Specific Energy Consumption and Drying Kinetics of Far-infrared Dried

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Abstract

This study was conducted to evaluate specific energy consumption in various drying systems including advantages of infrared assisted drying process. Tests were conducted using instant rice berry under various experimental conditions as follows: In far-infrared drying were 50 and 70^{0}C, air velocity levels 0.5 m/s and 2 intensity levels (1 and 2 kW/m^2). Drying kinetics and qualities in terms of moisture content final moisture of 8% (d.b.), color, morphology and rehydration of the instant rice berry were experimentally investigated. Experimental results showed that specific energy consumption at 2 kW/m^2 was 5.8 kWh/kg of water removed resulting in a 55% energy saving when compared to 1 kW/m^2 of far-infrared intensity. The drying rate rapidly increased to a maximum value and then gradually decreased into the falling rate period. The increase in far-infrared power caused a rapid increase in the temperature at the surface of kernels, resulting in an increase of the water vapor pressure inside the kernels and thus in higher drying rate. The higher far-infrared intensity, however, resulted in the larger total color differences of the product. Increasing far-infrared intensities from 1 kW/m^2 to 2 kW/m^2 led to the dramatic increase in rehydration ratio by 30%.

Keywords: Instant rice berry: Specific energy consumption: Drying kinetics

Introduction

Rice berry is a cross-bred unmilled rice possessing dark violet grain, which is a combination of Hom Nin Rice, with well-known antioxidant properties, and Thai Hom Mali Rice, also known as Thai Jasmine/ Fragrant Rice or KhaoDawk Mali 105 [1].

Instant rice has become more popular due to the fast preparation of dishes by people living modern lifestyles, travelling or simply. It's known as minute rice, is rice that has been pre-cooked and dehydrated so that it cooks more rapidly. Several companies, in Asian have developed brands for producing instant rice. Existing problem of instant rice is the inferior rehydrated texture compared to that of freshly cooked rice. However, many drying technics and drying methods with low investment and operating costs such as infrared drying. The mechanism of infrared radiation drying, heat is generated deep inside the grain and tends to be selectively absorbed in the regions with high moisture content [2,3]. Thus the vapour pressure would be the largest in these regions and the moisture diffusion will be in the direction toward the areas of lower vapour pressure such as the grain surface [4,5] Therefore, it may be possible to apply far-infrared radiation in the drying process to lower this limit. Noting the advantages of these coupled advantages of infrared radiation, the infrared radiation could provide beneficial effect for grains drying, especially maintained or in some cases to increase the head rice yield.

Therefore, the purpose of this present study was to compare the specific energy consumption and quality (moisture content, color, morphology and rehydration) rice berry dried by infrared radiation.

Materials and Methods

Rice berry used in this experimental study was purchased from organic farms in Thai-na rittidech, Maha Sarakham province, Thailand. It's dark violet grain as showed in Figure 1.

Figure 1 Rice berry from organic farms.

Several physical and thermal parameters of the sample material were monitored in real time. Those parameters included moisture and temperature of the sample, temperature and humidity of the intensity of thermal radiation. The experimental setup was developed in this experiment, the dryer is components are mainly comprised of a drying chamber, 4kW far infrared radiators, 4kW electric heaters controlled by PID controller (accuracy of ±1^{o}C) and a forward-curved fan driven by a 1kW. The sample tray was placed parallel to the infrared heater. The weight of the sample was continuously recorded using an electronic balance. Before starting, the rice berry was cooked and then dried by combined far-infrared radiation. During the test, the rice samples were taken at drying times of 1, 5, 10, 20, 30 and every 30 min until 180min to determine the moisture content, color, morphology and rehydration ratio.

The drying condition tests were carried out at far-infrared radiation intensities of 1 and 2kW/m^2. Each intensity was combined with constant drying parameters as follows: air velocity at 0.5m/s and air temperature at 50^{o}C and 70^{o}C. This is to match the climatic air temperature in the summer in Maha Sarakham province, Thailand which has highest temperatures of around 40^{o}C. Therefore, this temperature was used for this experiment. Ambient air was forced by an air blower through an electric heating element to heat it to 40^{o}C. Air velocity was set by adjusting blower speed and measuring air velocity with an anemometer (Testo 445).

The moisture content of instant rice berry was determined in a hot-air oven (Memmert: Model 100-800) at 103^{o}C, 72hr (ASA, 1990), and calculated on a dry basis (d.b.). The error in measuring moisture content by this method was less than 3%. In the experiment, three experiments were carried out under each set of conditions, so as to confirm the reproducibility of the experiments.

Specific Energy Consumption

The specific energy consumption (SEC) of rice berry under far-infrared radiation drying was measured by Clamp-On Power Meter (YOGOGAWA; CW 140; kWh). This energy was defined as the energy required remove a unit mass of water from the initial moisture content of 318±2% d.b. to the final moisture content of 8% d.b.. The total energy was measured as the sum of the energy consumption by the far-infrared radiation source (E_{FIR}), blower (E_{blower}) and electrical heater (E_{heater}), which was no heat recovery of the heat loss in the exhaust air. The specific energy consumption was expressed in a MJ/kg$_{water\ evaporate}$ unit. The specific energy consumption was determined as followed by Equation (1).

$$SEC = (E_{blower}+E_{FIR}+E_{heater})/(M_i m_s - M_f m_s) \quad (1)$$

where M_i and M_f refer to initial and final moisture content (d.b.), m_s mass of dry solid (kg).

Determination of Rehydration

The rehydration ratio was determined using 20g of dry instant rice berry added with 100ml water heated by microwave for 6mm, drains the excess water for 5min, and then weighed. The rehydration ratio was calculated as weight of rice before and after cooling (Equation (2)).

$$\text{Rehydration ratio} = (\text{weight}_{after})/(\text{weight}_{before}) \quad (2)$$

where w_{after} and w_{before} is weight of rice berry after cooking and weight of rice berry before cooking.

Determination of Morphology by Scanning Electron Microscopy

The instant rice berry was observed the microstructure by scanning electron microscope (SEM, JSM 6460-LV), Mahasakham University. These samples were bended along the cross-section. Before coating with gold-palladium, the samples were placed on adhesive tape attached to a SEM stub. After that, it was determined by SEM to investigate the pore.

Color Analysis

The quality of the dried of instant rice berry was assessed by measuring their total color change. Color L, a and b values were determined by a colorimeter (CR-200, Minolta, Osaka, Japan). The color indices represent light to dark ($0 \leq L \leq 100$), green to red ($-60 \leq a \leq 60$), and blue to yellow ($-60 \leq b \leq 60$). The total color change (ΔE) of cooked/dried material was measured in 12 different points on the samples. It can be calculated using the following Equation (3).

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (3)$$

where *L*, *a* and *b* are lightness, redness and yellowness of the sample after drying and L_0, a_0, and b_0 are the values before drying. Each dried sample was measured 12 times from different parts of the total sample and averages were determined from 30 samples.

Results and Discussion

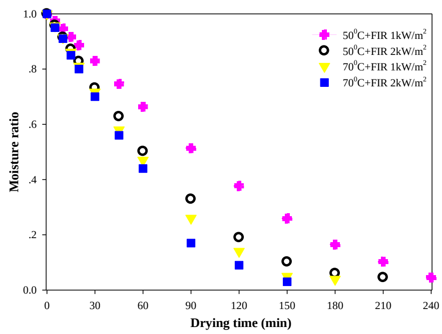


Figure 2 The moisture ratio of instant rice berry versus drying time.

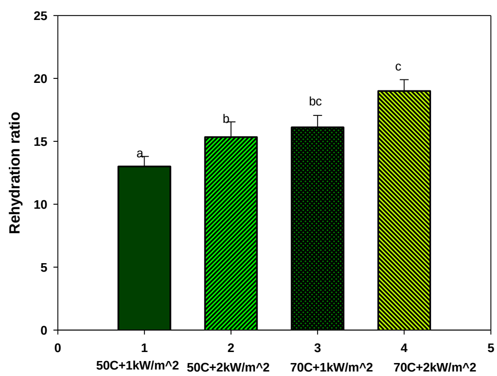
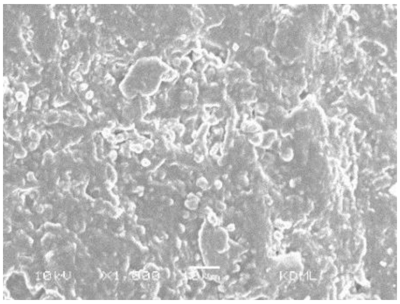
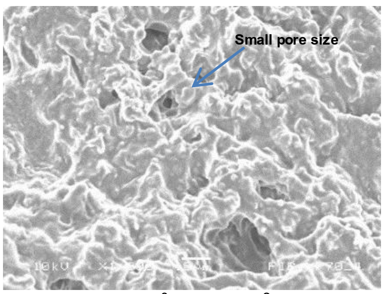


Figure 3 Rehydration ratio of instant rice berry.

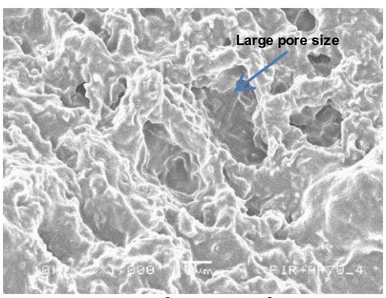
The moisture ratio of instant rice berry versus drying time with various far-infrared radiation intensities was experimentally investigated and the results are as shown in Figure 2. In this figure, the drying rate was rapidly increased with the increases of far-infrared radiation intensity. This was because more radiation far-infrared radiation intensity. This was because more radiation energy was absorbed by the water molecules at the penetrating layer, resulting in a faster drying rate during the first period of drying [3]. Besides, the decrease in the drying rate is also due to the reduction of moisture content leading to the lower concentration difference as the driving force of the mass transfer [2].



(A) Freshly cooked rice magnitudex1,000



(B) Instant rice berry 70^0C+1kW/m^2 magnitudex1,000



(C) Instant rice berry 70^0C+2kW/m^2 magnitudex1,000

Figure 4 The instant rice berry was observed the microstructure by SEM (JSM 6460-LV) at difference drying condition.

Rehydration ratio of instant rice berry was calculated by Equation (2) and the results are shown in Figure 3. The higher intensity induced larger pores, and allowed enhanced water absorption during rehydration and greater water retention inside the material cells, resulting in the higher degree of rehydration. Increasing far infrared intensity from 1 kW/m^2 to 2 kW/m^2 led to the dramatic increase in rehydration ratio by 30%.

Scanning electron micrographs of freshly cooked rice and instant rice berry are shown in Figure 4. To obtain morphology of instant rice berry after rehydration in terms of moisture content final moisture of 8% (d.b.), the dried sample seem to be more pores than the freshly cooked rice but, their morphologies could not be difference amongst the sample from far-infrared radiation intensities and drying temperature

Colors of the instant rice berry after the drying at different far infrared intensities are shown in Figures 5 and 6. It can be seen that dark violet grain, the colorimeter (CR-200, Minolta, Osaka, Japan) showed *L*- and *b*-values increased with far infrared intensity. The *L*-values were increased from 19.76±0.11 (freshly cooked rice) to 22.38±0.09 including *b*-values were increased from 3.09±0.02 to 3.27±0.01. In addition, *a*-values of the instant rice berry were decrease from 5.63 ± 0.01 to 4.61 ±0.01. The final product under drying temperature at 70^0C +1 kW/m^2 and 2 kW/m^2 radiation intensity were significantly different ($p<0.05$).

Figure 5 Color instant rice berry by the far infrared radiation drying at 2kW/m^2.

The total color difference value increased significantly with radiation intensity, total color intensity. These results are in accord with those of Afzal and Abe [4].

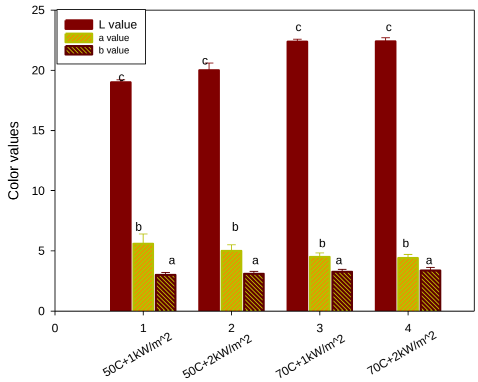


Figure 6 Colors of the instant rice berry after the drying at different far infrared intensities

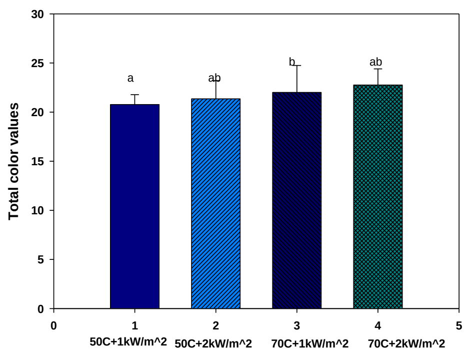


Figure 7 Total color difference of instant rice berry for difference far infrared radiation intensities

The specific energy consumption (SEC) of rice berry under far-infrared radiation drying it was also found that the drying rate increased with far infrared intensity. The increase in far infrared power caused a rapid increase in the temperature at the grain of rice berry. Clearly, the final moisture content of 8% (d.b.) amount of energy and time for drying at different far infrared intensities are depicted in Table 1. An increase of the applied intensity from 1 kW/m^2 to 2 kW/m^2 (50^{0}C) resulted in the shorter drying time and the reduced energy consumption by 30min and 2.82 kWh/kg $_{\text{water removed}}$, whilst drying temperature at 70^{0}C +1 kW/m^2 and 2 kW/m^2 radiation intensity were reduced energy consumption by 30min and 1.22 kWh/kg $_{\text{water removed}}$, respectively.

Table 1 Drying time and energy required for preparation of instant rice berry by the far infrared radiation drying at different far infrared intensities

Temperature (^{0}C)	Intensities (kW/m^2)	Drying time (min)	Energy consumption (kWh)	Specific energy consumption (kWh/kg$_{\text{water removed}}$)
50	1	240	3.20	8.62
	2	210	2.77	5.80
70	1	180	2.35	5.61
	2	150	1.41	4.39

Conclusions

Reduced energy consumption for instant rice berry were evaluated to ensure that the quality of the final product. Specific energy consumption at 2 kW/m^2 was 5.8 kWh/kg of water removed resulting in a 55% energy saving when compared to 1 kW/m^2 of far-infrared intensity. The drying rate increased with far-infrared power. The total color difference value increased significantly with radiation intensity. Increasing far-infrared intensity from 1 kW/m^2 to 2 kW/m^2 led to the dramatic increase in rehydration ratio by 30%. Dried sample seem to be more pores than the freshly cooked rice.

Acknowledgments

The authors would like to gratefully acknowledge the Rajabhat Maha Sarakham University (RMU), Thailand, for financial support under funding of research and development (Contract No. 2559A14702052)

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