Drying characteristic of unhulled rice in biomass energy and combination rotary dryer

A Rindang*, S Panggabean, A Sukoco and P C Ayu

Department of Agricultural Engineering, Faculty of Agriculture, Universitas Sumatera Utara, Medan, Sumatera Utara, Indonesia.

E-mail: *adian.rindang@usu.ac.id

Abstract. Drying of agricultural products aimed to extend the shelf life. The moisture content of the unhulled rice must be lowered to a limit of 14% to be able to maintain the quality and avoid post-harvest damage. Ciherang variety unhulled rice has been dried using biomass energy rotary dryer and biomass-heater combination for 180 minutes. In this study, several drying characteristics of unhulled rice have been analyzed including the determination of water content and the drying rate. The exponential equation illustrated the relationship between the unhulled rice water content (%) and the drying time (minutes), $\text{MC}=23.279 \times 0.002^t$ and $\text{MC}=27.255 \times 0.004^t$ respectively for the stage 1 decline drying rate in biomass energy and combination, while at the decline drying rate stage 2 found $\text{MC}=22.209 \times 0.002^t$ and $\text{MC}=27.576 \times 0.004^t$ respectively in biomass energy and combination. The relationship between unhulled rice drying rate ($\text{dM/dt}$) and drying time (minutes) was illustrated by the exponential equation $\text{v}=0.0466 \times 0.002^t$ and $\text{v}=0.0444 \times 0.002^t$ respectively for the decline drying rate stage 1 in biomass energy and combination while at the decline drying rate stage 2, $\text{v}=0.0444 \times 0.002^t$ and $\text{v}=0.0775 \times 0.003^t$ respectively in biomass energy and combination.

1. Introduction

Generally, after harvest process, the agricultural products tend to have a high water content that must be controlled to prevent damage to the harvested product which continues to produce quality degradation in the form of physical damage, nutrient content, and decreasing product weight loss. Post-harvest handling has an important role in maintaining the quality of agricultural products, such as maintaining the product life or product shelf life. Rice is the most important agricultural product in Indonesia and is the staple food of the communities. Rice with 12-14% water content percentage has a shelf life of 6 months [1]. Reciprocally to the Indonesian National Standard (SNI) stipulates that rice water content (grain) is 14%. Drying is one of the post-harvest activities that aims to extend the shelf life of agricultural products by reducing the water content contained in the ingredients to the extent that microorganisms cannot live anymore.

Drying of agricultural products can be conducted in two ways. The conventional method is conducted by utilizing the solar thermal energy. It is not easy to dry the unhulled rice in this way due to several obstacles including 1) the activity depends on the weather, so the drying time is uncertain 2) the thickness of the unhulled rice overlay in the drying area is difficult to control and 3) the cleanliness of unhulled rice. The second method is artificial drying sourced from heat generators. The advantage of the dryer in a rotating cylinder form is in the reversing process of the material during drying process can
be easily carried out, and the drying assumption that occurs in the cylinder is a thin layer drying. The selection of the energy used in the drying process is also important, one of the reasons why the conventional drying is still popular nowadays because of the low operational costs compared to the artificial drying. Utilization of biomass waste is typical to be considered as alternative energy. This study discussed the drying characteristics of unhulled rice using a rotary dryer sourced from biomass combustion energy and a combination of biomass combustion with heating elements, including the temperature distribution, relative humidity (RH), water content, and drying rate.

2. Materials and Methods

2.1 Experimental design
The research was carried out in the Laboratory of Agricultural Energy and Electricity, Faculty of Agriculture, Universitas Sumatera Utara, Medan, Indonesia. A total of 30 kg Ciherang varieties unhulled rice obtained from local farmers were dried using a rotary dryer (Figure 1), wherein one drying process was using 5 kg unhulled rice which was fed into the dryer with one bulk.

![Figure 1. The Installation of Rotary-Type Drying Machine.](image)

| Sensor Code | Amount | Location |
|-------------|--------|----------|
| 01          | 1      | The channel of wet unhulled rice feed |
| 02          | 1      | Inlet channel of the hot air inlet |
| 03          | 1      | Outlet channel of dried unhulled rice |
| 04          | 1      | Outlet channel of moist air |
| 05-08       | 4      | Around the base of the drying cylinder |
| 09-12       | 4      | Around the center of the drying cylinder |
| 13-16       | 4      | Around the tip of the drying cylinder |

The drying process was carried out in two ways. First, the unhulled rice was dried using heat sources derived from biomass combustion, in this case, was using rice husk as biomass. Second, the unhulled rice was dried using a heat source derived from a combination of biomass combustion and heating elements attached to the drying cylinder. Each method was carried out three times. The drying process was carried out for 180 minutes. Inside the drying cylinder, there were four temperature sensors and a relative humidity sensor, and 12 temperature sensors were placed around the cylinder wall (scheme of sensor placement can be seen in Table 1). The hot air which entered the drying cylinder was obtained
from the outside air drawn by a centrifugal fan and then heated on a galvanized pipe circuit located above the biomass combustion furnace. In the drying cylinder, the air was used by the unhulled rice to evaporate water, and then hot air will come out through the hole above the drying cylinder. Record of temperature data and RH were conducted every 30 minutes.

2.2 Calculation of water content

The water content of the material is the amount of water contained in an ingredient per unit of material weight. Water content can be determined using two methods, namely water content based on dry weight (Equation 1) and water content based on wet weight (Equation 2), where \( M \) is the wet base water content (% \( w_b \)), \( w_b \) is the wet mass (kg), and \( w_d \) is the dry mass (kg) [2].

\[
M_{wb} = \frac{w_b - w_d}{w_b} \quad (1)
\]

\[
M_{db} = \frac{100 M_{wb}}{100 - M_{wb}} \quad (2)
\]

3. Results and Discussion

Figure 2 showed the temperature distribution in the combustion furnace, the drying chamber and the unhulled rice temperature during the drying process (°C). Table 2 shows the drying airspeed, drying time and unhulled rice water content during drying. The temperature distribution in the furnace fluctuated, in the biomass energy treatment, the furnace temperature reached its peak in the 90th minute while in the combination treatment in the 150th minute. However, the temperature of the drying chamber in both treatments tended to increase along with the increasement of drying time, as well as the unhulled rice temperature had the same tendency as the drying chamber temperature. More specifically, the drying characteristics could be seen in Table 2.

![Figure 2](image-url)

Figure 2. Graph of unhulled rice temperature distribution during the drying process and several elements in the drying machine.

Drying process was divided into two phases; namely, the first period which was drying period with a constant drying rate and the second was drying period with a decline rate. At a constant drying rate, agricultural material still contained 25-30% water, therefore the evaporation rate of water that occurred on the material surface was equal to the evaporation rate on the surface of free water, where the evaporation rate itself very depended on the state of surrounding environment while the influence of the material itself was quite small. When the material surface has been covered by water, decline drying rate process will occur, where the remaining free water which was very small in amount would be evaporated, as well as the bound water in the material. In this period, water transfer from the inside of material to the surface of the material, and the vapor water transfer from the material surface to the surrounding air would occur. Then, both periods were limited by critical water content [3]. Critical water content is the lowest water content that occurs when the rate of free water inside the material is moving
towards the surface is equal to the rate of maximum water vapor retrieval from the material. In agricultural products in grain form, the water content while drying process is smaller than the critical water content, so that it could be said that the drying process that occurred was a decline drying rate process [2]. Furthermore, the decline drying rate is divided into two stages, where the critical water content also limits each stage. Figure 3 showed the relationship between water content (%) and time (minutes) at the decline drying rate in stages 1 and 2.

Table 2. Drying characteristic of biomass energy and combination rotary dryer

| Type of Energy | Air Velocity (m/sec) | Drying Time (minute) | The temperature of the Drying Cylinder (°C) | RH (%) | Water Content (%) |
|----------------|----------------------|----------------------|---------------------------------------------|--------|-------------------|
| Biomass        | 5.65                 | 0                    | 32                                          | 45.75  | 23.9              |
|                |                      | 30                   | 45.71                                       | 35.3   | 21.37             |
|                |                      | 60                   | 48.4                                        | 30.05  | 19.63             |
|                |                      | 90                   | 50.06                                       | 26.99  | 18.13             |
|                |                      | 120                  | 49.23                                       | 27.43  | 17.9              |
|                |                      | 150                  | 45.59                                       | 28.42  | 17.17             |
|                |                      | 180                  | 44.47                                       | 29.3   | 16.1              |
| Combination    | 5.65                 | 0                    | 32                                          | 73     | 27.5              |
|                |                      | 30                   | 46.7                                        | 44.4   | 24.4              |
|                |                      | 60                   | 49.95                                       | 37.38  | 22.2              |
|                |                      | 90                   | 51.22                                       | 33.6   | 21                |
|                |                      | 120                  | 51.26                                       | 31.66  | 17.77             |
|                |                      | 150                  | 54.32                                       | 28.97  | 15.8              |
|                |                      | 180                  | 52.51                                       | 28.88  | 14.07             |

Figure 3. Graph of the relation between water content and drying time at decline drying rate (a) stage 1 and (b) stage 2.

In Figure 3, an exponential equation [4] was obtained to illustrate the relationship between water content and drying time at stage 1 and 2 of decline drying rate. Summary of exponential equations obtained from the graph of water content (MC) (%) vs. drying time (t) (minutes) shown in Table 3.

The equation in Table 3 was then derived to determine the relationship between drying rate (dM/dt) and time (minutes), the result is shown in Figure 4, a summary of the drying rate equation (v) against
time (t) is shown in Table 4, while the relationship between drying rate (dM/dt) with water content (%) is shown in Figure 5. Results showed that the drying rate tended to decrease along with the increasement of drying time. At the decline drying rate, the first stage for the combined energy treatment was seen to be faster than the biomass energy due to the additional heat energy produced by the heater in the drying chamber accelerated the evaporation rate of water in the unhulled rice. At the decline drying rate stage 2, both biomass energy and combination showed the same drying rate, due to the amount of bound water contained in the unhulled rice was continue decreasing along the process which triggered a difficulty in the evaporation process. The result of drying rate was directly proportional to water content, which means that if the drying rate was low, therefore, the material water content that could be evaporated was low, and vice versa.

### Table 3. The equation of relation between water content and drying time at the decline drying rate stage 1 and 2

| Drying Rate Period       | Energy Treatment                |
|--------------------------|---------------------------------|
|                          | Biomass                         | Combination                     |
| Decline drying rate stage 1 | MC = 23.279 e^{-0.002t}         | MC = 27.255 e^{-0.004t}          |
| Decline drying rate stage 2 | MC = 22.209 e^{-0.002t}         | MC = 27.576 e^{-0.004t}          |

### Table 4. The equation of relation between drying rate and drying time at decline drying rate stage 1 and 2

| Drying Rate Period       | Energy Treatment                |
|--------------------------|---------------------------------|
|                          | Biomass                         | Combination                     |
| Decline drying rate stage 1 | v = 0.0466 e^{-0.002t}         | v = 0.109 e^{-0.004t}           |
| Decline drying rate stage 2 | v = 0.0444 e^{-0.002t}         | v = 0.0775 e^{-0.003t}           |

**Figure 4.** Graph of the relation between the drying time and the decline drying rate (a) stage 1 and (b) stage 2
Figure 5. Graph of the relation between the drying rate and the unhulled rice water content at decline drying rate (a) stage 1 and (b) stage 2

4. Conclusions
Decrease of unhulled rice water content was faster in drying process with combined energy treatment, and the water content could decrease from 27.5% to 14.01% in 180 minutes, equal to the drying rates occurred in combination energy treatments. Moreover, the relationship between the unhulled rice water content (%) and the drying time (minutes) was illustrated by the exponential equation, \( MC = 23.279 e^{-0.002t} \) and \( MC = 27.255 e^{-0.004t} \) respectively for the stage 1 decline drying rate in biomass energy and combination, while at the decline drying rate stage 2 found \( MC = 22.209 e^{-0.002t} \) and \( MC = 27.576 e^{-0.004t} \) respectively in biomass energy and combination. The relationship between unhulled rice drying rate (dM/dt) and drying time (minutes) was illustrated by the exponential equation \( v = 0.0466 e^{-0.002t} \) and \( v = 0.109 e^{-0.004t} \) respectively for the decline drying rate stage 1 in biomass energy and combination while at the decline drying rate stage 2, \( v = 0.0444 e^{-0.002t} \) and \( v = 0.0775 e^{-0.003t} \) respectively in biomass energy and combination

References
[1] Muchtadi T R and Sugiyono 2014 Prinsip dan Proses Teknologi Pangan (Food Technology Principles and Process) (Bandung: Alfabeta)
[2] Brooker D B, Bakker-Arkema F W and Hall C W 1992 Drying and Storage of Grains and OilSeed (USA: 4th edition van Nostrad)
[3] Henderson S M and Perry R L 1976 Agriculture Process Engineering. (Westport Connecticut: 3rd edition The AVI Publishing Company Inc)
[4] Ertekin C and Yaldiz O 2004 Drying of Eggplant and Selection of Suitable Thin Layer Drying Model Journal of Food Engineering 63 349-59

Acknowledgments
The research was funded by the Research Central of University Sumatera Utara, Medan for Internal Grand Research (TALENTA 2018) Number: 42/UN5.2.3.1/PPM/KP-TALENTA USU/2018 at 16th March 2018.)