Assessment of new approaches of on-farm, in-bin chilling aeration and drying management of rice

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Natural Air, In-Bin Drying

- Temperature/Relative humidity cable
- Headspace temperature/relative humidity sensor
- Insector
- Moist air
- Weather station
- Pressure/temperature sensor
- Green Rice (Wet)
- Drying Zone
- Dry Rice
- 18% 
- 19°C
- 16%
- 22°C
- 13%
- 24°C
- Transition duct
- Fan
- Exhaust vent
- Temperature cable
In-Bin Drying Challenges

- Discoloration
- Mold growth
- Uneven drying
- Fissuring
- Over drying
- Energy cost
A Design Criteria to address the Challenges of Grain Bin Drying

• Maintain the quality of the ambient air dried grains
• Increase the drying rate
• Realized an energy savings

Integrate grain chiller, grain cleaner and unique design of mass flow dryer
Flow diagram

- **Harvest** → **Stepwise Chilling aeration**
  - 30°C – 15°C
  - 3 – 5 days
- **Stepwise Chilling aeration** → **Holding**
  - no drying air flowing through the bin
- **Holding** → **Ambient aeration**
- **Cleaning** → **Mass flow dryer**
  - Avoid condensation
Grain chilling system

- Cold dehydrated air
- Heat register
- Hydrotherm unit
- Air cooler
- Water separator
- High pressure fan
- Dust filter
- Outside air
- Exhaust

Air distribution
Rotary Grain Cleaner
Mass flow dryer

US Patent # 14/289,088
Objectives

Evaluate the effect of the new on-farm chilling, cleaning, and drying management on:

- Quality characteristics
- Energy use/efficiency
- Overall drying cost
Samples

Gently dried in controlled chamber (26°C & 56% RH)

Quality Test:

- Mold count
- Head Rice Yield
- Discoloration

Initial samples with MC 14-24% from the field

1st sample

Chilling aeration from 22°C to 15°C

2nd sample

Holding & Ambient aeration

3rd sample

Cleaning

4th sample

Mass flow dryer

5th sample

Storage or sell
Enumeration

Milling

WinSeedle
In terms of energy use introduce “Water-Uptake Efficiency”
Temperature and relative humidity sensor locations
Air temperature, °C

Humidity ratio (H), kg/kg

T is theoretical
(maximum possible relative humidity)

Exhaust (E)
$T_E$, $RHE$

Plenum (P)
$TP$, $RHP$

Air temperature, °C

Humidity ratio (H), kg/kg
P is plenum
E is exhaust
T is theoretical

Humidity ratio (H), kg water/kg dry air

Water-uptake efficiency

\[ \eta_{wu} = \frac{\Delta H}{\Delta H_T} \]

\[ \Delta H = H_E - H_P \]

\[ \Delta H_T = H_T - H_P \]
CA = Chilling Aeration effect

CAA = Chilling & Ambient Aeration effect

CAAC = Chilling & Ambient Aeration with Cleaning effect

CAACR = Chilling & Ambient Aeration with Cleaning & Rapid air drying effect

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CA = Chilling Aeration effect

CAACR = Chilling & Ambient Aeration with Cleaning & Rapid air drying effect
Discoloration (%)

Control: 4.5
CA: 5.1
CAACR: 3.8

CA = Chilling Aeration effect
CAACR = Chilling & Ambient Aeration with Cleaning & Rapid air drying effect
Water-uptake efficiency during Chilling

- Big temperature gradient
- Differences in vapor pressure of the moisture surrounding the kernels

Evaporation of unbounded moisture
Moisture condensation

$R^2 = 49$
Water-uptake efficiency during Mass flow dryer

\[ \eta_{wu} \]

\[ R^2 = 63 \]
Energy efficiency

Minimum possible energy required to dry rice from a given $\text{MC}_i$ to $\text{MC}_f$

$$\eta = \frac{E_{\text{theoretical}}}{E_{\text{electrical}}} \times 100$$

Total energy supplied to the dryer to dry rice from a given $\text{MC}_i$ to $\text{MC}_f$
Theoretical energy

Energy = (MC\text{\textsubscript{i}} - MC\text{\textsubscript{f}}) (3,189,745 - 2,496 \cdot T) + (e^{-24.2MC\text{\textsubscript{i}}} - e^{-24.2MC\text{\textsubscript{f}}})

**Electric motor**

\[ kW = \frac{\sqrt{3} \cdot I \cdot V \cdot P_f}{1000} \]

\[ P_f = \frac{\text{True power}}{\text{Apparent power}} \]

\[ Z = \sqrt{(\text{Resistance})^2 + (\text{Reactant})^2} \]

\[ \Rightarrow \text{Apparent power (S)} = \frac{V^2}{Z} \]

\[ \Rightarrow \text{True power (P)} = I^2 \cdot R \]
**Electrical energy**

\[ kW = \frac{\sqrt{3} \times I \times V \times P_f}{1000} \]

Total cost energy = kW * fan hours * cost per kWh

Energy cost/bu = \(\frac{\text{Total cost energy}}{\text{Gross bushel}}\)
# 28 September – 22 October 2018

<table>
<thead>
<tr>
<th>Test</th>
<th>amp</th>
<th>volt</th>
<th>kW</th>
<th>kWh</th>
<th>Total cost</th>
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<tbody>
<tr>
<td>Chilling - Ambient</td>
<td>72</td>
<td>460</td>
<td>45.9</td>
<td>15,328</td>
<td>1,226.2</td>
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<tr>
<td>Cleaning</td>
<td>129</td>
<td>460</td>
<td>82.2</td>
<td>1,482.6</td>
<td>118.6</td>
</tr>
<tr>
<td>Mass flow dryer</td>
<td>48</td>
<td>460</td>
<td>30.6</td>
<td>14,930.3</td>
<td>1,194.4</td>
</tr>
</tbody>
</table>

Total cost = 2,539.2 $  
Gross bushels = 30,992.4

Energy cost/bu = 0.08 $/bu
### Compare to other drying strategy

<table>
<thead>
<tr>
<th>Drying strategy</th>
<th>Airflow (cfm/bu)</th>
<th>Drying cost (¢/bu)</th>
<th>Drying duration (days)</th>
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</thead>
<tbody>
<tr>
<td>Uncontrolled</td>
<td>0.5</td>
<td>12.9</td>
<td>119</td>
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<tr>
<td></td>
<td>1</td>
<td>18.9</td>
<td>41</td>
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<tr>
<td>EMC-controlled</td>
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<td>7.8</td>
<td>92</td>
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<tr>
<td></td>
<td>1</td>
<td>11.2</td>
<td>37</td>
</tr>
</tbody>
</table>

Location = Monticello, AR  
Harvest date = September  
CAACR  
8  ¢/bu  
24 days

Conclusion

• The percentage point MC reduction due to chilling and cleaning were 3.77% and 1.51% respectively, which indicates that inclusion of these steps could benefit overall drying requirement of the mass flow drying

• CAACR has effect on quality specially color characteristics

• Energy and cost savings could be achieved by integrating chiller, cleaner, and mass flow dryer

• Having a field study with control bin is recommended for future studies
Acknowledgments

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