ORIGINAL ARTICLE

Optimization of a drying process using infrared-vacuum drying of Cavendish banana slices

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Abstract

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The application of far infrared radiation (FIR) to vacuum drying is interesting since FIR leads to higher drying rates and yields the dried product of better quality. In this work far infrared radiation drying of Cavendish banana slices under vacuum was investigated. Cavendish banana slices with an initial moisture content of 300%(d.b.) were dried at various vacuum pressures (5, 10 and 15 kPa), temperatures (50, 55 and 60°C) and thicknesses (2, 3 and 4 mm) until the final moisture content of 7% (d.b.) was reached. The results revealed that the vacuum pressure, temperature and thickness had significant effects on the drying kinetics and various qualities of the dried banana viz. color, hardness and shrinkage. Combined FIR-vacuum drying shows good potential of producing a fat-free shuck-like product from banana. In addition, the optimum condition for infrared-vacuum drting is at temperature of 50°C, pressure of 5 kPa and thickness of 2 mm.

Key words : drying kinetics, color, hardness, shrinkage, temperature distribution

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การอบแห้งกล้วยหอมหั่นบางด้วยเครื่องอบแห้งสุญญากาศร่วมกับรังสีอินฟราเรดไกล
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การประยุกต์รังสีอินฟราเรดไกลกับการอบแห้งแบบสุญญากาศได้รับความสนใจเนื่องจากรังสีอินฟราเรดไกลทำให้อัตราการอบแห้งสูงขึ้น และผลิตภัณฑ์ที่ได้ยังมีคุณภาพดีขึ้น ในงานนี้การอบแห้งกล้วยหอมหั่นบางด้วยรังสีอินฟราเรดไกลภายใต้ความดันสุญญากาศได้ถูกศึกษา กล้วยหอมหั่นบางที่มีความชื้นเริ่มต้น 300 %มาตรฐานแห้ง ถูกทำให้แห้งที่ความดัน (5 10 และ 15 กิโลปาสคาล) อุณหภูมิ (50 55 และ 60°C) และความหนา (2 3 และ 4 มม.) ต่าง ๆ จนกระทั่งได้ความชื้นสุดท้าย 7 %มาตรฐานแห้ง ผลการศึกษาพบว่า ความดันสุญญากาศ อุณหภูมิ และความหนา มีผลต่อจลนพลศาสตร์ของการอบแห้ง และคุณภาพของกล้วยอบแห้ง ทางด้าน สี ความแข็ง และการหดตัว การอบแห้งด้วยเครื่องอบแห้งสุญญากาศร่วมกับรังสีอินฟราเรดไกล แสดงให้เห็นว่ามีศักยภาพที่ดีในการนำไปผลิตผลิตภัณฑ์ ขบ เคี้ยว จากกล้วย โดยจุดเหมาะสมสำหรับการอบแห้งสุญญากาศร่วมกับรังสีอินฟราเรดไกล คือ ที่อุณหภูมิ 50°C ความดัน 5 กิโลปาสคาล และความหนา 2 มม.

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Cavendish banana is an important fruit in many countries. Ripe banana is perishable and deteriorates rapidly after harvesting; hence there is a need to apply an appropriate post-harvest technology to prolong the shelf life of the fruit. Air drying and solar drying are among the most common techniques used to preserve banana. However, there is much loss of thermal energy in convective drying, making it a less efficient process. It is also well known that air drying leads to much quality degradation of the product, either in terms of its physical or nutritional properties. Far infrared (FIR) has recently received much attention as an alternative drying technique due to the minimal energy loss during the process. When infrared radiation is used to heat or dry moist material, the energy of radiation penetrates through the material and converts into heat (Ginzburg, 1969). Since the material is heated rapidly and more uniformly and since infrared radiation energy is transferred from the heating element to the product without heating the surrounding air, the energy consumption in infrared drying is relatively low compared to hot air drying.

Nowadays, infrared radiation is applied to several dryers because it has advantages of increased drying efficiency and space saving (Ratti and Mujumdar, 1995; Yamazaki, Hashimoto, Honda and Shimizu, 1992). The use of infrared radiation technology in dehydrating foods has several advantages as follows: decreased drying time, high energy efficiency, high quality product, uniform temperature in the product and reduced necessity for air flow across the product (Dostie, Seguin, Maure, Ton-That and Chatingy, 1989; Navari, Andrieu and Gevaudan,1992). Several researchers have applied FIR drying technique successfully to many food products, e.g., potato (Afzal and Abe, 1998), barley (Afzal and Abe, 2000), and rice (Abe and Afzal, 1997). Since most foods are heat sensitive in nature, it is desirable to be able to dry these products at low temperature to preserve its quality. Drying under vacuum is generally performed since under vacuum, water evaporates at low temperature; hence, drying can be performed at low temperature. Serveral researchers have indeed combined the advantages of FIR drying with that of vacuum drying to dry several food products. Mongpraneet, Abe and Tsurusaki (2002) examined the drying behavior of the leaf parts of welsh onion undergoing combined far infrared and vacuum drying. The results showed that the radiation intensity levels dramatically influenced the drying rate and the dried product qualities. Mongpraneet, Abe and Tsurusaki (2004) later determined the energy consumption in far infrared drying of onion. From their experiments, less than half of the energy input was utilized for evaporating water from the onion. Approximately 73-99% of the energy input, depending on the dryer configulation, was converted into radiant energy. The efficiency decreased with increasing distance between the heater source and drying materials. The distance of 10 cm between the heater and the onion surface resulted in the highest drying efficiencies in their work.

In this work, the drying characteristics of Cavendish banana slices undergoing FIR-vacuum drying were examined. The qualities of the banana slices in terms of color, shrinkage and hardness were also investigated with an aim to produce a fat-free snack-like product.

Materials and Methods

A schematic diagram of the FIR-vacuum dryer used in the present study is shown in Figure 1. The dryer consists of a stainless steel drying chamber, insulated with rock wool, with inner dimensions of 45x45x45 cm^3. An FIR heater, rated at 200W, is installed at the top of the drying chamber. The distance between the FIR heater and a tray, which has dimensions of 20x28 cm^2, is approximately 15 cm. The temperature at 5 cm above banana slices, the wall temperature and the banana surface temperature (1 mm beneath the surface) were measured continuously using type k thermocouples connected to an expansion board (model no. EXP 32, Omega Engineering, Stamford board, CT). Thermocouple signals were then multiplexed to a data acquisition card (model no. CIO-DAS16Jr., Omega Engineering, Stamford, CT) installed in a PC. LABTECH NOTEBOOK software (version 12.1, Laboratory Technologies Corp.) was used to read and record the temperature data. PID controller (model E5CN, Omron, Tokyo, Japan) was used to control the surface temperature of banana slices via switching on/off the heater. The vacuum condition in the drying chamber was maintained using a vacuum pump (model ET32030, Nash, Trumbull, CT). The change of the mass in the sample was detected continuously (at 1 min intervals) using a load cell (model Ucg-3kg, Minebea, Nagano, Japan), which was installed in a smaller chamber connected to the drying chamber by a flexible hose and also to an indicator and recorder (model AD 4329, A&D Co., Tokyo, Japan).

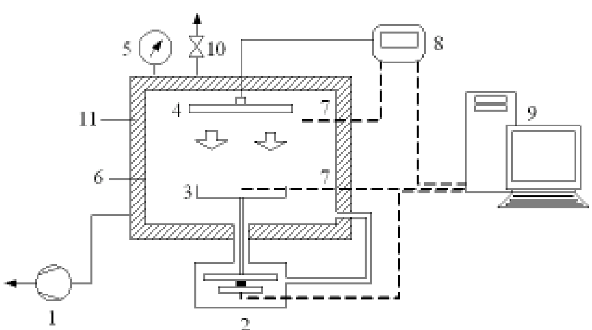

Figure 1. Schematic diagram of the far infrared-vacuum dryer and its accessories.

Fresh Cavendish banana with ripness level 5 (green tip) was obtained from a local supermarket. Prior to the start of each experiment Cavendish banana was peeled and cut into slices with thickness of 2, 3 and 4 mm. The banana slices (about 24 pieces) with initial moisture content of 300% d.b. were placed on a tray. The drying chamber was then sealed tightly. A vacuum pump was then switched on to evacuate the drying chamber to the desired operating pressure and the FIR heater was turned on. The experiments were performed at the following conditions: absolute pressures of 5, 10, and 15 kPa; surface temperatures of banana slices of 50, 55, and 60°C and thickness of banana slices of 2, 3, and 4 mm. The experiments were conducted until the final moisture content was 7% d.b. In experiment, the banana slices with tickness of 2,3 and 4 mm. were carried out at various pressures (5, 10 and 15 kPa). In addition, the surface temperatures of 50, 55, and 60°C were varied in each pressure.

Evaluation of drying qualities

The physical qualities of Cavendish banana slices evaluated were color, shrinkage and texture in term of hardness. Colors of the samples were measured in a Hunter Lab color system using a colorimeter (Juki Model JP100, Japan). For each drying experiment the color measurement was performed on five dried samples and the color values were compared with those of fresh samples. All experiments were performed in duplicate and the average values were reported. The color changes (L and b values only) were calculated by:

$$\Delta L = \frac{L - L_i}{L_i} \quad \text{and} \quad \Delta b = \frac{b - b_i}{b_i}$$

where L and b represent the lightness and yellowness of the samples, respectively. All experimental data were analyzed using an analysis of variance (ANOVA).

Calculation of shrinkage was based on the concept of fluid replacement. In this work, n-heptane was used as fluid because the Cavendish banana slices did not absorb n-heptane. Shrinkage was expressed in terms of the percentage change in the volume of the original sample.

$$\%Shrinkage = \left(\frac{V_i - V}{V_i}\right) \times 100 \qquad (4)$$

where V_i and V are respectively the volumes of Cavendish banana at the beginning and at the end of each drying experiment. The texture of the Cavendish banana slice was measured in terms of hardness (the force acting to break the Cavendish banana slice). Texture analyzer was conducted to examine this force. The results of the texture analysis were compared with commercial potato crisp (trade mark LAY) with round flat shape and diameter about 4 cm.

Results and Discussion

Drying kinetics of banana slices

Drying curves of banana slices with thicknesses of 2 and 3 mm undergoing FIR-vacuum drying at various temperatures and pressure are shown in Figure 2 and Figure 3, respectively. As expected, at the same vacuum level, the rate of moisture reduction increased with an increase in the drying temperature because of the increased temperature difference between the drying product and the surrounding, as well as the higher moisture diffusivity. Figure 4 and 5 illustrate the effect of vacuum level on the drying behaviour of banana slices. It is seen in these figures that the rate of moisture reduction increased with decreasing absolute pressure of the drying chamber since at a lower pressure, water boils and evaporates at a lower temperature. Hence, higher drying rates were obtained. The effect of the vacuum level on the drying behavior of banana slices was more pronounced at lower temperature. At 15 kPa, the boiling point of water is around 55^{o}C, so drying at this pressure implied the removal of water at

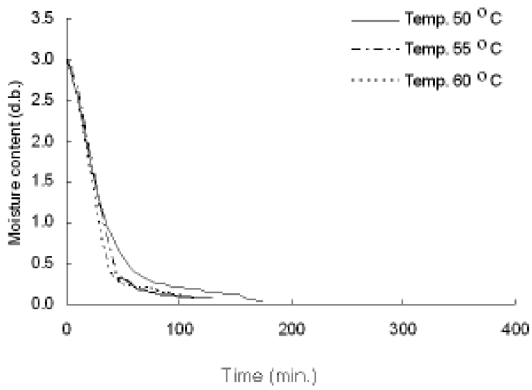

Figure 2. Drying curve with various temperatures at thickness 2 mm and pressure 10 kPa.

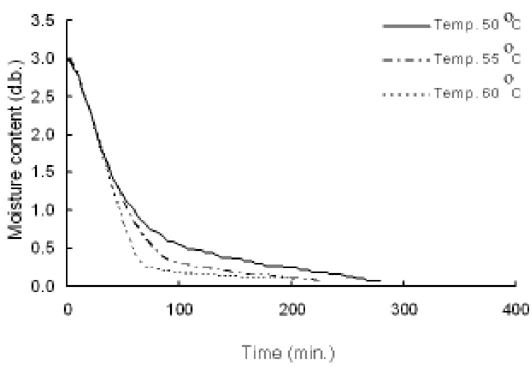

Figure 3. Drying curve with various temperatures at thickness 3 mm and pressure 10 kPa.

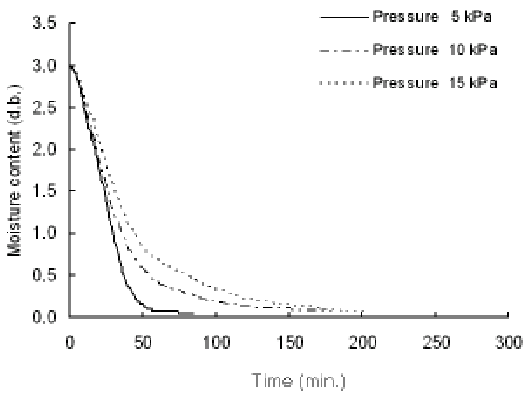

Figure 4. Drying curve of Cavendish banana slices with operating pressure as a parameter (thickness = 2 mm; T = 55°C).

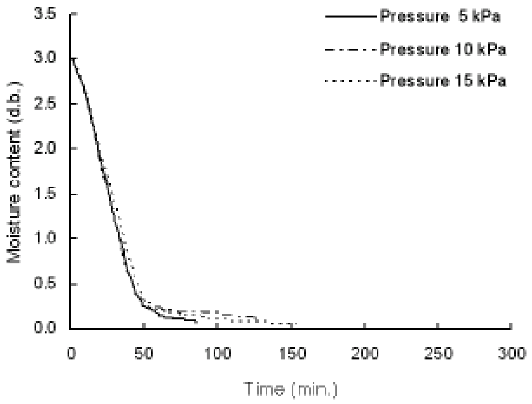

Figure 5. Drying curve of Cavendish banana slices with operating pressure as a parameter (thickness = 2 mm; T = 60°C).

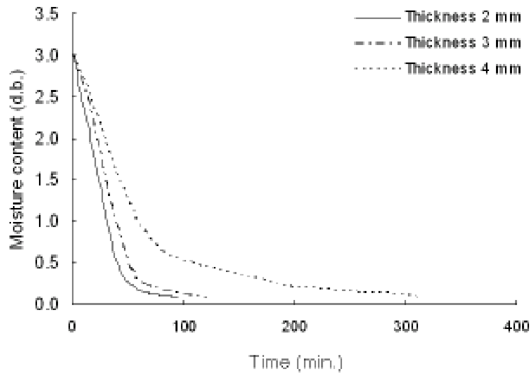

Figure 6. Drying curve of Cavendish banana slices with thickness as a parameter (P = 5 kPa; T = 50°C).

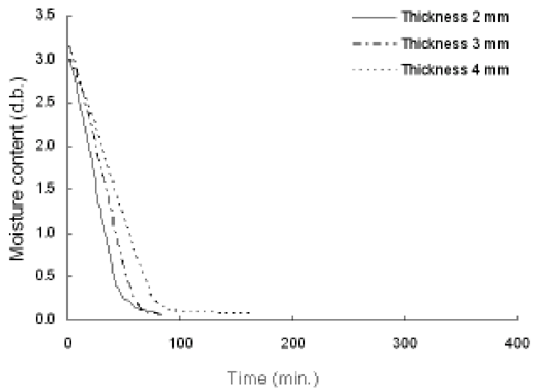

Figure 7. Drying curve of Cavendish banana slices with thickness as a parameter (P = 5 kPa; T = 60°C).

temperature very close to its boiling point. The drying rates at this pressure were, therefore, much lower than those at lower pressures, where water boils at lower temperatures. It can be seen from Figure 5, however, that if drying was conducted at temperatures higher than the boiling point of water at the corresponding operating pressure, the effect of the operating pressure would be much smaller. Figures 6 and 7 show the effect of slice thickness on the drying curves of Cavendish banana at 50°C and 60°C (at 5 kPa), respectively. The drying rate determined from slope in graph between moisture content and time decreased with increasing a sliced banana thickness because the penetrated FIR to a sliced banana decreased with increasing thickness. Figure 8 shows the temperature evolution at various points within a slice. At the beginning of drying, the temperature at the banana surface dropped quickly as water immediately evaporated from the banana surface due to abrupt pressure drop. As the water evaporated it removed heat from the banana surface in terms of the heat of vaporization; hence, the temperature drop. After this period, the surface temperature increased gradually due to the use of the FIR heater and approached the set controlled surface temperature. Temperature at 5 cm above banana surface reduced suddenly at the beginning of drying since pressure in the drying

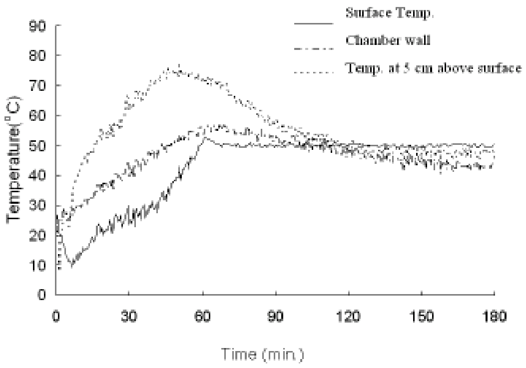

Figure 8. Temperature distribution with in a Cavendish banana slice (P = 5 kPa; T = 50°C; thickness = 3 mm).

Table 1. Color change of Cavendish banana slices.*

Pressure (kPa)	Temperature (°C)	Δ b/bi	Δ L/Li
5	50	0.167±0.033[a]	-0.063±0.013[a]
	55	0.245±0.034[b]	-0.084±0.008[b]
	60	0.350±0.045[c]	-0.110±0.015[c]
10	50	0.152±0.032[a]	-0.067±0.006[a]
	55	0.235±0.035[b]	-0.080±0.010[b]
	60	0.337±0.043[c]	-0.110±0.013[c]
15	50	0.182±0.037[a]	-0.070±0.007[a]
	55	0.245±0.036[b]	-0.082±0.004[b]
	60	0.344±0.038[c]	-0.121±0.017[c]

***Mean ± SD**
[a-d] In the same column with different superscripts means that the values are significantly different (P<0.05)
Note: b = yellowness; L = lightness

chamber was immediately reduced by vacuum pump. The temperature increased suddenly when the FIR heater operated. When the temperature at 5 cm above the banana surface reached maximum point, the banana surface temperature approached the set controlled surface temperature. At the set controlled surface temperature, the FIR heater switched off. Since the temperature at 5 cm above banana surface reduced gradually until the temperature was constant around the set controlled surface temperature. The chamber wall temperature increased gradually until it was constant near the set controlled surface temperature.

Qualities of dried Cavendish banana slices

Table 1 illustrates the color changes of Cavendish banana slices undergoing various banana surface temperatures and pressures. It was found that lightness decreased with increasing surface temperature, while yellowness increased with increasing surface temperature due to browning reaction occurring during drying process. Since the color of banana surface was more yellowness. As shown in Table 1, pressure change did not significantly affected the banana surface color. Table 2 illustrates shrinkage of Cavendish banana slices. The high shrinkage value increased with decreasing surface temperature, because drying at high temperatures was caused the banana surface to become dry. The water at the banana surface was removed from banana surface suddenly. Since hardening occurred at the surface, it assisted to maintain the shape of the banana. In addition, shrinkage increased with increasing pressure, because the increased pressure caused the banana surface to dry slowly. Table 3. shows the hardness in term of maximum force of the banana slices at various pressures and temperatures. From Table 3, the pressures and temperatures were not significant affect to the hardness of banana slices while the hardness increased with increasing thickness. Figure 9 shows a comparison in hardness of Cavendish banana slices and that of commercial potato chip with various thicknesses. It was found that a 2 mm. banana slices gave a hardness value close to that of the commercial potato crisp (LAY) (3.74±0.09 N).

The optimum criterion for drying banana slices were drying time and qualities of dried banana slices in terms of colour, shrinkage and hardness. As mentioned in the former section, it was found that the dried banana slices at temperature of 50°C, absolute pressure of 5 kPa and slice thickness of 2 mm. gave the good qualities (high lightness, low yellowness, low shrinkage and low hardness) while drying time is slightly higher than that of 55°C and 60°C. Since this point was choosen

Table 2. Shrinkage of Cavendish banana slices.*

Thickness (mm)	Pressure (kPa)	Temperature (°C)	% Shrinkage
2	5	50	25.35±0.78[a]
		55	24.31±0.71[a]
		60	22.25±1.40[a]
	10	50	26.86±1.85[cb]
		55	24.58±1.04[b]
		60	23.54±1.54[b]
	15	50	29.88±4.39[d]
		55	25.82±0.60[c]
		60	25.71±0.71[c]
3	5	50	40.86±1.78[ab]
		55	37.42±2.05[a]
		60	34.67±1.87[a]
	10	50	41.79±1.71[bc]
		55	39.98±2.82[b]
		60	38.45±2.16[ab]
	15	50	43.82±1.87[d]
		55	41.67±1.91[c]
		60	40.15±2.07[c]
4	5	50	46.39±0.87[ab]
		55	45.61±0.89[a]
		60	44.64±1.02[a]
	10	50	47.07±0.73[c]
		55	46.04±0.67[b]
		60	45.92±0.43[ab]

*Mean ± SD
[a-d] In the same column with different superscripts means that the values are significantly different (P<0.05)

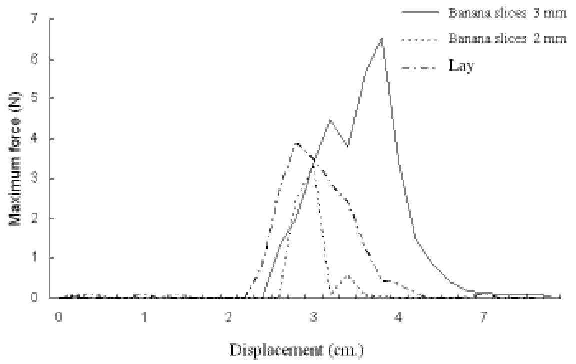

Figure 9. Comparison of hardness of Cavendish banana slices and that of commercial potato chip.

Table 3. Maximum force of the banana slices at various temperatures and pressures.

Thickness (mm)	Pressure (kPa)	Temperature (°C)	Max force (N)
2	5	50	3.40±0.11[a]
		55	3.39±0.17[a]
		60	3.44±0.12[a]
	10	50	3.43±0.15[a]
		55	3.44±0.16[a]
		60	3.41±0.13[a]
	15	50	3.42±0.11[a]
		55	3.40±0.18[a]
		60	3.41±0.13[a]
3	5	50	6.23±0.17[b]
		55	6.26±0.15[b]
		60	6.29±0.12[b]
	10	50	6.24±0.15[b]
		55	6.27±0.17[b]
		60	6.26±0.11[b]
	15	50	6.22±0.14[b]
		55	6.25±0.12[b]
		60	6.28±0.17[b]

*Mean ± SD
[a-b] In the same column with different superscripts means that the values are significantly different (P<0.05)

as the optimum condition for far infrared radiation-vacuum of banana slices.

Conclusion

Drying of Cavendish banana slices in a vacuum dryer with installed FIR was experimentally investigated in this work. The effects of temperature, vacuum level and thickness of Cavendish banana slices on the drying behavior and quality of banana slices were then examined. The result showed that the temperature, vacuum level and thickness of Cavendish banana slices had significant effects on the drying kinetics and various qualities tested of banana. Based on the results obtained and optimum criterion, the optimum conditions for drying Cavendish banana slices are at a temperature of 50°C, absolute pressure of 5 kPa and slice thickness of 2 mm.

Acknowledgements

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