Incorporation of sweet sorghum Juice in the current dry-grind ethanol process for improved ethanol yields, energy saving, and water efficiency

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William Rooney
Donghai Wang
Introduction
Ethanol production in the US

Production, availability, and use of fuel ethanol is expected to increase.

Varieties of Ethanol blended fuel exists in the US
Varieties of Ethanol blended fuel exists in the US
<table>
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<tr>
<th>State</th>
<th>Nameplate</th>
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<th>Total</th>
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<td><strong>13,966</strong></td>
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<td><strong>15,047</strong></td>
<td><strong>210</strong></td>
<td><strong>192</strong></td>
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</table>

Source: Renewable Fuels Association, January 2014

Source: U.S. Department of Energy/Energy Information Administration and RFA

*Estimated*
Sweet Sorghum
• Stem juice is rich in fermentable sugar - 53-85% sucrose, 9-33% glucose, and 6-21% fructose).
• Short period of growth period (140 days)
• Draught resistant.
• Higher biomass yield (45-80 t/ha).
• Environmentally friendly;
  – Requires less fertilizer, water usage for cultivation.
Objective
To develop a new technology for the current ethanol industry using sweet sorghum juice for ethanol production -
- to improve ethanol yield;
- safe water;
- energy conservation.
Conventional Dry – Grind Ethanol Production Process from Grain Sorghum

**Thermo-Stable Alpha Amylase**

**Glucoamylase**

**Yeast**

**Alcohol Recovery**

**Liquefaction**

**Saccharification**

**Fermentation**

**Distillation & Dehydration**

**Water**

**JET COOKER**

*100°C*

*5-8 MIN*

**SECONDARY LIQUEFACTION**

*95°C*

*90 MIN*

**$E_{\text{Cooking}} = 10-20\% \ E_{\text{Ethanol production}}$**

*pH adjustment steps are not shown*
Methodology
Three phases

1. Varying sorghum grain flour loading
Three phases

1. Varying sorghum grain flour loading

2. Varying enzymatic hydrolyzing time
Three phases

1. Varying sorghum grain flour loading

2. Varying enzymatic hydrolyzing time

3. Raw starch hydrolysis (by GSHE) (An energy conserving alternative process)
Ethanol Fermentation of sweet sorghum with varying sorghum grain flour loading

Grain Sorghum flour: 0 g, 6 g, 9 g, 12 g, 15 g
Ethanol Fermentation of sweet sorghum with varying sorghum grain flour loading

- Grain Sorghum flour
  - 0 g, 6 g, 9 g, 12 g, 15 g

- Sweet Sorghum juice (100 mL) → Slurring
Ethanol Fermentation of sweet sorghum with varying sorghum grain flour loading

Grain Sorghum flour

0 g, 6 g, 9 g, 12 g, 15 g

Sweet Sorghum juice (100 mL)

α-Amylase (Liquozyme)

Slurring

Liquefaction

@ 86 °C, 60 min, 180 rpm
Ethanol Fermentation of sweet sorghum with varying sorghum grain flour loading

- **Grain Sorghum flour**
  - 0 g, 6 g, 9 g, 12 g, 15 g

- **Sweet Sorghum juice (100 mL)**

- **α-Amylase (Liquozyme)**

- **Glucoamylase (Spirizyme) + *Saccharomyces cerevisiae* (Yeast)**

- **Slurring**
  - @ 86°C, 60 min, 180 rpm

- **Liquefaction**
  - @ 30°C, 72 hours, 150 rpm

- **Simultaneous Saccharification & Fermentation**
Ethanol Fermentation of sweet sorghum with varying sorghum grain flour loading

- **Grain Sorghum flour**
  - 0 g, 6 g, 9 g, 12 g, 15 g

- **Slurring**

- **Sweet Sorghum juice (100 mL)**
  - α-Amylase (Liquozyme)

- **Liquefaction**
  - @ 86°C, 60 min, 180 rpm

- **Simultaneous Saccharification & Fermentation**
  - Glucoamylase (Spirizyme) + *Saccharomyces cerevisiae* (Yeast)
  - @ 30°C, 72 hours, 150 rpm

- **Drying**
  - DDGS

- **Distillation**
  - Ethanol
Ethanol Fermentation of sweet sorghum with varying sorghum grain flour loading

Grain Sorghum flour

0 g, 6 g, 9 g, 12 g, 15 g

Sweet Sorghum juice (100 mL)

α-Amylase (Liquozyme)

Glucoamylase (Spirizyme) + *Saccharomyces cerevisiae* (Yeast)

Slurring

@ 86°C, 60 min, 180 rpm

Liquefaction

@ 30°C, 72 hours, 150 rpm

Simultaneous Saccharification & Fermentation

Drying

DDGS

Distillation

Ethanol
Results
<table>
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<tr>
<th></th>
<th>Juice sugar content (%)</th>
<th>Flour starch content (%)</th>
<th>Theoretical ethanol yield (V/V)</th>
<th>Actual Ethanol yield (V/V)</th>
<th>Ethanol fermentation efficiency (%)</th>
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</thead>
<tbody>
<tr>
<td>Juice only</td>
<td>18.89</td>
<td>0</td>
<td>12.12</td>
<td>11.29&lt;sup&gt;a&lt;/sup&gt;</td>
<td>93.15&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Juice + 6 g flour</td>
<td>18.89</td>
<td>71.57</td>
<td>15.21</td>
<td>14.36&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Juice + 9 g flour</td>
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<td>71.57</td>
<td>16.75</td>
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<td>71.57</td>
<td>18.29</td>
<td>16.81&lt;sup&gt;d&lt;/sup&gt;</td>
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<td>Juice + 15 g flour</td>
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<td>71.57</td>
<td>19.95</td>
<td>18.05&lt;sup&gt;e&lt;/sup&gt;</td>
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<tr>
<td>Control- 30 g flour (db)</td>
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<td>14.05&lt;sup&gt;b&lt;/sup&gt;</td>
<td>90.75&lt;sup&gt;d&lt;/sup&gt;</td>
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</table>

Means in the same column followed by different superscript letters indicate significant differences (P ≤ 0.05).
Ethanol Fermentation of sweet sorghum with varying hydrolyzing time

1. Grain Sorghum flour
2. Slurring
3. Liquefaction
   - α-Amylase (Liquozyme)
   - Sweet Sorghum juice (100 mL)
4. Simultaneous Saccharification & Fermentation
   - Glucoamylase (Spirizyme) + Saccharomyces cerevisiae (Yeast)
   - @ 86 °C, 30-45-60-90 min, 180 rpm
   - @ 30 °C, 72 hours, 150 rpm
5. Drying
6. Distillation
   - DDGS
   - Ethanol
   - 4 Samples (15 g)
### Ethanol Yield (v/v) vs. Fermentation Time (hrs)

![Graph showing the relationship between Ethanol Yield (v/v) and Fermentation Time (hrs)](image)

<table>
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<tr>
<th>Hydrolysis time (min)</th>
<th>Juice sugar content (%)</th>
<th>Flour starch content (%)</th>
<th>Theoretical ethanol yield (V/V)</th>
<th>Actual Ethanol yield (V/V)</th>
<th>Ethanol fermentation efficiency (%)</th>
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<td>18.05&lt;sup&gt;a&lt;/sup&gt;</td>
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Means in the same column followed by different superscript letters indicate significant differences (P ≤ 0.05).
Low temperature hydrolysis
Low Energy Ethanol Production Process

Granular Hydrolyzing Starch Enzyme

* pH adjustment steps are not shown
Ethanol Fermentation by Granular Starch Hydrolyzing Enzyme (No Cooking)

- **Grain Sorghum flour**
  - 0 g, 6 g, 9 g, 12 g, 15 g
- **Slurring**
- **Liquefaction**
  - @ 48 °C, 2 hours, 180 rpm
- **Simultaneous Saccharification & Fermentation**
  - @30 °C, 72 hours, 150 rpm
- **Saccharomyces cerevisiae** (Yeast)
- **Sweet Sorghum juice** (100 mL)
- **GHSE (Stargen 002)**

- **Drying**
  - DDGS
- **Distillation**
  - Ethanol
<table>
<thead>
<tr>
<th></th>
<th>Juice sugar content (%)</th>
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Means in the same column followed by different superscript letters indicate significant differences (P ≤ 0.05).
Conclusion
• Ethanol yield: **28%** higher than conventional ethanol method.

• Enzymatic hydrolysis time reduced by **30 minutes**.

• **Strong potential** for ethanol production from by granular starch hydrolyzing enzyme.
Acknowledgment

This material is based upon work supported by National Science Foundation Grant: From Crops to Commuting: Integrating the Social, Technological, and Agricultural Aspects of Renewable and Sustainable Biorefining (I-STAR); NSF Award No.: DGE-0903701.
Thank You!