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# Improvement of the Thepsatri Rajabhat-type household solar dryer for drying bananas

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**Abstract:** In this study, improvement of the Thepsatri Rajabhat-type household solar dryer is presented. The polycarbonate covering of this dryer can shield products from animals, dust, and rain. A drying temperature of no more than 50 °C is the right temperature when drying, it is not recommended that the temperature exceed 50 °C because it can cause dry bananas, not good quality. The side-loading solar dryer for drying bananas was put through a full-scale carried out between July and September 2021, during which season the temperature was quite high. Each drying batch of this solar dryer can dry up to 10 kg. The bananas were dried in six batches using the solar dryer to examine their effectiveness. The temperature control limit at 50 °C in a dryer decreased the moisture value of bananas from 70% (wet basis, wb) to about 30% (wb) within 3 days whereas it took about 5 days with natural sun drying in the same weather conditions. Compared to sun drying naturally, the dryer significantly reduced saving drying time by 67% and the average solar dryer's efficiency was 49.5%. The bananas that have been dried in a dryer are a good quality dried product in terms of colour and protected from insects and dust for human consumption.

***Keywords:*** *Bananas, Household solar dryer, Polycarbonate cover*

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## 1. INTRODUCTION

Thailand is a country that produces a lot of agricultural goods each season. Especially fruits and vegetables such as longan, lychee, mango, and bananas. In particular, bananas are an important economic plant in Thailand and can also be processed into dried bananas is a popular food in this country. This large-scale production is usually processed with processes such as fermentation, pickling, and drying. For bananas, it is necessary to use the drying process primarily. Most manufacturers use the natural sun drying method for drying bananas, which uses solar energy to dry them and dried bananas are frequently polluted by dust, animals, insects, and rain. But some areas of Thailand have mechanically dried bananas, which use mainly fossil energy, such as electricity and LPG gas. This makes bananas more costly, making it more difficult to sell bananas. One potential remedy for the drying issues with products of agriculture in developing countries has been solar drying. Due to the rising demand for premium dried fruits worldwide [1-3], solar drying is still the most widespread preservation method and is gradually replacing the marketing of fresh fruits. Over the past 10 years, several solar dryers have been created and manufactured [4-9]. However, solar dryers have also been developed to date to meet the particular drying of agricultural product to obtain quality products as well as energy savings. Designers should examine basic parameters such as size, temperature, relative humidity, air flow rate, and the characteristics of the product to be dried, this can be used to study the performance of solar drying systems. Many researches have been carried out on the performance of solar drying systems for drying agricultural product [10-12].

In order to satisfy the specific needs for drying of certain products and to provide the best performance with regard to specifications, the system design for the solar drying system must be appropriated. Designers should research the fundamental factors of drying weather conditions and the properties of the products that will be dried. Only the use of appropriate drying technologies will be possible to improve product quality and decrease losses. However, the drying process is a relatively energy-intensive process. The use of fossil fuels or electric power is therefore not suitable for industrial drying processes as this may lead to higher production costs. Drying of agriculture products using solar energy is therefore another option, which is environmental friendly. The process of solar drying, which is a successful way to use solar energy, and it is an efficient system of utilizing solar energy [3]. Banana drying may be made easier by utilizing solar drying technologies. This is because the places where dried bananas are produced are typically found in a tropical zone that receives a lot of solar radiation. In Thailand due to its proximity to the equator average yearly solar radiation is received at 18.2 $MJm^{-2}day^{-1}$ [13]. As a result, it is thought that using solar drying technology is the best alternative for agricultural product drying in this country. Additionally, solar drying is a sustainable and environmentally method.

Therefore, the development of solar drying systems for drying each product is of great important economic implications. The purpose of this research is to develop a household solar dryer and improvement the performance of the dryer for drying bananas. Allow the dryer to regulate the dryer's internal temperature from overdue. The experimental study, performances analysis, measurement of quality of banana, and economic analysis were explained in Section 2. Results of the dryer's testing of bananas dried were reported in Section 3.

## 2. MATERIALS and METHODS

### 2.1. Experimental Study

The dryer was constructed at Thepsatri Rajabhat University in Lopburi, Thailand. It comprises a solar collector and a parabolic roof constructed of polycarbonate sheets. In order to get a decent greenhouse effect within the dryer, polycarbonate sheets with a 6 mm thickness are used. The solar dryer's parabolic shape design help to lessen wind stress. These dryers have a 10 kg approximately loading capacity for ripe bananas. Iron bars coated in galvanized steel make up the dryer's framework. The dryer's measurements were determined to be 0.90 m ×1.90 m × 0.45 m. Two trays, each 0.80 m × 0.80 m in size, which uses in laying products dry. The solar dryer was ventilated using two 5 W DC fans that were conducted by a 20 W PV module and two 10 W DC fans powered by a battery 12 Volt DC connected to 20 W PV modules. It can control the temperature limit within the solar dryer. An illustration of the dryer is shown in Fig. 1.

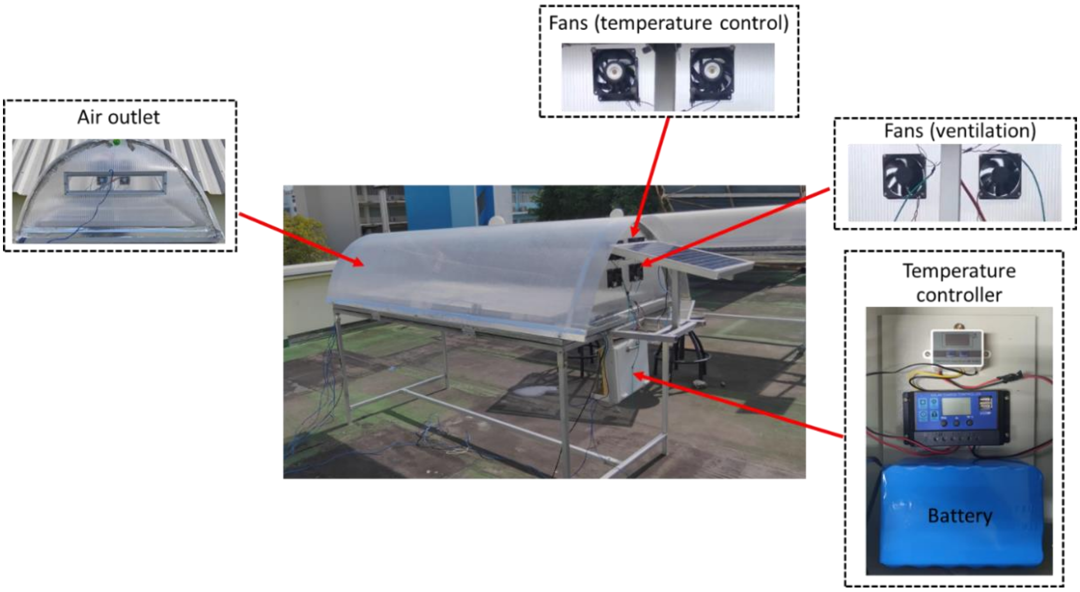


*Figure 1. An illustration of the household solar dryer.*

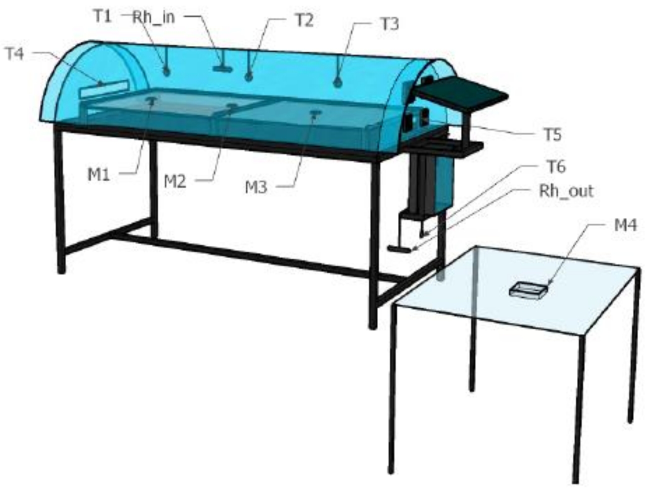


*Figure 2. The positions of the temperature measurements (T), relative humidity (Rh), and weighted product samples (M).*

To gauge solar radiation, a pyranometer (Kipp & Zonen model CMP 22, accuracy ± 0.5%) was positioned near the solar dryer. For air temperature in the solar dryer to be measured using thermocouples (type K, accuracy ± 2%). Fig. 2 shows the thermocouple positions for measuring temperature in the solar dryer. Periodically, the drying air and surrounding air's relative humidity have been measured using hygrometers (model EE23, Electronik, Engerwitzdorf, Austria; accuracy ± 2%). The voltage readings from the thermocouples, hygrometers, and pyranometer are recorded by a data logger (HIOKI, model LR8432-20) every 10 minutes. At the time of the drying experiments, a hot wire anemometer (Airflow, model UNI-T UT363BT, accuracy ± 2%) measured the airspeed of the dryer.

For this drying experiment, which dryer had a capacity of about 10 kg of ripe bananas that were placed out a thin layer. The studies ran from the morning at 8:00 am until around 6:00 pm. On the next days, the drying was maintained till the appropriate moisture content was attained (about 30% wb). Fig. 3 shows bananas in the solar dryer. An electronic balance (AND, model HT-500, accuracy ±0.1 g) was used to weigh product samples repeatedly at two-hour intervals after they were laid in the solar dryer in different positions. Additionally, the product samples were weighed every two hours, and moisture levels of those goods were compared to naturally sun-dried. The amount of moisture content throughout drying was determined using the product sample weight, and the sample's estimated dry solid mass. The solid mass was obtained by drying the product sample in the oven at 103 °C for 24 hours. (Oven method, precision ±0.5%).

## 2.2. Performances Analysis

The ratio of sample's moisture content as they dry is used to represent thin layer models using experimental bananas data, and it's written as follows: [14].

$$MR = \frac{M - M_e}{M_i - M_e} \tag{1}$$

where $M$, $M_i$ and $M_e$ represent, respectively, the moisture content, the initial, and equilibrium moisture content at any particular time. $MR$ is the moisture ratio. The amount of water that has to be removed from bananas after drying ($W$, kg) is known as the evaporation load can be expressed as [15].

$$W = \frac{m_0 (M_i - M_f)}{100 - M_f} \tag{2}$$

where $m_0$ represents the product's initial weight (kg), $M_i$ and $M_f$ represents its initial and final moisture content (% wb), respectively.

A drying system's total effectiveness can be determined by looking at its efficiency. It is described as the proportion of the heating system for the dryer to the energy needed to cause moisture to evaporate. The drying system efficiency can be obtained using Eq. (3), [15].

$$\eta_d = \frac{WL}{A_c G + P_f + P_h} \tag{3}$$

where $\eta_d$ is efficiency of solar dryer for drying product, $W$ is the evaporated of water that has been removed from the product (kg), $L$ is latent heat of vaporization (J/kg), $A_c$ is area of collector (m$^2$), $G$ is solar radiation (W/m$^2$), $P_f$ is the power of fan (W), and $P_h$ is the power of the heater.

Fudhali et al. [15] reported the benefits of solar drying systems for galangal, including time-saving while drying ($S$). The performance of solar drying and natural sun dried were compared using Eq. (4), [15].

$$S = \frac{t_{OS} - t_{SD}}{t_{OS}} \times 100 \tag{4}$$

where S is saving in drying time (%), $t_{OS}$ is the amount of time it takes for a thing to dry in the open sun (hour), $t_{SD}$ is the length of time required for solar drying (hour).

*Table 1. Information of parameters and underlying presumptions for a banana of solar dryer.*

| Items | Value |
|---|---|
| Product dried | Bananas |
| Drying capacity required | 10 kg |
| Initial moisture content of bananas | 70% (wb) |
| Final moisture content of dried bananas | 30% (wb) |
| Drying air temperature limit control | 50°C |
| Specific heat of air | 1.01 kJ/kg·K |
| Density of air | 1.06 kg/m$^3$ |
| Latent heat of vaporization of bananas [13] | 2,737.8 kJ/kg |
| Average solar radiation flux during drying | 539 W/m$^2$ |

### 2.3. Measurement of Quality of Bananas

HunterLab ColorFlex EZ Spectorphotometer was used to measure the colour of samples of dried banana using CIE (Commission Internationale I'Dclairage) chromaticity coordinates. Colour from black to white (*L**=0 to *L**=100), red to green (*a**>0 to *a**<0), and from blue-yellow (*b**<0 to *b**>0). The *L*a*b**, [16-17] and *L*C*h*, [19] systems were chosen since they are the most frequently used systems for judging the colour of dry food products. A white ceramic plate was used to standardize the instrument each time. The values of *L**, *a**, and *b** were averaged after three measurements were collected at each place on the sample's surfaces. The following equations were used to compute the various colour parameters, [20]).

The definition of a hue angle (h) representing colour combination is described as [20]:

$$h = \begin{cases} \tan^{-1}(b^*/a^*) & (\text{when } a^* > 0) \\ 180° + \tan^{-1}(b^*/a^*) & (\text{when } a^* < 0) \end{cases} \tag{5}$$

and the definition of chroma (*C**), which denotes color saturation is described as [20]:

$$C^* = (a^{*2} + b^{*2})^{1/2} \tag{6}$$

and the definition of the total color change ( $\Delta E$ ) is described as [18]:

$$\Delta E = \sqrt{(L^* - L_{ref}^*)^2 + (a^* - a_{ref}^*)^2 + (b^* - b_{ref}^*)^2} \tag{7}$$

### 2.3. Economic Analysis

The following calculation provides the solar dryer's ( $C_T$ )is total capital cost [21]:

$$C_T = C_d + C_l \tag{8}$$

where $C_d$ is the cost of the dryer's materials and $C_l$ is the cost of the labor. Eq. 9 is produced the annual cost estimate approach suggested by Audsley and Wheeler [22]:

$$C_{annual} = \left[ C_T + \sum_{i=1}^{N} (C_{maint.i} + C_{op,i})\omega^i \right] \left[ \frac{\omega - 1}{\omega(\omega^N - 1)} \right] \quad (9)$$

where $C_{annual}$ is the system's annual cost, $C_{maint,i}$ and $C_{op,i}$ are the maintenance cost and the operating cost as of year i. $\omega$ is denoted by Eq. 10 as [22]:

$$\omega = \frac{100 + i_{in}}{100 + i_f} \quad (10)$$

where $i_{in}$ and $i_f$ are the corresponding percent rates of interest and inflation respectively. The labour cost to operating the solar dryer combined with the cost of the electricity consumption usage make up the operational cost $C_{op}$ Eq. 11 may be used to express this cost as [23]:

$$C_{op} = C_{electric} + C_{labour,op} \quad (11)$$

The maintenance cost of the dryer in the first year is 1% of the capital cost. $C_{electric}$ is the electricity cost used in the drying system, but in this drying system it uses electricity from PV modules, so it cannot be charged in respect of electricity, and $C_{labour,op}$ is labor cost for operating the drying system.

The annual cost per dried product unit is known as the drying cost (Z, USD/kg). Equation 12 may be used to write it [23]:

$$Z = \frac{C_{annual}}{M_{dry}} \quad (12)$$

where $M_{dry}$ is the amount of dried product annually by this solar dryer. In Eq. 13, the payback period can be calculated as [23-24]:

$$\text{Payback period} = \frac{C_T}{M_{dry}P_d - M_f P_f - M_{dry} Z} \quad (13)$$

where $P_d$ is the price of the dry product (USD/kg), $P_f$ is the price of the fresh product (USD/kg), and $M_f$ is the amount of fresh product dried annually (kg).

## 3. RESULTS and DISCUSSIONS

### 3.1. Experimental Results

Between July and September in the year 2021, the researchers conducted experiments on drying bananas with a dryer. The moisture content initially of the bananas was around 70% (wb). In the product trays, bananas were put in a single in a thin layer. The studies ran from the morning at 8:00 am until the evening around 6:00 pm. The drying kept going in the days that followed until the required amount of moisture was obtained (about 30% wb), thereby stopping the experiment. This moisture content of this banana is consistent with the needs of the needs of the marketplaces and consumers.

Fig. 3 depicts the fluctuations in solar radiation that occurred when bananas were being dried experimentally in a solar dryer. During dried bananas, solar radiation greatly increased between morning and noon. On the first day of the drying experiment, between 13:10 – 13:40, it rained for about half an hour, but the average solar radiation intensity on the first day was still high. In addition, during the drying period the solar radiation significantly fell with changes brought on by clouds in the late afternoon. During the experiment, the solar radiation intensity was found to be the highest of 968 W/m$^2$, and the average intensity of solar radiation over the course of the three-day trial was 539 W/m$^2$. Bananas can be dried according to temperature control.

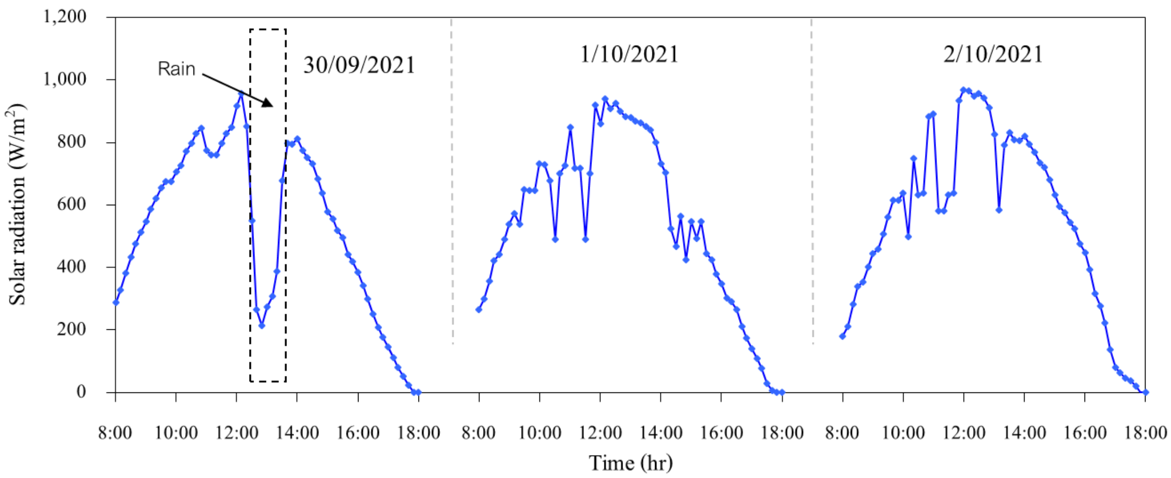


*Figure 3. The variations of the solar radiation during the bananas drying experiment.*

Fig. 4 compares the solar dryer's interior temperature to the ambient temperature (T6). In this experiment, the temperature was set to 50 °C, finding that between 11:00 – 15:00, the solar dryer's interior air temperature increased to 50 °C. The fans that keep the temperature from overdue will operate according to the temperature set. The temperature control system inside the dryer can work well and control the temperature from exceeding the limit. In addition, the inside temperature of the solar drying system at positions T1, T2, and T3 was found to be similar in all three positions over the course of the experiment. This indicates good temperature dispersion inside the drying system.

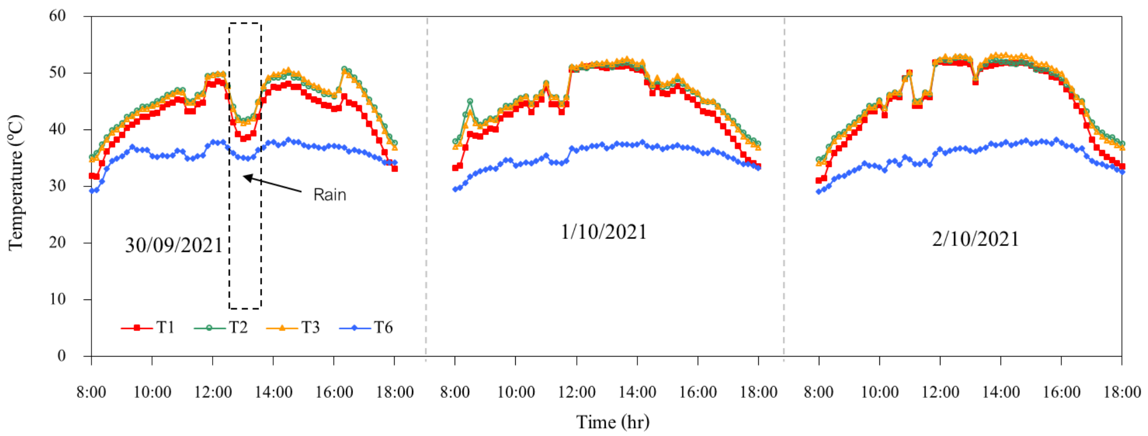


*Figure 4. Temperature (T) variations during the banana drying experiment at three positions inside (T1, T2, T3) and outside (T6) of the dryer.*

Fig. 5 is a variation of the solar dryer's interior relative humidity versus the environment. Experiments showed that the humidity value inside the drying system varies inversely with the temperature value within the drying system. When the temperature inside the drying system rises during daylight hours, resulting in low relative humidity values inside the drying system and about 25% lower than the average surrounding relative humidity. Consequently, the dryer has the potential to dry products extremely well.

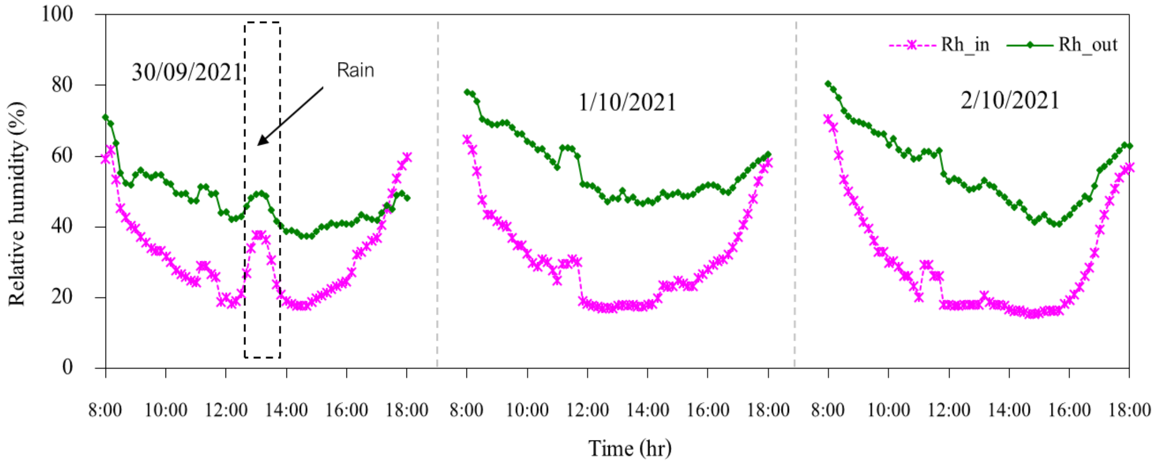


*Figure 5. Relative humidity (Rh_in) variation of air inside the dryer and relative humidity (Rh_out) variation external the dryer during the banana drying experiment.*

Fig. 6 shows a variation in the moisture value of a banana during drying inside the solar dryer (M1, M2, and M3) compared natural sun dried (M4). Bananas start out with a 70% (wb) moisture content, and the solar drying system can dry bananas reduced from 70% (wb) to 30% (wb) moisture within 3 days, compared to dried bananas with natural sun drying of 43% (wb) over the same timeframe. The moisture content of bananas is about 30% (wb) is the moisture content that meets the market demand and the resulting of the quality of the color of dried bananas obtained [25-26].

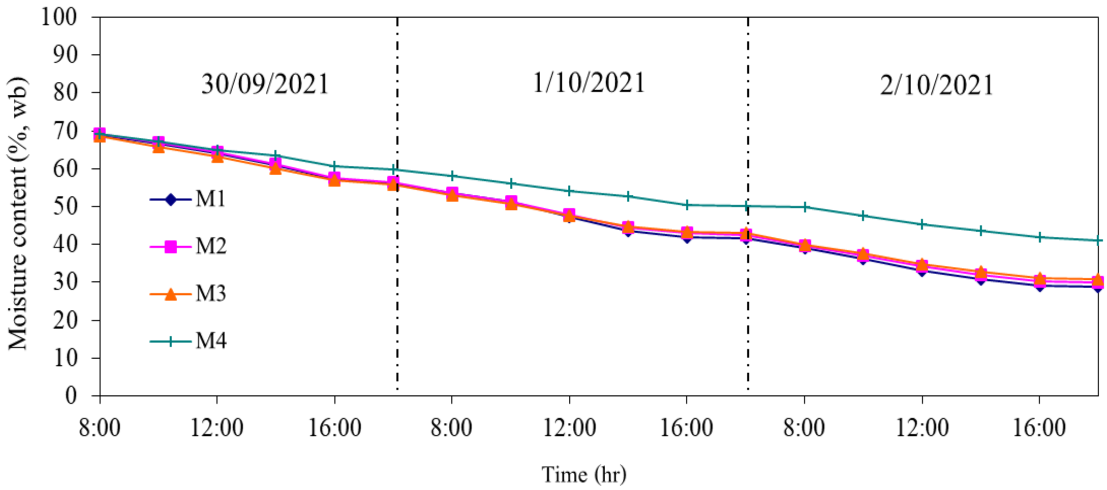


*Figure 6. Moisture content variation of bananas placed (M1, M2, and M3) in the dryer and moisture content variation of the natural sun drying (M4).*

### 3.2. Qualities of Dried Banana

The effect of measuring the color of bananas is shown in Table 2, comparing the color of drying bananas inside the solar dryer with natural sun dried. It is the color of bananas that is regulated by the temperature within the drying system not to exceed 50°C compared to the color of natural sun dried bananas. Experiments have shown that the color of dried bananas inside a solar dryer is light brown, unlike natural sun dried bananas, it is very dark brown, possibly as a result of radiation exposure to UV radiation. Bananas dried in a dryer saw a total color change ( $\Delta E$ ) was 25.45 whereas bananas dried natural sun dried a total color change was 31.72. The markets and to the consumers of bananas acceptable in the color change in bananas that have been dried in the dryer [26].

*Table 2. Color variations of fresh and dried whole bananas.*

| Status | Color Value | | | | | |
|---|---|---|---|---|---|---|
| | *L** | *a** | *b** | *C** | *h* | ΔE |
| Fresh bananas | 71.65 | 3.04 | 7.81 | 27.98 | 1.46 | 0.00 |
| Solar dried bananas at the temperature does not exceed 50°C | 47.72 | 6.46 | 19.85 | 20.87 | 1.26 | 25.45 |
| Natural sun dried of bananas | 41.78 | 8.81 | 18.80 | 20.76 | 1.13 | 31.72 |

### 3.3. Economic Evaluation

Structural values of solar dryer as well as temperature control system inside the dryer is 520 USD. The dryer's capacity is 10 of bananas at a time and about 6 kg of dried bananas. The pay-back period term is computed using these data and the method as outlined in section 2.4. It was duration was discovered to be 1.1 years. This proves that the investment in this dryer and using it in Thailand is an economically sound investment. Additionally, an average sunny day's dryer efficiency was 49.5%. The bananas that was dried in the dryer was of high quality and was totally shielded from dust, insects, and rain.

## 4. CONCLUSION

The dryer was used to dry the bananas. When compared to natural sun-dried, solar drying of bananas in a dryer significantly decreased drying time, and the color of bananas dried in the dryer is good quality dried products. Bananas was dried in solar dryer by controlling the temperature so that they do not exceed 50°C during drying. In addition, this solar dryer can load capacity of 10 kg of bananas. The solar dryer can dry bananas from an initial moisture content of 70% (wb) until the last moisture content remains only 30% (wb) within the drying period of 3 days, drying with temperatures not exceeding 50°C. Solar dryer with 49.5% efficiency in banana drying. The solar dryer is about 1.1 year's payback period, according to estimates. In Thailand's developing regions, where there is enough solar radiation, this drier may be used to solar dryer vegetables and fruits.

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