Solar Drying Characteristics of Palm Fruitlet Under Natural Convection

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ABSTRACT Heating is a post-harvest treatment for palm fruitlets that halts enzymatic activities that causes the rise of free fatty acid (FFA) in palm oil-related end-products and prevent deterioration of materials due to microbial contamination. Microwave heating has been extensively utilized for this process. However, due to limited access to electricity in rural areas, solar drying is proposed as an alternate method to perform the process. A proven solar drying system (UMS Eco-Solar Dryer) developed by Universiti Malaysia Sabah was used to perform the drying of palm fruitlet. This study focused on identifying the drying characteristics of palm fruitlet upon reaching its equilibrium moisture content (EMC) in an indirect type solar dryer under natural convection. Cumulative moisture loss of 17.05% was identified at EMC in 168 hours. An experimental drying curve of the drying process was established at the temperature range of 32.6 to 50.5 °C. The average air velocity measured at the drying chamber inlet was 0.26 m/s. Four mathematical models were used to describe the drying curve. Quadratic and logarithm equations are the best model to describe the constant rate period and falling rate period respectively.

KEYWORDS: Solar dryer; indirect; natural convection; palm fruitlet drying; drying characteristics
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INTRODUCTION

Globally, oil palm smallholders produce a substantial amount of the world's palm oil, around 4 million tonnes per year (Nagiah & Azmi, 2012). In Malaysia, 40% of the annual palm oil production is solely harvested by independent smallholders and 'scheme' smallholders (Abazue *et al.*, 2015). This has clearly presented that smallholders play a significant role in sustainable economic growth development. However, some of the palm fruitlets harvested by the smallholders are not sent for processing immediately resulting high amount of crude palm oil (CPO) produced from smallholders does not meet the quality standard for industrial utilization due to its high content of free fatty acid (FFA). It is vital to mitigate their problem as their contribution holds a massive amount of crude palm oil (CPO) which is correlated to our nation's economic growth development.

In order to prevent harvest loss of palm fruit and to implement the new mechanism of exporting palm fruit overseas, it is essential to employ immediate post-harvest treatment to preserve the quality of palm fruits. Drying is one of the oldest practices that involves the process of thermally removing volatile substances (moisture) from commodities for preservation purposes. In this case, the presence of heat energy during the drying process could halt enzymes activation in the palm fruitlet which causes the rise of FFA in the end products and prevent fungi growth through the moisture removal process (Hadi *et al.*, 2012; Poku, 2002). Chow and Ma (2001) confirm the practicability of using microwave heating in enzyme inactivation and palm fruits detachment. Through microwave volumetric heating, water in the palm fruits will be heated instantly and later extracted rapidly through evaporation. This process solubilizes the layer of dense meristematic cells between the fruits and pedicel resulting in easy detachment. However, the application of microwave heating is limited to industrial-scale processors provided with stable accessibility to electrical sources. Therefore, a solar dryer that harvests free, renewable, and non-polluting solar energy to operate is well considered to substitute microwave heating in the rural area. Nevertheless, there are several issues to be considered while employing solar drying for palm fruits processing. Due to the periodic characteristics of solar radiation, the temperature attained in the dryer could be too high or insufficient for the process. According to Chow and Ma (2007), excessive heating could severely damage the fruits and kernel. Whereas insufficient heating could result in a significant rise of FFA in the end-product. Umudee *et al.* (2013) studied the quality of palm fruits using microwave heating and identified an optimum heating temperature range of 50°C to 80°C. In addition, the final moisture content of the palm fruits could significantly affect the subsequent process. Chow & Ma (2007) observed that with more moisture removed from the fruits due to unnecessarily prolonged heating, hardened mesocarp will result in difficulty in detaching the fruits from the spikelets. Sarah and Taib (2017) determined a critical moisture loss of 14.2% for palm fruits heating, which is the lower limit to perform effective microwave heating for enzyme inactivation. On the other hand, moisture loss of more than 24% is not recommended as this indicates excessive heating on palm fruits. Hence, it is crucial to ensure that the heating process is performed between moisture loss of 14.2% to 24%. In an attempt to optimize and control the operating conditions in the solar dryer, it is vital to understand the transport mechanism and drying characteristics of palm fruits during the drying process. This information could also be used as a baseline study to determine the feasibility of using solar drying as an alternate method for palm fruits post-harvest treatment. According to the literature, there is a limited publication concerning the solar drying of palm fruits. Hence, the main objectives of this research were to study the drying characteristics of palm fruitlet in UMS Eco-Solar Dryer under natural convection and establish the drying characteristics curve of palm fruitlet under this condition. Mathematical models that can be used to predict the drying behavior of palm fruits will be evaluated.

METHODOLOGY

Solar Dryer Description

The solar dryer used in this study is a proven solar drying system (UMS Eco-Solar Dryer), suitable for the drying of various agricultural and marine products, designed and developed by Universiti Malaysia Sabah (UMS). It is classified as an indirect natural convection type solar dryer, consists of a solar heat collector, multi-trays drying chamber, and a chimney as shown in Figure 1. The drying capacity of the dryer is 50 kg. Atmospheric air flows into the solar heat collector (1.6 m^2) - made up of black-painted recycled aluminium cans and covered with acrylic sheet, through natural convection and enters into the drying chamber (0.918 m width x 0.987 m length x 2.5 m height) by either downdraft or updraft mode. Figure 2 is a schematic diagram of the solar dryer that demonstrates the airflow configuration in the drying chamber. Drying air that gains moisture during the drying process is then discharged out from the system through the thermosyphon effect in the chimney (0.224 m width x 0.112 m length x 2.028 m height). To enhance air circulation in the drying chamber, the chimney is designed with a transparent cover and a black painted zinc base to increase the temperature across the height to the top.

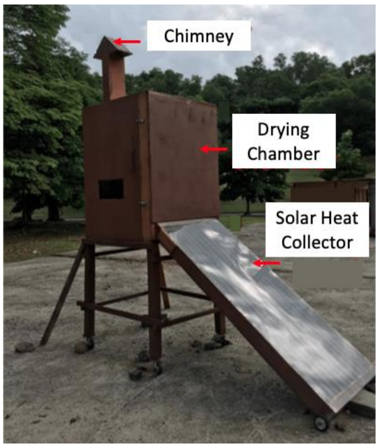

Figure 1. UMS Eco-Solar Dryer.

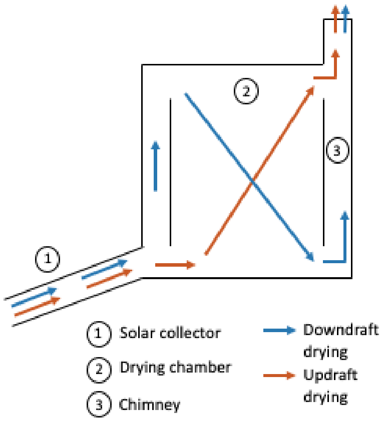

Figure 2. Schematic diagram of the solar dryer.

Experimental Set-up

Palm fruitlets (tenera variety) used for the experiment were collected from the local communities. The initial moisture content of tenera variety palm fruitlets is found to be in the range of 30% to 37% on a wet basis (Shaarani *et al.*, 2010). The drying process was performed from 8:00 AM to 5:00 PM daily and repeated the next day until equilibrium moisture content was achieved. To perform the evaluation, the dryer was fully loaded with 50 kg palm fruits and distributed on 5 trays. Moisture loss of palm fruits was measured every one-hour interval using weighting scale A&Z (FZ-200i) with 0.0001g precision. Relative humidity, air temperature, airflow, and solar radiation throughout the experiment period were measured. GLOBE Hygro Thermometers were used to measure the relative humidity inside and outside of the drying chamber. Air temperature before entering the dryer and inside the drying chamber was measured using a thermocouple. Air velocity at the outlet of the solar heat collector was measure with an anemometer and a Kipp & Zonen CMP3 pyranometer was used for solar intensity measurement.

Mathematical Modelling of Drying Curve

Drying data in this study were graphically analysed in terms of the average weight of palm fruit in gram (y-axis) with time in hours (x-axis). The mathematical modelling of the drying curve was intended to be obtained by using regression and curve-fitting in MS Excel software. The four curve fitting equations to accommodate the modelling of the overall drying process were linear, quadratic, logarithm, and exponential equations. Since two drying stages that show distinct patterns were expected, the drying curve was modelled separately according to the stages to obtain a more accurate model. Coefficient of determination (R^2) was used as a primary criterion to identify the best fit mathematical model to describe the drying of palm fruits. The model with the highest coefficient of determination was selected.

RESULT AND DISCUSSION

Commissioning Without Load

Performing commission of solar dryer without load aimed to determine drying parameters that have a significant effect on the drying process such as solar radiation, drying air temperature, and relative humidity. Overall, the minimum and maximum temperatures attained in the dryer were 32.6 °C and 50.5 °C respectively. This data was obtained under clear and sunny weather during the 8:00 AM to 5:00 PM drying period. The summary of experimental results recorded is shown in Table 1. Based on the results obtained, it can be inferred that the drying condition offered in the solar dryer does not exceed the upper limits for palm fruits heating. Sarah and Taib (2013) have computed a *z*-value of 71.5 °C, 77 °C, and 83 °C for microwave sterilization of 0.5, 1.5, and 1 kg palm fruits respectively to effectively inactivate lipase activity and prevent unnecessary moisture loss.

Table 1. Summary of experimental results

Drying parameters	Value	Unit
Initial weight of palm fruits	18.02	g
Final weight of palm fruits	14.95	g
Air flow range at drying chamber inlet	0.00 – 0.32	m/s
Average solar radiation	605.5	W/m^2
Average ambient temperature	33.1	°C
Maximum drying temperature	50.5	°C
Minimum drying temperature	32.6	°C
Drying time	168	hours

Determination of Drying Characteristics

The experimental result shows that the equilibrium moisture content of palm fruits was achieved in approximately 7 days (168 hours) with an average cumulative moisture loss of 17.05%, which is within the range of critical moisture loss reported by Sarah and Taib (2017). This indicates that the drying condition in the solar dryer offers effective enzyme inactivation throughout the process. Figure 3 represents the evolution of the average weight of palm fruits as a function of time. The drying characteristics curve established was based on the combined data observed in all 5 drying trays. It was observed that the rate of drying was higher at the initial stage (first 16 hours) and gradually decreases with the drying period. Two stages could be determined from the curve plotted – constant rate period and falling rate period. At the constant rate period (t = 0 to 16 hours), moisture removal from palm fruits is rapid due to the presence of unbound moisture on the surface of palm fruits. A similar trend was reported by Yoosa *et al*. (2018) in studying the weight profile of microwave-heated palm fruits where rapid weight loss was observed in the earlier stage. In solar drying, important factors that influence the drying rate of palm fruits in the constant rate period are drying air temperature, relative humidity, and airflow rate. Hence, while employing solar drying for palm fruits, adequate control on these drying parameters is crucial to prevent over-drying on the mesocarp before evaporation from the interior part that promotes easy fruits detachment from the pedicel occurs.

The presence of falling rate was observed at t = 16 hours to t = 168 hours. At this stage, the rate of moisture loss from palm fruits decreasing while approaching its equilibrium moisture content due to the reduction of moisture to be removed. Moisture movement is driven by capillary forces and diffusion of moisture caused by the difference in the concentration of solutes at the exocarp and in the mesocarp of palm fruits. As presented in Table 2, the average cumulative moisture loss at t = 16 hours was 7.93%. This indicates that moisture evaporation from the interior of palm fruits occurs only after moisture loss of 7.93% is achieved. Thus, it can be inferred that the critical moisture loss to ensure effective solar drying for fruits detachment is 7.93%. At t = 168 hours where equilibrium moisture content was attained, continue drying at this point will eventually dry up unbound moisture available in the fruits and deteriorate the quality of palm fruits due to overheating.

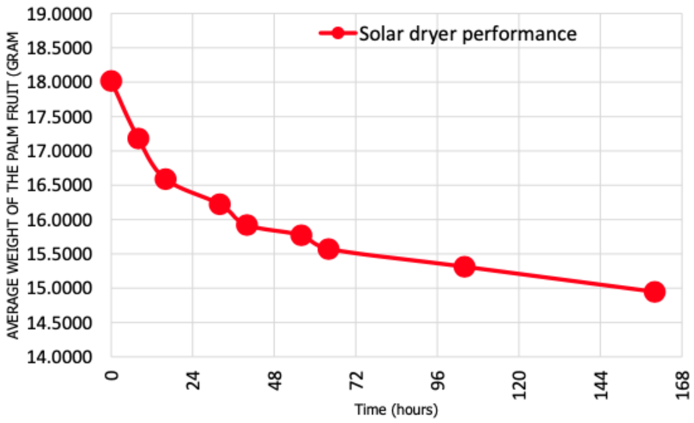

Figure 3. Overall drying kinetics of palm fruits.

Table 2. Experimental data of average palm fruits weight and cumulative moisture loss throughout the drying period.

Drying time	0	8	16	32	40	56	64	104	160
Average palm fruit weight (g)	18.02	17.18	16.59	16.22	15.92	15.77	15.57	15.31	14.95
Cumulative moisture loss (%)		4.66	7.93	9.97	11.65	12.47	13.59	15.02	17.05

Mathematical Modelling of Drying Curve

Drying curve obtained were fitted with four equations and the acceptability of drying models were identified based on regression value R^2. The experimental and predicted drying characteristics of palm fruits for these 2 stages are shown in Figure 4 and Figure 5 respectively. Based on the result, quadratic equation and logarithm equation was the best model to describe constant rate period and the falling rate period respectively. Table 3 summarizes the curve fit regression values and its corresponding equation constant for each drying stage respectively. Figure 6 shows the combined equations model for the drying process. For this combined equation, an average of 0.2% error was determined to the experimental data.

Table 3. Coefficients of the models to describe the drying characteristics of palm fruits.

Model name	Coefficient	R^2
First stage: Constant rate period		
Linear equation	a = -0.0893 b = 17.977	0.9899
Quadratic equation	a = 0.0019 b = -0.1205 c = 18.019	1
Exponential equation	a = 17.89 b = -0.005	0.9921
Second stage: Falling rate period		
Quadratic equation	a = 8E-05 b = -0.0246 c = 16.894	0.9775
Exponential equation	a = 16.482 b = -7E-04	0.9001
Logarithm equation	a = -0.72 b = 18.623	0.9892

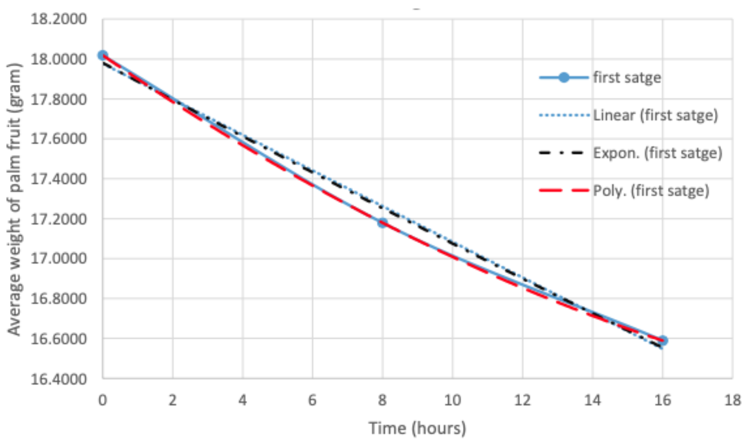

Figure 4. Experimental and predicted drying characteristics of palm fruits in constant rate period.

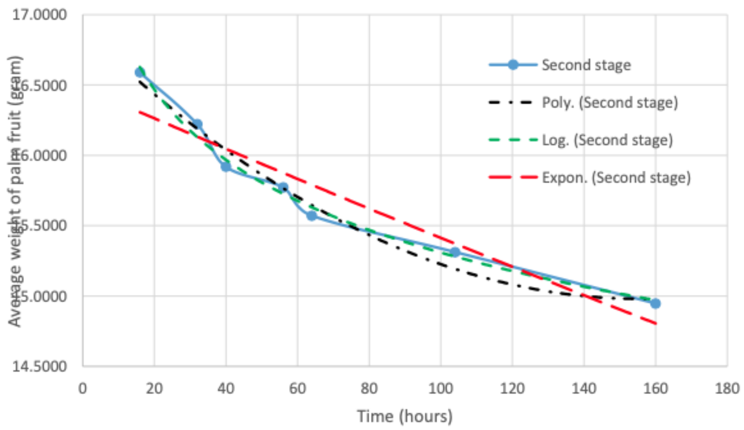

Figure 5. Experimental and predicted drying characteristics of palm fruits in falling rate period.

CONCLUSION

50 kg of palm fruitlets were dried in an indirect type solar dryer under natural convection until equilibrium moisture content was achieved. The drying process was performed in the temperature range of 32.6 to 50.5 °C and requires approximately 168 hours to obtain an average cumulative moisture loss of 17.05%. The drying characteristics of the drying process were identified. Drying curve established shows two drying stage occurs – constant rate period and falling rate period. This approach provides valuable information to predict the drying kinetics of palm fruits throughout the

process and can be used for process optimization in solar dryers. The mathematical model that best describes the two-stage drying curve is quadratic and logarithm equation respectively.

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