Drying characteristics of whole Musa AA group ‘Kluai Leb Mu Nang’ using hot air and infrared vacuum

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Abstract. Dried Musa AA group ‘Kluai Leb Mu Nang’ are the famous processing goods of Chumphon province, the south of Thailand. In this paper, we improved the qualities of whole Musa AA group ‘Kluai Leb Mu Nang’ by using the hot air and infrared vacuum (HA and infrared vacuum) drying method which has two stages. The first stage of the method is the hot air (HA) and hot air-infrared (HAI) drying for rapidly reducing the moisture content and the drying times at atmospheric pressure, and the second stage, the moisture content, and color of the samples can be controlled by the HA and infrared vacuum drying. The experiment was evaluated by the terms of firmness, color change, moisture content, vacuum pressure and energy consumption at various temperatures. The results were found that the suitable temperature of the HAI and HA and infrared vacuum drying stages at 70°C and 55°C, respectively, while the suitable vacuum pressure in the second process was -0.4 bar. The samples were dried in a total of 28 hrs using 13.83 MJ/kg of specific energy consumption (stage 1 with 8.8 MJ/kg and stage 2 of 5.03 MJ/kg). The physical characteristics of the 21% (wb) of dried bananas can be measured the color change, L* = 38.56, a* = 16.47 and b* =16.3, was approximate the goods from the local market, whereas the firmness of them was more tender and shown a value of 849.56 kN/m³.

1. Introduction

Banana is an important food and cereal after rice and corn for the world’s human population. Thailand has been ranked as the third largest producer of bananas in Asia [1], has more than 30 varieties: Kluei Khai, Kluei Roy Wee, Kluei Nam Wah, Kluei Hom and Kluei Leb Mu Nang and M. acuminate. Kluei Leb Mu Nang is one important Thai banana cultivars. There is native and well known as local economic bananas at Chumphon province in southern Thailand. However, the productions of banana are needed an appropriate post-harvest technology and agricultural engineering to prolong the shelf life fruits in the storages and logistics process. Ripe banana is perishable and deteriorates rapidly after harvesting, especially [2]. Drying technology is wildly used in food industry preservation which has several techniques for the qualities of food dried production. Food drying is also a method of food preservation to remove moisture and water such as vegetables, fruits, and another agricultural production. Meanwhile, Drying is one of the technologies that can be used to preserve banana, there are many techniques to dry banana. Most common techniques for drying banana are HA drying [3] which is the oldest method of food preservation. In this process, heat transferred from the HA to the
sample and removal of water to the air by convection. In addition, infrared (IR) drying is based on the operation of IR wavelength radiation from the heat source, and heat transported into the internal structure of the vegetables and fruits, thus increases its temperature [4]. Furthermore, the combination of HA and IR drying method is gaining popularity in food preservation because of uniform heating and inherent over only HA drying. However, drying methods have been developed for high qualities of food preservation product [5]. At present, HA and infrared vacuum drying are useful in food preservation for drying of thin slices [6] and the whole of fruits [7], [8] which are widely applied in agriculture and food technology. Therefore, the drying processes have been developed to produce the quality foods conservative productions for increasing efficiency and value.

In this study, the experiment was investigated to the terms of drying rate, color change, moisture content, vacuum pressure and energy consumption at various temperatures to improve the qualities of whole Musa AA group ‘Kluai leb Mu Nang’ by using the HA and infrared vacuum drying method.

2. Hot air and infrared vacuum drying setup

2.1. Structural dryer

![Figure 1. The combined of HA and infrared vacuum system.](image)

Kluai Leb Mu Nang’ with HA and infrared vacuum drying setup was developed at King Mongkut’s Institute of Technology Ladkrabang Prince of Chumphon Campus (KMITL PCC) laboratory which has volume of stainless steel (food grade) chamber of 65.3 L, the chamber has 8 trays for the bananas drying in the uniform vertical dimension in which the sample can be received the external heat into the chamber thoroughly as shown in Figure 1. In addition, the apparatus have a bucket for water released from banana with 5% of the volume.

2.2. Infrared heater

An infrared heater is a high efficiency of heat transfer radiation which can be propagated into absorbed materials. In this experiment, we used an infrared heater 3 rods having a horizontal burning position which has diameter with 1.7 cm and length of 30 cm, the input power of 650 W, 220 volts. An infrared radiation is ranged from 3 to 10 mm wavelength by convection and conduction into the samples from the surface to the internal of bananas.
2.3. Vacuum pump
Vacuum is generated by a vacuum pump, depending on the requirements of suction power and pressure conditions. In this case, the vacuum pump (Single stage vacuum pump: RT, 185 L/min, 220V/50Hz) was connected to under the oven chamber as shown in Figure 1.

2.4. Materials
The bananas were produced by agriculturist in Pathiu district, Chumphon province, Thailand. We selected certainly ripe level (all yellow) and obtained from a local market, stored at room temperature of 27°C. The samples were peeled by hand which have diameter of 2 to 2.5 cm and length with 11 to 12 cm. There were washed in 3% sodium chloride (NaCl) solution to control color, after that the samples were uniformly placed in a single layer on the trays for 10 minutes before drying process to measure initial moisture content of the fresh bananas, was determined using hot air oven (MEMMERT Model600) at 105 °C for 24 hours.

2.5. Drying process
In this experiment, the experimental conditions of drying (Figure 2) can be divided into two stages. The first stage, the drying characteristics of bananas (whole Musa AA group ‘Kluai Leb Mu Nang’) were combined the airflow and infrared radiation dryer system, temperature and moisture content can be controlled by using airflow 0.3 L/min of 60°C, 70°C and 80°C at atmospheric pressure to evaluate optimal temperature for HA and HAI drying. The second stage, the optimal temperature of the first stage can be used the standard to test the properly of vacuum pressure for HA and infrared vacuum drying of whole bananas which varied the temperature of 50°C, 55°C and 60°C with vacuum pressure range of -0.1 to -0.6 bar. Finally, the humidity, color, bananas texture, energy efficiency and physical properties were analysed to find the optimal conditions of HA and infrared vacuum drying. In addition, the study can be varied airflow at 0.0, 0.3 and 0.6 L/min.

![Figure 2. Diagram of the drying process: two stages with the drying conditions.](image)

3. Results and discussion
A comparison between HA and HAI drying characteristics, we found that the HAI of 70°C can be preserved the qualities of whole bananas higher than HA drying because the drying rate with the slope in the graph between moisture content and time presented the least square linear regression as shown in Figure 3. Furthermore, the temperature drying of 60°C and 80°C in the chamber cannot be uniformly distributed temperature of the total trays (8 trays) effecting to color and texture of the
samples and over dehydrated which made bananas dried to decreased quality, respectively. Therefore, the HA and HAI drying results showed the suitable temperature of 70°C at atmospheric pressure which is standard error estimate (SEE) of 1.085 less than another temperature of 4 hrs drying time was shown in Table 1.

Table 1. Drying rate of HA and HAI methods.

| HA Drying | 4 hrs | 6 hrs |
|-----------|-------|-------|
| Temperature (°C) | $y_0$ | $a_0$ | R | SEE | $y_0$ | $a_0$ | R | SEE |
| 60 | 73.529 | -0.115 | 0.407 | 0.425 | 73.527 | -0.114 | 0.481 | 0.466 |
| 70 | 73.568 | -0.415 | 0.966 | 0.181 | 73.576 | -0.422 | 0.980 | 0.187 |
| 80 | 73.393 | -1.825 | 0.894 | 1.500 | 73.346 | -1.790 | 0.890 | 2.061 |

Hence, the trays were alternated to above and below by producer for thoroughly qualities and physical properties of the bananas drying. Therefore, the suitable temperature of Klaui Leb Mu Nang drying with the atmospheric pressure was 70°C in which have dried of 48 hrs that accorded with the ordinary attribute which is corresponding to the Klaui Leb Mu Nang drying production of agriculturist at Chumphon province. The drying temperature and heating method of the first experiment at the atmospheric pressure were evaluated with the least square regression of drying rate in each period was shown in Figure 3 and the least square is shown by equation (1).

\[ \text{Moisture} = y_0 + a_0 \text{Time} \]  

(1)

where

- Moisture is the wet basis moisture content (%wb).
- $y_0$ is the initial moisture content (%wb).
- $a_0$ is the slope of line (%wb/hr).

The $a_0$ was estimated by the drying rate for various temperature and technical heating. Table 1 showed the interpretations of drying condition and found that the drying rates increased, the
temperature increased too. Figure 4 was shown the effect of HA and infrared vacuum drying of whole banana sample which receives the radiation from infrared heater and hot airflow which used to control the surface color and the suitable temperature for qualities of the bananas drying at vacuum pressure of -0.1 and -0.4 bar.

The experimental results of the HA and infrared vacuum drying have shown a suitable state for heating temperature of 55°C at -0.4 bar of vacuum pressure within 28 hrs (•) drying time in Figure 4, which is the samples could rapidly dehydrated of moisture content by using SEC of 13.83 MJ/kg and the percentage of damaged sample was 18.2% less than the drying condition with -0.1 bar at the same temperature. The physical characteristics of the 21% (wb) of dried bananas can be measured the color change, \( L^* = 38.56, a^* = 16.47 \) and \( b^* = 16.3 \), was approximate the goods from the local market, where as the firmness of them was more tender and shown a value of 849.56 kN/m³. The standard qualities banana are the color change, \( L^* = 39.53, a^* = 11.20, b^* = 29.39 \), and firmness of 990.91 kN/m³ have shown in Table 2.
Table 2. The color change and firmness of the methods.

| Drying Technique                         | L*   | a*   | b*   | Firmness (kN/m²) |
|------------------------------------------|------|------|------|------------------|
| HA                                       | 26.83| 9.76 | 26.22| 943.73           |
| HA and Infrared vacuum                   | 38.56| 16.47| 16.30| 849.56           |
| Standard sample from the local market    | 39.53| 11.20| 29.39| 990.91           |

However, HA and infrared vacuum drying technique are expensive for the system setup in which the temperature and vacuum pressure can be controlled by automatics the system, even if the drying time less than other the hot air dryer of the agriculturist, but the qualities of the dried samples can be preserved the same as dried banana production on the market by the dryer which do not alternate the trays during drying process.

4. Conclusion

The combined drying process of the whole Musa AA Group ‘Kluai Leb Mu Nang’ with the HA and infrared vacuum drying characteristics was determined in this work. The experimental results have shown the effect of temperature, infrared heating radiation and vacuum pressure on the whole bananas dried, the optimized drying temperature was found of 70°C at atmospheric pressure with HA and HAI dryer within 4 hrs period time. After that the samples have been dried by the infrared vacuum with the vacuum pressure of -0.4 bar using a suitable temperature was 55°C for 24 hrs. Therefore, The qualities of whole Musa AA Group ‘Kluai Leb Mu Nang such as color, moisture content, temperature, texture and physical properties can be preserved by the combined HA and infrared vacuum technical drying for banana and food preservation. However, this experimental apparatus is a primary combined HA and infrared vacuum which has been developed for higher efficiency food preservative dryer in the future.

5. References

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