesel are the barriers to biodiesel widely replacing petroleum based diesel.
- PETROSS lipid cane are the genetically modified sugarcane that will produce oil, which can be used to produce biodiesel.
- Highly productive PETROSS lipid cane can solve the shortage problem of the biodiesel’s feedstock.
- Technoeconomic analysis is warranted before the acceptance from the farmers and industries.

**OBJECTIVES**

The objectives of the study were:

- To develop the technoeconomic models to estimate the production cost of biodiesel and ethanol from the PETROSS lipid cane.
- To compare the commercial soybean biodiesel and corn ethanol published process models to evaluate economic feasibility of the PETROSS lipid cane process.

**LIPID CANE COMPOSITION**

![Graph showing lipid cane composition](image)

- 2% LIPID CANE
- 10% LIPID CANE
- 20% LIPID CANE

**PROCESS DESCRIPTION**

- **Simplified Flow Diagram of the Process**
  - **Lipid cane**
  - **Crude Glycerol**
  - **Biodiesel**
  - **Anhydrous Ethanol**
  - **Turbine**
  - **Transesterification**
  - **Oil Purification**
  - **Gasification & Pyrolysis**
  - **Bioelectricity**

**RESULTS & DISCUSSION**

- **As lipid content increased from 2% to 20%, the biodiesel and ethanol production cost from lipid cane decreased accordingly.**

**Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Operation capacity (MT/year)</td>
<td>1,600,000</td>
</tr>
<tr>
<td>Extraction Efficiency: sugar extraction in the mill tandem</td>
<td>96%</td>
</tr>
<tr>
<td>- lipid extraction in the mill tandem</td>
<td>90%</td>
</tr>
<tr>
<td>- sugar loss during purification</td>
<td>1%</td>
</tr>
<tr>
<td>- lipid loss during purification</td>
<td>2%</td>
</tr>
<tr>
<td>Conversion Efficiency: fermentation to produce ethanol</td>
<td>99%</td>
</tr>
<tr>
<td>- Transesterification to produce biodiesel</td>
<td>99%</td>
</tr>
<tr>
<td>- Boiler (65 bar pressure)</td>
<td>80%</td>
</tr>
<tr>
<td>Turbine</td>
<td>40%</td>
</tr>
</tbody>
</table>

**Cane Intermediate Products**

- Anhydrous ethanol purity: 99.7%
- Biodiesel purity: 99.2%
- Glycerol purity: 80%
- Bagasse moisture content: 50%

**RESULTS & DISCUSSION (cont’d)**

- **Total value of production per acre**

**CONCLUSIONS**

- The biodiesel production cost decreased from $3.74/gal to $2.74/gal as the lipid content in lipids cane increased from 2% to 20%.
- Compared to soybean and corn, lipid cane can produce much higher amount of biodiesel and total value of products from each acre of the land use.
DIFFUSION AND PRODUCTION OF CARBON DIOXIDE IN BULK CORN AT VARIOUS TEMPERATURES AND MOISTURE CONTENTS

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The effective diffusion coefficient of carbon dioxide (CO₂) through bulk corn was determined at various temperatures (10, 20 and 30°C) and grain moisture contents (14.0, 18.8 and 22.2% wb). The diffusion coefficient measurements were conducted using a diffusion cell surrounded by a water jacket, which was used to control bulk corn temperature in the diffusion cell. A source term (CO₂ respiration rate) was introduced in the diffusion equation to account for CO₂ production by corn during the diffusion process. Corn respiration rate increased when temperature and grain moisture content increased. As respiration rate increased, it had a larger effect on the diffusion pattern when measuring the effective CO₂ diffusion coefficient. Effective CO₂ diffusion coefficients through bulk corn ranged between 3.10 and 3.93 × 10⁻⁶ m²/s, depending on temperature and moisture conditions. As temperature increased from 10 to 30°C, the effective CO₂ diffusion coefficient through bulk corn increased from 3.21 to 3.76 × 10⁻⁶ m²/s. As corn moisture content increased from 14.0 to 18.8% wb, the effective CO₂ diffusion coefficient through bulk corn decreased from 3.59 to 3.39 × 10⁻⁶ m²/s, respectively. There was no difference observed in the effective CO₂ diffusion coefficient when corn moisture content increased from 18.8 to 22.2%.
Diffusion and production of carbon dioxide in bulk corn at various temperatures and moisture contents

Haibo Huang, Mary-Grace C. Danao*, Kent D. Rausch, Vijay Singh
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Abstract
The effective diffusion of carbon dioxide (CO₂) through bulk corn was determined at various temperatures (10, 20 and 30 °C) and grain moisture contents (14.0, 18.8 and 22.2 % w.b.). The diffusion coefficient measurements were conducted using a diffusion cell surrounded by a water jacket used to control bulk corn temperature. A source term, CO₂ respiration rate, was introduced in the diffusion equation to account for CO₂ production by corn during the diffusion testing. Corn respiration rate increased when temperature and grain moisture content increased. As respiration rate increased, it had a larger effect on the diffusion pattern when measuring the effective CO₂ diffusion coefficient.

Background
Postharvest losses due to spoilage during grain storage remain a major problem around the world. Temperature monitoring has been the typical method for detecting grain spoilage during storage since microorganisms produce a large amount of heat in the spoilage location. However, temperature monitoring is usually not sensitive enough to low thermal diffusivities in bulk grain [1,2]. Furthermore, temperature measurements are not easy to interpret due to the influence of ambient air temperature fluctuations. CO₂ concentration in stored bulk grain can be compared to ambient CO₂ concentration (approx. 400 ppm) as a standard to interpret CO₂ concentration measurements [3]. In the last decade, it has been reported that monitoring CO₂ concentration in the headspace of a storage bin can lead to earlier detections of grain spoilage compared to temperature monitoring [4,5]. CO₂ monitoring in bulk grain in silo bags is even more important since elevated CO₂ is an indicator of whether hermetic conditions are being maintained. In order to further develop effective CO₂ sensors for grain monitoring, knowledge of CO₂ movement by diffusion in bulk grain is necessary. While previous studies have measured CO₂ diffusivity coefficients in bulk grains (e.g., wheat, canola, barley), none have considered the effect of respiration by diffusion in bulk grain is necessary. While previous studies have measured CO₂ diffusivity coefficients in bulk grains (e.g., wheat, canola, barley), none have considered the effect of respiration rate and production of CO₂ in bulk corn were determined.

Results and Discussion

Table 1. Effective CO₂ diffusion coefficients (10⁻⁶ m² s⁻¹) through bulk corn at various temperatures and moisture contents.

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Moisture content % w.b.</th>
<th>CO₂ diffusion coefficient 10⁻⁶ m² s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>14.0</td>
<td>3.30 ± 0.00</td>
</tr>
<tr>
<td>20</td>
<td>14.0</td>
<td>3.53 ± 0.06</td>
</tr>
<tr>
<td>30</td>
<td>14.0</td>
<td>3.93 ± 0.07</td>
</tr>
<tr>
<td>10</td>
<td>18.8</td>
<td>3.10 ± 0.10</td>
</tr>
<tr>
<td>20</td>
<td>18.8</td>
<td>3.43 ± 0.10</td>
</tr>
<tr>
<td>30</td>
<td>18.8</td>
<td>3.63 ± 0.11</td>
</tr>
<tr>
<td>10</td>
<td>22.2</td>
<td>3.23 ± 0.15</td>
</tr>
<tr>
<td>20</td>
<td>22.2</td>
<td>3.50 ± 0.20</td>
</tr>
<tr>
<td>30</td>
<td>22.2</td>
<td>3.70 ± 0.12</td>
</tr>
</tbody>
</table>

*Values followed by the same letter in the same column are not different (p > 0.05).

Materials and Methods

- Corn (P1395R, Dupont Pioneer, Johnston, IA) harvested at 22.2 % (w.b.) moisture content was used.
- Corn was dried at 49 °C in a convection oven to 18.8 and 14.0 % (w.b.).
- A diffusion apparatus was fabricated based on the concepts described in Ref. [6] (Fig. 1). The diffusion apparatus was fabricated based on the concepts described in Ref. [6] (Fig. 1).

Figure 1. An apparatus for CO₂ diffusivity measurement: (a) schematic and (b) fabricated. CO₂ gas of known concentration was injected into chamber A. After allowing gas to be well mixed, the retractable seal was opened to start the diffusion process from chamber A to chamber B. Each gas chamber is of length L and grain column is of length L.

- Corn respiration was measured according to procedures outlined in Ref. [7].
- The transient diffusion of CO₂ through bulk corn could be described by Fick's second law with a source term [9] with the following initial and boundary conditions:

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} + q$$

where C is CO₂ concentration (mol m⁻³); t is time (s); D is the effective CO₂ diffusion coefficient through bulk corn (m² s⁻¹); x is the distance from the interface between gas chamber A and the grain column (m); and q is the corn volumetric respiration rate (mol m⁻³). Initial conditions: $C(x,0) = C_0$ at $H \leq x \leq L$; $C(x,0) = C_1$ at $0 < x < H$. Boundary conditions: $V_1 \frac{\partial C}{\partial x} = \frac{S D}{V_2} \frac{\partial C}{\partial x}$ at $x = 0$ and $V_2 \frac{\partial C}{\partial x} = -S D \frac{\partial C}{\partial x}$ at $x = L$, where $V_1$ and $V_2$ are the volumes (m³) of gas chambers A and B, respectively. $S$ is the cross sectional area (m²) of the diffusion chamber.

These equations were solved numerically using Crank-Nicolson implicit finite difference method in MATLAB (Mathworks, Inc., Natick, MA).

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Acknowledgments
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References


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PROCESSING AND GENETIC EFFECTS ON RESISTANT STARCH IN CORN FLAKES

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During dry milling of whole kernels into grits, grain components with high nutrient concentrations are removed. During processing of flaking grits into corn flakes, grain is subjected to mechanical and heat stresses that have potential to alter nutritional value. Corn genetics influence dry milling efficiency and flaking grit yields (Brekke et al., 1971, Rausch, et al., 2009). We aim to provide insight into the effects of genetics and processing on changes in resistant starch (RS) contents in corn grain.

A corn flaking procedure was developed for a batch size of 100 g grits; procedure reproducibility was measured. Cooking (103 kPa, 121°C, 1 hr), drying (100°C, 30 min), tempering (room temperature, 30 min) and toasting (200°C, 60 s) resulted in laboratory corn flakes with similar color parameters ($L$, $a$ and $b$ values) but different RVA parameters (peak, trough, final, breakdown and setback viscosities) compared to commercial corn flakes. Cooking caused the largest decrease in RS content of commercial corn grits (from 14.9 to 5.3%); RS remained at similar levels through subsequent processing stages (drying, flaking and toasting). RS contents were determined for raw grits, cooked grits and toasted flakes for each of these hybrids for each of seven hybrids, with 3 replications each, flaked with the developed procedure. At each processing stage, no differences were observed among hybrids and for each hybrid; cooking caused the largest decrease in RS content (from 6.7 to 3.0%) with subsequent processing stages increasing RS to 3.3%. The corn flaking procedure reduced RS content in corn grain to about half its original amount and did not vary among corn grain genetic backgrounds.

LITERATURE CITED

Development of a Laboratory Scale Corn Flaking Procedure

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Introduction

Corn is an important human dietary component. During dry milling from whole kernels to grits, grain components with high nutrient concentrations (e.g., germ and aleurone layer) are removed. During processing from flaking grits to flakes, grain is subjected to mechanical and heat stresses that have potential to alter nutritional value.

Objectives

1. Develop a laboratory scale corn flaking procedure representative of industrial processing conditions and characterize the flake product.
2. Evaluate the effect of genetics and processing on resistant starch (RS) in corn flakes.

Methods

- **Cooking**
  - Mix flavor solution and 100 g grits
  - Cook (15 psig, 121°C) for 1 hr in pressure cooker
  - Moisture content 60%

- **Drying, Tempering**
  - Dry at 100°C for 30 min and Tempar at room temp. in a closed vessel for 30 min for easy flaking
  - Moisture content 55%

- **Flaking, Toasting**
  - Flake dough with tortilla maker. Store flakes overnight at room temperature.
  - Toast flakes in convection oven at 200°C for 60 s
  - Moisture content 5%

- **Tempering**
  - Flakes prepared in laboratory were examined under polarized light for loss in birefringence (Axio Observer.Z1).

Results

1. 
   - Cooking resulted in complete loss of birefringence, indicating starch was properly cooked (Fig 1 and Fig 2).

2. 
   - Toasting resulted in flakes with similar lightness and yellowness but different redness ($p \leq 0.05$) (Fig 3).

3. 
   - Total RS content decreased with cooking (Fig 4). This can be attributed to increased digestibility of starch due to gelatinization. Drying and toasting heat cycles did not increase RS content in corn flakes. Others have reported decreased RS with pressure cooking in rice and increased RS with roasting in finger millet (5).

Conclusions

1. 
   - Developed a small scale corn flaking procedure to flake a batch size of 100 g corn grits.
2. 
   - RS decreased with cooking and remained at a similar level through subsequent processing stages such as drying, flaking and toasting ($p \leq 0.05$) for each hybrid.
3. 
   - No differences were found among the seven hybrids at each processing stage. No interaction was observed between the genetic and processing effects (Fig 5).

Acknowledgements

This work is partially supported by the USDA National Institute of Food and Agriculture under Hatch project no. ILLU-741-324.

References

IMPROVEMENT OF ETHANOL YIELDS USING RICE STRAW WITH ALTERED CARBOHYDRATE CONTENT

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Rice straw is a potential feedstock for cellulosic ethanol. It is abundantly available worldwide and contains starch, unlike perennial grasses. The high starch content in rice straw (up to 24% dry weight) could increase ethanol production (Park et al., 2009) because starch has an easily hydrolyzed structure. We investigated the effects of starch in rice straw on ethanol production. Transgenic rice straw has higher starch and cellulose and lower hemicellulose and lignin, compared with conventional rice straw (control).

Samples were pretreated by dilute acid, hot water or dilute ammonium hydroxide. To evaluate starch solubility during pretreatment, samples were hydrolyzed enzymatically with and without a washing step. Unwashed samples had 60 and 79% higher glucose and ethanol yields, respectively, than washed samples. Also, the high starch and cellulose contents in transgenic rice straw increased the final ethanol yields irrespective of pretreatment technology. Up to 26% higher ethanol yields were achieved for transgenic samples, compared with control samples. Unwashed transgenic samples pretreated with dilute acid, hot water or ammonium hydroxide achieved ethanol yields of 17.5, 14.9 or 20.4% g/g biomass, respectively. Therefore; transgenic rice straw is a promising biofuel feedstock.

LITERATURE CITED

**Introduction**

Rice straw is a potential feedstock for bioethanol.

(1) Abundantly available

(2) Contains starch, unlike perennial grasses

Rice straw: 731 million tons/yr
Corn stover: 204 million tons/yr
Wheat straw: 354 million tons/yr

Developments in biotechnology enable the increase of starch in rice plants by altering the activity of enzymes related to starch metabolism in the plant. Advantages of transgenic rice mutants include the availability of high starch content in both rice seed and rice straw.

**Objectives**

- Determine the impact of high starch content in rice straw on ethanol production.
- Evaluate starch solubility during different pretreatment methods: dilute acid, hot water and dilute ammonium hydroxide.

**Methods**

- Transgenic and control rice straw plants were studied. Transgenic rice plants were generated using RNA interference to target the glucan water dikinase, dual specificity protein phosphatase and isoamylase genes.

**Pretreatment**

- Dilute acid (0.5% v/v, 160ºC, 10 min)
- Hot water (160ºC, 10 min)
- Ammonium hydroxide (5% v/v, 160ºC, 10 min)

**Washing step**

- Washing
- No washing

**Hydrolysis & Fermentation**

Glucose and xylose yields after 72 hr hydrolysis, and ethanol yields after 48 hr fermentation. To evaluate starch solubility during pretreatment, pretreated samples were either washed or unwashed prior to enzymatic hydrolysis. A washing step after pretreatment decreased glucose, xylose and ethanol yields. Transgenic samples achieved higher ethanol yields than control samples for all three pretreatments.

**Conclusions**

- Greater starch content in transgenic rice straw led to increased ethanol yields compared to control rice straw.
- Starch was solubilized and hydrolyzed during all three pretreatments.

**Results**

**Composition:** Compositional analysis of transgenic and control rice straw samples (% g/g biomass). Higher starch and cellulose contents, and lower hemicellulose contents were found in the transgenic sample than in the control sample.

<table>
<thead>
<tr>
<th></th>
<th>Starch</th>
<th>Cellulose</th>
<th>Hemicellulose</th>
<th>Lignin</th>
<th>Ash</th>
<th>Extractives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transgenic</td>
<td>17.6</td>
<td>31.0</td>
<td>11.4</td>
<td>9.90</td>
<td>8.25</td>
<td>22.9</td>
</tr>
<tr>
<td>Control</td>
<td>9.30</td>
<td>26.7</td>
<td>12.5</td>
<td>10.7</td>
<td>8.34</td>
<td>25.4</td>
</tr>
</tbody>
</table>

**Pretreatment:** Sugar yields in pretreatment liquor before the washing step. For dilute acid pretreatment, higher glucose yield in the pretreatment liquor was obtained from transgenic rice straw than the control sample.

<table>
<thead>
<tr>
<th></th>
<th>Glucose yield in pretreatment liquor (g/g biomass)</th>
<th>Xylose yield in pretreatment liquor (g/g biomass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilute acid</td>
<td>Hot water</td>
<td>Ammonium hydroxide</td>
</tr>
<tr>
<td>Transgenic</td>
<td>14.9 ± 1.39</td>
<td>1.30 ± 0.07</td>
</tr>
<tr>
<td>Control</td>
<td>6.94 ± 0.30</td>
<td>2.18 ± 0.08</td>
</tr>
</tbody>
</table>

**References**

CORN ETHANOL PRODUCTION IN THE US: LAND USE, CORN GRAIN YIELD, ETHANOL PROCESSES AND COPRODUCT UTILIZATION

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The system for producing yellow corn grain is well established in the US, but its role among other biofeedstock sources should be balanced with its predominant purpose for human and animal food as well as economics, land use and environmental stewardship. We modeled land usage attributed to corn ethanol production in the US to evaluate effects of anticipated technological change in corn grain production, ethanol process methods and livestock nutrition through a multidisciplinary approach (Mumm et al., 2014). Seven scenarios were evaluated: four considered advances in corn grain production, two focused on improved efficiencies in ethanol production and one reflected inclusion rates of ethanol coproducts (e.g., DDGS) in diets for dairy cattle, pigs and poultry. For each scenario, land area attributed to corn ethanol production was estimated for three time periods: 2011 (current), the period at which the 15 billion gallon Renewable Fuel Standard limit for corn ethanol was reached and 2026 (15 years from 2011).

Although 40.5% of corn grain was utilized for ethanol processing in 2011, only 25% of US corn acreage was attributable to ethanol after accounting for coproduct utilization for animal use. By 2026, land area attributed to corn ethanol production was reduced to as little as 11% depending on corn grain yield associated with the four corn production scenarios and considering oil replacement associated with the soybean meal substituted in livestock diets with DDGS. Increased efficiencies in ethanol processing, while producing more ethanol per bushel of corn processed, resulted in lower coproduct production and therefore increased corn acreage. Shifting DDGS use in animal diets to dairy cattle, pigs and poultry reduced land area attributed to corn ethanol production. However, because DDGS substitutes at a higher rate for soybean meal, oil replacement requirements intensify and land use estimates are elevated. It is important to account for anticipated technological changes in the corn ethanol system to understand associated land base ascribed. This approach may aid in calibrating parameters for land use models in biofuel life cycle analyses.

LITERATURE CITED
**Introduction**

- Debate and policy have not considered adequately future expectations for corn and ethanol production and how these factors will interact with animal food supply.
- The US produced 12.4 billion (B) bu corn in 2011 [1]. Limits (15 B gal ethanol) have been established for corn grain use for biofuels [2]. These limits originated from debates on “food vs fuel” and land use change (LUC) associated with biofuel production.
- Technological advancements are expected:
  - Improved efficiencies and accelerated yield gains for corn production.
  - Greater efficiencies in ethanol production.
  - Increased usage of corn ethanol coproducts in livestock feeding and a shift to greater use in poultry, swine and dairy cattle diets.
- DDGS is coproduced with ethanol, which replaces corn and soybean meal (SBM) in livestock diets. DDGS replaced corn and SBM utilization that required and estimated 12.1 M ac corn and soybeans in 2010 [4].
- Oil replacement: expected canola production increase due to soy acres reduced when DDGS displaces SBM.

**Model Scenarios**

1. **Medium** – Corn grain yield estimates based on historical performance using technological improvements from conventional breeding, advanced breeding and biotech trait developments, as well as agronomy (Fig. 1).
2. **Low growth** – Scenario 1 reduced by 10%
3. **High growth** – Scenario 1 increased by 10%
4. **Minimal** – grain yield estimates based on USDA projections; minimal impact of yield technology.
5. **Full starch** – residual starch in DDGS (6%) converted to ethanol
6. **Complete fiber** – conversion of cellulosic portion of corn grain increases ethanol yield 13% [5]
7. **Livestock feeding** – this scenario adjusts the corn:SBM (soybean meal) ratio to 65:35 due to changes in feeding to livestock types; currently, 71:29 is fed to livestock.

**Objectives**

Our goal is to understand how land use for corn ethanol is affected by interactions and long-term potential for corn grain yield, ethanol production and livestock nutritional requirements [3].

1. Model the US corn-ethanol system considering corn grain production, livestock feeding and oil use for biofuels (Fig. 2).
2. Explore the effects of seven scenarios representing technological changes in production of corn grain, fuel ethanol and livestock.
3. Estimate land use for three time horizons: 2011 (current), time period at which the 15 B gallon cap for ethanol is reached and 2026.

**Discussion of Model Results**

- In 2011, 25% of production acreage for US corn grain was used for ethanol production based on reported corn yields and accounting for replacement of soybean oil with reduced demand for soybean production (Fig. 3).
- Assumptions increases in corn grain yields with anticipated new technologies, land use could be reduced to 11 to 19% of US corn land by 2026.
- Anticipated improvements in ethanol processes had small impact on land use for ethanol, because these technologies result in reduced amounts of coproducts for livestock diets.
- ‘Full Starch’ and ‘Complete Fiber’ Scenarios (5 and 6) result in small increases in land use compared to the Medium Scenario (1):
  1. Increased ethanol output is accompanied by a decreased coproduct output.
  2. Less corn and soybean meal is substituted.
  3. Land use requirement is increased for ethanol production.
- By 2026, only 12% of total US corn acreage for grain is dedicated to ethanol production with a 65:35 ratio of corn:SBM substitution which reflects a diminished proportion of coproducts fed to beef cattle.
- The 15 B gallon cap is reached with grain yields ≥157 bu/ac (all scenarios).

**Conclusions**

- 25% of corn acreage was needed to produce ethanol, although 40% of the US corn grain crop was channeled to ethanol production.
- Corn grain yield has a large impact on land area needed for production of 15 B gallons ethanol.
- In 2011, 25% of corn acreage is needed.
- By 2026, acreage needed is only 13% (Scenario 1) or to 19% assuming the most conservative grain yield growth (Scenario 4).
- Coproduct use reduces land usage attributable to ethanol.
- As land required to produce a given volume of grain is reduced, land use change associated with current demand for corn ethanol is shown to be unlikely.

**References**

SEASONAL VARIATION IN DRY GRIND ETHANOL PRODUCTION ASSOCIATED WITH INCOMING CORN VARIABILITY

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Corn from an ethanol plant (commodity corn) and an identity preserved corn hybrid from a seed company (control corn stored at 4°C) were used to study the effects of incoming corn variability on dry grind ethanol concentrations. Using a conventional dry grind procedure, ethanol concentrations were determined biweekly for one year. Variations in ethanol concentrations and variability patterns for commodity and control corn followed the same trend. For control corn, storage time affected ethanol concentrations. Ethanol concentrations initially increased, at a rate of 0.07% v/v per week, during the first 14 weeks and decreased, at a rate of 0.02% v/v per week, from weeks 14 to 36. Starch, protein and oil contents of commodity and control corn did not change across time; therefore, variation in ethanol concentrations over time were not attributable to corn composition.

Effects of different enzyme treatments on mean ethanol concentrations over a year were evaluated. Two liquefaction enzymes (optimum pH of 5.8 or 5.1), two saccharification enzymes (optimum pH of 5.0) and one protease were used in five enzyme treatments (I, II, III, IV and V). Final ethanol concentration with enzyme treatment V was 17.5 ± 0.49% v/v. This was 0.6% greater than enzyme treatment I resulting in an additional ethanol production of 600,000 gallons/year in a 100 million gallon/year ethanol plant. Using more effective enzymes increased overall dry grind ethanol production and improved ethanol plant profitability.
Introduction

- Dry grind ethanol plants encounter seasonal variations in ethanol yields and residual starch contents in Distillers dried grains with solubles (DDGS). It has been noticed that ethanol yields are low soon after harvesting, higher during the next six to seven months and decreases at yearend [1].
- Variability in ethanol yields is often associated with incoming corn quality which affects its processing and results in substantial economic losses for the ethanol industry. Using more effective enzymes can reduce the overall variability and increase the overall ethanol yield.

Objective

- To study variations in ethanol concentrations (conc.) over time utilizing different enzyme combinations.

Materials and Methods

- **Commodity Corn**: Composite samples collected biweekly from Midwestern ethanol plant.
- **Control Corn**: Identity preserved corn hybrid obtained from a Midwestern ethanol plant.
- **Enzymes**:
  - AA-1 (First generation liquefaction enzyme)
  - AA-2 (Advanced liquefaction enzyme)
  - GA-1 (First generation glucoamylase enzyme)
  - GA-2 (Advanced glucoamylase enzyme)
- **Protease**

  - Enzyme combinations (Comb.) used:
    - I: AA-1 + GA-1
    - II: AA-1 + GA-2
    - III: AA-1 + GA-2 + protease
    - IV: AA-2 + GA-2
    - V: AA-2 + GA-2 + protease
  - AA = alpha amylase; GA = glucoamylase

- **Dry grind procedure**: Performed as listed in Fig 1.
- **Statistical analysis**: Entire time series was divided into three segments and rates of change (µ) of ethanol conc. at different time periods for commodity and control corn were compared using least squares regression in PROC AUTOREG and evaluated at P < 0.05.

Results and Discussion

- Data for 12 months (Oct 2012-Sept 2013) of the study are presented (Figs. 2 and 3).
- Rate of changes in ethanol conc. for commodity and control corn were similar in all three time segments.
- Ethanol conc. were initially low after harvest and increased at the rate of 0.058% (v/v) per wk till week 14 and then decreased at the rate of 0.039% (v/v) per wk from weeks 14 to 36 for commodity corn (Fig. 2).
- Comb. V resulted in the highest mean ethanol conc. (17.5% v/v per period of 12 months (Fig.3).
- Addition of protease in Comb. III and Comb. V resulted in an average increase of 0.1% v/v ethanol conc., respectively.
- Mean ethanol concentrations for treatments IV and V with advanced liquefaction enzyme were 0.2% v/v higher compared to treatments II and III.
- Comb. V resulted in profit of $1.32 million at a 100 MGY ethanol plant (Table 1).

Acknowledgements

This research project is funded by Novozymes North America, Franklinton, NC. Authors would like to thank Novozymes NA for providing enzymes and partial financial support.

**Table 1. Economics at a 100 MGY ethanol plant**

<table>
<thead>
<tr>
<th>Enzyme Combination</th>
<th>Mean Ethanol Conc. (%) v/v</th>
<th>Gain in ethanol conc. (%) v/v</th>
<th>Additional dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>16.9e</td>
<td>Baseline</td>
<td>Baseline</td>
</tr>
<tr>
<td>II</td>
<td>17.2d</td>
<td>0.3</td>
<td>660,000</td>
</tr>
<tr>
<td>III</td>
<td>17.3c</td>
<td>0.4</td>
<td>880,000</td>
</tr>
<tr>
<td>IV</td>
<td>17.4b</td>
<td>0.5</td>
<td>1,100,000</td>
</tr>
<tr>
<td>V</td>
<td>17.5a</td>
<td>0.6</td>
<td>1,320,000</td>
</tr>
</tbody>
</table>

*Mean ethanol concentrations followed by the same letter (abcd) in a column were not different (P<0.05). LSD value was 0.0567. Current ethanol price 2.3 $/gallon (National weekly ethanol summary USDA).
LABORATORY MEASUREMENT OF YIELDS AND COMPOSITIONS OF DRY MILLED CORN FRACTIONS USING A SHORTENED, SINGLE STAGE TEMPERING PROCEDURE

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Corn is dry milled using tempering and degeneration processes in which the kernel is separated into several fractions containing endosperm, pericarp and germ. Endosperm fractions are classified by size to produce a variety of products including flaking grits, meal, cones and flour. Larger grit sizes typically have higher value; whereas, pericarp and germ components typically are valued at less than corn (Rausch and Belyea, 2006). Variations in yields and compositions of dry milling fractions affect processing efficiency and long term profitability for the processor. Processors and corn breeders assume milling characteristics (proportion and composition of grits, flour and hominy feed fractions) vary considerably among corn hybrids. For determining dry milling characteristics, there were no publications that reported a single step tempering method and a small (1 kg) batch size. We describe a laboratory scale dry milling procedure that used single stage tempering and determine the effect of hybrid on yields and fraction compositions in milled corn. One kg samples of 11 commercially available hybrids were processed to produce milling fractions of large grits, small grits, fines, germ and pericarp. Compositions of milling fractions (protein, neutral detergent fiber, ash and crude fat) were determined. The procedure used a single stage tempering step that increased corn moisture from 15 to 23.5% wb during an 18 min tempering period. Germ was separated from endosperm particles using a roller mill followed by screening over a sieve with 1.68 mm openings. Coefficients of variability were small, indicating acceptable repeatability. Overall yield means were 39.2, 25.3, 13.8, 78.2, 14.3 and 6.8 g/100 g (db) for large grits, small grits, fines, total endosperm, germ and pericarp, respectively. Correlations (r) among endosperm fractions (large grits, small grits and fines) ranged from 0.54 to 0.92. Correlations among endosperm fractions and germ and pericarp were <0.68. The developed dry milling method estimated milling yields among hybrids with low standard deviations relative to the means and should be a useful tool for research and industry in measuring dry milling characteristics.

LITERATURE CITED


Laboratory Measurement of Yield and Composition of Dry Milled Corn Fractions Using a Shortened, Single Stage Tempering Procedure

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Introduction
- Laboratory dry milling methods have been used to quantify milling characteristics (1, 2, 3, 4).
- Previous researchers have used two or three stage tempering methods; however, single stage methods have been shown to be effective in producing large grit yields (2, 3).
- A laboratory method has been in use at the University of Illinois at Urbana-Champaign to process several hundred milling samples.
- The objective was to quantify procedure repeatability and measure effects of hybrid on dry milling characteristics.

Methods
- Single stage tempering for 18 min increased moisture from 15.0 to 23.5% wb (4). Corn was mixed gently during tempering (Fig. 1).
- Tempered corn was passed through horizontal drum degerminator, conditioned in forced air oven (49°C, 2 hr) and sieved through 5 mesh screen (4.0 mm openings).
- Roller milling flattened germ particles, allowing separation by 10 mesh screen (1.68 mm openings).
- Larger (+5 mesh) and smaller (-5 mesh) particles were rolled and sieved separately before being mixed with +10 mesh material for aspiration.
- Endosperm particles were separated from germ and pericarp using 10 mesh screen.
- Large grits passed through 10 mesh screen.
- Small grits passed over 24 mesh screen (0.707 mm openings); fines passed through 24 mesh screen.
- Pericarp was separated from germ and small grits using an aspirator (model 6DT4, Rice Products Co., Wichita, KS).
- Ten dent corn hybrids were processed to produce 5 fractions (large and small grits, fines, germ and pericarp). Each hybrid was processed with three replications.
- Each fraction was analyzed for composition (total protein, neutral detergent fiber, crude fat, ash) using standard methods.
- Means were analyzed for differences (P<0.05).

Results
- Effects due to hybrid were detected (P<0.05) for all milling fractions (Table 1).
- Procedure was reliable, indicated by large treatment effect (hybrid) relative to replication effect.
- Endosperm fractions had low (<2.0% db; Table 2) lipid contents; most lipid was found in germ (17 to 20% db) and pericarp (2 to 5% db).

Conclusions
- We estimated milling yields among hybrids with low standard deviations relative to the means (4).
- Hybrid had an effect on milling fraction yields and compositions.
- Fat contents of grits fractions were similar to previous laboratory methods but higher than commercial grit products.
- Due to its smaller sample size and relatively short process length, the procedure should be useful for dry milling research.

Table 1. Comparison of mean yields among hybrids.

<table>
<thead>
<tr>
<th>Milling Fraction</th>
<th>Hybrid A</th>
<th>Hybrid B</th>
<th>Hybrid C</th>
<th>Hybrid D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Grits</td>
<td>38.1cd</td>
<td>35.0e</td>
<td>37.2d</td>
<td>36.6de</td>
</tr>
<tr>
<td>Small Grits</td>
<td>27.3bc</td>
<td>28.3b</td>
<td>25.7b</td>
<td>28.4bc</td>
</tr>
<tr>
<td>Fines</td>
<td>12.1d</td>
<td>17.3a</td>
<td>13.8c</td>
<td>14.0c</td>
</tr>
<tr>
<td>Germ</td>
<td>17.6a</td>
<td>13.0d</td>
<td>16.4ab</td>
<td>13.8c</td>
</tr>
<tr>
<td>Pericarp</td>
<td>4.1f</td>
<td>6.1de</td>
<td>7.2bc</td>
<td>6.4cd</td>
</tr>
</tbody>
</table>

Overall: 39.2

Table 2. Composition of milling fractions (% db).

<table>
<thead>
<tr>
<th>Milling Fraction</th>
<th>Analyte</th>
<th>Hybrid A</th>
<th>Hybrid B</th>
<th>Hybrid C</th>
<th>Hybrid D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td>1.9a</td>
<td>1.7b</td>
<td>1.8a</td>
<td>1.5a</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>0.56a</td>
<td>0.49ab</td>
<td>0.42bc</td>
<td>0.37c</td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>3.9a</td>
<td>5.2a</td>
<td>4.7a</td>
<td>4.7a</td>
<td></td>
</tr>
<tr>
<td>TP</td>
<td>8.1a</td>
<td>10.8a</td>
<td>8.0a</td>
<td>7.4a</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>0.59a</td>
<td>0.41b</td>
<td>0.59a</td>
<td>0.39b</td>
<td></td>
</tr>
<tr>
<td>Fat</td>
<td>1.7a</td>
<td>1.8a</td>
<td>1.0b</td>
<td>1.2a</td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>6.8a</td>
<td>6.8a</td>
<td>4.2c</td>
<td>4.5d</td>
<td></td>
</tr>
<tr>
<td>TP</td>
<td>9.0a</td>
<td>8.9ab</td>
<td>8.8b</td>
<td>7.9c</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>0.63a</td>
<td>0.52ab</td>
<td>0.69a</td>
<td>0.42b</td>
<td></td>
</tr>
<tr>
<td>Fat</td>
<td>1.7a</td>
<td>1.8a</td>
<td>1.0b</td>
<td>1.2a</td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>5.9 ab</td>
<td>8.1 c</td>
<td>6.6 a</td>
<td>5.2 b</td>
<td></td>
</tr>
<tr>
<td>TP</td>
<td>7.1 a</td>
<td>7.1 a</td>
<td>7.1 a</td>
<td>6.5 b</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>0.56a</td>
<td>0.49 ab</td>
<td>0.42 bc</td>
<td>0.37c</td>
<td></td>
</tr>
<tr>
<td>Fat</td>
<td>1.2 a</td>
<td>1.8 b</td>
<td>1.0 a</td>
<td>0.9 a</td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>25.3 a</td>
<td>26.4 a</td>
<td>26.7 a</td>
<td>30.8 b</td>
<td></td>
</tr>
<tr>
<td>TP</td>
<td>18.0 a</td>
<td>17.3 a</td>
<td>16.5 b</td>
<td>16.1 b</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>5.7 a</td>
<td>4.8 c</td>
<td>5.2 b</td>
<td>5.3 a</td>
<td></td>
</tr>
<tr>
<td>Fat</td>
<td>20.1 a</td>
<td>17.6 a</td>
<td>16.6 b</td>
<td>18.3 a</td>
<td></td>
</tr>
<tr>
<td>NDF</td>
<td>48.0 a</td>
<td>41.2 a</td>
<td>35.9 a</td>
<td>38.3 a</td>
<td></td>
</tr>
<tr>
<td>TP</td>
<td>9.5 a</td>
<td>8.4 b</td>
<td>8.2 b</td>
<td>8.2 b</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>1.5 a</td>
<td>0.77b</td>
<td>0.93b</td>
<td>0.71a</td>
<td></td>
</tr>
<tr>
<td>Fat</td>
<td>4.7 a</td>
<td>2.5 b</td>
<td>2.8 b</td>
<td>1.8 c</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same letter are not different (P<0.05). NDF: neutral detergent fiber; TP: total protein (N × 6.25).

References
NUTRIENT FLOWS IN MAIZE WET MILLING STREAMS

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Coproducts may contain high nutrient concentrations which may limit demand and value, due to the potential to increase nutrients in animal wastes and create disposal issues. Few data are published that characterize process streams in corn wet milling. Understanding concentrations of nutrients will identify opportunities to modify wet milling methods, allowing nutrient concentrations to be altered with increased value of wet milling coproducts.

Sampling took place at 23 streams in three wet milling facilities with 8 to 12 observations per plant. Total nitrogen (N), phosphorus (P) and sulfur (S) were measured using standard methods. Flows of N, P and S were estimated for a 105,000 bushel (2,700 tonne) per day corn wet milling plant using values from the literature and a simulation model developed by the University of Illinois and Eastern Regional Research Center, ARS, USDA.

Process streams with high nutrient concentrations and that had not been dewatered (ie, <45% total solids) represent opportunity for improved coproduct composition. Process streams with the highest N concentrations were heavy steepwater, pressed germ and heavy gluten, having 30,400, 15,900 and 22,000 mg N/kg, respectively. P concentrations were highest in heavy steepwater with 14,590 mg P/kg; other process streams and final coproducts were lower in concentrations by a factor of three. Process streams with the highest S concentrations were heavy steepwater, pressed germ and heavy gluten, having 3,200, 1,400 and 1,800 mg S/kg, respectively. Wastewater had low concentrations of N, P and S. For finished coproducts, most N (23,100 kg N/day) and S (2,300 kg S/day) were recovered in corn gluten meal, most P (2,400 kg P/day) was recovered in CGF (Rausch et al 2005, 2007).

Composition of streams had large variability within and among plants. About 57% of P and 97% of S inputs could be accounted for in coproduct outputs (corn gluten feed, germ, corn gluten meal, starch slurry and final effluent from waste treatment). Recovery of N in coproduct outputs was over estimated by 24%. Process technologies to enhance compositions of these streams could lead to wet milling coproducts with improved value.

LITERATURE CITED
**Nutrient Flows in Maize Wet Milling Streams**

Kent D. Rausch1,*, Ronald L. Belyea2, Vijay Singh1, Thomas E. Clevenger2, M. E. Tumbleson1 and Lutgarde M. Raskin1

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**Introduction**

- Maize wet milling is an important processing market, using ~2.0 billion bushels annually in the US [1].
- High concentrations of nutrients may limit demand for coproducts, because of potential to increase nutrient concentrations in animal wastes and to create disposal issues [2].
- Understanding concentrations of nutrients in process streams will identify opportunities to modify wet milling methods, allowing improved coproduct composition.

**Methods**

- Sampling took place at 23 streams in 3 plants with 8 to 12 observations per plant (Figure 1).
- Total nitrogen (N), phosphorus (P) and sulfur (S) were analyzed using standard methods.
- Flows of N, P and S were estimated for a 105,000 bushel (2,700 tonne) per day plant using a simulation model developed by University of Illinois and Eastern Regional Research Center, ARS, USDA.

**Results**

- Nutrient concentrations in process streams had large variability within and among plants.
- Streams (<45% solids) with highest N concentrations were heavy steepwater, pressed germ and heavy gluten (30,400, 15,900 and 22,000 mg N/kg, respectively; Table 1).
- P concentrations were highest in heavy steepwater (14,600 mg P/kg); other streams and coproducts were lower in concentration by a factor of three [3].
- Streams (<45% solids) with highest S concentrations were heavy steepwater, pressed germ and heavy gluten (3,200, 1,400 and 1,800 mg S/kg, respectively).
- Final effluent contained low concentrations of N, P and S (Table 1).
- Most N (23,100 kg N/day) and S (2,100 kg S/day) were recovered in corn gluten meal (Fig. 1).
- Most P (2,400 kg P/day) was recovered in corn gluten feed (Fig. 1).
- 57% of P and 97% of S inputs could be accounted for in coproduct outputs. Recovery of N was over estimated by 24%.

**Conclusions**

- Process streams with high nutrient concentrations and <45% total solids represent opportunity to modify coproduct composition.
- Processes to enhance compositions of streams could lead to coproducts with improved value.

**References**


**Acknowledgments**

Funded in part by Waste Management Research Center, Champaign, IL (DNR Contract No. HWR01168), Illinois State Geological Survey, Champaign, IL and Urbana Champaign Sanitary District, Urbana, IL.
MEASUREMENT OF GRAIN RESPIRATION FOR DRY MATTER LOSS ESTIMATION

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Dry matter loss (DML) estimates over a wide range of moisture contents and temperatures have been useful in the development of maximum allowable storage time guidelines for grains. Current guidelines (ASABE Standard D535, 2010) specify the maximum allowable storage times for shelled corn at various temperature/moisture combinations to reach 0.5% DML, which corresponds to a decrease in corn grade of one level (e.g., from U.S. No. 2 to U.S. No. 3). In general, as moisture and temperature decrease, the number of days required to reach 0.5% DML increases.

A respiration measurement system was developed to estimate DML through monitoring carbon dioxide from grain respiration by gravimetric analysis. The system consisted of three parts: conditioned air input, grain respiration column and moisture and carbon dioxide absorption columns, allowing for respiration tests over a range of grain moisture contents (12 to 20% wb) and temperatures (25 to 45°C). These condition combinations will be useful for producers in low latitude (±20°) regions where grains typically are stored at these elevated temperatures. Compared to other respiration measurement systems reported in the literature, a unique component of the system is use of sets of parallel moisture and CO2 absorption columns ensuring continuous accounting of respired products during daily measurements. Another feature is use of glycerol/water solutions in varying ratios to obtain desired equilibrium relative humidity. While the system has been developed to monitor grain respiration, it may be used with other feed or biomass feedstock also to estimate DML, which is useful in developing storage time guidelines.

LITERATURE CITED

ASABE. 2010. Shelled corn storage time for 0.5% dry matter loss. ASAE D535. Standards Engineering Practices Data. ASABE: St. Joseph, MI.
**Summary**

A respiration measurement system (Figure 1) was developed based on principles described by Al-Yahya (1993) to estimate dry matter loss (DML) through monitoring carbon dioxide (CO₂) from grain respiration by gravimetric analysis. The system consists of three parts: input air conditioning; grain respiration column; and moisture and carbon dioxide absorption columns, allowing for respiration tests over a range of grain moisture contents (MCₙ = 12 to 20%) and temperatures (T = 25 to 45°C) to be conducted. These T-MCₙ combinations will be useful for producers in low latitude (±20°) regions where grains are typically stored at these elevated temperatures.

Testing of each system component indicated the following:

- Temperatures of 24.5 ± 0.2 and 35.1 ± 0.4°C were maintained (Table 1) using a water bath to generate air with humidity ratio (W) from 11.65 to 31.22 kg g⁻¹, maintaining equilibrium moisture content (EMC) of the grain using a range of glycerol solutions with concentrations of 34.9 to 68.1% (w w⁻¹). The desired humidity (Figure 2) was achieved after a time period of approx. 30 min.
- The rates of moisture absorbed by the Drierite columns (Figure 3) were tested with conditioned air at W = 45 kg g⁻¹ at 40.5 ± 0.5°C and at flow rates, V = 200, 400, 1000 and 2000 ml min⁻¹. The rate of accumulated water over a 3.5 h period, measured every 30 min, was similar across flow rates tested (Figure 4). The ratio of the amount of water passed through the column to the amount absorbed over time was approx. 1:1, up to 27 g H₂O.
- Dry CO₂-air mixture (200,000 ppm certified) was passed through a KOH-vermiculite mixture (Figure 4) at 400 and 800 ml min⁻¹. Results showed, for total of 33.2 g and 56.9 g CO₂, passed through the column at 400 ml min⁻¹, only 31.6 g and 33.2 g, respectively, were absorbed. Similar tests showed 80% of CO₂ passed through the column at 800 ml min⁻¹.
- The compressed input air was filtered using a 12 µm filter membrane and flow was precisely regulated using a computerized gas dilution system. T and W of the air needed to be conditioned prior to entering the grain respiration column to help maintain the equilibrium moisture content EMC of the grain. To achieve this, the T and equilibrium relative humidity (ERH) of the air was controlled by bubbling the air through glycerol-water mixtures (Forney and Brandl, 1992). The conditioned air flowed through a temperature-controlled grain respiration column. Air exiting the grain respiration column contained the products of respiration: moisture was absorbed in indicating Drierite filled columns and carbon dioxide was absorbed in columns packed with KOH-vermiculite mixtures. A rotameter and infrared CO₂ sensor was placed downstream to check air flow rate and CO₂ levels in the exit air stream.

**Future Work**

1. Anticipating respiration experiments will run continuously for 3 to 5 d, a protocol for maintaining T and W by the humidification system needs to be tested.
2. A minimum residence time is needed for CO₂ to be captured in the CO₂ absorption columns. This residence time, and subsequent flow rate, needs to be determined and optimized.
3. Preliminary respiration tests showed that the KOH-vermiculite columns dried out prior to reaching 0.5% dry matter loss by the soybeans. Therefore, the optimum moisture content and preparation of KOH-vermiculite mixtures still need to be determined at 400 ml min⁻¹ and 800 ml min⁻¹.

**Acknowledgments**

This work was supported in part by the ADM Institute for the Prevention of Postharvest Loss at the University of Illinois and by the NIFA Hatch Project No. ILLU-741-384. The authors thank Haibo Huang and Tim Lechter for their technical assistance.

**Works Cited**


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**Table 1. Glycerol-water solutions used to maintain a equilibrium moisture content (EMC) during testing.**

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>RH (%)</th>
<th>Glycerol (w w⁻¹)</th>
<th>W (g kg⁻¹)</th>
<th>W (g kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>59.7</td>
<td>60.09</td>
<td>12.91</td>
<td>11.65</td>
</tr>
<tr>
<td>35</td>
<td>69.2</td>
<td>65.28</td>
<td>24.41</td>
<td>25.61</td>
</tr>
<tr>
<td>75</td>
<td>74.3</td>
<td>54.14</td>
<td>15.55</td>
<td>14.17</td>
</tr>
<tr>
<td>35</td>
<td>76.2</td>
<td>51.41</td>
<td>28.92</td>
<td>24.96</td>
</tr>
<tr>
<td>25</td>
<td>77.6</td>
<td>43.83</td>
<td>16.59</td>
<td>14.21</td>
</tr>
<tr>
<td>35</td>
<td>85.7</td>
<td>38.38</td>
<td>31.96</td>
<td>31.22</td>
</tr>
</tbody>
</table>

**Figure 1. A mixture of compressed air (80% N₂, 20% O₂, and < 50 ppm CO₂) was supplied at 137.9 kPa using a flow controller to provide 400 ml min⁻¹ flow through the system.**

**Figure 2. Glycerol-water solutions of varying concentrations were used to deliver humidified air with W ranging from 11.65 to 31.22 kg g⁻¹ at T = 25°C and 35°C.** The conditioned air was maintained for durations of 3 to 5 d as set each T.

**Figure 3. Flow rates ranging from 2000 to 200 ml min⁻¹ were used to monitor the absorption capacity of the supplied humidified air at moisture contents.** The weight ratio of input accumulated water vs. absorbed water through the column was approx. 1:1.

**Figure 4. The CO₂ absorption columns supplied with 33.2 g and 56.9 g CO₂ measured absorbed values of 31.6 g and 33.2 g CO₂ at 400 ml min⁻¹ respectively.**

**Figure 5. The CO₂ absorption column supplied with 33.2 g and 56.9 g CO₂ measured absorbed values of 31.6 g and 33.2 g CO₂ at 400 ml min⁻¹ respectively.**
VARIABILITY OF REACTION EFFICIENCIES AND PASTING PROPERTIES OF ACETYLATED MAIZE STARCH FROM VARIOUS COMMERCIAL HYBRIDS

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With the use of hybridization and biotechnology, the world corn supply has become more genetically diverse. Diversity has allowed producers to grow maize with increasing yields and a variety of uses, but it also has introduced more raw material variability into maize processing. Investigators have shown a hybrid effect in a variety of processes during maize wet milling, including steeping (Singh et al., 1997), starch extraction (Zehr et al., 1995) and waxy maize starch acetylation (Wilkins et al., 2003a, 2003b). We showed how starch from dent maize hybrids differed in functional properties and reaction efficiencies after being modified. If hybrid effects on dent maize starch modification were detected, processors could select hybrids that produce starches modified more efficiently and have properties that are desirable.

Maize samples grown during two crop years were wet milled in the laboratory. A 180 g sample of starch from each milling was acetylated with 10.8 g acetic anhydride and 1.5% NaOH at 30°C and pH 8.0 to 8.4. Each starch sample was tested for acetyl content and analyzed by rapid viscoamylograph (RVA). Reaction efficiencies were determined from the amount of acetyl added during reaction and the acetyl content in starch samples after the reaction. Differences among hybrids were found for reaction efficiencies and RVA properties, indicating a hybrid effect on dent starch acetylation.

LITERATURE CITED
Introduction

- World corn supply is becoming more diverse through hybridization and biotechnology. This diversity has enabled producers to experience yield increases and other agronomic benefits, but also has introduced increased variability into maize processes, including starch modifications.
- Acetylation is a common starch modification, which increases starch visosity and resistance to retrogradation while decreasing gelatinization temperature.
- Other corn processes have shown variability due to hybrids. These include wet milling (1), dry milling (2, 3) and waxy corn starch acetylation (4, 5).
- The objective of this study was to determine differences in pasting properties and reaction efficiencies among starch from hybrids of yellow dent corn.

Materials and Methods

Milling and Acetylation

- 10 commercial dent hybrids grown in 1998, 9 hybrids grown in 1999, at the same location.
- Three samples (1 kg) from each hybrid were wet milled using procedure of Edhoff et al. (6).
- 200 g from each starch sample was acetylated (Fig. 1).
- Acetic anhydride (AA) was added at 0.24 ml/min.
- Five 200 g samples of commercial dent starch were acetylated and used to assess repeatability of the procedure.
- Acetyl content of starch was measured using a colorimetric method (7).

Pasting Properties

- RVA (Newport Scientific, Model RVA-4) measured peak and final viscosities and pasting temperature.
- Analysis used a 5% starch suspension (w/w) and temperature profile of Staley-02 method (8).

Experimental Design

- Variables were analyzed using randomized complete block design. Hybrids were compared using two way ANOVA (α = 0.05) with dependent variables being hybrid and block.

Results and Discussion

- 1998 samples: Differences among dent hybrids were observed in peak, final, trough and setback viscosities and pasting temperature.
- 1999 samples: Differences among hybrids were observed in final, trough and breakdown viscosities.
- Reaction efficiency was correlated to NaOH consumed in each reaction (Fig. 2).
- Hybrid affected pasting properties of unmodified and acetylated samples. Differences among 1999 hybrids in pasting properties observed in acetylated samples were also observed in unacetylated samples.
- Higher reaction efficiency did not result in lower pasting temperature or increased peak viscosity. Waxy starch exhibited similar behavior (4).
- Reaction efficiency was correlated to final viscosity and setback viscosity (Fig. 3).
- Larger variation in reaction efficiencies occurred within 1999 samples compared to 1998 samples.
- Differences among 1999 hybrids in pasting properties appeared linked to factors prior to acetylation, similar to trends observed for waxy corn hybrids (3).
- Crop year affected reaction efficiency and all pasting properties except for breakdown. Some variations among samples of the same hybrid were found in some pasting properties; these variations were similar to those found in a previous study on waxy starch acetylation (3).
- Waxy hybrid had an effect on the extent of acetylation, as measured by reaction efficiency, and pasting properties; reaction efficiencies varied from 47 to 73% (4).
- Dent hybrids exhibited more variability in pasting properties than waxy hybrids.
- Absolute amyllose content and amyllopectin branch chain length distribution have been shown to have an effect on starch pasting properties (9). Amylose content was not measured in this study.

Conclusions

- Hybrid had no effect on the extent of acetylation, as measured by reaction efficiency. However, reaction efficiencies were observed to range from 35 to 56%.
- Reaction efficiencies for starch samples from 1998 hybrids were lower overall than samples from 1999 hybrids.
- Reaction efficiency variation within 1999 hybrids was greater than reaction efficiency variation within 1998 hybrids. Higher reaction efficiency resulted in greater pasting viscosities and lower pasting temperature.

Acknowledgements

The Illinois Council for Food and Agricultural Research provided funding through the External Grants Program. The authors acknowledge Cereal America USA (now Cargill) for providing assistance with laboratory analyses and starch samples.

References

TEMPERATURE EFFECTS ON FOULING CHARACTERISTICS OF THIN STILLAGE

Y. Bruce Zhang1*, David B. Johnston2, Nicki J. Engeseth1, Vijay Singh1, M. E. Tumbleson1 and Kent D. Rausch1

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Heat transfer fouling is the accumulation and formation of unwanted materials on heat transfer surfaces which leads to a decrease in the overall heat transfer coefficient. Fouling of heat transfer equipment increases energy consumption and maintenance costs and thus decreases processing efficiency. In the dry grind industry, evaporator fouling takes place when thin stillage is concentrated. Thin stillage is the liquid fraction of unfermented materials, composed of carbohydrate, protein, fat and ash, from fermentation.

Past researchers (Singh et al., 1999, Wilkins et al., 2006ab, Arora et al., 2010, Challa et al., 2014) focused on the effects of corn oil, pH, Reynolds number, solids concentration and carbohydrates. However, temperature effects on fouling rates have not been studied. The objectives were to investigate the influence of bulk temperature, initial probe temperature and their temperature difference on thin stillage fouling characteristics. Experiments were conducted using model thin stillage (1% starch solution) and commercial thin stillage with different temperature conditions. Bulk temperatures varied from 60 to 80°C and initial probe temperatures varied from 100 to 120°C; thus temperature differences varied from 20 to 60°C. Fouling resistances were measured using an annular probe with a 7 L batch system. Mean fouling rate, maximum fouling resistance and induction period were analyzed to characterize fouling behavior.

LITERATURE CITED


Temperature Effects on Fouling Characteristics of Thin Stillage

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1University of Illinois at Urbana-Champaign and 2Eastern Regional Research Center, ARS, USDA  *krausch@illinois.edu

Introduction

- Heat transfer fouling is the accumulation and formation of unwanted materials on heat transfer surfaces which leads to a decrease in the overall heat transfer coefficient [1].
- Fouling of heat transfer surfaces is one of the major problems in heat transfer equipment that occurs in food and bio process industries and leads to an increase of cleaning costs for maintenance and energy and consumption[2,3,4].
- The effects of temperature on fouling characteristics of thin stillage in corn dry grind industry were studied.

Methods

- A 7 L batch system was used to simulate the evaporation process (Fig. 1) [2,3,4,5,6].
- An annular fouling probe (Fig. 2) was used to measure fouling resistance $R_f$ by recording surface probe temperature and bulk temperature. $R_f$ was determined as:

$$R_f = \frac{1}{U_{fouled}} - \frac{1}{U_{unfouled}} = \frac{(T_b - T_i)}{Q/A} - \frac{1}{U_{unfouled}}$$

- Experiments were conducted using model thin stillage (1% starch solution) and commercial thin stillage with different bulk temperatures (60, 80°C) and initial probe temperatures (100, 120°C).
- Temperature increased with time as fouling occurred and tests were terminated after 5 hours or $T_{probe}$ reach 200°C.

Results

Fouling of model thin stillage

- No induction period was observed at $T_i = 120^\circ C$ and $T_b = 80^\circ C$, maximum fouling resistance $R_f = 0.70 \ m^2 \cdot K/kW$ was reached in 0.68 hr.
- $T_i = 60 \ T_b =120^\circ C$ had induction period of 1.04 hr and maximum $R_f = 0.36 m^2 \cdot K/kW$
- Induction period longer than 5 hours for $T_b = 80 \ T_i =100^\circ C$ and $T_i = 60 \ T_b =100^\circ C$

Fouling of Commercial thin stillage

- Commercial thin stillage at $T_i = 80 \ T_b = 120$ reach maximum $R_f = 0.48 m^2 \cdot K/kW$ in less than 2 hr while at $T_b = 80 \ T_i =120$ reached maximum $R_f = 0.39 m^2 \cdot K/kW$ after 4.5 hr.
- Fouling resistance of commercial thin stillage at $T_b = 80 \ T_i =100$ reach 0.10 m$^2 \cdot K/kW$ in 5 hr while at $T_b = 60 \ T_i =100$, induction period was longer than 5 hr and no observable fouling occurred.

Comparing model and commercial thin stillage

- Both commercial and model thin stillage showed a trend of increasing fouling resistance and decreasing induction period with the increase of temperatures.
- Deposit sloughing took place in both thin stillage samples when more severe fouling occurs.

Conclusions

- Temperature had an effect on thin stillage fouling characteristics.
- Fouling rate and maximum fouling resistance increased with the increase of initial probe temperature.
- Induction period of fouling decreased with the increase of bulk temperature.

References


Acknowledgements

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Oral Presentations
A NOVEL METHOD FOR PRODUCING MALTOSE RICH SYRUP

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A NOVEL METHOD FOR PRODUCING MALTOSE RICH SYRUP
ONE STEP PROCESS

Pauline Teunissen
ISTC 2015 – Urbana-Champaign
2/4/2015

Aim

- High DP2
- Single pH
- High solubility
- Low DP1
- High %DS
Classification of commercial high maltose syrup

- Produced with acid-enzyme or enzyme-enzyme conversion of starch to maltose rich syrup
- Different ratios of glucose, maltose are specified by customers
- OPTIMALT® BBA, CLARASE® are commercial enzymes for maltose syrup applications

<table>
<thead>
<tr>
<th>Syrup Type</th>
<th>Sugar Composition (%)</th>
<th>Recommended Enzyme(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maltose Syrup</td>
<td>40 - 55</td>
<td>Fungal alpha-amylase</td>
</tr>
<tr>
<td></td>
<td>1 - 10</td>
<td>CLARASE® L or OPTIMALT® BBA</td>
</tr>
<tr>
<td>High Maltose Syrup</td>
<td>55 - 60</td>
<td>Beta-amylase</td>
</tr>
<tr>
<td></td>
<td>1 - 5</td>
<td>OPTIMALT® BBA</td>
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<tr>
<td>Very High Maltose Syrup</td>
<td>&gt; 60</td>
<td>Beta-amylase + pullulanase</td>
</tr>
<tr>
<td></td>
<td>&lt; 1</td>
<td>OPTIMALT® BBA + OPTIMAX® L-1000</td>
</tr>
</tbody>
</table>

Mechanism of enzymes for maltose
Mechanism of enzymes for maltose

Beta-amylase

- Maltose producer

Pullulanase

Starch granule

Beta-amylase

Alpha-amylase
Alpha-amylase

Solubility driver

alpha-amylase

Effect on corn starch

20 x 20 μm
Conventional specialty syrup production process

- **Two temperature and pH process**
  - Chemical and process costs

- **Long saccharification time**
  - Throughput restrictions
  - Incubation tanks

- **High risk of microbial contamination as pH >5.0 and temperature <60°C**
  - The maltose syrup sacch is 24 hours compared to glucose syrup sacch of 48 hr
Thermostable Beta-amylase (TBA):
Potential for a differentiable process

- A beta-amylase from the bacterium *Thermoanaerobacterium thermosulfurigenes*
- pH profile tested by incubating thermostable beta-amylase with 2% potato amylopectin at 50°C from pH 3 to 10.
- Temp profile tested by incubating thermostable beta-amylase with 2% potato amylopectin at pH 5 from 30 to 95°C.
SPEZYME® Xtra and TBA

- Single step incubation at 80°C and pH 5.5.
- The experiments were carried out using 30% ds granular tapioca starch, with DI water making up the 100% of the liquid phase.
- At the end of 7.5 hours:
  » DP2 content is greater than 50% and DP1 is less than 1%
  » Solubility > 95%
  » The DP4+ is on higher side

<table>
<thead>
<tr>
<th>Enzymes</th>
<th>Incubation time, Hr</th>
<th>% Sugar composition</th>
<th>% Solubility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DP1</td>
<td>DP2</td>
<td>DP3</td>
</tr>
<tr>
<td>0.13 kg/MT dss SPEZYME® Xtra</td>
<td>1.25</td>
<td>0.29</td>
<td>41.92</td>
</tr>
<tr>
<td>+ 24.95 TBA/g dss TBA</td>
<td>3.5</td>
<td>0.46</td>
<td>53.40</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>0.59</td>
<td>57.15</td>
</tr>
<tr>
<td>0.13 Kg/MT. dss SPEZYME® Xtra</td>
<td>1.25</td>
<td>0.28</td>
<td>50.49</td>
</tr>
<tr>
<td>+ 49.9 TBA/g dss TBA</td>
<td>3.5</td>
<td>0.46</td>
<td>59.07</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>0.60</td>
<td>61.18</td>
</tr>
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</table>

One step process

- Further tests:
  » Role of a debranching enzyme
  » Source of the alpha amylase
  » Source of the starch
  » Conventional 10 DE SPEZYME® FRED liquefact
  » Other enzymes
SPEZYME® Xtra and TBA with pullulanase

- Single step incubation at 70°C and pH 5.0
- The experiments were carried out using 30% ds granular tapioca starch, with DI water making up the 100% of the liquid phase
- At the end of 24 hours:
  - DP2 content is greater than 50% and DP1 is less than 1%
  - Solubility > 90%
  - The DP4+ is lower for incubation with pullulanase

<table>
<thead>
<tr>
<th>Enzymes</th>
<th>Incubation time, hr</th>
<th>% Sugar composition</th>
<th>% Solubility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DP1</td>
<td>DP2</td>
<td>DP3</td>
</tr>
<tr>
<td>0.13 Kg/Mt. dss SPEZYME® Xtra + 24.96 TBA/s g dss TBA</td>
<td>4</td>
<td>0.42</td>
<td>53.90</td>
</tr>
<tr>
<td>0.13 Kg/Mt. dss SPEZYME® Xtra+ 24.95 TBA/s g dss TBA + 1.0 kg/Mt OPTIMAX® L-1000</td>
<td>24</td>
<td>0.76</td>
<td>59.65</td>
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</tbody>
</table>

Different sources of alpha amylases and TBA

- Single step incubation at 80°C and pH 6.0 for 30% ds tapioca starch
- At the end of 4 hours:
  - DP2 content is greater than 50% and DP1 is less than 1%
  - Different sources of alpha amylase work well with difference in DP1 and DP2 results

<table>
<thead>
<tr>
<th>Enzymes</th>
<th>Incubation time, hr</th>
<th>% Sugar composition</th>
<th>% Solubility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DP1</td>
<td>DP2</td>
<td>DP3</td>
</tr>
<tr>
<td>0.13 Kg per Mt dss SPEZYME® Xtra + 49.9 TBAs/g dss TBA</td>
<td>1</td>
<td>0.41</td>
<td>43.59</td>
</tr>
<tr>
<td>10.0 LU/s g dss SPEZYME® Fred + 49.9 TBAs/g dss TBA</td>
<td>1</td>
<td>0.27</td>
<td>47.64</td>
</tr>
<tr>
<td>3.0 μg/s dss AmyE + 49.9 TBAs/g dss TBA</td>
<td>1</td>
<td>0.23</td>
<td>37.32</td>
</tr>
</tbody>
</table>

2/4/2015 15
Higher AmyE dosage with TBA

- Single step incubation at 80°C and pH 6.0 for 30% ds tapioca starch
- At the end of 4 hours:
  » DP2 content is greater than 45%
  » DP1 can be increased to >2% with increased AmyE

<table>
<thead>
<tr>
<th>Enzymes</th>
<th>Incubation time, hr</th>
<th>% Sugar composition</th>
<th>% Solubility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DP1</td>
<td>DP2</td>
</tr>
<tr>
<td>3.0 μg/g dss AmyE + 49.9 TBAs/g dss TBA</td>
<td>1</td>
<td>0.23</td>
<td>37.32</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.52</td>
<td>44.30</td>
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<tr>
<td></td>
<td>3</td>
<td>0.62</td>
<td>46.37</td>
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<tr>
<td></td>
<td>4</td>
<td>0.75</td>
<td>47.72</td>
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<td>12.0 μg/g dss AmyE + 49.9 TBAs/g dss TBA</td>
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<td>0.90</td>
<td>34.78</td>
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<td></td>
<td>2</td>
<td>1.79</td>
<td>42.11</td>
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<td>3</td>
<td>2.27</td>
<td>44.60</td>
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<td>4</td>
<td>2.61</td>
<td>45.91</td>
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<td>1</td>
<td>2.20</td>
<td>36.57</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.74</td>
<td>42.79</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>4.74</td>
<td>44.70</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5.66</td>
<td>46.38</td>
</tr>
</tbody>
</table>

Different sources of starch and TBA

- Single step incubation at 80°C and pH 6.0 for 30% ds starch
- At the end of 4 hours:
  » DP2 content is greater than 50% and DP1 is less than 1%
  » Tapioca and corn starch worked well. But wheat starch became very viscous and samples could not be taken

<table>
<thead>
<tr>
<th>Starch source</th>
<th>Incubation time, hr</th>
<th>% Sugar composition</th>
<th>% Solubility</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>DP1</td>
<td>DP2</td>
</tr>
<tr>
<td>Tapioca starch</td>
<td>1</td>
<td>0.41</td>
<td>43.59</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.64</td>
<td>49.65</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.81</td>
<td>51.65</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.96</td>
<td>53.25</td>
</tr>
<tr>
<td>Corn starch</td>
<td>1</td>
<td>0.26</td>
<td>45.71</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.35</td>
<td>52.08</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.42</td>
<td>54.74</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.46</td>
<td>56.49</td>
</tr>
</tbody>
</table>
Conventional liquefact and TBA

- A 10 DE SPEZYME® Fred corn starch liquefact at 34% ds incubated at 80°C and pH 6.0 with TBA
- Only 5 hours for >50% DP2
- For conventional liquefact also DP4+ is high

<table>
<thead>
<tr>
<th>Enzymes</th>
<th>Incubation time, hr</th>
<th>% Sugar composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPEZYME® Fred liquefact at 10 DE + 49.9 TBAs/g dss TBA</td>
<td>1</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Conventional vs one step process

**Conventional Process**
- Jet Cooking
  - Temperature: 102-108°C
  - Time: 5-8 minutes
- Liquefaction
  - Temperature: 90-95°C
  - Time: 2-3 hours
- Malto-saccharification
  - Temperature: 55-65°C
  - Time: 16-24 hours

**STARCH SLURRY pH 5-6**

**One Step Process**
- Simultaneous Liquefaction and Malto-saccharification
  - Temperature: 75-95°C
  - Time: 2-12 hours

**Total:**
- 2-12 hours in 1 step
- **Product:** High Maltose Syrup

**Conventional:**
- 18-27 hours in 3 steps
- **Product:** High Maltose Syrup

**Present Innovation**
Meeting the unmet needs: one step specialty syrup production

- Two temperature and pH process
  » Chemical and process costs

- Long saccharification time
  » Throughput restrictions

- High risk of microbial contamination as pH is > 5.0 and temperature <60°C
  » The maltose syrup sacch is 24 hours compared to glucose syrup sacch of 48 hr

- One temperature and one pH process
  » Reduced chemical and process costs

- Incubation time of 2-6 hours
  » Higher throughput

- Low risk of microbial contamination as temperature is >80°C
  » Lower residence time for the specialty syrup saccharification

Summary

**From starch to maltose:**

- With a combination of a thermostable beta-amylase and an alpha-amylase
  - High maltose (>50 %)
  - Acceptable solubility (>90 %)
  - Low DP1 (<1 %) and/or medium DP1 (1-10%)
Acknowledgements and contact

Thanks to:
Vivek Sharma, Kyle Poyta, Tom Kleinhout, Andy Finn, Steve Bacsí,
Zhongmei Tang, Jing Ge and Jay Shetty

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CENTRIFUGES FOR A GREEN FUTURE

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Alfa Laval Inc., 321 Foster Avenue, Wood Dale, IL, 60191
(630-835-6769) dell.hummel@alfalaval.com

Gustaf de Laval invented the first disc stack centrifuge for cream separation in 1878. Alfa Laval has since grown into the largest manufacturer of disc stack centrifuges in the world and a leading global supplier of separation, heat transfer and fluid handling equipment. The Alfa Laval corporate mission is “To optimize the performance of our customers’ processes, time and time again”. We have made a commitment to reduce the carbon footprint of our customers by developing equipment that is more energy efficient. In 2013 alone, Alfa Laval pumped $112 million (2.4% of annual sales) into the research and development of new and improved products.

Alfa Laval is a leading supplier of decanter centrifuges to the ethanol industry. The decanter centrifuge is used in the ethanol process to dewater the whole stillage after distillation. Our decanters have earned a reputation for reliability (high up time), low maintenance costs, high separation efficiencies, high capacities, low power consumption and low noise level. In 2011, a new SG3-805 decanter centrifuge was introduced into the ethanol market. The performance of the SG3-805 decanter is unprecedented and unmatched. As a result of innovative design features which reduce power consumption up to 45%. The first feature is the set of power plates which replace the plate dams installed in the liquid discharge end of the decanter bowl. The power plates discharge the liquid backwards (opposite from the direction of bowl rotation). This reduces the power consumption 15 to 20%. The second feature is the separately rotating feed zone. The feed zone in a traditional decanter is installed in the conveyor and rotates at a speed only a few RPM lower than the bowl speed. The feed zone in the SG3-805 decanter is driven separately from the conveyor and rotates at a lower speed than the bowl. Introducing the feed at a lower speed reduces the power consumption by another 15 to 25%. The end result is a total reduction in power consumption of 30 to 45%.

The other important benefit of the lower speed feed zone is a higher separation efficiency due to reduced turbulence. When replacing a decanter with similar bowl size and similar bowl speed, the SG3-805 can be operated at the same feed rate, provide the same thin stillage quality (for efficient evaporator performance) and reduce the cake moisture level to reduce natural gas consumption in the DDGS dryer. The combination of power consumption savings and dryer savings reduce the customer’s carbon footprint and result in an attractive payback.
The Alfa Laval Merco disc nozzle centrifuge is the work horse of the starch industry. In the corn wet milling process, the Merco is used for mill stream thickening, gluten thickening, starch recycle clarification, modified starch washing, modified starch recovery and the primary separation of starch and gluten. The Merco has unique design features which make it the preferred solution for these applications. The internal recycle feature provides easy single point process control (underflow valve), enables the use of larger bowl nozzles to prevent rotor plugging, requires no external pump, provides cleaning action within the rotor to prevent solids build up and provides high efficiency displacement washing of the starch in primary separation and modified starch washing. The overhead rotor suspension feature counters vibration and unbalance, allows easy access to the rotor assembly, keeps the bearings in a clean location, eliminates sealing problems and accepts large bowls.

The Merco BH-36B centrifuge has earned a reputation for reliability and high separation efficiencies at high capacities. In 2007, Alfa Laval redesigned the BH-36B and introduced the new CH-38 centrifuge to the starch market. The CH-38 has innovative features to increase capacity, use less power and make maintenance easier. Those features include high efficiency solids discharge nozzles, special nozzle removal tool, a more efficient feed inlet, additional disc stack area, a new lock ring and a new lock ring removal tool. The CH-38 provides the customer with multiple opportunities to reduce their carbon footprint. The CH-38 can be operated at feed rates 20 to 30% higher than the BH-36B, provide the same separation efficiency and use the same or less power. The CH-38 also can be operated at the same feed rate as the BH-36B, provide a higher separation efficiency and use 25 to 30% less power. In gluten thickening service, the higher separation efficiency can result in an increase in gluten meal production and a significant reduction in the centrifuge payback time. One CH-38 can replace multiple centrifuges that are smaller in size and less efficient. This also results in a significant reduction in power consumption.

Alfa Laval will continue to push the envelope to develop new equipment to reduce the carbon footprint of our customers, time and time again.
9th International Starch Technology Conference
University of Illinois
Champaign, IL
February 3, 2015

Centrifuges for a Green Future

Dell Hummel
Sales Manager
Separation Equipment
Natural Resources
Wood Dale, IL

The Company

Alfa Laval is a leading global provider of specialized products and engineered solutions.
Processes

We help customers to heat, cool, separate and transport products such as oil, water, chemicals, beverages, foodstuff, starch and pharmaceuticals.

Solutions

Alfa Laval aims at creating better everyday conditions for people by providing highly efficient and environmentally responsible solutions for water supply, energy production and food.
Our Corporate Mission

To optimize the performance of our customers’ processes. Time and time again.

We Serve Most Industries

**Biofuels**
- Biotech and pharmaceutical
- Chemicals
- Crude oil refinery
- Engine and transport
- Fluid power
- Food and beverages
- HVAC
- Industrial fermentation
- Latex
- Machinery
- Marine and diesel

**Starch**
- Metal working
- Mining and mineral processing
- Oil and gas
- Power
- Pulp and paper
- Refrigeration and air-conditioning
- Semiconductor systems
- Steel and coke oven gas
- Sugar
- Wastewater treatment
Gustaf de Laval (1845-1913)

“The Man of High Speeds”

• 200 projects and inventions
• 92 patents, including the milk separator (1878) and the steam turbine (1883)
• Started 37 companies

A Global Company

• 34 major manufacturing units
• 106 service centres
• Sales companies in 55 countries
• Sales representation in 45 other countries
• 16,000 employees (2013)
• $4.6 Billion sales (2013)
Key Technologies

Separation
Efficient separation of liquids from liquids, of particles from liquids and of fluids and solids from gases

Products:
• High speed separators
• Decanters
• Membrane filtration

Key Technologies

Heat Transfer
Energy saving solutions for heating, cooling, ventilation, evaporation and condensation

Products:
• Plate heat exchangers, including brazed and welded heat exchangers
• Shell-and-tube heat exchangers
• Air heat exchangers
• Spiral heat exchangers
• Thermal fluid systems
• Boilers
Key Technologies

Fluid Handling
Safe transport and control of fluids

Products:
• Pumps
• Valves
• Mixers
• Tank equipment
• Installation material

Focus on R&D

• Launching 35-40 new products every year
• More than 1,900 patents
• Alfa Laval has made a commitment to reduce the carbon footprint of our customers by developing equipment that is more energy efficient.
• R&D investments (2013): $112 million (2.4% of total net sales)
Centrifuge Development

Dry Mill Ethanol Process

SG3-805 Decanter Centrifuge

Distillery Flow Diagram

- Mill
- Cooker
- Mash
- Fermentation
- Still
- Multi Effect Evaporator
- Dryer
- Decanter Centrifuge


- Alcohol
- Spent Wash
- Cake
- Syrup
- Dark Grains
- Water
- Malted Barley and/or Enzyme
Alfa Laval is a leading supplier of Decanter Centrifuges to the US ethanol industry.

Sold (327) Decanter Centrifuges for whole stillage dewatering since 2001.

Alfa Laval Decanter Centrifuges have earned a reputation for reliability (high up time), low maintenance costs, high separation efficiencies, high capacities, low power consumption and low noise level.

Alfa Laval introduced the new SG3-805 decanter centrifuge to the ethanol market in 2011. The performance of the SG3-805 decanter is unprecedented and unmatched. The SG3-805 has innovative design features which reduce power consumption up to 45% and provide higher separation efficiency.

Alfa Laval SG3-805 Decanter Centrifuge

All Global Markets:
(66) 720 mm Decanters Sold
US Ethanol Market:
(7) SG3-805 Decanters Sold
(4) SG3-805 Decanters In Operation
(First Machine Started In October 2011)
Standard Decanter Centrifuge Cut Away

- Back Drive
- Gear Box
- Main Drive
- Coupling
- Support Frame
- Bowl
- Main Bearings
- Conveyor
- Casing
- Feed Tube
- Feed Inlet
- V-Belts
- Solids Outlet
- Liquid Outlet
- Conveyor Bearings
- Feed Zone
- Vibration Isolators

Standard Decanter Centrifuge Liquid Outlet with Plate Dams
SG3-805 Decanter Centrifuge
Liquid Outlet with Power Plates

- Directs discharge backwards
- Recovers power (15-20% power reduction)
- New Sales and After Sales
- Patent applied for

Standard Decanter Centrifuge
Fixed Feed Zone

The feed zone in a standard decanter is installed in the conveyor and rotates at a speed that is only a few RPM lower than the bowl speed.
SG3-805 Decanter Centrifuge
Separately Rotating Feed Zone

- Driven separately from conveyor
- Rotates at much lower speed than bowl
- Gentle acceleration
- Improved separation
- 15-25% power reduction

Alfa Laval Stillage Decanter Centrifuges
SG3-805 (720 mm) vs SG2-800 (740 mm)
US Corn Ethanol Plant
November 2011

2.5% reduction in cake moisture level
Same recovery (80%)
Same capacity (400 GPM)
<table>
<thead>
<tr>
<th>Model</th>
<th>SG2-800</th>
<th>SG3-805</th>
<th>Net Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Rate (GPM)</td>
<td>400</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>% Suspended Feed Solids</td>
<td>6.0%</td>
<td>6.0%</td>
<td></td>
</tr>
<tr>
<td>% Suspended Solids Recovery</td>
<td>80.0%</td>
<td>80.0%</td>
<td></td>
</tr>
<tr>
<td>% Suspended Centrate Solids</td>
<td>1.42%</td>
<td>1.40%</td>
<td></td>
</tr>
<tr>
<td>% Total Cake Solids</td>
<td>34.0%</td>
<td>36.5%</td>
<td></td>
</tr>
<tr>
<td>Centrate Water (lb/hr)</td>
<td>160,256</td>
<td>162,615</td>
<td>2,359</td>
</tr>
<tr>
<td>Cake Water (lb/hr)</td>
<td>20,813</td>
<td>18,453</td>
<td>-2,359</td>
</tr>
<tr>
<td>% Backset</td>
<td>30.0%</td>
<td>29.6%</td>
<td></td>
</tr>
<tr>
<td>Backset Water (lb/hr)</td>
<td>48,077</td>
<td>48,077</td>
<td></td>
</tr>
<tr>
<td>Evaporator Feed Water (lb/hr)</td>
<td>112,179</td>
<td>114,538</td>
<td>2,359</td>
</tr>
<tr>
<td>% Total Evaporator Syrup Solids</td>
<td>40%</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Evaporator Syrup Water (lb/hr)</td>
<td>18,016</td>
<td>18,332</td>
<td>316</td>
</tr>
<tr>
<td>Water Evaporated (lb/hr)</td>
<td>94,163</td>
<td>96,206</td>
<td>2,043</td>
</tr>
<tr>
<td>Dryer Feed Water (lb/hr)</td>
<td>38,828</td>
<td>36,785</td>
<td>-2,043</td>
</tr>
</tbody>
</table>

**Alfa Laval Stillage Decanter Centrifuges**

SG3-805 (720 mm) vs SG2-800 (740 mm)

**US Corn Ethanol Plant**

**November 2011**

- **44% reduction in power consumption**
- Same capacity (400 GPM)
Evaporator Cost Increase:
2,043 lb/hr x $2.27/1,000 lb x 24 x 360 = $40,069 / year

Dryer Cost Reduction:
2,043 lb/hr x $7.35/1,000 lb x 24 x 360 = $129,739 / year

Power Cost Reduction:
80 HP/1.341 = 59.7 kW
59.7 kW x $0.075/kWH x 24 x 360 = $38,686 / year

Total Cost Savings:
$129,739 + $38,686 - $40,069 = $128,356 / year

Centrifuge Development
Corn Wet Milling Process

Merco CH-38 Disc-Nozzle Centrifuge
The Alfa Laval Merco disc nozzle centrifuge is the work
horse of the starch industry.

Installed base of approximately (600) Merco centrifuges
in the US starch industry.

The Merco has unique design features which make it
the preferred solution for the corn wet milling process.

The internal recycle feature provides easy single point
process control (underflow valve), enables the use of
larger bowl nozzles to prevent rotor plugging, requires
no external pump, provides cleaning action within the
rotor to prevent solids build up and provides high
efficiency displacement washing of the starch in primary
separation and modified starch washing.

©Slide 30

The overhead rotor suspension feature counters
vibration and unbalance, allows easy access to the rotor
assembly, keeps the bearings in a clean location,
eliminates sealing problems and accepts very large
bowls.

The Merco BH-36B centrifuge has earned a reputation
for reliability and high separation efficiencies at high
capacities.

Alfa Laval redesigned the BH-36B and introduced the
new CH-38 centrifuge to the starch market in 2007.
Merco CH-38 Centrifuge

Global:

(119) Total CH-38’s

US:

(31) Complete CH-38’s
(28) CH-38 Conversions

Merco H38
Merco CH-38 Centrifuge

**Goals:** Higher Capacity & Easier Maintenance

**Higher Capacity**
- 20 - 30% higher capacity than H36B
- More disc stack area
- High efficiency nozzles
- More efficient return impeller
- More efficient feed inlet
- H36B easily converted to H38
- Lower HP per GPM (power reduction of 25% or more at the same flow rate as H36B)

**Easier Maintenance**
- New jam nut
- New nozzles & nozzle removal tool
- New lock ring & lock ring tool
- Disc stack can be removed with feedwell
- New one piece return impeller
- Primary bowl easily converted to concentrator bowl (only have to change disc stack, feed tubes, return tubes and feed impeller)
Merco CH-38 Centrifuge

- **MST**
  1000 GPM Nominal @ 8 Be (1200 GPM Maximum)
- **Primary**
  1100 GPM Nominal @ 10 Be (1300 GPM Maximum)
- **GT**
  850 GPM Nominal @ 3 oz/gal (1000 GPM Maximum)
- **CL**
  1000 GPM Nominal @ 5 Be (1200 GPM Maximum)

Merco CH-38 Centrifuge

Opportunities to reduce carbon footprint

- The CH-38 can be operated at feed rates 20-30% higher than the BH-36B, provide the same separation efficiency and use the same or less power.
- The CH-38 can be operated at the same feed rate as the BH-36B, provide a higher separation efficiency and use 25-30% less power. In gluten thickening service, the higher separation efficiency can result in a significant increase in gluten meal production and a significant reduction in the centrifuge payback time.
- One CH-38 can replace multiple centrifuges that are smaller in size and less efficient. This results in a significant reduction in power consumption and often provides a higher separation efficiency.
Case Study A

US Corn Wet Milling Plant

Gluten Thickener Centrifuges (before project):

(1) Merco BH-36B GT centrifuge
(1) Merco BH-30 GT centrifuge
(1) Merco BH-30 GT centrifuge

February - April 2013

Average Grind Rate: 78,222 Bu / Day
Gluten Meal Yield: 2.761 Lb / Bu
Gluten Meal Production: 108 Tons/Day
Gluten Meal Price: $660 / Ton
Gluten Meal Income: $71,270 / Day

Goal: Increase gluten meal yield by cleaning up the process
water (overflows) from the gluten thickener centrifuges

Gluten Thickener Centrifuges (after project):

(1) Merco CH-38 centrifuge (started up May 2013)
(1) Merco BH-36B GT centrifuge
(1) Merco BH-30 GT centrifuge
(1) Merco BH-30 GT centrifuge

July - August 2013

Average Grind Rate: 79,816 Bu / Day
Gluten Meal Yield: 2.913 Lb / Bu
Gluten Meal Production: 116 Tons / Day
Gluten Meal Price: $660 / Ton
Gluten Meal Income: $76,726 / Day
Gluten Meal Income Increase: $1.96 million / year

7 Month Centrifuge Payback (based on installed cost)
Case Study B

US Corn Wet Milling Plant

Converted BH-36B GT centrifuge to BH-38 GT centrifuge in 2007

Tested BH-38 GT centrifuge side by side with a BH-36B GT centrifuge

Both centrifuges tested at the same conditions:

- Feed Rate: 650 GPM
- Feed Concentration: 2.6 oz/gal (7.2% spin)
- Underflow Concentration: 18.5 oz/gal (47% spin)

Average Power Consumption:

- BH-38: 215 amps (149 kW)
- BH-36B: 316 amps (219 kW)

Power Cost Reduction:

\[ 70 \text{ kW} \times \$0.075/\text{kWh} \times 24 \times 360 = \$45,360/\text{year} \]

Average overflow spins:

- BH-38: 0.06 ml (95.3% gluten recovery)
- BH-36B: 0.16 ml (87.7% gluten recovery)

Potential income increase for complete plant in 2015:

- Grind Rate: 200,000 Bu/Day
- Gluten Meal Yield: 2.70 Lb / Bu (based on 87.7% recovery)
  \[ 2.93 \text{ Lb} / \text{Bu} \text{ (based on 95.3% recovery)} \]
- Gluten Meal Production: 270 Tons / Day (based on 87.7% recovery)
  \[ 293 \text{ Tons} / \text{Day} \text{ (based on 95.3% recovery)} \]
- Gluten Meal Price: $628 / Ton
- Gluten Meal Income Increase: $5.2 million / year
Case Study C

US Corn Wet Milling Plant.

Primary Centrifuges (before project):
- (9) Merco B-30-SPS centrifuges
- Total Connected HP: 9 x 125 HP = 1125 HP
- Average Underflow Baume: 18.5 Be
- Average Underflow Protein Spin: 0.8 ml

Primary centrifuges (after project):
- (1) Merco CH-38 centrifuge (started May 2014)
  nicknamed “Robotron” by plant operators
- (3) Merco B-30-SPS centrifuges
- (6) Merco B-30-SPS centrifuges
- Total Connected HP: (1 x 350 HP) + (3 x 125 HP) = 725 HP

CH-38 Feed Rate: 1150 GPM (normal)
  1300 GPM (maximum)

Feed Baume: 13.0 Be
Underflow Baume: 19.5 Be
Underflow Protein Spin: 0.5 ml

Power Reduction:
- 1125 HP - 725 HP = 400 HP (298 kW)

Power Cost Reduction:
- 298 kW x $0.075/kWH x 24 x 360 = $193,104 / year
Case Study C

Potential income increase due to 1.0 Be increase in underflow baume and 0.3 ml reduction in underflow protein spin.

Sends more protein to the gluten thickener centrifuges which could result in higher gluten meal production.

Sends less water to the cyclone starch washing system which should reduce volume of water recycled to clarifier centrifuges, primary centrifuges and GT centrifuges. Separations will improve due to lower feed rates.

Sends less protein to the cyclone starch washing system which should reduce the amount of fresh wash water required and reduce the amount of water evaporated.

Alfa Laval will continue to push the envelope to develop new equipment that reduces the carbon footprint of our customers, time and time again.
MAXIMISING STARCH CONVERSION TO ETHANOL (ISTC)

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(919-494-3419) JEDS@novozymes.com

A basic introduction into the composition of corn starch and of the corn to ethanol process will be presented. Starch gelatinization and the effects that corn drying, storage, milling and other process conditions have on the degree of gelatinization will be discussed. Factors that affect an enzyme’s ability to access and hydrolyze starch will be covered. A selection of analytical tools for measuring the starch hydrolysis process will be reviewed.
Maximizing Starch Conversion to Ethanol

AGENDA

- Introduction of corn starch, enzymes, and the dry grind process
- Factors that affect efficiency of Starch Conversion
- Measurement of the process
Composition of Corn

Starch Basics

Different starches have different morphology
Starch Basics cont.

- Starch structure
  - Granules: Physical arrangements of amylose and amylopectin
  - Glucose chains form double helices and crystalize
  - Crystalline region is insoluble and resistant to being hydrolyzed
  - Glucose chains in amorphous region have flexibility

![Corn Starch Granules](image)

**Native Starch Types**
- Amylose (linear)
- Amylopectin (branched)

**Amylopectin Tree Structure**
Revised from Gallant etc., 1997

Comparison of amylose and amylopectin

<table>
<thead>
<tr>
<th></th>
<th>Amylose</th>
<th>Amylopectin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linkage</td>
<td>α-1,4</td>
<td>α-1,4 &amp; α-1,6</td>
</tr>
<tr>
<td>Size (DP)</td>
<td>200–2,000</td>
<td>&gt;&gt;2,000</td>
</tr>
<tr>
<td>Shape</td>
<td>Linear</td>
<td>Branched</td>
</tr>
<tr>
<td>Amylase digestibility</td>
<td>~100%</td>
<td>50–60%</td>
</tr>
<tr>
<td>Complex formation</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Solution stability</td>
<td>Poor</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

![Amylose and Amylopectin Linkage Diagrams](image)
Enzyme Basics - What is an Enzyme?

- Protein
  - Found in all living organisms

- Catalyst
  - Lowers Energy of Activation

Enzymes as Catalysts

- Accelerate chemical reactions ... but undergo no permanent change themselves
- The active site binds only to substrate molecules that have the specific complementary shape
- Enzymes are **active** during reaction but are not **alive**
In Conventional Dry-Grind Ethanol Production

- The efficiency of conversion of starch to glucose is affected by:

1. The degree of starch gelatinization
   - 1) Corn drying conditions
   - 2) Compositional change during storage
   - 3) Corn milling
   - 4) Process conditions

2. The accessibility of enzyme to starch
   - 1) Starch-protein-fiber network
   - 2) Amylose-lipid complex
   - 3) Retrogradation
Factors that Affect Starch Gelatinization

Starch Gelatinization

- Gelatinization
  - The disruption of molecular order within starch granules as they are heated in the presence of water (Whistler and BeMiller, 1999)
  - Granules swell up by heating and absorbing water, with increasing viscosity and clarity
  - When reaching to the maximum viscosity, granules break apart and viscosity decreases
  - Loss of crystallinity
  - The gelatinization temperature depends on the composition of the starch
    - The ratio between amylose and amylopectin, the presence of fats and other components as well as the initial water content
    - Normally for corn: 62 °C to 72 °C
    - Normally for wheat: 52 °C to 63 °C
Effect of Corn Drying Conditions

### Source | Temperature, °C | Note
---|---|---
Grain company | 82-88 | Recommendation to growers
Equipment manufacturer | 88-110 | Usually a OK range
Feed mills | 49-54 | Nutrient digestibility is important
Food grade | 49-54 | Reduced stress cracks
Viable seed | 38 | For viable seed production

- Higher drying temp
  - Higher starch gelatinization temperature
  - More starch conjugated with proteins
  - Less available starch for enzymes
  - More Maillard products

- Ethanol response to drying temp is not consistent
- Tends to be lower for < 38 °C and > 52 °C

---

Evaluation of Drying on Corn Quality

- Proma test
  - A measurement to assess the intensity of the thermal shock received by the grain during drying process.
  - A good indicator of separation between protein and starch
  - Used by the Starch Wet-Mill industry to monitor starch quality and corn nutritional value
  - Example:

<table>
<thead>
<tr>
<th>Drying Temp, °C</th>
<th>80</th>
<th>110</th>
<th>140</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proma value</td>
<td>33</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Good</td>
<td>Fair</td>
<td>Fair</td>
</tr>
</tbody>
</table>

- Germability / Viability Test
  - To test whether the corn can germinate or not
  - An indication of damage on the corn
  - By a color reaction with 2, 3, 5-triphenyltetrazolium chloride.

---

M. Haros etc., 2003 & G. Reicks etc., 2009
Compositional Change of Corn During Storage

- Ethanol yield decreases 6-7 months after harvest
- Starch content
  - No overall change at low temperature storage
  - Decreased by 4.7% and 8.2% at 6 mo and 12 mo of storage at 30 °C
- Amylose content
  - Decreased by 10% and 21% after 6 mo and 12 mo of storage at 30 °C
- Protein content
  - No overall change during storage

![Graphs showing changes in Starch and Amylose content](image)

M. Labuschagne etc. 2014
D. Ramchandran, 2014

Particle Size Distribution (PSD) During Milling

- PSD is affected by both equipment and corn characteristics
- Corn hybrid, kernel moisture and density affect how corn kernels break apart, also impact PSD
- Can impact processing conditions, fermentation kinetics, and ethanol yield
- Expressed as the proportion of material recovered in each particle size category
Effect of Smaller Particle Size

- Smaller screen sizes showed
  - Lower viscosities
  - Faster fermentation kinetics and higher ethanol titers
  - Increased surface area for easier and more access to enzyme for starch hydrolysis
- Reducing particle size could have adverse affects on downstream processing
  - Reduced efficiency of centrifugation and evaporation due to increased solids

K.D. Rausch etc., 2005 & K. Liu, 2009

Factors that Affect Starch Accessibility
Starch-Protein-Fiber Network

- The network:
  - Fiber as backbone
  - Protein as the glue filling
  - Starch embedded

- Protein matrix:
  - Blocks water penetration
  - Delays gelatinization
  - Reduces starch digestibility

- Formation of disulfide-bonded zein oligomers during cooking
  - Accessibility of starch to enzyme may be obstructed

Model of Starch Hydrolysis

Typical AA/GA can release a pool of accessible starch that is available for SSF. However, bound starch is still trapped and remains in the distiller's grains.

AA/GA + Cellulase With AA, GA, and Cellulase combined, an additional pool of bound starch is released, resulting in an increase in ethanol yield.
Effect of Cellulase

- A high dose of cellulase removes fiber, exposing starch granules for hydrolysis.
- Fiber is degraded.
- More starch is accessed allowing for greater starch conversion and higher ethanol yields.

- Starch bound in the fiber matrix cannot be accessed.
- Due to the absence of starch granules, the matrix collapses.

Amylose-Lipid Complex

- Can be naturally present or formed upon gelatinization
  - DP 18-24 for one lipid molecule
  - Aliphatic chain inside the cavity, polar head outside
  - Resistance to hydrolysis increases with amylose and lipid chain length
  - Type I
    - --- ≤ 60°C complexation temp
    - --- Dissociate between 95-105 °C
  - Type II
    - --- ≥ 90°C complexation temp
    - --- AM > DP 60
- Definition of lipid
  - Only fatty acid or monoacylglycerol
  - Not triacylglycerols

J.A. Putseys etc., 2010, X.Wu etc., 2006 & S. Srichuwong etc., 2011
http://feinmantheother.com/category/triglycerides/
Starch Retrogradation

- Changes occur in gelatinized starch
  - Amorphous state to a more ordered or crystalline state
  - Increased viscosity
  - Loss of water-holding capacity
  - Insoluble and less access for enzyme hydrolysis

- The greater the amylose content
  - The more reassociations of amylose molecules to form retrogradation
  - Amylose chains DP 80-100 retrograde most quickly
  - The lower starch to ethanol conversion efficiency

M. Gudmundsson, 1994
http://www.food-info.net/uk/carbs/starch.htm

Measurements of the Process
--- Beyond HPLC
Residual Starch Determination

- Achievable Residual Starch:
  - If given enough incubation, they could be converted to ethanol eventually
- Total Residual Starch:
  - Includes resistant starch

InDex - See Beyond DE!

Insight into Dextrinization, or InDex, is an HPLC-based measurement for liquefaction quality

- DE lets you know how much dextrin cutting has been done
- Not how efficient a system is at making starch available
- Not the distribution of dextrin sizes
**InDex** Gives a More Complete Picture

Three InDex parameters:

- **%DI** = quantifies dextrin size reduction
  - Measures dextrinization in a similar fashion to DE with the advantage of being HPLC based

- **%SI** = quantifies starch going into solution (solubilization)
  - Can potentially be converted to fermentable sugars

- **%GI** = quantifies glucose generation
  - Allows separation of the performance of alpha-amylase activity from that of glucoamylase activity

---

**GPC Basics**

- **Gel Permeation Chromatography / Size Exclusion Chromatography (GPC/SEC)**

- Primary Function: To measure the MW distribution

- Separation Mechanism:
  - Polymer molecules are separated according to size
  - Larger molecules elute first
Maximizing the Starch Conversion by:

- Avoiding high drying temperature
- Monitoring the storage conditions
- Reducing the particle size with milling
- Adding accessory enzymes (i.e. cellulase) with conventional enzymes
- Using corn with less amylose content
- Applying multiple techniques for process optimization
References


Thank you!

Questions?
DEVELOPMENT OF SYNTHETIC CHROMOSOMES AND IMPROVED MICROBIAL STRAINS TO UTILIZE CELLULOSIC FEEDSTOCKS AND EXPRESS VALUABLE COPRODUCTS FOR SUSTAINABLE PRODUCTION OF BIOFUELS FROM CORN

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A sustainable biorefinery must convert a broad range of renewable feedstocks into a variety of product streams, including fuels, power and value added bioproducts. To accomplish this, microbial based technologies that enable new commercially viable coproducts from corn to ethanol biofuel fermentations are necessary. Peptides and proteins have potential as coproducts from a biorefining process. Developing a robust protein/peptide expression system as a technology platform will provide opportunities to create novel microbial catalysts via genetic engineering and mutagenesis that enable sustainable processes for producing biofuel from corn biomass and liquid waste streams while concomitantly producing several value added products.

A synthetic chromosome system for stable expression of enzymes for pentose utilization and of a peptide coproduct was developed and transformed into Saccharomyces cerevisiae. This yeast strain is being evaluated for yield of coproduct and production of ethanol from corn. Other microbial yeast strains to bioprocess all sugars and proteins of a plant biomass and produce a mixture of yeast cells, oil, biofuels and other high value products also are being developed and evaluated. An artificial chromosome expression platform utilizing mutant Yarrowia lipolytica host strains that produce high levels of ammonia and oil is being evaluated for improved renewable gas and biodiesel and for increasing the range of feedstocks used for commodity chemicals production, including ammonia, concomitantly with expression of genes for value added protein coproducts.
A robotic workcell process is being used for the rapid assembly of chromosomes and transformation of *Yarrowia lipolytica* in a single operation without need for traditional cloning strategies. Chromosomes are assembled de novo using PCR and oligonucleotide assembly paradigms coupled with strategies for optimizing various regions of this synthetic chromosome. Automated assembly of the chromosome units allows production of the telomeric regions with selectable markers followed by screening for promoter and terminator regions for polyprotein expression cassettes and offers the possibility of adding other optimized expression cassettes. In this presentation, we will focus on the development of new microbial catalysts with synthetic chromosomes to ferment waste biomass streams, such as stover, cobs and other agricultural waste materials, for production of food, feed, fertilizer, biofuel, value added proteins and peptides, renewable gas and biobased chemicals.
Automated Continuous High-Throughput Synthetic Chromosome Assembly and Transformation of Improved Yeast Strains for Expression of Recombinant Protein Coproducts to Increase Profitability of Advanced Biofuel Production

*PEPTALK 2015*
*Pipeline 4: Recombinant Protein Expression and Production. January 21, 2015 Town and Country Resort & Convention Center in San Diego, CA*

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Overview
Presentation Overview

- Impetus and drawbacks for using yeast to express valuable peptide or protein pharmaceuticals as coproducts in the sustainable production of advanced biofuels
- Novel gene open reading frame (ORF) assembly and expression strategy using amino acid scanning mutagenesis and custom fusion tags for improved protein folding, optimum expression levels and desired location inside or outside the cell
- High-throughput integrated automated platform to synthesize, clone, and express heterologous gene ORFs, and screen expressed proteins for optimized function
- Construction of synthetic yeast artificial chromosome (YAC) containing optimized ORFs in a polyprotein cassette for expression of multiple genes behind the chosen promoter
- Selection of host strain mutagenized for robust growth in a specific biorefinery feedstock and transformation of strain with synthetic YAC
- Screening of transformed strains in high-throughput for production of antibody or other therapeutic proteins
- Facility for automated chromosome assembly and host cell transformation and screening
- Integrated biorefinery for scale-up of expression and production of recombinant proteins
- Regulatory considerations for expressing biosimilar recombinant biopharmaceuticals from yeast

Impetus and Drawbacks for Using Yeast Strains to Express Biosimilars

- Conventional and innovative biomedical approaches require cost-effective protein drugs with high therapeutic potency
- In 2010, the 6 top biopharmaceuticals accounted for 43% of Medicare Part B drug budget, and by 2016, 7 of the top 10 drugs worldwide are projected to be biopharmaceuticals
- On March 23, 2010, the US enacted the Biologics Price Competition and Innovation Act as part of the Affordable Care Act to create an abbreviated licensing pathway for biological products shown to be biosimilar to (or interchangeable with) an FDA-licensed biological reference product
- This pathway permits a biosimilar product to be licensed with a reduced amount of product-specific nonclinical and clinical studies reducing cost of licensing
- Extensive comparative physicochemical and functional studies are required to demonstrate that reference and proposed products are highly similar and therefore can use this pathway
- Therapeutic proteins can be produced by microbial or animal cells with microbial systems generally having easier operation and lower process costs
- Expression systems have significant effects on types and extent of translational and post-translational modifications and therefore on similarity
- Both microbial and animal expression systems exhibit drawbacks mainly related to intracellular retention of product, lack of post-translational modifications, and conformational stresses

1 McCamish M, FDA ACPS-CP Update on Biosimilars, FDA White Oaks Conference Center, Silver Spring, MD, August 8, 2012.
2 FDA Guidance, Quality Considerations in Demonstrating Biosimilarity to a Reference Protein Product, February 2012.
Definition of Biosimilar/Biosimilarity in Biologics Price Competition and Innovation (BPCI) Act

- **Biosimilar or biosimilarity** is defined in Section 351 of the PHS Act to mean that “the biological product is highly similar to the reference product notwithstanding minor differences in clinically inactive components,” and that “there are no clinically meaningful differences between the biological product and the reference product in terms of the safety, purity, and potency of the product”.

- Section 7002(b)(2) of the Affordable Care Act, amending section 351(i) of the PHS Act.

---

**BIOLOGICS ARE MORE COMPLEX THAN SMALL MOLECULES AND MABS MORE COMPLEX THAN SIMPLE BIOLOGICS**

- **Aspirin®**
  - Small chemical molecule
  - Molecular weight = 180 Daltons
  - 0 amino acids

- **Calcitonin**
  - Simple biologic
  - Molecular weight = 3,455 Daltons
  - ~32 amino acids
  - w/o host cell modifications
  - produced in yeast, bacteria

- **Monoclonal Antibody (IgG)**
  - Complex biologic
  - Molecular weight = 150,000 Daltons
  - ~1300 amino acids
  - w/host cell modifications (glycosolations, etc)
  - produced in mammalian cells
Expression Systems and Characterization

- Differences between the chosen expression system of the proposed biosimilar product and that of the reference product should be carefully considered.
- The type of expression system and host cell will significantly affect the types of process-and product-related substances and impurities.
- The stepwise approach should start with extensive structural and functional characterization of both the proposed product and the reference product, which serves as the foundation of a biosimilar development program.
Gene Open Reading Frame Assembly

Automated Gene Assembly and Amino Acid Scanning Routine

- Oligonucleotide synthesis
- PCR assembly
- Resulting in assembled clonal open reading frame collections
- Performed without DNAse or other costly molecular biology enzymes and reagents
- Seamlessly incorporated into synthetic chromosome assembly routines

Figures:
- ORF assembly
- Automated gene assembly

Novel Gene ORF Assembly Using Amino Acid Scanning Mutagenesis

- Shuffle several known sequences or change existing amino acid sequences to obtain new patents
- Make polyprotein ORF
- Merge into optimal clone with best folding
- Speed up or slow down catalysis of enzymes
- Improved bioavailability and bioactivity
- Affect stability and pharmacokinetics
- Increase amount of a recombinant produced
- Find minimal ORF needed
Automated Molecular Biology Routines for Assembly and Expression of Plasmid-Based Gene ORFs

High-Throughput Integrated Automated Platform to Synthesize, Clone, and Express Gene ORFs
### Analysis of Mutagenized Gene ORFs Produced on Automated Platform

**Functional Testing of Lycotoxin-1 Mutant Peptides Expressed from Plasmid Clones on Automated Platform**

<table>
<thead>
<tr>
<th>Yeast strain</th>
<th>Day 1 (% killed)</th>
<th>Day 2 (% killed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>XI yeast control</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>XI Lyt-1 C3 (template ORF #59, has mutations K24P and L25W)</td>
<td>3.4</td>
<td>71.0</td>
</tr>
<tr>
<td>XI Lyt-1 A6 (variant has mutations F8H, K24P, L25W)</td>
<td>13.2</td>
<td>94.1</td>
</tr>
<tr>
<td>XI Lyt-1 B9 (variant has mutations G10Q, Q20H, Q21S, K24P, L25W)</td>
<td>0.0</td>
<td>97.2</td>
</tr>
<tr>
<td>XI Lyt-1 C6 (variant has mutations L9S, K24P, L25W)</td>
<td>3.7</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Scanning Electron Micrograph Indicates Lycotoxin-1 C3 Variant Has Cell-Penetrating Properties and Moves to Surface of Cells

Assembly of Synthetic Expression Chromosome
Assembly of Non-Plasmid Yeast Synthetic Chromosome (YSC) for Expression of Multiple Gene ORFs

- Manageable Sequence Can Be Assembled Quickly
- Use to Screen Large Numbers of Mutant Proteins
- Transform into Several Types of Yeast Strains
- Operations Readily Performed in High Throughput

Platform for Automated Assembly and Transformation into *Saccharomyces cerevisiae* of a YSC Expressing Multiple Proteins
Advantages of Yeast Synthetic Chromosomes

- Allows introduction of multi-gene cassettes
- Multiple proteins expressed simultaneously from single promoter
- Easily track sequence of ORFs and chromosome
- Facilitates performing iterative changes to ORFs and chromosome to improve expression
- Maintains integrity of host chromosome
- Gives stable expression in yeast strains

Expression of SUMO-Tagged Polyprotein Sequence from YSC for the Cellulosic Sugar Utilization Enzymes
<table>
<thead>
<tr>
<th>Medium</th>
<th>INVS&lt;sup&gt;c&lt;/sup&gt;1 with artificial chromosome YAC4 SUMO-XI·XKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-Galactose</td>
<td>INVS&lt;sup&gt;c&lt;/sup&gt;1 control</td>
</tr>
<tr>
<td>D-Glucose</td>
<td></td>
</tr>
<tr>
<td>YPD</td>
<td></td>
</tr>
<tr>
<td>D-Mannose</td>
<td></td>
</tr>
<tr>
<td>D-Xylose</td>
<td></td>
</tr>
</tbody>
</table>
Production of Cellulosic Ethanol By Yeast Strain Transformed with YSC Expressing Cellulosic Sugar Utilization Enzymes

GMAX1 Cellulosic Yeast Sugar Utilization From Whole Corn Hydrolysate

Host Industrial Strain Development
UV-C Irradiation to Improve Industrial Yarrowia Yeast Host Strain

**Step one: HTS Plate Preparation of Mutagenized Strains**
- Two duplicate 96-well microtiter plates with 1 liter LBG medium
- March KB-014 deep-well plates with baffled bottoms
- Place plates in dark
- 128 x 20 mm trays

**Step two: Clone Mutant Strain Selection**
- After 48-hour incubation, the plates were screened to select the largest mutant colonies with the most intense dark halo indicating the highest production of ammonia.

**Step three: Assays for Determination of Oil and Ammonia Intensity**
- Individual colonies were isolated by limiting dilution, and the isolated colonies were replicated on plates with 1% glucose (LNG) containing 0.1 mg/L BTEX medium and 0.5 mg/L ampicillin.
- Cultures were incubated at 30°C for 48 hours.
- Colonies with the highest intensity were selected.

**Graph: Kill Curve of Yarrowia lipolytica NRRL YB-567**
- Number of Surviving Cells
- Time (hours)
- Flasks 1 and 2
Scanning Electron Micrographs Showing Effects of UV-C Irradiation of Yarrowia Host Strain

Light Microscope Photographs Showing Effects of UV-C Irradiation of Yarrowia Host Strains Selected for Increased Ammonia and Oil Production
Facility for High-Throughput Automated Assembly of Expression Chromosome
Automated Assembly of Expression Synthetic Chromosome with Antibody Polyprotein Open Reading Frame, Transformation, and Expression

Recombinant synFab Antibody Expression YSC
Integrated Biorefinery Using Improved Yeast Strains
Integrated Biorefinery Process Concept with Whole Corn (Starch and Cellulosic)

• Each component of coffee waste degraded by microbial fermentation followed by extraction, hydrocracking, and hydroformylation
Regulatory Considerations for Licensing Biosimilars from Yeast

• Since 1996, FDA has approved numerous manufacturing process changes for licensed biopharmaceuticals, where the manufacturer has comprehensive knowledge about the product and process
• More extensive data are required to demonstrate a proposed recombinant product is biosimilar to an FDA-licensed reference product because the proposed product likely has a different manufacturing process (different host cell, raw materials, equipment, processes, controls, acceptance criteria) from the reference product
• Physicochemical assessment of the proposed biosimilar and reference product must consider primary, secondary, tertiary, and quaternary structure, post-translational modifications and functional activities
• If activity includes binding or immunochemical properties, analytical tests must be performed to characterize the product in terms of these specific properties
• Product- and process-related impurities must be characterized, identified and quantified
• Additional details are provided in: FDA Guidance, Quality Considerations in Demonstrating Biosimilarity to a Reference Protein Product, February 2012

Summary

• Improved yeast strains are currently under development for production of advanced biofuels and valuable coproducts using automated high-throughput molecular biology platforms to synthesize, clone, express, and screen heterologous optimized gene ORFs for transformation of selected host strains
• Novel directional cell-penetrating peptide tags and SUMO tags for enhanced expression and proper folding are being used to increase productivity of heterologous recombinant protein expression
• Automated construction of synthetic yeast artificial chromosomes (YACs) containing optimized ORFs in a polyprotein cassette for expression of multiple genes behind one promoter allows rapid evaluation of proteins produced
• Industrial host strains optimized for heterologous gene ORF expression and low-cost feedstock utilization will be transformed with these YACs
• Facility for automated chromosome assembly and host strain transformation under construction
• An integrated biorefinery setting is planned for scale-up of growth and production of recombinant proteins
• Characterization of biopharmaceutical proteins produced as coproducts will be performed to meet the requirements as biosimilars
LATEST TRENDS IN HIGH POTENCY SWEETENERS

Eric Shinsato
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Latest Trends in High Potency Sweeteners

Presented at University of Illinois

International Starch Technology Conference

Eric Shinsato
Sr. Project Leader

FEBRUARY 4, 2015

Agenda

• Benefits of low calorie sweeteners
• The consumer and the market for natural and artificial high potency sweeteners
• Stevia market trends
• What is stevia?
• Sweetness sensory, sweetener comparisons and formulation challenges
Expert panel establishes consensus statement

- Low calorie sweeteners (LCS) do not increase appetite and have no discernible effect on satiety
- LCS help to reduce energy intake when used in place of higher energy ingredients
- LCS can enhance weight loss when used as part of a behavioral weight loss program
- LCS help reduce post prandial glycemic response
- LCS have dental benefits when used in food, beverages, toothpaste and medications

1 International Sweeteners Association, Brussels, Belgium

Source: Foodbev.com December 3, 2014

LCS may form part of healthy, active lifestyle

- Consumers of LCS
  - tend to have better diets\(^2\) and exercise regimes
  - have “significantly higher” healthy eating scores
  - more physically active
  - less likely to smoke
  - less likely to consume solid fats, added sugars and alcohol

1 University of Washington
2 Healthy Eating Index (USDA)

Source: Foodbev.com January 14, 2015
The skinny on natural and artificial sweeteners

- Consumers understand the impact of too much sugar in their diet
- 21% seek no-calorie sweeteners for health issues (diabetes) and 29% no sugar added products¹
- Prefer “natural” due to concern over potential health problems when using artificial sweeteners
- Increasing market share for natural high potency sweeteners (stevia 17%)²

¹ Source: Mintel
² Source: Natural Marketing Institute
Why stevia?

- Consumers continue to demand naturally derived reduced sugar options
  - Sugar reduction is a concern of more than 70% of Americans*
- Stevia is the perfect solution for formulators who want to be on trend and meet market need for low sugar alternatives
- Can be used in combination with caloric natural sweeteners to help drive down calories and cost
- Low glycemic load makes it safe for diabetics
- Clean label related positioning accounts for almost one-fourth of all food and beverage product launches worldwide**

*Source: 2013 HealthFocus International Trend Report
**Innova Product Insights

Comparative market size of 2014 North America new product introductions with stevia

Note: Units are % of total launches excluding healthcare. “Other” includes RTD’s, bakery, sauces, hot beverages, alcoholic beverages, sugar and gum, and processed meat/fish

Source: Mintel GNPD
What is stevia?

• Stevia (*stevia rebaudiana*) is a small shrub, a member of the chrysanthemum family, originally found in Paraguay that has been used for centuries by native people to sweeten tea.

• Stevia leaves contain sweet compounds called steviol glycosides.

• Each variety of stevia plant contains a different ratio of steviol glycoside which impacts sweetness and taste profile.
What is Reb A?

- A specific steviol glycoside extracted from the leaves of the stevia rebaudiana bertoni plant and purified
  - One of the sweet components of the plant
- Reb A is a natural zero-calorie, high potency sweetener
- Approximately 250x sweeter than sucrose
- Very stable under most temperature and pH conditions
- Reb A is non-cariogenic

Rebaudioside A Extraction Process

1. Harvest and dry leaves
2. Steep in water
3. Refine and purify
4. Dry and package

Leaves are grown in Brazil with a fully transparent agricultural process. Drying occurs with minimal environmental impact due to close proximity to the manufacturing plant.

Leaves are steeped to release the natural sweetness of the plant, similar to the way in which tea leaves are steeped.

Using food grade alcohol and a minimalistic, high tech process the sweetest parts of the leaves are extracted and refined.

The product is dried at the end of the process and packaged using two layers of plastic to ensure that no water is allowed into the packaging.
Measure multiple solution concentrations vs. sugar to find the ideal level for your sweetness ingredients.

Rate sweetness potency in the mouth measure changes every 20 seconds. Isolate any flavor note to help you build the exact flavor profile you seek.
Sucrose at 8% matched with stevia at 600 ppm compared to aspartame and sucralose
Flavor and Texture adjustment

- Sucrose is a unique nutritive sweetener – it provides the sweetness quality, viscosity and flavor profile (plus “brown” flavors) familiar to consumers
- Every food category and formulation offers unique flavoring opportunities and challenges for a high-potency sweetener
- When necessary, adjustments are usually possible through combination of other ingredients such as sweeteners, texture agents, acidulants, salts, flavor enhancer/systems, etc.
- There is no “quick-fix” or “flavor kit” that works in your unique product, just as there is no “one flavor” that works across all applications

Some challenges cut across market segments

- Flavor Release
- Sweetness
- Concentration Response
- Masking/Enhancing
- Aftertaste/Linger

Challenges with Calorie & Sugar Reduction

- Ice Crystal Formation
- Freeze Point Depression
- Water Activity
- Batter Gravity
- Starch Gelatinization

Texture & Mouthfeel

- Viscosity
- Texture Characteristics
- Shape
- Weight
- Slip
- Osmolality

Processing

- Browning
- Pumping - Dosing
- Flowability of Blend
- Liquid v. Dry
Global Beverage - New Product Launches

<table>
<thead>
<tr>
<th>Company/ Product Name</th>
<th>Country</th>
<th>Photo</th>
<th>Date</th>
<th>Description/Claims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odwalla/ Smoothie Mo’ Beta</td>
<td>USA</td>
<td><img src="image" alt="Odwalla Smoothie Mo’ Beta" /></td>
<td>Oct 2014</td>
<td>Odwalla Smoothie Mo’ Beta Fruit Smoothie Blend contains 100% juice and is not from concentrate. Claims Include: Low/No/Red. Allergen, GMO-Free, Kosher, Vegan, Ethical – Env. Friendly Package, Gluten-Free</td>
</tr>
<tr>
<td>BOH Plantations/ Lemon Lime Flavored Instant Ice Tea Mix</td>
<td>Singapore</td>
<td><img src="image" alt="BOH Lemon-Lime Flavored Instant Ice Tea Mix" /></td>
<td>Oct 2014</td>
<td>BOH Lemon-Lime Flavored Instant Ice Tea Mix is said to refresh with its fruity tang of natural lemon extract, vitamin C and less sugar. Claims include: Halal, Time/Speed, Low/No/Reduced Sugar</td>
</tr>
<tr>
<td>Coca-Cola, Finley Fines Bulles Lemon and Elderberry Flower Drink</td>
<td>Belgium</td>
<td><img src="image" alt="Coca-Cola, Finley Fines Bulles Lemon and Elderberry Flower Drink" /></td>
<td>Oct 2014</td>
<td>Finley Fines Bulles Boisson au Citron et Fleur de Sureau (Lemon and Elderberry Flower Drink) contains citrus juices, and is low in calories. Claims include: No Additives/Preservatives, Low/No/Reduced Calorie</td>
</tr>
</tbody>
</table>

Beverages – Challenges and Solutions

- **RTD**
  - Balancing the expectations of low/no calorie with full taste experience
  - Natural bulking and mouthfeel enhancement (Erythritol, Native Starches, and/or hydrocolloids)
- **Powdered Beverages**
  - Pack weight and dispersion
  - Replacing the weight of sugar changes the serving size and dispersion of minor ingredients (Erythritol, Enliten TG, agglomeration)
- **Liquid Beverage Enhancers**
  - Solubility and stability of Rebaudioside A and flavor compromises
  - Controlling ion concentration, pH, and total solids in solution
- **Alcoholic Beverages**
  - Total Fermentable Carbohydrates, gas retention, mouthfeel
  - Flavor Masking and Regulatory Consideration
Conclusion

• Consumers are looking to reduce sugar
• Prefer natural sweeteners
• Stevia is widely accepted
• Understanding physical and sensory attributes are key to successful formulating
Thank You!

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ANDRITZ SEPARATION IN THE STARCH INDUSTRY

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ANDRITZ Separation in Starch Industry
9th International Starch Technology Conference

Contents

- Introduction

- Starch processing

- ANDRITZ Separation

- A-SE Key Equipment in Starch Industry
  - Decanter Centrifuges (dewatering)
  - Filter Press (dewatering)
  - Peeler Centrifuge (dewatering)
  - Drum Dryers (pre-gelatinized, drying)
  - Paddle Dryers (sterilization, dextrination)
The ANDRITZ-GROUP

Overview

Company

- ANDRITZ AG, Graz, Austria (Group headquarters)
- More than 220 production and service sites worldwide
- Employees: approx. 23,700 worldwide as of year-end 2013

Key financial figures 2013

- Order intake: 5,611 MEUR*
- Net income: 53 MEUR
- Sales: 5,711 MEUR
- Equity ratio (as of year-end 2013): approx. 17%  

Products and services

Plants and services for hydropower stations, the pulp and paper industry, the metalworking and steel industries, and the solid/liquid separation in the municipal and industrial sectors

Company Profile

A world market leader in most business areas

HYDRO
Electromechanical equipment for hydropower plants (turbines and generators); pumps (e.g. for water transport and irrigation); turbo-generators for thermal power stations

PULP & PAPER
Systems and equipment for production of pulp, paper, tissue, and board; energy boilers; production equipment for bio-fuel (2nd generation), nonwovens, and plastic films

METALS
Presses for metal-forming; systems for production and processing of stainless steel, carbon steel, and non-ferrous metal strip; industrial furnace plants

SEPARATION
Equipment for solid/liquid separation for municipalities and various industries; systems and equipment for production of animal feed and biomass pellets

* Average share of ANDRITZ GROUP’s total order intake

* MEUR = million euro
Starch Processing
Sources & Appearance

- Found in almost every green plant
- Leaves, seeds, tubers, roots and fruits of plants
- Reserve food supply
- Deposited as tiny white granules, varying in size from 1 to 100 micron

- Two types of molecules:
  - Amylopectine – branched structure
  - Amylose – linear polymer

- Major sources for industrial production:
  - Corn (maize)
  - Potato
  - Tapioca (manioc / cassava)
  - Wheat

Starch Processing
Properties – 1/3

Starch granule properties

<table>
<thead>
<tr>
<th>Starch</th>
<th>Type</th>
<th>Granule size diameter</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>range [micron]</td>
<td>number average [micron]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>weight average [micron]</td>
<td></td>
</tr>
<tr>
<td>Potato</td>
<td>tuber</td>
<td>5 – 100</td>
<td>28</td>
</tr>
<tr>
<td>Maize</td>
<td>cereal</td>
<td>2 – 30</td>
<td>10</td>
</tr>
<tr>
<td>Wheat</td>
<td>cereal</td>
<td>1 – 45</td>
<td>8</td>
</tr>
<tr>
<td>Tapioca</td>
<td>root</td>
<td>4 – 35</td>
<td>15</td>
</tr>
<tr>
<td>Waxy maize</td>
<td>cereal</td>
<td>3 – 15</td>
<td>10</td>
</tr>
</tbody>
</table>

Amylose & Amylopectine contents & Degree of Polymerisation (DP)

<table>
<thead>
<tr>
<th>Starch</th>
<th>Amylose Content[%]</th>
<th>Amylopectine Content[%]</th>
<th>Average DP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato</td>
<td>21</td>
<td>79</td>
<td>3000</td>
</tr>
<tr>
<td>Maize</td>
<td>28</td>
<td>72</td>
<td>3000</td>
</tr>
<tr>
<td>Wheat</td>
<td>28</td>
<td>72</td>
<td>3000</td>
</tr>
<tr>
<td>Tapioca</td>
<td>17</td>
<td>83</td>
<td>3000</td>
</tr>
<tr>
<td>Waxy maize</td>
<td>0</td>
<td>100</td>
<td>–</td>
</tr>
</tbody>
</table>
Typical composition of raw materials (in % by weight)

<table>
<thead>
<tr>
<th>Source</th>
<th>Starch</th>
<th>Moisture</th>
<th>Protein as N × 6.25</th>
<th>Lipids</th>
<th>Fibre</th>
<th>Starch on dry substance</th>
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<tbody>
<tr>
<td>Potato</td>
<td>17</td>
<td>78</td>
<td>2</td>
<td>0.1</td>
<td>1</td>
<td>77</td>
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<tr>
<td>Maize</td>
<td>60</td>
<td>16</td>
<td>9</td>
<td>4</td>
<td>2</td>
<td>71</td>
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<tr>
<td>Wheat</td>
<td>64</td>
<td>14</td>
<td>13</td>
<td>2</td>
<td>3</td>
<td>74</td>
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<tr>
<td>Tapioca</td>
<td>26</td>
<td>66</td>
<td>1</td>
<td>0.3</td>
<td>1</td>
<td>77</td>
</tr>
<tr>
<td>Waxy maize</td>
<td>57</td>
<td>20</td>
<td>11</td>
<td>5</td>
<td>2</td>
<td>71</td>
</tr>
</tbody>
</table>

Gelatinisation characteristics of native starches

<table>
<thead>
<tr>
<th>Starch</th>
<th>Pasting temperature [°C]</th>
<th>Peak viscosity range [BU]</th>
<th>Peak viscosity average [BU]</th>
<th>Swelling power at 95 °C *** [%]</th>
<th>Solubility at 95 °C [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato</td>
<td>60 – 65</td>
<td>1000 – 5000</td>
<td>3000</td>
<td>1153</td>
<td>82</td>
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<tr>
<td>Maize</td>
<td>75 – 80</td>
<td>300 – 1000</td>
<td>600</td>
<td>24</td>
<td>25</td>
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<tr>
<td>Wheat</td>
<td>80 – 85</td>
<td>200 – 500</td>
<td>300</td>
<td>21</td>
<td>41</td>
</tr>
<tr>
<td>Tapioca</td>
<td>60 – 65</td>
<td>500 – 1500</td>
<td>1000</td>
<td>71</td>
<td>48</td>
</tr>
<tr>
<td>Waxy maize</td>
<td>65 - 70</td>
<td>600 – 1000</td>
<td>800</td>
<td>64</td>
<td>23</td>
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</tbody>
</table>

Source: AVEBE Product Information; Ref.no. 05.00.03.006 EF; J.J.M. Swinkels

Brabender viscosity curves of native starches

Source: AVEBE Product Information; Ref.no. 05.00.03.006 EF; J.J.M. Swinkels
Starch Processing
Starch Modification

Why modifying starch?
- Ability to produce viscous paste is main functional property
- Native starch as extracted from plant is not optimal product for particular applications or processes

Rudimentary division:
- Physically (heat treatment, pressure, mechanical action)
- Chemically (bleaching, derivation)
- Bio-chemically (enzymatic)

Starch Processing
Extraction from Source & Modification

- Extraction from source (corn, potato, tapioca, rice, etc.) requires specific process and equipment
- Other components from source (proteins, fat, fibers, ash) need to be separated from starch
- Starch modification is done both on wet / rewetted starch slurries and dried native starch powder
- All processes (for extraction and for modification) require dewatering or drying to some extent
- ANDRITZ Separation has various solutions for these sub-processes
ANDRITZ SEPARATION
Overview of offering

With more than 150 years’ experience in the separation business, we are one of the world’s largest suppliers of mechanical and thermal solid / liquid separation technologies.

Have a look at our wide range of technologies and services, which can be applied in various process steps, applications and industries.

Main process steps:
- Screening
- Sedimentation
- Filtration
- Separation
- Concentration
- Washing
- Thickening
- Drying
- …

The right ingredients for your success - whether you are an international group or a family company, our mission is the same: to provide reliable, sanitary, and efficient solutions that improve the quality of your end products.

The right ingredients for your success
In a wealth of applications

- Within the food industry chances are high that we have both the technology and process knowledge to help you create the product your customers demand
- It is a 360 degree approach that provides you with all the right ingredients for your success in the food industry
ANDRITZ SEPARATION
Global presence

- Offices in 24 countries serving your local requirements

ANDRITZ SEPARATION
Test centers

- Availability of well equipped test centers to support your research and development activities
- USA: Florence, KY and Arlington, TX
- Process support before, during and post contract
- State-of-the-art analytical equipment to determine physical properties of customer products
- Simulation and / or pilot equipment available for equipment sizing and performance guarantees, also at customer site (rental)
- Detailed reporting
- Extensive knowledge / database
ANDRITZ Separation

Key equipment in starch industry

- Decanter Centrifuges (dewatering)
- Filter Press (dewatering)
- Peeler Centrifuge (dewatering)
- Drum Dryers (pre-gelatinized, drying)
- Paddle Dryers (sterilization, dextrination)
Decanter Centrifuge
Decanter centrifuge for starch recovery

Design suitable for pea starch / fiber / protein
Design properties:
- Sanitary 2 phases design with high g force
- Easy to clean with integrated software
- Operator friendly with skimmer / pipette and scroll control for variable pond operation
- Tailor made scroll design
Decanter Centrifuge
Starch recovery in potato chips factory

- Feed from potato slicer or wash
- Starch used for animal feed
- Capacity range from 5 m³/h to 40 m³/h

Decanter Centrifuge
Potato starch processing

- Starch recovery and Red Water separation
- Cellulose pulp separation
- Protein separation
- Waste Water Treatment in starch plants
ANDRITZ Filter Press
Starch Application

Dewatering with Andritz Filter Presses
Filter Press General Arrangement
Dewatering with Andritz Filter Presses
Typical Process Applications for Filter Presses

- Food
- Chemicals & Pigments
- Mining & Minerals
- Waste Water
- Water Treatment
- Municipal sludge treatment

Dewatering with Andritz Filter Presses
Dewatering of Starch Slurry using Andritz Filter Press

Starch Slurry

Clear Filtrate to the waste Treatment

LESS Energy

Starch Dryer

Starch End Product
Andritz Filter Presses
Side Bar Filter Press SE

Dewatering with Andritz Filter Presses
Filtration Principle: Membrane and Washing Process
Dewatering with Andritz Filter Presses

Process Sequence – Membrane Press

- Filter press full of slurry
- Membranes at support body
- Start of cake formation
- Partial cake formation
- Membranes at support body
- Filtration resistance increases
- Feeding switched off
- Membranes compress the cake
- Effective subsequent dewatering
- Core blown out
- Membranes without load
- Cake discharge

Dewatering with Andritz Filter Presses

Simplified layout
ANDRITZ Krauss-Maffei Horizontal Peeler Centrifuge
Highly efficient starch dewatering

Krauss-Maffei Peeler Centrifuges HZ
Technology & Process

- **Batch operated** filtration centrifuge with siphon basket

- **Processing parameters (based on corn starch):**
  - Feed solids concentration: 20 – 22 Bé
  - Protein content in slurry: ~ 0.4 % wt
  - Solids throughput for 1 machine: up to 15 t/h (commercial dry, 12 % moisture)
  - Residual moisture after centrifuge: down to 33 %
  - Protein content after centrifuge: ~ 0.2 %

- **Design Parameters**
  - Available basket diameter: 1000 mm – 2000 mm
    - **Biggest peeler centrifuge in the world!**
  - Filter area: 2.0 m² – 9.0 m²
  - Siphon basket volume: 165 L – 1900 L
Krauss-Maffei Peeler Centrifuges HZ
Standard operation steps

Slurry with 20 – 22 °Be → Feeding 1 → Main filtration → Main filtrate

Slurry with 20 – 22 °Be → Feeding 2 → Overflow → Main filtrate + Protein

Liquid skimming → Liquid with protein

Dewatering → Filtrate

Solids discharge → Solids with up to 66 % DS

Backwashing liquid → Backwashing

Animation of Krauss-Maffei Peeler Centrifuge HZ
Krauss-Maffei Peeler Centrifuges HZ

**General arrangement**

- Main drive with V-belts
- Terminal boxes
- Concrete or steel foundation block (by customer)
- Lubrication and hydraulic unit
- Visco dampers
- Door skimming pipe
- 2nd feed pipe

**Starch features**

- **2nd feed pipe** to create overflow
  - => higher capacities
  - => reduction of protein
- **Door skimming pipe**
  - => higher filtration rates
  - => reduction of protein
- **Automatic cleaning procedure**
  - => every 8 h – 10 h
  - => no opening of the centrifuge needed
Krauss-Maffei Peeler Centrifuges HZ
Capacities native corn starch

Throughput Starch
commercial dry (moisture 12 % w/w)

Krauss-Maffei Peeler Centrifuges HZ
Reference list for starch

**References**
- Peeler Centrifuge HZ 322
- Vacuum Drum Filter 7
- Vertical Centrifuge VZ 3

**Starch (since 1949) 332**
- Maize (Corn) 228
- Wheat 44
- Tapioca / Manioc 36
- Potato 14
- Rice 7
- Others 3
Drum drying of starch is physically modifying native starch into pre-gelatinized starch by fast evaporation of water to obtain desired properties of the starch (instant solubility) for further processing.

- Drum dryer is only dryer that can handle viscous, pasty and/or sticky products.
- Starch is heavy duty application due to high viscosity and stickiness.
- High stresses on machine.
ANDRITZ Gouda Drum Dryer
Applications for drum dried starches

- Water binder
- Thickener
- Texture agent
- Stabilizer
- Filler
- Dry strength increase of paper
- Adhesives in paper bag industry
- “Do-it-yourself” wallpaper adhesive
- Protective coating on yarn, which increases tensile strength and improves abrasion resistance during weaving, in textile industry

ANDRITZ Gouda Drum Dryer
Starch drum dryer pictures
ANDRITZ Gouda Drum Dryer
Starch drum dryer features

Starch is heavy duty application:
- Cast iron drum (no chromium plating)
- Sturdy cast iron frame, painted with special paint containing SS particles
- Stainless steel applicator rolls
- Knife holder:
  - Stainless steel cladded for hygiene
  - Cast iron core for rigidity and vibration-free performance
- Product discharge with pre-breaker (strong product film)
- Heavy duty drive(s) due high shear (forces) between main drum and applicator rolls
ANDRITZ Gouda Drum Dryer

References

- More than 300 Gouda drum dryers delivered worldwide 
  (excl. other brands owned by ANDRITZ Gouda: Duprat, Escher-Wyss and Dietzel)
- Own pilot plant for testing to obtain optimal processing conditions for any starch, 
  pre-modified or native
ANDRITZ Gouda Paddle Reactor
Starch dextrination and sterilization

- Heating of dried native starch with acids or enzymes
- Chemical change to starch is not yet fully understood
- Probably 3 major reactions involved:
  - hydrolysis (breakdown of starch molecule)
  - transglucosidation (recombination, resulting in more branched structures)
  - repolymerization (into larger molecules)
- Types of dextrin's:
  - White: lower temperature (80 – 110 °C = 176 – 230 °F), short reaction time
  - Yellow: higher temperatures (150 – 170 °C = 302 – 338 °F), longer reaction times)
  - (British gum)

ANDRITZ Gouda Paddle Reactor
Applications for dextrins

- Glue
- Paper production
- Binder for pigments
- Coating in textile
- Adhesive
- ........
ANDRITZ Gouda Paddle Reactor

Paddle reactor features

- Heated trough + 2 heated shafts with heated paddles
- Closed process chamber (no air)
- Heating with steam or thermal oil
- Overflow weir to keep full machine
- No back mixing
- Compact design & plant layout
- Uniform product treatment
- Perfect hygienization guaranteed
- Energy efficient, no heat loss
- Low mechanical speeds – low wear
- Continuous dryer

ANDRITZ Gouda Paddle Reactor

Starch paddle reactor features

Animation of ANDRITZ Gouda paddle reactor
ANDRITZ Gouda Paddle Reactor

References

- In total 16 units for sterilization of flours and starch and dextrination of starch
- Nearly 300 machines for all kinds of applications:
  - Drying of waste water sludge
  - Drying of minerals and ores
  - Drying and cooling of SAP (superabsorbent for diapers)
  - Crystallization and heating of PET
  - Drying of gypsum
  - Etc.

ANDRITZ Separation

We look forward to working with you!

ANDRITZ Separation
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