SOLAR DRYING OF GALANGAL SLICES (*ALPINIA GALANGAL* (LINN.) SWARTZ.) USING HOUSEHOLD SOLAR DRYER

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Abstract

This paper presents a method for drying galangal slices using hot air from a household solar dryer. The solar dryer was developed and installed at the Division of Physics, Faculty of Science and Technology, Thepsatri Rajabhat University, Lopburi, Thailand (14.80°N, 100.62°E). The dryer has a parabolic shape to facilitate the construction. A polycarbonate plate covers the solar collector with an area of 0.90×1.90 m^2. The polycarbonate cover is used to reduce heat loss while allowing the incident solar radiation to be transmitted into the solar dryer. Two direct current 12-Volt fans powered by 1 10-Watt photovoltaic module ventilate the dryer. To investigate the experimental performances of the solar dryer for drying galangal slices, 6 full-scale experimental runs were conducted. For each batch, between 5-6 kg of galangal slices were dried. The drying air temperature varied between 30°C to 55°C from 8:00 am to 6:00 pm during drying. The drying time in the solar greenhouse dryer was 1 day to dry the galangal from an initial moisture content of 89% (wb) to a final moisture content of 12% (wb), compared to 2-3 days with natural sun-drying under similar conditions. The payback period of the dryer is estimated to be 0.9 years. The galangal dried in this dryer was completely protected from insects, animals, and rain, and a good quality of the galangal was obtained.

Keywords: **Experimental performance, galangal, polycarbonate, solar dryer, solar drying**

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Introduction

Galangal (*Alpinia galangal* (Linn.) Swartz.) is a medicinal plant which is commonly known in Thai as *kha*, and is well known for human health benefits. Galangal is an important ingredient in the daily cuisine in Thailand. Galangal has underground stems called rhizomes which have a strong aromatic smell with conspicuous nodes and internodes (Jirawan, 2005). The rhizomes are characterized externally by a dark reddish-brown colour, and cuttings of the inner rhizome are characterized by the presence of a dark center. It is surrounded by a wider and paler layer on the outer rim that also darkens considerably when the rhizome is dried during processing. As mentioned, the rhizomes of galangal have a strong aromatic odor, and they have a spicy or pungent taste (Subramanian and Nishan, 2015).

Fresh and dried galangal is a common household herb used for cooking. Thai cuisine uses healthy herbs as ingredients and almost every dish has 4 flavours: salty, spicy, sour, and sweet. However, most of the galangal in Thailand is dried with natural sun-drying and the dried galangal is often contaminated with dust. Drying is the oldest preservation technique for agricultural products and it is an energy-intensive process. In developing countries, the traditional sun-drying method is commonly used for drying herbs. Although it is the cheapest method, the dry products are of poor quality due to rewetting of the products during drying when it rains, a too slow drying rate in the rainy season, and toxic substances such as aflatoxins produced by mould which is often found in dried products.

Solar drying can be used as an alternative method to natural sun-drying as it is a promising and attractive application of a solar energy system. Many research studies have reported on natural convection solar dryers for drying agricultural products (Gbaha *et al.*, 2007; Jain and Tewari, 2015; Sekyere *et al.*, 2016). However, the success achieved by natural convection solar dryers has been limited due to the low buoyancy-induced air flow. This has prompted researchers to develop forced convection solar dryers. Many research and performance studies have reported on forced convection solar dryers (Kaewkiew, *et al.*, 2011; Fterich *et al.*, 2018; Murugavelh and Karthikeyan, 2018).

Thailand, being situated near the Equator, receives abundant solar radiation with the annual average daily solar radiation measuring 18.2 $MJm^{-2}day^{-1}$ (Janjai *et al.*, 2005). Therefore, utilization of solar drying technology is considered to be an obvious option for drying agricultural products in this country. Moreover, solar drying is a renewable and environmentally friendly technology.

Although many types of solar dryers have been developed during the last 2 decades, their applications are still limited. Nevertheless, solar drying systems must be properly designed in order to meet the particular drying requirements of specific products and to give satisfactory performance. Designers should investigate the basic parameters such as dimensions, temperature, airflow rate, relative humidity, and the characteristics of the products to be dried. Therefore, development of a solar dryer that performs well is of significant economic importance. The purposes of this study are to determine the experimental performance of a solar dryer for drying galangal and the dryer's test results are reported in this paper.

Materials and Methods

Experimental Study

The solar dryer was developed and installed at the Division of Physics, Faculty of Science and Technology, Thepsatri Rajabhat University, Lopburi, Thailand (14.80°N, 100.62°E). It consists of a parabolic roof structure made from a polycarbonate plate on a solar collector. The polycarbonate plate was selected to be the transparent cover of the dryer because it has high transmittance (0.8) in shortwave solar radiation and low infrared transmittance (about 0.2) (Janjai *et al.*, 2009), thus creating a good greenhouse effect in the dryer. The parabolic cross-sectional shape helps to reduce the wind load in the case of a tropical rainstorm. The structure of the dryer is made of galvanized iron bars. The dryer has a width of 0.90 m, length of 1.90 m, and height of 0.45 m. The galangal was placed in a thin layer on 2 trays. Two direct current fans operated by a 10-Watt photovoltaic module were installed in the wall opposite to the air inlet to ventilate the dryer. A pictorial view of the dryer is shown in Figure 1, and the structure and dimensions of the dryer are depicted in Figure 2.

The drier was place on a raised platform and it was not in the shade of any buildings from 8:00 am to 6:00 pm. Six sets of full-scale experimental runs on the solar drying of galangal were carried out between October and December in 2018.

Thermocouples (type K) were used to measure the air temperatures in the dryer as these are a good option in terms of accuracy, convenience for measurement of temperatures in remote corners, and the availability of interface facilities to connect to computers for data acquisition. Prior to their utilization, they were tested by measuring the boiling and freezing temperatures of water to determine the accuracy (±2%). The position of these measurement devices are shown in Figure 2. Voltage signals from the thermocouples were recorded every 10 min with a multi-channel data logger (model LR8432-20, Hioki E.E. Corp., Ueda, Japan,).

Five kilograms of galangal were cut with a thickness of about 5 mm and were placed in a thin layer on the 2 trays. The experiments were conducted between about 8:00 am to 6:00 pm. The drying was continued on subsequent days until the desired moisture content was reached. Product samples were placed in the dryer in various positions and were weighed periodically at 2-hour intervals using a digital balance (Kern, model 474-42, accuracy ±0.1 g, Kern & Sohn GmbH, Balingen, Germany). The moisture contents of the product inside the dryer were compared against the control samples (open-air sun-dried). The moisture content during drying was estimated from the weight of the product samples and the estimated dried solid mass of the samples. At the end of the experimental drying, the exact dry solid weight of the product samples was determined by the oven method (103°C for 24 h, accuracy ±0.5%).

Performances Analyses

The moisture content is usually expressed in the percentage of moisture present in the product. The moisture content of the product in the dryer can be given on the basis of total weight of the product to be dried and the amount of solid weight present in the product. The moisture content on a wet basis is given by the following Equation (1) (Bala, 1997):

$$M_w = \frac{W_w}{W_w + W_d} \times 100 , \qquad (1)$$

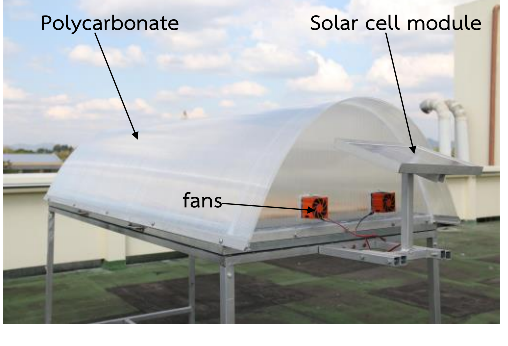

Figure 1. Pictorial view of the solar dryer

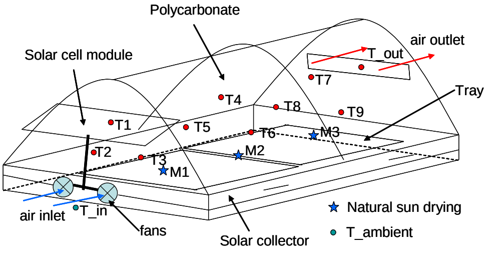

Figure 2. The structure and dimension of the dryer and the positions of the thermocouples (T) and product samples (M)

Where M_w is the moisture content on a wet basis (%, wb.), W_w is the weight of the moisture, and W_d is the weight of the bone-dry product.

Thin layer drying models of the experimental data of the galangal are expressed in the form of the moisture content ratio of the samples during drying, and are expressed (Janjai *et al.*, 2011) as:

$$MR = \frac{M - M_e}{M_i - M_e}, \quad (2)$$

where MR is the dimensionless moisture content ratio and M, M_i, and M_e are the moisture content at any given time, the initial moisture content, and the equilibrium moisture content, respectively.

The performances of solar drying systems for galangal have been reported by Fudhali *et al*. (2014), such as on the saving in drying time (S). The performance of solar drying compared with that of open-sun drying was calculated using the following Equation (3) (Fudhali *et al*., 2014):

$$S = \frac{t_{OS} - t_{SD}}{t_{OS}} \times 100, \quad (3)$$

where S is the saving in drying time (%), t_{OS} is the time taken for drying the product in open sun (hour), and t_{SD} is the time taken for solar drying (hour).

The system's drying efficiency is defined as the ratio of the energy required to evaporate moisture to the heat supplied to the dryer. The drying system efficiency is a measure of the overall effectiveness of a drying system. The drying system's efficiency can be obtained using the following Equation (4) (Fudhali *et al*., 2014):

$$\eta_d = \frac{WL}{A_c G + P_f + P_h}, \quad (4)$$

where η_d is the efficiency of the solar dryer for drying the product, W is the mass of water evaporated from the product (kg), L is the latent heat for the vaporization of water at the exit air temperature (J/kg), A_c is the collector area (m^2), G is the solar radiation (W/m^2), P_f is the power of the fan(s) (W), and P_h is the power of the heater (W).

The mass of water removed (W) from a wet product can be expressed (Fudhali *et al*., 2014) as:

$$W = \frac{m_0 (M_i - M_f)}{100 - M_f}, \quad (5)$$

where m_0 is the initial weight of the product (kg), M_i is the initial moisture content fraction on a wet basis (%), and M_f is the final moisture content fraction on a wet basis (%).

Measurement of Quality of Galangal

To assess the quality of the galangal, a composition analysis was conducted. The colour before and after drying of the galangal was measured with a chromometer (HunterLab ColorFlex EZ Spectrophotometer, Hunter Associates Laboratory, Inc., Reston, VA, USA) in the CIE (Commission Internationale I'Eclairage International Commission on Illumination) chromaticity coordinates. L*, a*, and b* represent black to white (L*=0 to L* = 100), red to green (a*>0 to a*<0), and blue to yellow (b*<0 to b*>0), respectively. Out of 5 available colour systems, the L*a*b* (Krokida *et al*., 1998; Maskan, 2001) and L*C*h* (Zhang *et al*., 2003) systems were selected because these are the most used systems for evaluation of the colour of dried food materials. The instrument was standardized each time with a white ceramic plate. Three readings were taken at each place on the surface of the samples and then the values of L*, a*, and b* were averaged. The different colour parameters were calculated using the following equations (Lopez Camelo and Gomez, 2004).

The hue angle (h) indicating colour combination is defined in Equation (6) (Lopez Camelo and Gomez, 2004) as:

$$h = \begin{cases} \tan^{-1}(b^*/a^*) & (\text{when } a^* > 0) \\ 180^\circ + \tan^{-1}(b^*/a^*) & (\text{when } a^* < 0) \end{cases}, \quad (6)$$

Chroma (C*) indicating colour intensity or saturation is defined in Equation (7) (Lopez Camelo and Gomez, 2004) as:

$$C^* = (a^{*2} + b^{*2})^{1/2}, \quad (7)$$

and the total colour change (ΔE) is defined in Equation (8) (Maskan, 2001) as:

$$\Delta E = \sqrt{(L^* - L_{ref}^*)^2 + (a^* - a_{ref}^*)^2 + (b^* - b_{ref}^*)^2}, \quad (8)$$

Economic Analysis

The total capital cost for the solar dryer (C_T) is given by Equation (9) (Nabnean *et al*., 2016) as:

$$C_T = C_m + C_1, \quad (9)$$

where C_m is the material cost of the dryer and C_1 is the labour cost for the construction.

The annual cost calculation method proposed by Audsley and Wheeler (1978) yields Equation (10):

$$C_{annual} = \left[C_T + \sum_{i=1}^{N} (C_{ma\,int.i} + C_{op,i})\omega^i \right] \left[\frac{\omega - 1}{\omega(\omega^N - 1)} \right], \quad (10)$$

where C_{annual} is the annual cost of the system, and $C_{ma\,int,\,i}$ and $C_{op,i}$ are the maintenance cost and the operating cost at the year i, respectively. ω is expressed by Equation (11) (Audsley and Wheeler, 1978) as:

$$\omega = \frac{100 + i_{in}}{100 + i_f}, \quad (11)$$

where i_{in} and i_f are the interest rate and the inflation rate in percent, respectively.

The operating cost C_{op} consists of the electricity consumption cost and the labour cost for operating the dryer. This cost can be expressed by Equation (12) (Smitabhindu, 2008) as:

$$C_{op} = C_{electric} + C_{labour,\,op}, \quad (12)$$

The maintenance cost of the first year was assumed to be 1% of the capital cost. $C_{electric}$ is the cost of electricity required by the water pump and blower and $C_{labour,\,op}$ is the labour cost for operating the dryer.

The annual cost per unit of the dried product is called the drying cost (Z, USD/kg). It can be written in Equation (13) (Smitabhindu *et al*., 2008) as:

$$Z = \frac{C_{annual}}{M_{dry}}, \quad (13)$$

where M_{dry} is the amount of dried product obtained from this dryer per year (kg). The payback period can be computed in Equation (14) (Thuesen and Fabrycky, 2001; Smitabhindu *et al*., 2008):

$$\text{Payback period} = \frac{C_T}{M_{dry}P_d - M_f P_f - M_{dry}Z}, \quad (14)$$

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

Results and Discussion

Experimental Results

Galangal was dried to demonstrate the potential of the dryer for drying this product. A total of 6 full-scale experimental runs were conducted during the period of October-December, 2018. The galangal had an initial moisture content of about 85%-90% (wb). In this study, about 2 kg of galangal was dried in the solar dryer. The galangal was placed on the 2 trays in a thin layer. The experiments were between 8:00 am to 6:00 pm and the drying continued on subsequent days until the desired moisture content (about 10% wb) was reached. This moisture content corresponded to the moisture content of high quality dried products available from local markets.

The typical results of the experimental runs are illustrated in Figures 3 to 5. During the drying experiment, the variations of the drying air temperature at 3 different locations inside the dryer and the ambient air temperature are shown in Figure 3. The patterns of the temperature changes in different positions were comparable for all locations. It is clearly seen that the drying air temperature during the period 13:00-15:00 h is relatively high (50-55°C), and even at 18:00 h the drying air temperature is still high (30-35°C). Temperatures in different positions at these 3 locations vary within a narrow band. In addition, temperatures at each of the locations differed significantly from the ambient air temperature.

Figure 4 shows the variations of the air temperatures inside the dryer. The temperature at the inlet of the dryer increased from 8:00 am until noon and decreased in the afternoon. The average rise of the temperature at the outlet of the dryer is 10°C above the ambient air temperature.

Figure 5 shows the variations in the moisture content of galangal at different positions in the dryer for the typical experimental run compared to the control sample dried by natural sun-drying. The moisture content of the galangal in the dryer decreased from 89% (wb) to 12% (wb) within 1 day, whereas the moisture content of the sun-dried samples reduced to 34% (wb) within the same period. Statistical analysis shows that there is no significant difference in the moisture content of the galangal at different positions inside the dryer. This demonstrates the uniform moisture content of the product in the dryer. However, there was a significant difference between the moisture content of the galangal dried in the dryer and the sun-dried galangal product at a significance level of 1%.

Qualities of Dried Galangal

The colour of the galangal was measured and the results are shown in Table 1. The values of the colour indices indicated that the colour of the galangal dried in the dryer was bright white while that of galangal dried

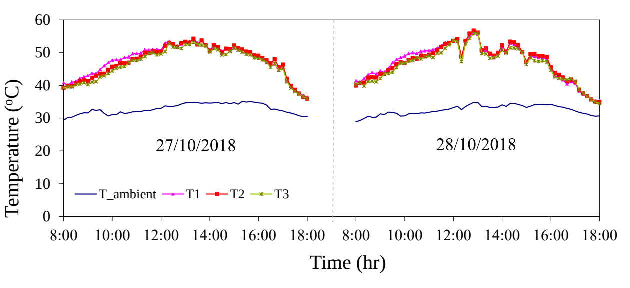

Figure 3. Variations of ambient air temperature and the temperatures inside the dryer during drying of the galangal

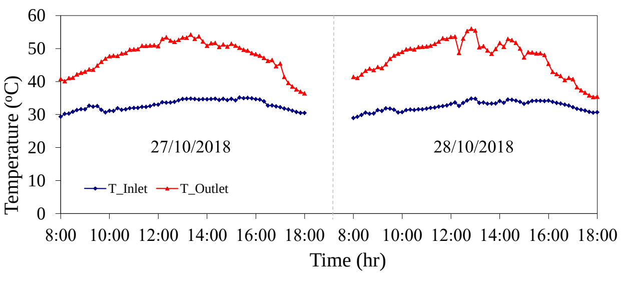

Figure 4. Variations of ambient air temperature at the inlet (upper curve) and those at the outlet (lower curve) of the dryer for the typical experimental run

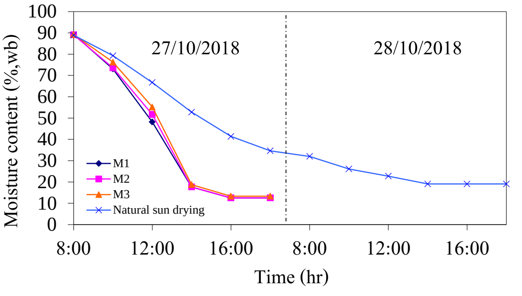

Figure 5. Comparison of moisture contents at 3 different positions inside the dryer with those obtained by the traditional sun-drying method for galangal

with natural sun outside the dryer was light white-brown. The total colour change (ΔE) of the galangal dried in the dryer was 139.20, while the total change of the galangal naturally sun-dried was 137.68. The colour change in the case of the galangal dried in the dryer is acceptable in the markets and to the consumers of galangal.

Table 1. Colour variations of fresh and dried whole galangal

Status	Colour Value				
	L*	a*	b*	C*	h
Fresh galangal	44.89	-0.33	9.09	41.37	-87.92
Solar dried galangal	50.35	4.51	11.61	77.56	67.87
Natural sun-dried galangal	44.61	6.46	15.51	141.15	67.38

Economic Evaluation

The capital cost for construction and installation of the dryer with a polycarbonate cover is 375 USD and the capacity of the dryer is 5 kg. The price of dried galangal slices obtained from this dryer is about 30% higher than that obtained from natural sun-drying. Using these data the pay-back period is calculated using the method previously described. It was found that the pay-back period is 0.9 years. This demonstrates that investment in this dryer is economically promising for its use in Thailand.

Furthermore, the saving in drying time and dryer efficiency on a typically sunny day were 43% and 32%, respectively. The galangal dried in the dryer was of good quality and was completely protected from insects, dust, and rain.

Conclusions

Drying of the galangal slices was conducted in the solar dryer. Solar drying in the dryer resulted in a considerable reduction in the drying time as compared with the natural sun-drying. The colour of the galangal slices dried in the solar dryer are of a high quality for dried products. The drying air temperature varied between 30°C and 55°C during the drying of the galangal. It is also economical to use the dryer for a full load capacity of 5 kg of whole galangal slices per batch. The estimated payback period of the solar dryer is about 0.9 years. This dryer can be used for solar drying of fruits and vegetables in developing areas of Thailand where sufficient solar radiation is available.

Acknowledgments

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