Evaluation of Banana Solar Dryer by Its Dried Products

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Abstract

This paper proposes the design and evaluation of a solar dryer that has been built to produce dried banana. 7-levelled ripeness bananas obtained locally at the initial average moisture percentage of 66.82 were used as raw material and then dried for 40 hours at different hot air speeds inside the dryer. From the main parts of the dryer, consisting 2x1.2 m^2 solar collector and 1.2x0.5x1.2 m^3 drying chamber, the maximum inside temperature could be reached as high as 50°C. The banana moisture was decreased as an increase of hot air speed and it suggested that at the hot air velocities of 0.9 m/s, the product moisture was brought to well within standard. However, the position of bananas inside the dryer during drying process also affected the texture of the products, i.e. the feelings during chewing food. In order to evaluate the dryer performance, moisture content together with the texture analyser resulted in terms of shear force, hardness, adhesiveness and springiness were observed and discussed.

***Keywords**:* solar dryer, solar dried banana, food mechanical properties, texture analyser, and sensory analysis.

1. Introduction

Banana (*Musa sapientum* L.), a climacteric tropical fruit, is locally grown in all parts of Thailand. It is well-known as a plenty available and cheap fruit. So, there are many value added processed products made of bananas such as dried banana, rolled banana and sugar-coated banana made in local communities. Among those, dried banana is one of the most popular. People tend to love its sweet taste and soft texture. Moreover, the product can be kept for long time as a result of drying process, which reduces moisture of banana and hence lower the number of harmful microorganism.

Normally, there are two ways to produce dried banana, 1) drying by direct sun light and 2) using solar dryer [1]. The direct sun-drying method has been widely used because of its lower cost and simplicity however there is a chance of dust and germ contamination from the open air. Solar dried banana in closed area heating with various conventional heat sources hence have been widely developed in order to solve this problem. Most of the time, the focus of the design is to produce dried products to achieved desired moisture content but sensory analysis representing consumers' satisfaction is rarely mentioned.

In this research, a simple, mixed-mode type solar dryer was designed and built for dried banana processing. The need requirement was analysed and design parameters were set to achieve design goals including drying chamber temperature and moisture content of the final dried banana. It was intended to bring some texture analysis parameters which concerned consumers' satisfaction such as shear force (bite force), hardness, adhesiveness and springiness or the feelings during chewing food to be considered with the original design goals. The dried bananas were then tested with texture analyser, a small test rig that could imitate human biting and chewing and report results as force and energy used. Then the results were determined in order to evaluate the designed solar dryer performance consistency.

2. Methodology

2.1 Design of the mixed-mode solar dryer

The mixed-mode solar was designed based on the initial needs which were

1. To produce a simple solar dryer that was able to dry 10 kg of banana per one batch.
2. The final moisture content of dried banana was less than 21% (wet basis). [2]
3. The ideal temperature inside the drying chamber was 40°C and the maximum temperature could reach as high as 50°C.
4. Dried bananas produced from the dryer were tender and soft not just hard, brittle or dry. All products' texture properties in the same batch should have been consistent.
5. Mixed-mode type solar dryer consisted of two main parts, solar collector and drying chamber. Small electric fans were installed to enhance hot air flow though the chamber.

2.1.1 Design of drying chamber

This part of solar dryer was not only designed to contain the drying products, but also to prevent the products from rain, insects, dust or other dirtiness. Size of the grating was calculated from the Eq. (1) and Eq. (2) [3].

$$V = \frac{m}{\rho} \qquad (1)$$

$$Grating = \frac{V}{d_b} \qquad (2)$$

where

ϑ = Volume of banana, m^3

æ = Mass of banana, kg

ρ = Density of banana, kg/m^3

‘, = diameter of banana, m

Grating = Grating area, m^2.

2.1.2 Design of solar collector

The solar collector was used to collect the solar energy in order to heat up the air flowing into the chamber. In this research, ideal aimed temperature was 40°C. So, the solar conductor was designed as flat surface with back-pass air-heating based on Eq. (3) [4]. Fig. 1 shows the schematic representation of a mixed type solar dryer.

$$A = \frac{\dot{m} C_p (T_o - T_i)}{I\eta} \qquad (3)$$

where

A = Collector solar-energy collection area, m^2

$\dot{m}$ = Mass flow rate, kg/s

I = Insolation, W/m^2

η = Collector efficiency, %

C_p = Specific heat capacity of working fluid (i.e. air), kJ/kg-°C

T_o = Collector outlet temperature, ^oC

T_i = Collector inlet temperature, ^oC

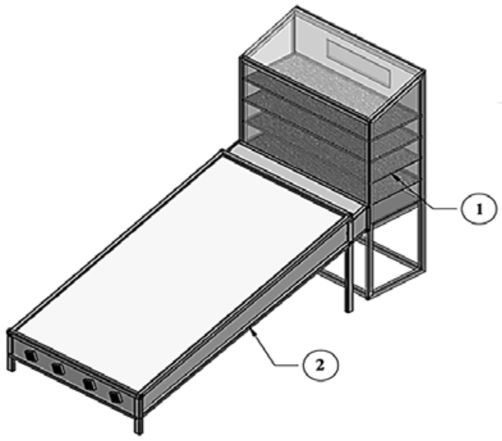

Fig. 1 Schematic representation of Mixed Type Solar Dryer: (1) Solar Dryer; (2) Solar Collector

2.2 Raw material and banana drying procedure

Matured bananas obtained locally from Chiang Mai municipal market were selected. The average size of these bananas was about 4-cm wide and 12-cm long. Fresh bananas were kept for 5-7 days to reach the 7-levelled ripeness then were soaked in salt water (5% saline solution) for 15 minutes before drying as shown in Fig. 2.

Fig. 2 7-levelled ripeness bananas soaked in salt water (5% saline solution) before drying

The soaked bananas were then place carefully in the drying chamber, which consisted of 4-levelled storage (4 storeys). At each level, 42 bananas were placed. Totally this could make around 170 bananas in one batch. All bananas were left in the chamber for 40 hours, 8 hours per day. Inside the chamber, there were a set of electric fans that could aid hot air flowing at the velocities of 0.45, 0.65 and 0.9 m/s. At each air velocity, the bananas were dried and collected for testing later.

2.3 Operating temperature assessment and measure of product physical properties

Exit air temperature of solar collector and drying chamber temperature were measured using thermocouples installed inside the dryer in order to confirm the drying condition. Physical properties of the dried bananas were assessed in terms of wet basis moisture and texture analyser measurement. Firstly, to evaluate the dryer performance by measuring product moisture according to the standard for community's dried product, banana samples from different positions were randomly collected every 8 hours to monitor moisture reduction rate using Ohaus MB45 moisture analyser. The best condition for drying were chosen and the dried bananas from that condition were put for texture evaluation using Brookfield's texture analyser model CT3 (see Fig. 3) where compression test mode and texture profile analysis (TPA) mode were performed using cutting head, 60-mm length probe (TA7) and cylindrical flat head, 12.70-mm diameter probe (TA12), respectively. The former test represented shear force while the latter resulted in product's hardness, adhesiveness and springiness.

The assessments represented the physical properties of the dried banana as a result of heat, hot air velocities and stacking layer of the solar dryer and hence could be used to evaluate the designed dryer from the finishing product view point.

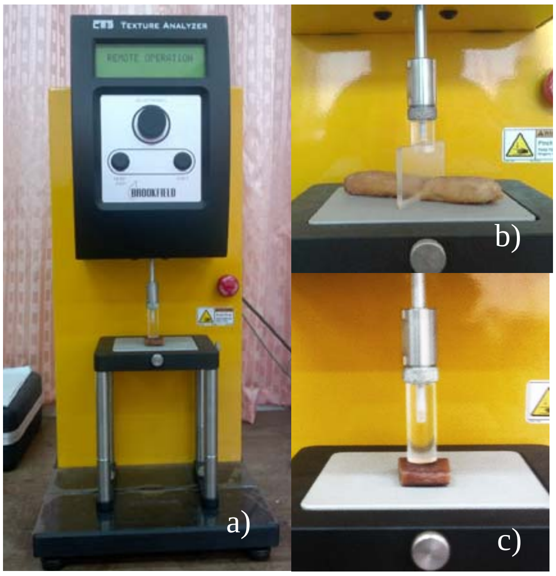

Fig. 3 Test Performed Using CT3 Brookfield's Texture Analyser: a) The Test Rig, b) The TA7 Probe and c) The TA12 Probe.

3. Results and Discussions

3.1 Mixed mode type solar dryer

The designed initial needs and calculation suggested size of the drying chamber and solar collector of the mixed-mode type as 1.2x0.5x1.2 m^3 and 2x1.2 m^2 respectively (see Fig. 1).

In order to easily see the samples, the drying chamber were designed to be externally mounted with transparent material. Internally, it was parted into 4 storeys using 1.15x0.49m^2 stainless steel gratings.

The 1.20x2m^2 back-pass, air-heating, solar collector with 18-degree inclination were laid with 3 layers. The first layer was the insulator panel, the second layer was solar absorber plate and the last one was grazing layer. 4 small electric fans were installed at the front of the solar collector to blow hot air through the drying chamber.

Table. 1 shows the exit temperature of the solar collector at various air speeds of 0.45, 0.60 and 0.90 m/s. The exit temperature was increased as an increase of hot air speed due to higher heat conduction rate. The average temperature of all settings was around 42^{o}C.

Table. 1 Exit temperature of Solar Collector

Velocity (m/s)	Exit Temp (^{o}C)
0.45	40.31
0.60	42.42
0.90	43.24
Average	42.00

Fig. 4 shows the drying chamber temperature changing in one day started from 9.00-17.00 at different storeys inside the chamber, ranged from 1st to 4th from the bottom to the top. Inside temperature was changed according to the time of the day following the direction of the sunlight. The highest temperature was detected on the 4th storey where the maximum temperature was 53^{o}C at 13.00. Considering all-day average value, the temperature at this point was 43.5^{o}C. This was just marginal different from the designed temperature. However, there were some difference of temperature from the top to the bottom. The highest temperature at the top part was mainly affected from solar radiation.

Nevertheless, the drying chamber could be heated up to the design temperature. Considering thermal efficiently, the better results came from the setting air velocities of 0.60 and 0.90 m/s rather than 0.45 m/s.

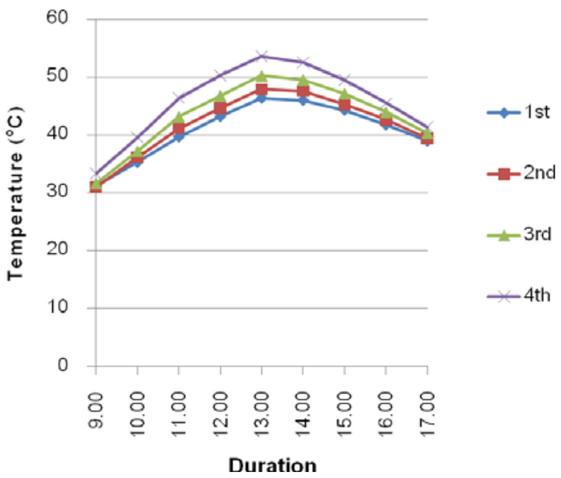

Fig. 4 Average temperature of the drying chamber at different storey, from 1th to 4th

3.2 Moisture content of dried bananas

Moisture content (wet basis) was measured before and every 8 hours during drying process until finished at 40 hours. Samples collected from each storey at all speed of hot air. All data were recorded and displayed as in Fig. 5-7.

At 0.45 m/s hot air velocity, the final moisture contents of dried banana in the first, second, third and fourth storey were 24.56, 23.80, 21.70 and 21.59% of wet basis, respectively.

At 0.60 m/s hot air velocity, the final moisture contents of dried banana in the first, second, third and fourth storey were 21.14, 20.52, 19.70 and 19.13% of wet basis, respectively.

At 0.90 m/s hot air velocity, the final moisture contents of dried banana in the first, second, third and fourth storey were 20.12, 19.98, 19.10 and 18.10% of wet basis, respectively. This was the only settings that could produce dried bananas conformed to the target of 21% moisture content.

When considering period of drying, the moisture test results were decreased almost constantly. Based on the theory of drying, the first period of drying time, the moisture content in banana is only slightly decreased or its drying rate is stable because the moisture in banana just move to its surface. The moisture drops faster later in the drying process. The heat that banana obtained from direct solar and drying chamber is used to evaporate surface water out of banana. After that, moisture in banana then become lower. The moisture in food is lessened and so spread to the surface of banana discontinuously. The banana's surface started to be dry and let the internal temperature higher. That's mean the moisture of banana is easier to evaporated so that the moisture content decreased. A study suggested that the first period could be as long as 8 hours [5].

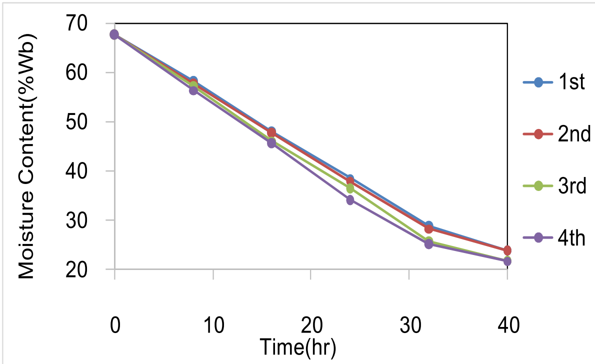

Fig. 5 Moisture content of dried banana at hot air velocity of 0.45 m/s

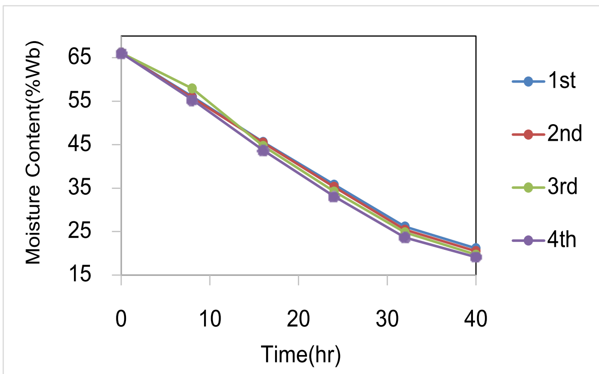

Fig. 6 Moisture content of dried banana at hot air velocity of 0.60 m/s

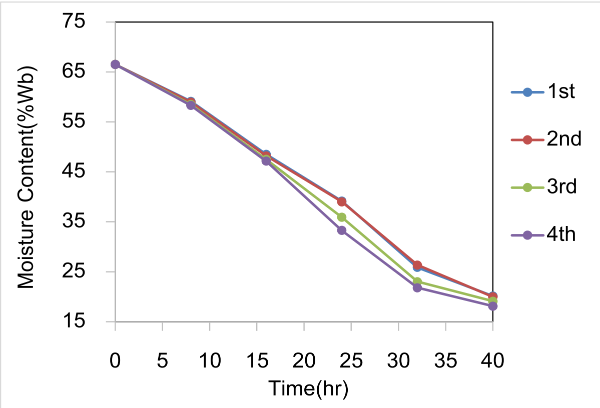

Fig. 7 Moisture content of dried banana at hot air velocity of 0.90 m/s

The results from this paper are different. The moisture content dropped right away from the start as a result of higher energy applied to the chamber yielding fast dehydration. Samples from the third and the fourth storey received more heat combined from the solar collector and direct sunlight so the samples were dryer than the rest.

Besides, the moisture content also depended on velocity of hot air. Final moisture content in banana when drying at higher hot air speed was lower than at low hot air speed. Faster hot air flow creates the period of higher rate of drying than slower hot air [6].

The average final moisture content of banana in the case of 0.45 m/s hot air velocity was 22.72% (wet basis). While in the case of 0.60 and 0.90 m/s hot air velocity, the average final moisture contents were 20.12 and 19.33% of wet basis, respectively. However only when using 0.90 m/s hot air velocity that all samples from all storeys had moisture content within the standard value of 21%.

3.3 Texture Analyser results

3.3.1 Compression test Mode

Compression test mode was chosen to find out the shear force of dried bananas when cutting or biting. The test results are illustrated in Fig. 8. At all hot air velocities, the average shear force of dried bananas from the fourth storey was the highest following by bananas from the third, second and first storey. This also mean that it is most difficult to bite dried banana from the top storey. The effects were amplified as the hot air speed was increased. At the 0.45 m/s hot air velocity, the shear force of banana in all storeys were slightly different while at the velocity of 0.60 and 0.90 m/s gave significantly differences. As a result of the rising of heat convection due to the amount of the hot air flowing though the drying chamber, moisture content on the surface of dried banana was reducing more quickly thus causing shear force to increase. Another reason was that the top storey got more solar radiation than the others.

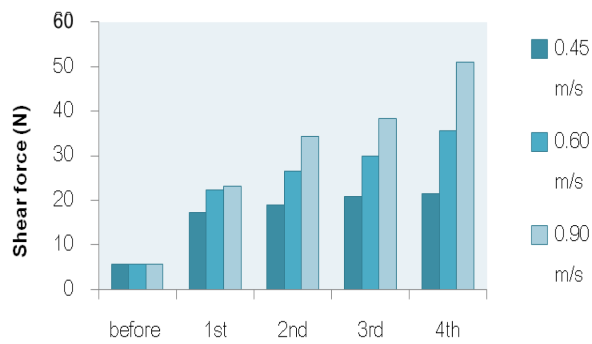

Fig. 8 Average shear force of dried banana at various hot air speed

3.3.2 Texture Profile Analysis (TPA) test Mode

To focus on dryness of banana, as a result of different drying storeys, affected on the product texture, TPA test mode was selected to find hardness, adhesiveness and springiness of finished, dried bananas only of the case of 0.90 m/s hot air velocity. This can be done by pressing the samples 2 times to imitate human double bite. The test results are presented in Fig. 9 and Table. 2.

As expected, samples from the top of the chamber (4th storey) gave the highest force or hardness at the first compression as suggested by the TPA curve in Fig. 9. Considering the area beneath the TPA curves, the same samples required the highest chewing energy among all. This required chewing force and energy reduced from the top to the bottom of the chamber (from 4th to 1st storey).

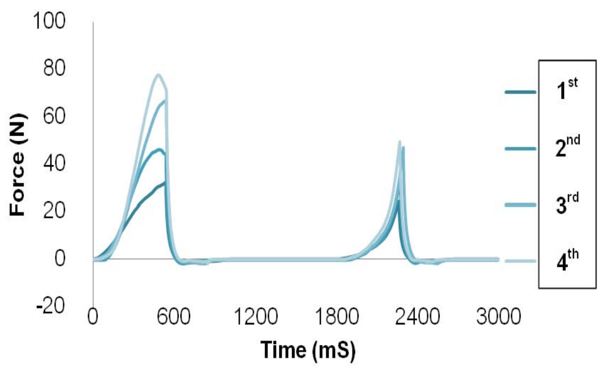

Fig. 9 Sample of TPA Testing results of dried banana from different storeys in the chamber

Table. 2 Average TPA results

Storey	Hardness (N)	Adhesive-ness (mJ)	Springi-ness (mm)	Moisture content (%)
1st	30.39	2.06	5.75	20.15 ± 0.15
2nd	42.02	3.63	6.08	19.92 ± 0.30
3rd	59.89	4.94	5.66	18.91 ± 0.73
4th	66.54	4.41	6.77	16.55 ± 0.32

Of all cases, no fracture line could be observed indicated that the dried bananas had soft and tender texture. The negative force resulted in Fig. 9 represented small adhesion between test probe and samples during the time when the probe was taken back. The closed area made by this curve implies how much energy a person needs to pull his jaw back from the food when he is chewing. For clearer understanding, the results from all samples including hardness, adhesiveness, springiness and moisture content were averaged and compared in Table. 2. It can be seen that the dryer the banana is, not only the hardness, but the more adhesiveness it will has. However, the adhesiveness is merely changed at lower moisture content. The springiness, indicating how bouncy the banana was, was merely different when moisture changed.

It can be concluded that, dried banana obtained from each storey in the drying chamber are different in both moisture content and some texture properties. The dried banana with lower moisture is harder and stickier causing higher bite and chewing force and also more energy required for chewing but the springiness or bouncing reaction of the banana in the mouth are merely different. The results indicate unequal product quality in one batch specifically the moisture content and biting and chewing energy. However, this dryer design can offer dried banana with moisture content agreed within standard limit.

The suitable moisture content should be defined not only refer to the standard limit but also from the consumers' satisfaction. There are still more sensory analysis to be performed on the targeted customers. Then the results should be brought to reconsider the process settings. Anyway, from the start, at least the dryer should be about to produce more consistent finished product moisture content. For this design, the key factor that affected moisture and texture of dried banana was the difference of temperature and solar radiation on each storey due to translucent grazing material, In order to reduce the difference, the design may be improved by controlling internal hot air flow inside the chamber to stabilize temperature and use opaque grazing with insulation to reduce the solar radiation effect. Alternatively, manually reordering bananas to different position frequently is an essential.

5. Conclusions

From this paper, the following conclusions can be drawn,

1. A mixed-mode type solar dryer was designed and produced according to some initial needs. The equipment was able to dry bananas at 3 various hot air speeds of 0.45, 0.60 and 0.90 m/s.
2. Sets of product experiment and laboratory tests were performed in order to evaluate the performance of designed solar dryer.
3. Dried bananas obtained from different storeys inside the solar dryer were different in terms of moisture content, shear force, hardness and adhesiveness due to the effect of heat from solar radiation but there was merely change in springiness. The most dried banana came from the top of the chamber.
4. In one batch, moisture content and some product texture properties were varied depending on the dried position even though all of them could pass moisture content standard. These results suggest that the dryer performance needs to be improved by better control of inside chamber temperature and air flow.
5. Not only moisture content but also product texture that will reflect on consumers' acceptance in the market later. More sensory tests should be performed to get those properties for reconsidering suitable process settings and designed requirements.

6. Acknowledgement

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