## 4. Conclusion

The study dealt with the development of a low cost bamboo reinforced concrete silo for farm level storage of rough rice. The structural safety of the developed structure was analyzed using the finite element method and the results were compared with Janssen's theory and design codes. The numerical method has been adjudged as one of the most reliable and versatile tools for development of innovative structures of various scales. The selection of input parameters for the FE model is a critical process affecting the prediction of the method. Dynamic pressures developed during filling of grains have been quantified in this study.

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# Increase of Paddy Moisture with Automatic Aeration in a Warehouse Guided by Adsorption Equilibrium Absolute Humidity Equation

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## Abstract

An automatic bulk monitoring and aeration controller was programmed with an adsorption equilibrium absolute humidity (CAE)equation and was used to aerate paddy with the aim to increase moisture content (MC) and preventing fissuring. The ventilation control window for rewetting paddy was developed according to two conditions: (i) the average grain bulk temperature ($t_g$) is higher than the dewpoint temperature ($DPT_a$) of the atmosphere; and (ii) the equilibrium absolute humidity ($EAH_g$) of grain moisture content plus 1 percentage point is lower than the absolute humidity ($AH_a$) of the atmosphere. The ventilators were turned on when the atmosphere state point was within the ventilation windowand turned off outside that window. In a humid subtropical monsoon climate, during Oct. 8th to Nov. 1st, 2013, the system was used for a paddy depot of 1035 t in Dianjiang, Chongqing province. The natural humid air was introduced into the paddy bulk by negative pressure suction aeration during the 10-12 h night time period and allowed to equilibrate with grain kernels during the 12-14 h day time period. Aeration increased grain MC by 0.6 percentage points with two 1.5 kW axial flow ventilators and power consumption of 209 kW·h. The unit energy consumption was 0.336 KW·h (1% moisture·t)$^{-1}$. The broken milled rice percentage was decreased by 2-3 percentage points. In the warm temperate semi-humid monsoon climate, during April 13th to June 16th, 2017, the system was used to rewet japonic paddy in a 2489 t depot in Qihe, Shandong province. The conditions for running two 0.85 kW axial flow fans were: (i) when the atmosphere relative humidity ($RH_a$) is ≤80% and its temperature ($t_a$) is <28°C, $t_g$>$DPT_a$, and $EAH_g$<$AH_a$; and (ii) when $RH_a$ >80% and $t_a$ <28°C. Whenever $t_a$ was >28°C, the two fans were switched off. This rewetting aeration increased grain MC from 13.5% to 14.0%, and the unit energy consumption was 0.455 kW·h (1% moisture·t)$^{-1}$. The percentages of average head rice yield and damaged grains after aeration were 71.7% and 7.7%, respectively.

**Keywords**: Paddy, EMC, moisture adsorption, increasing moisture, automatic aeration.

## 1. Introduction

Rice is the staple food for approximately 65% of the Chinese population. China is the world's largest rice producer with annual production over 144 million metric tons (FAO, 2014), and due to its large population, about 40% of its production is assigned to store for two years in the form of paddy with deterioration controlled largely through moisture content (MC) and temperature. For improving physical control in paddy storage, sound knowledge of the relationship between equilibrium moisture content (EMC) and equilibrium relative humidity (ERH) is essential (Jayas & Mazza, 1991; Sun, 1999; Li et al 2010; Li & Jiang, 2014). After two-year storage, paddy in China usually has moisture losses over 1.5-2.0% wet basis (w.b.). In order to increase the head rice yield and milled rice quality, rewetting up to 14% w.b. 1-3 months before retrieving from storage is needed. The present study investigated increasing paddy moisture with automatic mechanical aeration in a flat warehouse based on an adsorption equilibrium absolute humidity equation (CAE) with the aim to determine suitable aeration rewetting conditions.

## 2. Materials and Methods

### 2.1. Using the CAE equation in a computer controlled grain aeration system

In a computer controlled grain aeration system (Wu, 1987; Wu and Li, 1994), the parameters known as the CAE model for paddy adsorption (Li et al., 2014) was used to make curve graphs for determining the equilibrium relative humidity ($ERH_g$) of paddy kernels with particular MC at certain temperature. The following equation (1) was used to make the curve graphs for determining the equilibrium absolute humidity ($EAH_g$) of paddy kernels with particular MC at certain grain temperature and dewpoint temperature ($DPT_g$) of grain at this absolute humidity:

$$\mathrm{EAH_g} = \exp\left\{\frac{\left[\frac{D}{222}\left(\exp\left(\frac{B_1-MC}{A_1}\right)-\exp\left(\frac{B_2-MC}{A_2}\right)\right)+0.9845\right]\cdot\left(1737.1-\frac{474242}{273+t_g}\right)+D\left[1-\exp\left(\frac{B_1-MC}{A_1}\right)\right]-68.57}{87.72}\right\} \quad (1)$$

where $EAH_g$ is grain bulk equilibrium absolute humidity (mm Hg), MC is grain moisture content (% w.b.), $t_g$ is grain temperature (°C). $A_1$, $A_2$, $B_1$, $B_2$, D are five parameters of the CAE equation.

The dewpoint temperature ($DPT_g$in °C) of the grain bulk was calculated by equation (2):

$$\mathrm{DPT_g} = \frac{474242}{1872.7-89.1\lg(\mathrm{EAH_g})} - 273 \quad (2)$$

The atmosphere absolute humidity ($AH_a$) and dewpoint temperature ($DPT_a$) were respectively calculated with equations (3) and (4):

$$\mathrm{AH_a} = 100\exp\left\{\frac{87.72\lg(\mathrm{RH_a})+0.9845\left(1737.1-\frac{474242}{273+t_a}\right)-270.57}{87.72}\right\} \quad (3)$$

$$\mathrm{DPT_a} = \frac{474242}{\frac{474242}{273+t_a} - 89.1\lg(\mathrm{RH_a}) + 410.34} - 273 \quad (4)$$

where $AH_a$ is atmosphere absolute humidity (mm Hg), $RH_a$ is atmosphere relative humidity (%), and $t_a$ is atmosphere temperature (˚C), $DPT_a$ is atmosphere dewpoint temperature (˚C).
The relative humidity or absolute humidity in equations (1) - (4) was calculated on the basis of sea level atmospheric pressure. The values of $DPT_g$ and $DPT_a$ were used in characterizing whether dew condensation would occur with a decrease in temperature.

## 2.2. Aeration window controlling ventilator operation

The ventilation window for increasing grain moisture was constructed according to two conditions of aeration control: (i) the grain bulk temperature ($t_g$) is higher than the dewpoint temperature ($DPT_a$) of the atmosphere; and (ii) a condition in the Grain Industry Standard LS/T 1202-2002 of the PRC was modified as follows: the equilibrium absolute humidity ($EAH_g$) of grain moisture plus 1 percentage point is lower than the absolute humidity ($AH_a$) of the atmosphere, and not the grain moisture content plus 2.5 percentage points. Whenever both conditions were true then the axial flow ventilators were switched on. Fig. 1 shows the aeration rewetting window. If the grain state (13.5% MC) has an adsorption equilibrium absolute humidity of 10 mmHg and grain temperature of 15.8˚C, and the atmosphere has an equilibrium absolute humidity of 12 mmHg and dewpoint of 14˚C, airflow with lower temperature and higher humidity could increase the moisture of the paddy bulk, and thus the axial flow ventilators would be switched on.

The aeration controlling system included the hardware such as ventilator-controlling module, digital humidity transmitter, new type temperature measuring cable, and protective filter cover for humidity sensors. This system automatically detected grain bulk temperature and the air temperature and relative humidity of the headspace in the warehouse every 15 min, and the atmosphere temperature and relative humidity outside of the warehouse every 5 min. An aeration window was constructed by the curves of paddy adsorptive equilibrium absolute humidity and the saturation absolute humidity. When the atmosphere state point lied within the aeration window, the axial-flow ventilators were turned on to increase paddy MC. When the atmosphere state point was outside the aeration window, the axial-flow ventilators were turned off.

## 2.3. Two in-situ experiments for remoisturizing aeration in flat warehouses

### 2.3.1. The remoisturizing aeration in a warehouse in Dianjiang, Chongqing

The first experiment was carried out at the Dianjiang State Grain Reserve Depot, Dianjiang, Chongqing, China. Dianjiang lies in a basin (30°N, 107°E, 450 meters of average altitude) with a subtropical humid monsoon climate. The experimental No. 12 warehouse made of steel frame, concrete wall and tile roof, is 31.4 m in length and 14.12 m in width. It has six ground cage-channels equipped with two axial-flow ventilators, each ventilator responsible for three channels. The gap between two channels is 4.7 m, the percent of aperture in each cage-channel at the beginning and the end are 25% and 35%, respectively. The ratio of longest to shortest pathway of air is 1.5. The indica paddy of 1330 tonne was garnered in January 2012 and had a 5.12 m bulk height and 0.6% of foreign material. During April to September 2013, 295.5 tonnes of paddy was sold and the rest of the 1034.5 tonnes of paddy were used for the rewetting experiment starting on October 7th. The warehouse doors were closed, and its four windows in the sides above the grain surface were opened. Aeration used negative suction pressureto draw air into the warehouse through the windows then passed downward through the layers of the grain bulk, and was exhausted from the ground-level ventilators. The two ventilators (SFG4-2 type, 1.5 kW power) generate 320/220 Pa of full/static pressure, 11000 $m^3$/h of air volume, and 2800 r/min of rotational speed, thus the calculated airflow rate is 10.6 $m^3h^{-1}t^{-1}$. In order to accurately determine the electricity consumption, an intelligent electricity meter was used for aeration manipulation. The actual power consumption was 0.567 kW·h (1%moisture·t)-1.

### 2.3.2. Rewetting aeration in a flat warehouse in Qihe, China

The second experiment was carried out at Shandong Grain Reserve Depot for Army Provision, Qihe, Shandong province, China. Qihe lies in a basin (36.8°N, 116.8°E, 20 meters of average altitude) with warm temperate semi-humid monsoon climate. The experimental No. 13 warehouse is 39.8 m in length and 20.4 m in width. It has five U-shaped air channels equipped with two axial-flow fans, each fan is connected to 2.5 U-shaped air channels. The ratio of longest to shortest pathway of air is 1.4. The japanic paddy of 2489 tonne from the northeast China was garnered in December 2016, with 5.0 m bulk height, 14.0% MC and 0.6% foreign material. After levelling the grain bulk surface, the equalizing-temperature aeration decreased the average grain bulk MC to 13.5% during January 2017. Aeration was negative suction pressure suction with air entering the warehouse through five vents and then passed upward through the paddy bulk layers, and finally exhausted from the two fans fixed on the windows in the roof structure. The warehouse doors were closed, its five vents in the warehouse side bottom were opened, and the two axial-flow fans fixed on the windows at opposite sides above the paddy surface were opened. The two fans (FTA-75 type, 0.85 kW power) have 320/220 Pa of full/static pressure, 13800 $m^3$ $h^{-1}$ of air volume, and 2300 r $min^{-1}$ of rotational speed, thus the calculated ventilation rate is 8.9 $m^3$ $h^{-1}$ $t^{-1}$. The No. 13 warehouse of paddy was used for the reweeting experiment with natural humid air during April 13$^{th}$ to June 16$^{th}$, 2017.

#### 2.3.2.1. Protocol for rewetting paddy in No. 13 warehouse

Firstly, the local daily 24-h data of atmosphere temperature and RH during April to June in 2015 and 2016 were collected from Qihe County Bureau of Meteorology. A paddy desorption equilibrium moisture equation (eqn. 5) was used to predict paddy static moisture content near the warehouse vents:

$$\mathrm{EMC_p} = 36.953 \cdot \mathrm{RH}^3 - 48.528 \cdot \mathrm{RH}^2 + 30.791 \cdot \mathrm{RH} + 0.03859 \cdot \mathrm{RH}^2 \cdot \mathrm{t} + 0.006744 \cdot \mathrm{RH} \cdot \mathrm{t} - 0.08611 \cdot \mathrm{t} + 5.089 \qquad (5)$$

where $EMC_p$ is the predicted EMC (%w.b.) of paddy, RH and t are the relative humidity (%) and temperature (°C) of the atmosphere, respectively.

Secondly, the aeration channels in the paddy warehouse were used for automatic rewetting aeration. The temperature of the grain bulk was similar to the atmoshperic temperature thus the atmospheric RH should be 25% higher than the RH of the grain bulk. Thirdly, the grain bulk temperature and grain moisture near the vents and at the bulk surface were checked regularly. The percentage of head rice yield and damaged grains from sampling sites were determined.

## 3. Results

### 3.1. The rewetting aeration in No. 12 flat warehouse in Dianjiang, Chongqing

#### 3.1.1. Change in the BCDE area of rewetting aeration window

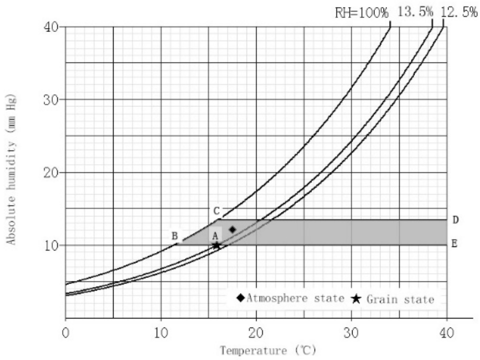


**Fig. 1** The operating window for aeration to rewet paddy rice.

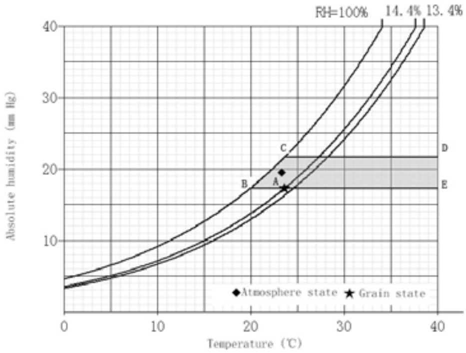


**Fig. 2** The ventilators were running at 23:31 on October 8th, 2013.

At 23:31 on October 8th, 2013, the automatic detection system showed average grain bulk temperature ($t_g$) of 23.6°C in No. 12 warehouse, atmosphere temperature of 23.3°C, and atmosphere RH of 92%. The moisture of grain bulk was determined to be 13.4% using a LSKC-4B type moisture meter (Wuhan Electronic Devices Second Factory, China). The $t_g$ was higher than the dewpoint temperature ($DPT_a$, 21.93°C) of the atmosphere. The atmosphere state point was within the BCDE area of the rewetting aeration window (Fig. 2), and the ventilators were turned on.

At 19:01 on October 20th, 2013, the moisture of the grain bulk was 13.8%, the automatic detection system showed average grain bulk temperature ($t_g$) of 16.5°C, atmosphere temperature of 18.0°C, and atmosphere RH of 91%. The $t_g$ was equal to the dewpoint temperature ($DPT_a$, 16.5°C) of the atmosphere. The atmosphere state point was at the edge of the BCDE area of the rewetting aeration window (Fig. 3), thus the rewetting aeration condition was not satisfied and the ventilators were turned off.

At 22:00 on October 21th, 2013, the moisture of the grain bulk was 13.8%, the automatic detection system showed average grain bulk temperature ($t_g$) of 16.8°C, atmosphere temperature of 17.3°C, and atmosphere RH of 92%. The $t_g$ was higher than the dewpoint temperature ($DPT_a$, 15.98°C) of the atmosphere. The atmosphere state point was within the BCDE area of the rewetting aeration window (Fig. 4), thus the rewetting aeration condition was sufficient and the ventilators were turned on.

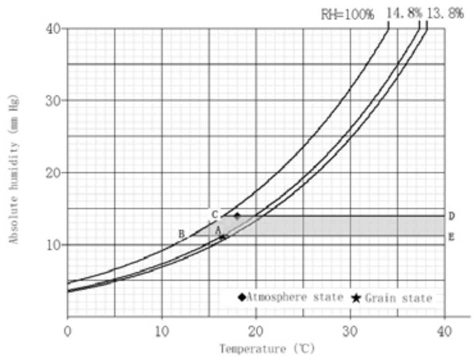


**Fig. 3** The ventilators were turned off at 19:01 on October 20th, 2013.

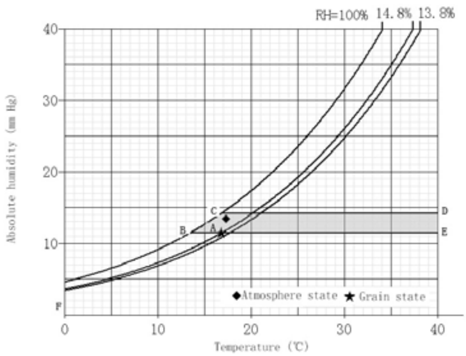


**Fig. 4** The ventilators were running at 22:00 on October 21th, 2013.

At 11:14 on October 31th, 2013, the moisture of the grain bulk was 14.1%, the automatic detection system showed average grain bulk temperature ($t_g$) of 15.6°C, atmosphere temperature of 15.8°C, and atmosphere RH of 95%. The $t_g$ was slightly higher than the dew temperature ($DPT_a$, 15.01°C) of the atmosphere. The atmosphere state point was outside of the BCDE area of the rewetting aeration window (Fig. 5), and the ventilators were turned off.

The rewetting aeration in No.12 warehouse was ended on November 2nd, 2013. Table 1 shows the data of automatic bulk detection. At 10:29, the grain bulk had a maximum temperature of 16.3°C, a minmum temperature of 15.8°C, and a mean temperature of 16.0°C. The temperature gradient in the grain bulk was ≤1°C $m^{-1}$ grain layer. The air temperature and RH above the grain bulk surface was 16.0°C and 91%, respectively; the temperature and RH of the atmosphere were 16.3°C and 95%, respectively. The moisture of the grain bulk was 14.2%.

### 3.1.2. Energy consumption and profit anlysis for automatic paddy aeration

The rewetting manipulation was being carried out while the grain bulk was retrieved from storage. The moisture of the outbound grain was 14.1-14.2%. The moisture content in the remaining 612 t of paddy was 14.1% on November 2nd, and rewetting aeration was stopped. The total output grain was 1324 t until November 12th, and grain loss was 5.85 t. The aeration system ran 181.5 h, and power consumption was calculated to be $181.5 \times 2 \times 0.576$=209.1 kWh The annual mean grain loss in the depot was 0.8%, the grain loss for 1330 t paddy should be 10.64 t. Therefore, the increase in grain weight by rewetting was 4.79 t. The price for output paddy was 2.16 yuan $kg^{-1}$, the sale of 4.79 t of paddy was 10346.4 yuan. The electricity charge per kW·h was 0.92 yuan, and electricity cost was 192.37 yuan, thus the net profit was 10154.03 yuan. The unit energy consumption [kW·h $(1\%\text{moisture}\cdot t)^{-1}$] was $\frac{209.1}{10346.4\times(14.1-13.5)\%} = 0.3336$.

**Tab. 1** Detection data in No. 12 paddy warehouse before and after rewetting aeration**.**

| Time | Grain layer | Mean grain layer temp. (°C) | Min. grain temp. (°C) | Max. grain temp. (°C) | Mean grain bulk temp. (°C) | Temp. above bulk surface (°C) | Atmo-sphere temp. (°C) | RH above bulk surface (%) | Atmo-sphere RH (%) |
|---|---|---|---|---|---|---|---|---|---|
| 23:31 Oct. 8th, 2013 | 1 | 23.6 | 23.5 | 23.8 | 23.6 | 23.3 | 22.3 | 92.0 | 92.0 |
| | 2 | 23.6 | | | | | | | |
| | 3 | 23.7 | | | | | | | |
| | 4 | 23.8 | | | | | | | |
| 10:25 Nov. 2nd, 2013 | 1 | 16.0 | 16.3 | 15.8 | 16.0 | 16.0 | 16.3 | 91.0 | 95.0 |
| | 2 | 16.1 | | | | | | | |
| | 3 | 15.9 | | | | | | | |
| | 4 | 15.9 | | | | | | | |

**Tab. 2** The running time of two ventilators.

| Date | Running time | Date | Running time |
|---|---|---|---|
| Oct.8th-9th | 9 h 43 min | Oct.22th-23th | 12 h 20 min |
| Oct.9th-14th | Turned off | Oct.23th-24th | 11 h 10 min |
| Oct.15th-16th | 14 h 19 min | Oct.24th-25th | 10 h 54 min |
| Oct.16th-17th | 19 h 52 min | Oct.25th-26th | 10 h 42 min |
| Oct.17th-18th | 9 h 59 min | Oct.28th-29th | 10 h 21 min |
| Oct.18th-19th | 9 h 44 min | Oct.29th-30th | 19 h 30 min |
| Oct.20th-21th | 12 h 10 min | Oct.30th-31th | 14 h 30 min |
| Oct.21th-22th | 9 h 34 min | Oct.31th-Nov.1st | 8 h 30 min |
| | | Amount | 181 h 38 min |

## 3.2. The rewetting aeration in No. 13 warehouse in Qihe, Shandong province

### 3.2.1. Predicting paddy EMC from meteorological data

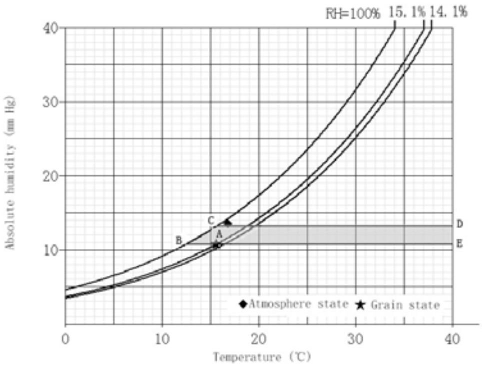


**Fig. 5** The ventilators were turneded off at 11:14 on October 31th, 2013.

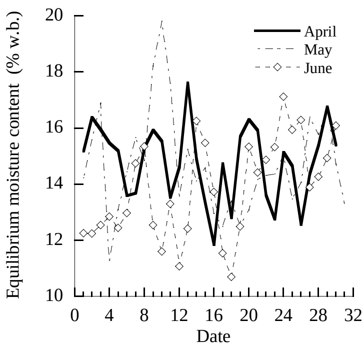


**Fig. 6** The predicted EMC of paddy in Qihe, Shandong province.

The daily atmosphere RH and temperature during 17:00 to 8:00 from April to June in 2015 and 2016 was reviewed to predict the EMC of paddy. The number of days that the predicted desorption EMC is above 13.5% w.b. was 25, 22, and 16 in April, May, and June, respectively. The mean desorption EMC in April, May, and June was 14.81%, 14.71%, 13.83%, respectively, yielding an average of 14.45%. This indicated that the local atmosphere RH and temperature could be used to rewet paddy to 14% MC with automatic aeration.

### 3.2.2. Efficacy of automatic rewetting aeration

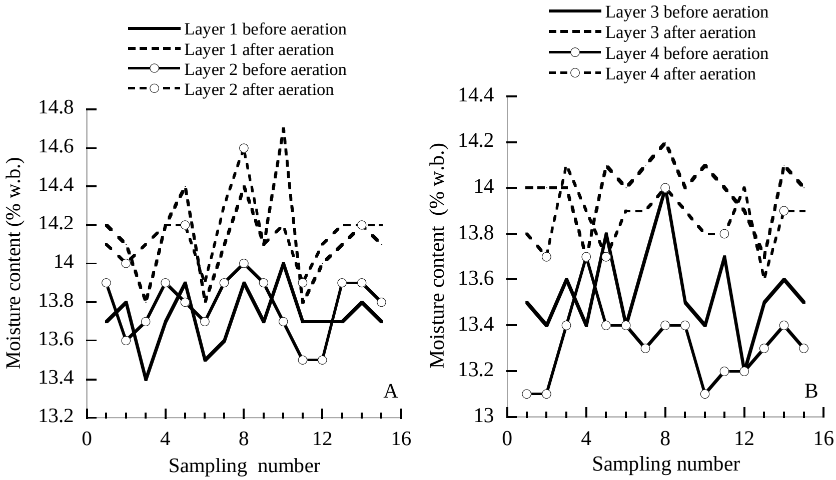


**Fig. 7** Change in sample MC in paddy with automatic rewetting aeration.

Sampling number shows the average value of four bulk layers.

**Tab. 3** Effect of controlled rewetting aeration on percentage of head rice yield in samples.

| Sampling | Before | aeration | | | After | aeration | | |
|---|---|---|---|---|---|---|---|---|
| site | Layer 1 | Layer 2 | Layer 3 | Layer 4 | Layer 1 | Layer 2 | Layer 3 | Layer 4 |
| | | | Head | rice | yield | (%) | | |
| 1 | 67.4 | 69.9 | 67.5 | - | 70.6 | 73 | 71.9 | - |
| 2 | 68.1 | 66.4 | - | - | 71.3 | 70.8 | - | - |
| 3 | 68.2 | - | 69.5 | - | 72.1 | - | 72.8 | - |
| 4 | - | 70.1 | - | 68.3 | - | 71.8 | - | 71.4 |
| 5 | - | 68.1 | - | 66.3 | - | 70.6 | - | 72.2 |
| 6 | - | 69.1 | 68.8 | 70.5 | - | 71.2 | 72 | 71.9 |
| 7 | - | 67.7 | 67.5 | 68.2 | - | 71.2 | 72.1 | 70.4 |
| 8 | 67.5 | - | 66.2 | - | 71.6 | - | 70.8 | - |
| 9 | 68.3 | 67.8 | - | - | 72.2 | 71.3 | - | - |
| 10 | - | 68.5 | 67.7 | - | - | 71.6 | 70.9 | - |
| 11 | - | 67.9 | | 68 | - | 71.2 | - | 70.7 |
| 12 | 70.1 | 69.5 | 68.8 | 68.2 | 71 | 72.4 | 71.9 | 71.5 |
| 13 | 67.5 | 67.2 | | 69.3 | 72.2 | 71.4 | - | 72.6 |
| 14 | - | 68.1 | 69.4 | - | - | 70.9 | 72.4 | - |
| Average | 68.2 | 68.4 | 68.2 | 68.4 | 71.6 | 71.8 | 71.9 | 71.5 |

The No. 13 warehouse in Qihe depot was chosen for rewetting on April 13th, and the treatment ended on June 16th, 2017. During automatic aeration over two months, three conditions were set: (i) when the atmosphere relative humidity ($RH_a$) is ≤80% and its temperature ($t_a$) is <28°C, the average grain temperature ($t_g$) is higher than the dew temperature ($DPT_a$) of the atmosphere, and the equilibrium absolute humidity ($EAH_g$) of grain moisture plus 1 percentage point is lower than the absolute humidity ($AH_a$) of the atmosphere, the two axial-flow fans were turned on; and (ii) when $RH_a$ >80% and $t_a$ <28°C, the two axial-flow fans were turned on. Whenever the $t_a$ is above 28°C, the two fans were switched off.

This rewetting aeration increased grain moisture from an initial moisture content of 13.5% to 14.0% (Fig. 7) within the accumulated power consumption of 566.1 kWh using two 0.85 kW axial-flow fans. The unit energy consumption was 0.455 kW·h $(1\%\ \text{moisture}\cdot t)^{-1}$. The percent of average head rice yield in the whole depot after aeration was 71.7% (Tab. 3), significantly higher than that (68.2%) of the non-rewetted paddy. The Chinese national standard of paddy (GB1350-2009, China) stipulates that the percentage of head rice yield of first grade japanic paddy should be higher than 61%. Tab. 4 shows the percent of damaged grains at each sampling location. It had some difference among different sampling sites in each bulk layer, but its mean values among four layers were not significantly different, indicating even moisture distribution in the whole paddy bulk. The percent of damaged grains in the whole warehouse was 7.7±1.8%.

**Tab. 4** The percentage of damaged kernels in samples after controlled rewetting aeration.

| Sampling site | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Layer 1 | 10.01±2.89b | 4.22±0.98ab | 5.80±4.39ab | 2.01±1.22b | 10.41±4.64ab |
| Layer 2 | 5.77±5.34bc | 4.13±1.41ab | 6.54±0.44a | 2.99±1.42b | 14.50±1.97a |
| Layer 3 | 0.45±2.01c | 6.22±2.06a | 0.82±2.07b | 10.92±4.61a | 8.08±1.21b |
| Layer 4 | 13.34±0.42a | 3.45±0.48b | 10.47±3.68a | 13.45±0.86a | 7.38±2.34b |
| Sampling site | 6 | 7 | 8 | 9 | 10 |
| Layer 1 | 5.34±1.34a | 3.20±1.58b | 1.76±1.38c | 3.62±2.01b | 2.99±0.96b |
| Layer 2 | 7.94±3.78a | 8.41±3.36a | 16.82±0.84a | 9.34±1.34b | 9.27±2.81a |
| Layer 3 | 4.03±1.27a | 5.76±2.11ab | 10.08±4.65b | 16.65±4.37a | 0.50±2.23b |
| Layer 4 | 3.41±2.41a | 10.04±4.34a | 21.20±4.11a | 7.73±4.47b | 9.34±0.84a |
| Sampling site | 11 | 12 | 13 | 14 | Average |
| Layer 1 | 5.92±1.27b | 10.75±4.81bc | 5.83±0.53a | 5.34±0.15b | 5.52±2.98a |
| Layer 2 | 2.22±1.79c | 7.52±1.98c | 0.61±2.27b | 6.47±1.81b | 7.24±4.58a |
| Layer 3 | 11.13±1.64a | 24.92±4.11a | 5.83±1.11a | 9.62±1.17a | 8.22±6.68a |
| Layer 4 | 9.97±0.15a | 11.20±0.91b | 8.36±3.21a | 8.15±6.91ab | 9.83±4.43a |

The damaged kernel was determined as described by Li et al. (2016). The different small letters in the same column show significant different ($p<0.05$) at LSD-test.

## 4. Discussion

Banaszek and Siebenmorgen (1990) reported that air conditions of 12.5°C/RH 50%, 15°C/RH 50% and 12.5°C /RH 90% were not obtainable with the RH and temperature control unit used for their adsorption EMC experiment with rough rice. The reason is not clear. We found that for "Longyang" variety japanic paddy samples from northeast China with 13.57% initial MC and under 65% ERH it had moisture adsorption at 10°C, but had moisture desorption at 20 to 35°C. Below 86% ERH condition, it had moisture adsorption at 10 to 35°C (Li, et al., 2015). These results suggest that paddy samples with 13.5% MC could be rewetted at 80% RH and 10-25°C of ambient condition.

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## Drying Ginger and Preserving 6-Gingerol

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### Abstract.

Ginger rhizome (*Zingiber officinale*) is widely used as a spice or as a medicinal plant. The major bioactive compound in fresh ginger rhizome is 6-gingerol and it is known for having a number of physiological effects. This compound is heat-sensitive and during cooking or drying will transform into 6-shogaol. Hence, the 6-gingerol content is used to evaluate the quality of dried ginger. The content of 6-gingerol during drying was measured using HPLC. Several factors that could affect the 6-gingerol content were considered and a predictive model for changes in 6-gingerol has been developed from the experimental data. The predictive model includes a single term drying model that predicts the changes of moisture content during drying. Drying time and relative humidity (ranging from 10% to 40%) impacted 6-gingerol content whereas drying air temperature (ranging from 30°C to 60°C) had a lesser effect. It was also found that the 6-gingerol content in fresh rhizomes was highly variable and thus required thorough testing prior to drying to be able to make the prediction more accurate.

**Keywords:** ginger, air drying, 6-gingerol, HPLC, predictive model.

### 1. Introduction

#### Background

Ginger, with a scientific name of *Zingiber officinale* Rosc, is a member of the tropical and sub-tropical family Zingiberaceae. It originates in tropical rainforests in southern Asia and spread to Mediterranean regions by the 1st century. In ancient Rome, ginger was a popular spice used to make delicacies. Throughout the history of global trade, ginger has been traded longer than most other spices. In the ancient world, it was regarded as a costly herb for its medicinal merits and nutritional value.

Over the long history of ginger trading around the world, ginger has been planted on most continents. Given different growing environment, ginger has developed into several cultivars. In commercial trading, ginger is often designated by the country where it originates from, such as Chinese ginger, Indian ginger, Australian ginger or Jamaican ginger. However, ginger has a large cultivar diversity, so that even in one country, there could be dozens of cultivars. Generally, a cultivar comes from a specific growing place, and hence many cultivars were named after their growing place.

#### Chemical composition of ginger

Ginger rhizomes contain a variety of compounds. Researchers have found more than one hundred compounds which can be classified into three groups: essential oils, gingerol and diarylheptanoids.

Essential oils are hydrophobic liquids, containing volatile chemical constituents. Distillation and extractions are the most common ways to isolate the essential oils. The major components of essential oils are the terpenoids, including monoterpenes and hemiterpenes. Most compounds from these two groups have a strong volatile aroma and biological activity, which are important ingredients in medicine, cosmetics and food production.