Heat Transfer Analysis in the Drying Process of Sorghum Rice Instant

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ABSTRACT

As a commodity with high adaptability to climate change, sorghum has high potency in food sustainability. Sorghum grain can be diversified to be various kinds of food products including rice sorghum instant. The heat transfer process during the drying of sorghum rice instant is an interesting factor to be evaluated that influences the physical properties of sorghum rice. This research is aimed to analyze and compare the heat transfer in sun drying and cabinet drying in the production of sorghum rice instant. The heat transfer has been approached by the lumped-capacitance model with the case of a spherical particle. The heat transfer in the drying process was conducted in the heat capacity of 3.61 kJ/kg℃ to 3.843 kJ/kg℃, the particle dimension of rice of 0.38 m^2 to 0.42 m^2, and the rice density of 1.11 g/mL to 1.17 g/mL. The heat transfer coefficient during sun drying is 1.24 W/m^2. ℃, while in the cabinet drying at the temperature of 60 ℃, 50 ℃, and 40 ℃ were 12.17 W/m^2.° C; 9.55 W/m^2.° C; and 4.87 W/m^2.° C respectively, influenced by the drying temperature. The drying temperature influenced the heat transfer and the color change in sorghum rice instant caused by the Maillard reaction with the activation energy of 26.28 kJ/mol.

Keywords: *Coefficient, Heat transfer, Instant rice, Lumped-capacitance, Maillard reaction, Sorghum, Temperature*

1. INTRODUCTION

Climate change is a serious problem that is being concerned by many people today. It is caused by anthropogenic greenhouse gas emissions, especially carbon dioxide (CO2) and global temperatures. Gas emissions increased by more than 70% from 1970 to 2004 and could increase to 95% by 2030. Global temperature increases from about 0.6 to 1-3.7℃ [1,2,3]. Gas emissions and high temperatures will have an impact on the environment and agriculture such as water stress and poor soil fertility so production results are difficult to maintain [4].

Climate change threatens global food availability, energy sustainability, and population growth nutritional demand [5]. It is needed an anticipation strategy and technology application to face the challenge that is tolerant of unstable conditions. Sorghum seems to be a promising crop with interesting functions during climate change because it is tolerant to unstable conditions [4,6,7].

Sorghum (*Sorghum bicolor* L. (Moench)) grows in the tropic and subtropic areas. It is an important food crop in Africa, Central America, and South Asia. The dimension is small and round. Sorghum can adapt to extreme environments and has an important role in climate change. It is included in the 5 most important grain seeds in the world together with wheat, maize, rice paddy, and barley. The nutritional value is similar to maize in that contains protein, fat, crude fiber, carbohydrates, starch, and minerals. Sorghum is also produced 350 kcal of calories, calcium, phosphorous, carotene, thiamine, and antioxidants [4,8]. Sorghum has some potential in the food and industrial sectors by

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adding value. It can be a traditional drink and water, ready-to-eat product, animal and poultry feed, biofuel, and bioplastics [5].

Sorghum rice is one example of sorghum innovation which is boiled to get a soft texture. Not only Indonesia, but also other countries have sorghum rice on their menus such as India, Bangladesh, Botswana, China, Ethiopia, and Nigeria. The skin of sorghum seed contains tannin which is a polyphenolic compound and negatively affects the nutritional quality of sorghum by binding and precipitating proteins. It makes the protein indigestible [8].

Figure 1 Sorghum [9]

Recently, the convenience of instant rice in eating attracted people especially who have little time to cook and prepare the food. In this modern life, many people want to do anything in a fast time, so instant rice is a great choice to make it easier for people to move more quickly and practically. Instant rice has a promising market in the future [10], [11]. Sorghum instant rice is an innovation that could adapt to modern times. Moreover, there is a climate change issue that requires people to maintain food sustainability with tolerant crops to the food supply.

Figure 2 Sorghum Rice [9]

The sorghum instant rice production is involving heat transfer with the concept of a lumped-heat-capacity method using spherical particles. This concept uses the assumption that the internal conductor resistance of the system is very small and the temperature inside the material is assumed to be uniform [12,13]. It has an assumption of the Biot number that is less than 0.1. With the low Biot number, the temperature gradient is very small and the product temperature is uniform [14].

Many studies that found that the process of instant rice products can lead to changes in color and other characteristics of the products, especially when the products are exposed to high temperature. The increase in temperatures and exposure time increases the color change in the appearance of raw grains. The quality change increased nearly with air temperature. [10,15]. Most research on instant rice from with rice or a mixture with other ingredients [16]. There is still no research on sorghum instant rice, especially in heat transfer analysis during production. Need advanced research on sorghum instant rice to know the change during the process, especially for the characteristics of the product to analyze the heat transfer and color change. This research aims to analyze the heat transfer of sorghum instant rice production and color change during the production in conventional and mechanical ways.

2. METHODS

2.1. Material

White sorghum from Muntilan market was harvested in Kendal regency, Central Java, Indonesia, and was transported to “Food and Post-Harvest Engineering Laboratory”, Faculty of Agricultural Technology, Universitas Gadjah Mada.

2.2. Sample Preparation dan Procedures

Sorghum grains were washed and soaked in hot water overnight to remove the tannin and to make easily open the skin. Then, they were boiled in a pan for 2 hours to get a soft texture into sorghum rice. Then they are dried into sorghum instant rice using a cabinet dryer. The temperature change in the sorghum rice and the surrounding temperature were measured by the thermocouple during the drying. The color change of the rice was also measured by a colorimeter.

2.3. Heat Transfer of Sorghum Instant Rice Production

Several parameters involved in the heat transferred analysis were measured and determined. The parameters consisted of the volume, surface area, and moisture content of rice. The initial and the change of temperatures during the process were also measured. The heat transfer of sorghum instant rice production was analyzed by the lumped capacity concept to determine the coefficient value of heat transfer convection. The predicted temperature using the coefficient value was compared with the observed temperature.

Based on the research that was done by Sharma & Thompson (1973), the specific heat of sorghum rice can be developed into Equation (1).

$$Cp = 1.394 + 0.0322\ m \tag{1}$$

Where m is the measured content of sorghum rice before drying (% wet basic).

Dimension measurement of sorghum rice can be adopted from the research that was done by Simonyan et al., (2007). The method measured triaxially along the principal axis, major (L_1), intermediate (L_2), and minor (L_3). The three-axis can be analyzed into arithmetic mean diameter, geometric mean diameter, and square mean diameter as shown in Equations (2), (3), and (4).

$$F_1 = \frac{(L_1 + L_2 + L_3)}{3} \tag{2}$$

$$F_2 = (L_1 L_2 L_3)^{\frac{1}{3}} \tag{3}$$

$$F_3 = \left(\frac{L_1 L_2 + L_2 L_3 + L_3 L_1}{3}\right)^{\frac{1}{2}} \tag{4}$$

Where F_1 is Arithmetic mean diameter, F_2 is Geometric mean diameter, and F_3 is Square mean diameter. The equations (2), (3), and (4) can be determined into an Equivalent Diameter as shown in Equation (5).

$$De = \frac{F_1 + F_2 + F_3}{3} \tag{5}$$

The surface area of the sorghum rice was calculated as a surface of spherical ball. The measurement can be shown in Equation (6).

$$L = 4.\pi.r^2 \tag{6}$$

Where L is the surface area of a sorghum rice (m^2) and r is the radius of sorghum rice.

The ratio of the internal to external resistance is called Bi (biot) number as shown in Equation (7) [12], [13].

$$Bi = \frac{h\ .\ L_c}{k} \tag{7}$$

Where h is the coefficient of convection heat transfer (kW/m².℃) and k is the solid thermal conductivity. The value of L can be determined using Equation (8).

$$L = \frac{V}{A} \tag{8}$$

where V is the volume of the sorghum rice (m³) and A is the area of the sorghum rice (m²).

The energy change during the heat transfer process during the sorghum instant rice drying can be written in Equation (9).

$$Q = h\ .\ A\ .\ \Delta T \tag{9}$$

$$Q = -m\ .\ Cp\ .\frac{dT}{dt} \tag{10}$$

From the energy balance, the Equation (11) was arranged from Equations (9) and (10).

$$\ln\left(\frac{T_t - T_l}{T_0 - T_l}\right) = -\left(\frac{h.A}{m.Cp}\right)t \tag{11}$$

The Equation (11) can be approached using a linear graph as y = bx, where b is can be calculated from Equation (12) and (13).

$$h = -\frac{b.Cp.m}{A} \tag{12}$$

$$T_t = \left((T_0 - T_l).e^{-\left(\frac{h.A}{m.Cp}\right)t} + T_l\right) \tag{13}$$

Where Q is the energy during the drying (kW), Cp is the heat capacity (kJ/kg.℃, h is the convection heat transfer coefficient (kW/m².℃), A is the surface area of the product (m²), t is time (h), T_0 is the initial temperature, and T_l is the ambient temperature.

2.4. Color Change

The color was measured by a colorimeter. The values of a* and b* were used to determine the hue angle as a value of color scale using Equation (14).

The color change was evaluated from the value of H, a*, and b* respectively.

$$H\ (°) = \arctan\left(\frac{b*}{a*}\right) x\ 57.3 \tag{14}$$

Where values of a* and b* were interpreted as a color parameter from the colorimeter. The change in the Hue angle's value was analyzed using a kinetics approach as shown in Equation (15).

$$\frac{dC}{dt} = -k.C^n \tag{15}$$

Where C is the value of hue angle during the drying.
The effect of temperature could be analyzed by the Arrhenius equation to get the activation energy in Equation (16).

$$k = A\ .\ e^{-\frac{Ea}{R.T}} \tag{16}$$

Where A is collision frequency, Ea is energy activation (kJ/mol), R is the gas constant (0.00831 KJ/mol.K), and T is the environmental temperature (K).

2.5. Statistical Analysis

The statistics analysis was done by One Way ANOVA and variable factors are the ambient temperature of sun-drying and cabinet dryer temperature at 60 ℃, 50 ℃, and 40 ℃.

3. RESULT AND DISCUSSION

3.1. Heat Transfer during the Drying in the Production of Sorghum Instant Rice

Several parameters that were conducted to calculate the coefficient of the convection heat transfer in Equation (11) were the temperature of the product and environment, the heat capacity, the surface area of rice, and the mass of the product. The heat capacity of the product was stretched between 3.61 kJ/kg℃ to 3.843 kJ/kg℃. The particle dimension was ranged from 0.38 m² to 0.42 m², while the density was from 1.11 g/mL to 1.17 g/mL. The coefficient of convection heat transfer was analyzed by equation (11 as shown in Table 1.

Table 1. Coefficient of Convection Heat Transfer

Temperature (°C)	Coefficient of Convection Heat Transfer (W/m².°C)
60	12.17 ± 1.82^{d}
50	9.55 ± 0.95^{c}
40	4.87 ± 1.63^{b}
Sun-drying	1.24 ± 0.87^{a}

The average ± standard deviation
In the same column, different superscript shows the coefficient of convection heat transfer is different at $p<0.05$

The coefficient values of convection heat transfer during the drying of sorghum instant rice in the temperature of 60, 50, and 40 °C were 12.17 ± 1.82; 9.55 ± 0.95; and 4.87 ± 1.63 W/m².°C respectively. The values were higher than the coefficient of convection heat transfer during the sun-drying of sorghum instant rice which was 1.24 ± 0.87 W/m².°C. The highest coefficient of convection heat transfer during the sorghum instant rice production is at the highest temperature of drying, 60 °C. The convection heat transfer was the fastest among the other drying temperatures. The lowest was in the sun-drying methods due to unstable temperature and humidity, so it needs the longest time to dry the sorghum rice among the other variations. According to [19], the higher of drying influence the higher energy. The higher temperature of the drying, the faster the convection heat transfer process than other temperatures. Each correlation between the observed temperature and the predicted temperature of sorghum rice during the process involving the value of the coefficient of convection heat transfer in Table 1 was illustrated in Figure 3.

The validation of the observation and prediction of product temperature was done by the R^2 value. The R^2 values of the cabinet dryer with temperatures at 60, 50, and 40 °C were close to 1. The validation was so different in the sun-drying, due to the unstable temperature and environment during the process.

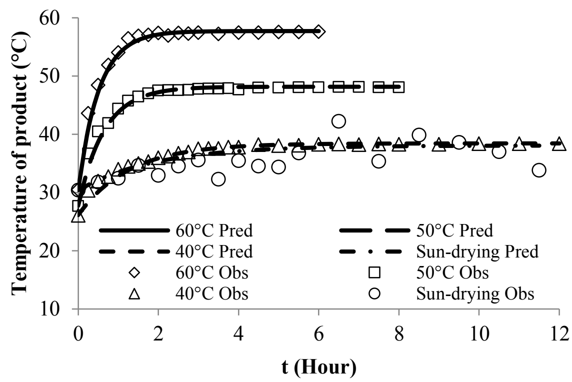

Figure 3 The observation and prediction of product temperature

3.2. Color Change

The color evaluation was conducted using the history of the Hue Angle value which states the color numerically. Each change of the values was illustrated in Figure 4.

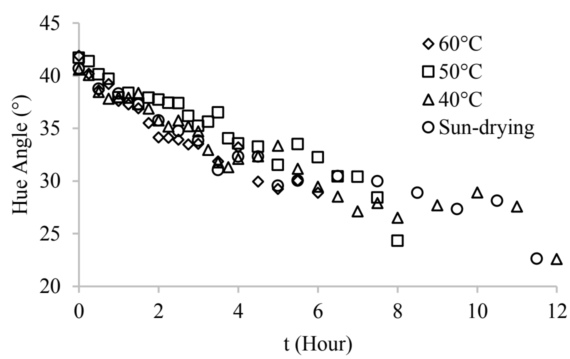

Figure 4 Hue Angle during sorghum instant rice production

Hue angles in each drying temperature ranged from 20 to 45°. It means that the color of sorghum instant rice was red color during the process [20]. The red color during the process was supposed to be affected by the reaction of the phenolics or the Maillard reaction reactions between lysine and reducing sugars with heat [5]. The higher temperature during processing, the higher the browning reaction [21].

Table 2. Kinetics of Hue Angle Change

Temperature (°C)	Kinetics of Hue Angle Change (°/hour)
60	3.02 ± 1.20
50	1.86 ± 0.94
40	1.62 ± 0.31
Sun-drying	1.18 ± 0.32

From the kinetics approach, the constant value of the change of hue angle change during the drying at the temperature of 60, 50, and 40 ℃ were 3.02 ± 1.20; 1.86 ± 0.94; and 1.62 ± 0.31 °/hour, respectively. The constant value of the sun-drying was 1.18 ± 0.32 °/hour. The results showed that the highest constant value of the color change based on the Hue angle during the drying of sorghum rice production was at the highest temperature, 60 ℃. From the kinetic equation of hue angle, the change of the rice's color value can be predicted by the Arrhenius Equation, as shown in Table 3 within the collision frequency factor and activation energy. From the Arrhenius Equation, the color change prediction can be seen in Figure 5.

Table 3. The collision frequency factor, activation energy, and Arrhenius Equation of the product

A	Ea (kJ/mol)	Arrhenius Equation
45524.23	26.82	$k = 45524.23.\ e^{-\frac{26.82}{0.00831.T}}$

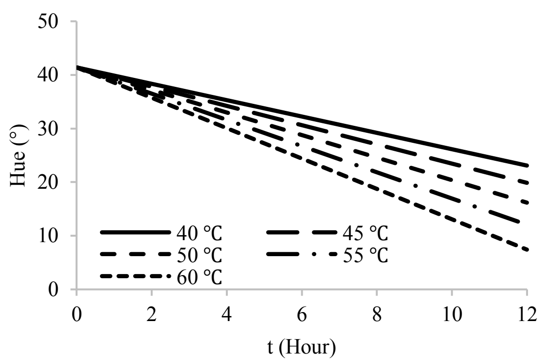

Figure 5 The predicted color value of sorghum instant rice during the drying in the sorghum instant production

4. CONCLUSION

The convection heat transfer during the drying of sorghum instant rice can be analyzed using a lumped capacitance method as a kinetics approach, by assuming the rice in a spherical particle. The analysis involved several heat transfer parameters such as the heat capacity of rice from 3.61 kJ/kg℃ to 3.843 kJ/kg℃, the particle dimensions from 0.38 m² to 0.42 m², and the rice density from 1.11 g/mL to 1.17 g/mL. The coefficient value of the convective heat transfer was 1.24 W/m².℃ in the sun-drying, and the ones were 12,17 W/m².°C; 9,55 W/m².°C; dan 4,87 W/m².°C temperature of 60 ℃, 50 ℃, and 40 ℃ respectively of the cabinet dryer. The drying temperature affected the convective heat transfer and the color change of sorghum instant rice with the activation energy of 26.28 kJ/mol .

AUTHORS' CONTRIBUTIONS

Author 1: conception and design of research, methodology, data analysis and interpretation, writing, editing; Author 2: conception and design of research, methodology, data analysis and interpretation, writing, editing; Author 3: conception and design of research, methodology, data analysis and interpretation, writing, editing.

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