LOW COST TELEMONITORING TECHNOLOGY OF SEMISPHERICAL SOLAR DRYER FOR DRYING ARABICA COFFEE BEANS
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TEKNOLOGI TELEMONITORING BERBIAYA RENDAH PADA PENGERING SURYA TIPE *SEMI-SPHERICAL* UNTUK PENGERINGAN BIJI KOPI ARABIKA

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ABSTRACT
This study focusses on the development of a low-cost Internet of Things (IoT) system for semispherical solar dryers to dry arabica coffee beans. The temperatures and relative humidity (Rh) of a solar dryer room are measured using a DHT22 sensor module. The moisture content of hard arabica coffee beans is calculated by measuring the mass of the dried product using the load cell sensor module. All detected data are then sent using wireless networks and saved on a database cloud server. Tests are conducted to evaluate the uniformity of the DHT22 sensor module in a semispherical solar dryer, measure the temperature and Rh and reduce the mass of the dried coffee beans. The performance of the DHT22 sensor module at the uniformity testing stage shows promising results in terms of temperature and Rh, with standard deviations of 0.46 and 3.55, respectively. In addition, the performance of the semispherical solar dryer in relation to the drying kinetics of arabica coffee beans is evaluated. Arabica coffee beans are dried from 49.59% (w.b.) to 10% (w.b.) moisture content within 69 h. In addition, the drying kinetics of coffee arabica beans are investigated. Three models are compared with experimental data on arabica coffee beans dried in a semispherical solar dryer. The Page model is selected to represent the thin layer drying behaviour of arabica coffee beans.

ABSTRAK
Dalam penelitian ini, kami fokus pada pengembangan sistem internet of things (IoT) berbiaya rendah untuk alat pengering surya semi-spherical biji kopi arabika. Suhu dan kelembapan relatif ruang pengering diukur menggunakan modul sensor DHT22. Kadar air biji kopi arabika dihitung dengan mengukur massa produk kering menggunakan modul sensor load cell. Semua data yang diukur kemudian dikirim menggunakan jaringan internet dan disimpan di server cloud database. Pengujian dilakukan untuk mengevaluasi keseragaman modul sensor DHT22 dalam pengering surya semi-spherical, mengukur suhu dan kelembapan relatif serta pengurangan massa biji kopi yang dikeringkan. Kinerja modul sensor DHT22 pada tahap pengujian keseragaman menunjukkan hasil yang menjanjikan dalam hal suhu dan kelembapan relatif dengan standar deviasi masing-masing sebesar 0.46 dan 3.55. Selain itu, evaluasi kinerja alat pengering surya semi-spherical dalam kaitannya dengan kinetika pengeringan biji kopi arabika juga dilakukan. Biji kopi arabika dikeringkan dari 49.59% (b.b.) hingga 10% (b.b.) kadar air dalam waktu 69 jam. Selain itu, kinetika pengeringan biji kopi arabika juga diselidiki. Tiga model dibandingkan dengan data eksperimen pada biji kopi arabika yang dikeringkan dalam pengering surya semi-spherical. Model Page ditemukan dapat mewakili perilaku pengeringan lapisan tipis biji kopi arabika dalam alat pengering ini.

INTRODUCTION
Monitoring and control systems are being considered in modern drying equipment technology to enable the control of dryer performance. *Zhang et al.* (2018) and *Sitorus et al.* (2020) investigated the acquisition of data on the moisture content of products that are dried in a non-invasive fluidisation dryer. Information on the percentage of moisture content is crucial in controlling the quality of dried products and the performance of

dryers. However, relevant monitoring systems are rarely integrated into solar dryers, mainly because they are likely to increase the costs of solar dryers.

Goud et al. (2019) and *Lingayat et al.* (2020a) used six RTD Pt−100 sensors (accuracy of 1%) to measure temperature with 16 channel data loggers. The reduction in the mass of the dried product was measured with a weight balance (Model: OHAUS PA 214) with an accuracy of ±0.2 mg. In their experimental procedure, the proposed indirect solar dryer with inlet fans powered by solar PV panels was obviously not integrated with a data acquisition system (*Goud et al.*, 2019; *Lingayat et al.*, 2020a). *Vijayan et al.* (2020) used K-type thermocouples connected to a digital temperature indicator with a resolution of 0.1 °C. Relative humidity was observed using a thermo-hygrometer with an accuracy of ±2% and a resolution of 0.01%. The weights of the samples were checked using a digital weighing machine with a resolution of 1 g. According to the experimental setup described in their study (*Vijayan et al.*, 2020), the process of recording dryer performance data is not integrated into the solar dryer. Therefore, the recording of performance data from the developed solar dryer remains offline and is not performed in real time.

The use of monitoring technology based on the internet of things (IoT), i.e. telemonitoring, is growing rapidly. Several researchers have highlighted the use of this technology in agriculture (*Villa-Henriksen et al.*, 2020; *Tzounis et al.*, 2017), fishery (*Wang et al.*, 2020; *Kumar and Sivaperumal*, 2020; *Chen et al.*, 2017) and animal husbandry (*Zhou et al.*, 2019; *Stojkoska et al.*, 2018; *Babalola G. et al.*, 2018) so that data can be accessed anywhere and at any time. On the one hand, the tools for developing systems towards the use of IoT have developed rapidly. Such tools make devices easy and inexpensive to use in various fields. On the other hand, monitoring equipment for drying technology, especially solar dryers, still uses devices that are scientific and are thus expensive (*Lakshmi et al.*, 2019; *Lingayat et al.*, 2020a; *Goud et al.*, 2019; *Vijayan et al.*, 2020). Therefore, monitoring technology is generally not integrated into solar dryer units. In such a case, the monitoring instruments are removed from the solar dryers after the drying performance is tested.

Solar dryers can be used for low temperature drying. In particular, greenhouse dryers are widely popular, especially in remote areas. In the last two and half decades, greenhouse dryers have been used for low temperature drying with the aid of solar radiation (Prakash et al., 2016). The popularity of solar dryers in remote areas can be attributed to the abundance of solar energy and the need to dry and thereby preserve agricultural materials. Therefore, these devices are beneficial, especially in Indonesia. Scientific studies aiming to optimise solar dryer technology have also been carried out; examples include the works of *Ekka et al.* (2020) on black ginger, *Lingayat et al.* (2020a) on apple and watermelon, *Djebli et al.* (2020) on potatoes and *Ouaabou et al.* (2020) on Moroccan sweet cherry. Other researchers have conducted relevant reviews (*Lingayat et al.*, 2020b; *Vijaya. et al.*, 2012). Meanwhile, several studies have focused on drying kinetics, thin-layer drying models and the evaluation of the performance of solar dryers for red chili (*Fudholi et al.*, 2014b; *Fudholi et al.*, 2013), seaweed (*Fudholi et al.*, 2014a), salted silver jewfish (*Fudholi et al.*, 2016) and palm oil fronds (*Fudholi et al.*, 2015a).

Solar dryers can be classified into four groups: direct, indirect, mixed, and hybrid solar dryers. Solar dryers can be also categorised as tent dryers, cabinet dryers and greenhouse dryers according to the type of drying chamber. *Fudholi et al.* (2015b) and *Fudholi et al.* (2015c) reviewed air- and water-based types of solar dryers in Malaysia. In Indonesia, *Yahya et al.* (2016) developed a solar dryer system for cassava and rice paddies (*Yahya et al.*, 2018; *Yahya et al.*, 2017). However, existing research is still focused on finding an optimal method for harvesting solar energy and studying the kinetic drying modeling of dried products. Therefore, the objective of the current study is to compare suitable mathematical drying models for Arabic coffee beans and to analyse the performance of a semispherical solar dryer for Arabic coffee beans. The main objective of this study is to develop a low-cost IoT system for monitoring semispherical solar dryers. The proposed system is expected to complement solar drying by allowing drying performance to be monitored anywhere and at any time.

MATERIALS AND METHODS

This research was carried out at the Research Centre for Appropriate Technology, National Research and Innovation Agency, Subang. The solar dryer equipped with a telemonitoring system is located at 6°33'16.0"S–107°45'41.6"E at an altitude of 87 m asl. The telemonitoring system performance test was carried out in August 2019. The development of the telemonitoring system was carried out in three stages, namely, (i) designing the telemonitoring system, (ii) testing the uniformity of temperature and relative humidity sensors and (iii) testing the performance of the telemonitoring system integrated into the solar dryer.

The telemonitoring system integrated into a solar dryer is presented in Figure 1. The solar dryer developed at the Research Centre for Appropriate Technology is of the semispherical type (*Uğur et al.*, 2018). The dryer has a width of 2.8 m, length of 4.2 m and height of 3.1 m. It comprises three layers, each of which has two racks on which to place the products to be dried. The solar dryer frame is made of galvanized iron with a diameter of 38.1 mm and its walls and roof are coated with 14% UV plastic with a thickness of 170 microns. The floor of the solar dryer is made of bricks that are attached directly to the ground.

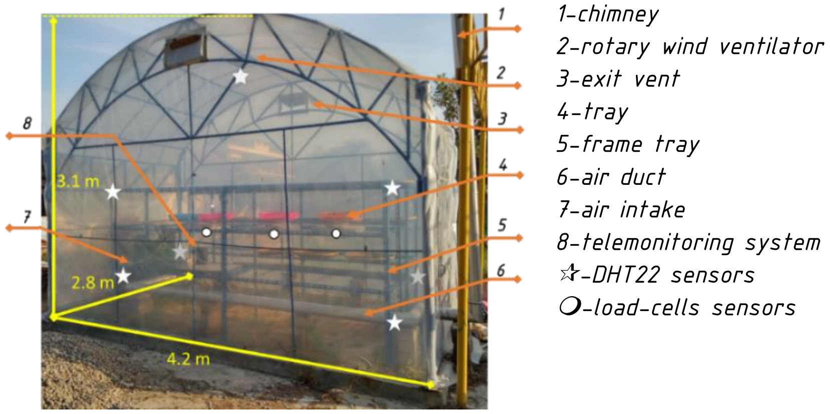


Fig. 1 – Solar dryer developed in this study

When designing the telemonitoring system, the cost and availability of materials used for the construction were considered. The system consists of a temperature telemonitoring unit and a product mass telemonitoring unit. The temperature telemonitoring unit uses seven DHT22 sensor modules to measure temperature and relative humidity (Figure 2). The product mass telemonitoring unit comprises three racks equipped with load cell sensors which measure the changes in the mass of the products being dried. This unit indicates the decreases in the mass of the products that are dried in the solar dryer (*Sitorus et al.*, 2020). All sensor data are recorded and sent to the NodeMcu Esp8266 microcontroller via WLAN every 2 s. A datasheet of the DHT22 sensor modules and load cells is presented in Table 1. The list of components used in the design of the telemonitoring unit is shown in Table 2. The capital cost for the construction and installation of this system is 130.70 USD. This cost is not much higher than that of other low-cost systems, such as *Putra* (2020), which is a portable sensing system integrated with an on-the-go fertilizer application system.

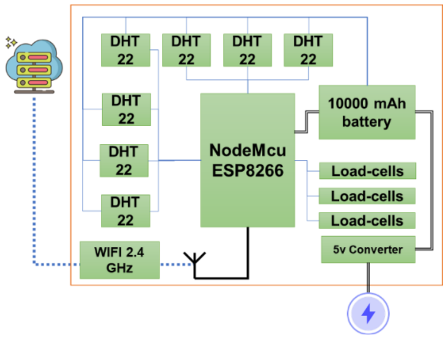


Fig. 2 – Telemonitoring system architecture

The performance testing of the telemonitoring system was carried out in two stages. The first stage involved testing the level of uniformity of the DHT22 temperature sensors and their sensitivity to temperature changes in the solar dryer. For this stage, the DHT22 sensor modules in the middle of the solar dryer room were collected. Then, the system was turned on for three days.

The level of measurement uniformity was indicated by the standard deviation parameters of the seven DHT22 sensors that are calculated using Equation 1. At this stage, the DHT22 temperature sensors were placed at several points in the solar dryer room. The drying racks were also equipped with load cell sensors. The second stage involved the use of wet coffee beans with hard skins (Java Preanger Arabica coffee, Indonesia) (*Happyana et al.*, 2020) with a water content of 49.80% (w.b.). All data were sent to the database using the internet network. The selected coffee type is one of the oldest agricultural products that is continuously preserved in West Java Province, Indonesia. Even today, extensibility continues to meet market demands.

$$S = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \mu)^2}{n-1}} \quad (1)$$

Where S is the standard deviation, x_i denotes the data sent to i, μ is the mean and n is the amount of data.

Table 1

Datasheet of DHT22 and load-cells sensor

Parameter	DHT22 sensor module Temperature	DHT22 sensor module Relative humidity	Load-cells sensor
Operating Voltage	5 V		3.3 V – 5 V
Operating Current	1.5 mA		1.5 mA
Operating Temperature	-20 °C – +80 °C		-35 °C – +80 °C
Range measurement	-40 °C – +80 °C	0 – 100%	0 – 5 kg
Deviation	±0.5 °C	± 2.0%	0.05%
Resolution	0.1 °C	0.1%	1.0±0.15 mv/V

Table 2

List of components of the low-cost system and their price (as of November 2021)

No	Component	Quantity	Price unit (USD)	Remark
1	NodeMCU Lolin V3	3	7.29	ESP8266
2	Temperature and Rh Sensor	7	37.80	DHT22 DFRobot
3	Loadcell + Amplifier	3	6.43	HX711
4	Sensor cable	1	21.43	AWM 24x3
5	Connector	10	3.57	USB male-female
6	Electronic box	1	2.54	
7	Battery	1	11.79	10000 mAh
8	Switch	1	0.14	
9	PCB	1	0.29	
10	Spacer	10	0.86	
11	Indicator LED	1	0.07	
12	Pin Header	1	0.07	
13	Jumper	1	0.36	
14	Plastic Basket	3	3.21	
15	Metal sheet	3	8.57	
16	Internet network	1	32.14	
17	5-VDC Adapter	1	1.43	
Total cost of developing telemonitoring system			**~130.70**	

Table 3

Uncertainties of the parameters during the experiment

Parameter	Unit	Comment
Uncertainty in the temperature measurement		
Drying room temperature	°C	±0.2872
Ambient air temperature	°C	±0.2872
Uncertainty in the time measurement		
Uncertainty in the time measurement	min	±0.1000
Temperature values	min	±0.1000
Uncertainty in the mass loss measurement	g	±0.5123
Uncertainty of the measurement of relative humidity of air	%	±0.1414
Calculated values		
Total uncertainty for moisture rate	%	±0.5220
Total uncertainty for drying rate	%	±0.5220

Uncertainty analysis focuses on uncertainties or errors in experimental data. In general, errors can be particularly systematic errors or random errors. According to *Akpinar* (2010), errors and uncertainties in experiments on solar dryers can arise from instrument selection, condition, calibration, environment, observation, reading and test planning. Therefore, the uncertainty analysis of the experimental measurement and results is a powerful tool when used in the planning and design of experiments. In the current study, an uncertainty analysis was performed using Equation 2 (*Akpinar*, 2010; *Holman*, 2001).

$$\omega_R = \left[\left(\frac{\partial R}{\partial x_1} \omega_1 \right)^2 + \left(\frac{\partial R}{\partial x_2} \omega_2 \right)^2 + \ldots + \left(\frac{\partial R}{\partial x_n} \omega_n \right)^2 \right]^{1/2} \quad (2)$$

where: R- is the function of the independent variables $x_1, x_2, x_3, \ldots, x_n$,; w_R-uncertainty in the result and $w_1, w_2, \ldots, w_n$.

Total uncertainties of the measured parameters and calculated experimental parameters are presented in Table 3. Each uncertainty value was considered to be within a suitable range.

Table 4 and Table 5 show the equations of the drying analysis, including the drying rates, moisture contents of the arabica coffee beans and drying mathematical models. Four drying mathematical models were fitted with the experimental data of the semispherical solar dryer for arabica coffee beans: Newton model, Page model, Henderson and Pabis model and the modified Page model. These models were calculated using Excel, and the constants were determined using a curve method. The values of determination (R^2), mean bias error (*MBE*) and root-mean-square error (*RMSE*) coefficient were used to select the most suitable drying mathematical models. The model that produced the highest R^2 and the lowest *RMSE* in describing the drying curve was considered the best model. The statistical parameters were calculated using the following Equations 3 and Equations 4.

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2 \quad (3)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2} \quad (4)$$

where: $MR_{exp,i}$ is experimental value of moisture ratio, $MR_{pre,i}$ is simulated value of moisture ratio, and N is number of data points (observations).

Table 4

Drying analysis equations

Drying analysis	Unit	Comment	Equation
Drying rate (*DR*)	(g/g)/h	M_t is moisture content at time *t*, and M_{t+dt} is moisture content at time *t* + *dt*	$DR = \frac{M_{t+dt} - M_t}{dt}$ (5)
Moisture content wet basis	(% w.b.)	*w(t)* is mass of wet materials at instant *t* (kg), *d* is mass of dry materials (kg)	$M = \frac{w(t) - d}{w}$ (6)
Moisture content dry basis	(g/g)		$M = \frac{w(t) - d}{d}$ (7)
Moisture ratio (*MR*)		*M* is the moisture content at any time *t*, M_e is equilibrium moisture content, and M_i is initial moisture content.	$MR = \frac{M - M_e}{M_i - M_e}$ (8)

Table 5

Drying mathematical model

Model name	Model solution with Excel solver	Model equation
Newton	The exponential curve of Newton's model, which represents the correlation between MR and drying time	$MR = \exp(-kt)$ (9)
Page	*ln (-ln MR) = ln (k) + n ln (t),* The correlation ln (−*ln MR*) with *t*, which is the curve of the logarithmic equation	$MR = \exp(-kt^n)$ (10)
Henderson and Pabis	*ln MR = -kt + ln (a),* a plot of ln MR versus drying time produced a straight line with intercept *ln (a)* and slope *k*	$MR = a \cdot \exp(-kt)$ (11)

The heat utilisation factor (*HUF*) and coefficient of performance (*COP*) were evaluated for the semispherical solar dryer for arabica coffee beans. *HUF* is defined as the ratio between temperature decrease due to cooling air during drying and temperature increase due to heating of air, as shown in Equation 12. *COP* is calculated by Equation 13 (*Prakash et al.*, 2016; *Sayyad et al.*, *2015*).

$$HUF = \frac{(T_d - T_e)}{(T_d - T_a)} \quad (12)$$

$$COP = \frac{(T_e - T_a)}{(T_d - T_a)} \quad (13)$$

$$HUF + COP = 1 \quad (14)$$

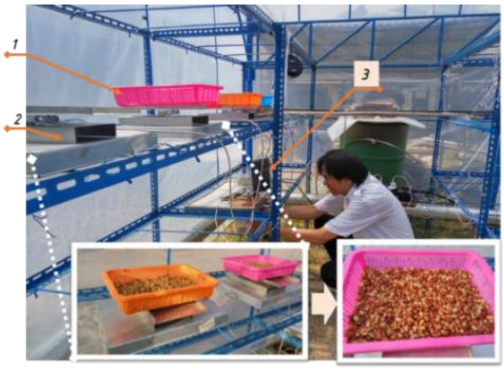
where:

T_a, T_d and T_e are the ambient temperature, drying temperature and exhaust air temperature, respectively.

RESULTS

A telemonitoring system was successfully developed and integrated into the solar dryer (Figure 3). The telemonitoring unit consisted of two control boxes, each of which comprised seven temperature sensors; each mass sensor had three control boxes. Telemonitoring systems can record and send data to servers via WLAN.

The data can then be accessed wherever and whenever using devices such as smartphones to monitor the performance of solar dryer units and dried products. Telemonitoring devices are expected to improve the process of identifying the performance of solar dryers and dried products. The resulting data are important for drying agricultural and food products because according to some studies, agricultural and food products are highly perishable (*Sivakumar et al.*, 2016; *Bruce et al.*, 2019; *Ogawa et al.*, 2017) due to various factors, including improper drying temperature monitoring.



1-tray product
2-loadcells frames
3-control box telemonitoring system

Fig. 3 – Telemonitoring devices integrated into the solar dryer

Open-source software (Arduino IDE) was used to develop a logarithm for the telemonitoring system. Open-source software Notepad++ was used to design the data recording information system for web logging. An example of a data recording page is presented in Figure 4.

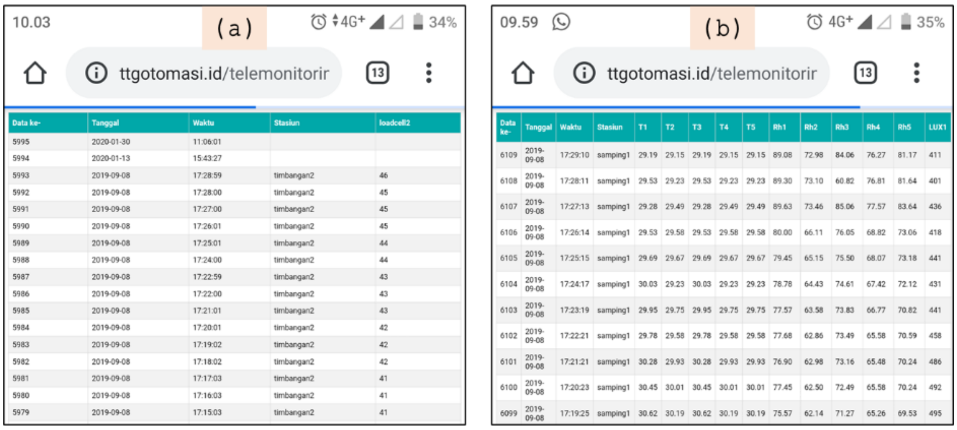


Fig. 4 – Data pages accessed via smartphone

Temperature and relative humidity are important parameters in the drying process. Therefore, it is important to ensure that every sensor used meets reliability requirements. Seven DHT22 sensors were used in the uniformity test. Each sensor was placed at one point in the solar dryer room. The setup was aimed at determining the differences in sensor readings of changes in temperature and relative humidity.

The average temperature readings of the DHT22 sensors followed by standard deviations are presented in Figure 5a. The tests were carried out from August 3 at 10:45:53 am to August 6 at 02:24:51 am. A total of 3276 temperature recordings followed the patterns of temperature changes in the solar dryer. However, from the seven temperature recording sensors, the NAN data recorded were 7.94%, 7.78%, 7.84%, 9.13%, 12.52%, 3.24% and 11.48%. The presence of NAN data, which are called unsuccessfully recorded data, is in line with the research by *Dahlan et al.* (2018), who found similar results from the use of DHT22 sensors. However, their work did not mention the percentages; therefore, no comparison could be made. The highest, lowest, and average temperatures during the uniformity test were 52.07±10.24 °C, 18.86±0.04 °C and 30.42±0.46 °C, respectively. The results of the test indicated that the standard deviations of the temperature sensors tended to increase with increasing temperature of the solar dryer room, and vice versa.

The average relative humidity readings from the DHT22 sensors followed the standard deviations and are presented in Figure 5b. The test was carried out from 3 August at 10:45:53 am to 6 August at 02:24:51 am. A total of 3276 relative humidity recordings followed the patterns of relative humidity changes in the solar dryer. However, from the seven relative humidity recording sensors, the NAN data were 7.94%, 7.78%, 7.84%, 9.13%, 12.52%, 3.24% and 11.48%. The highest, lowest, and average relative humidity during uniformity testing were 85.05%±24.47%, 20.27%±1.29% and 58.14%±3.55%, respectively. The results of this test indicated that the standard deviation of the relative humidity sensor tended to decrease with increasing relative humidity in the solar dryer room, and vice versa.

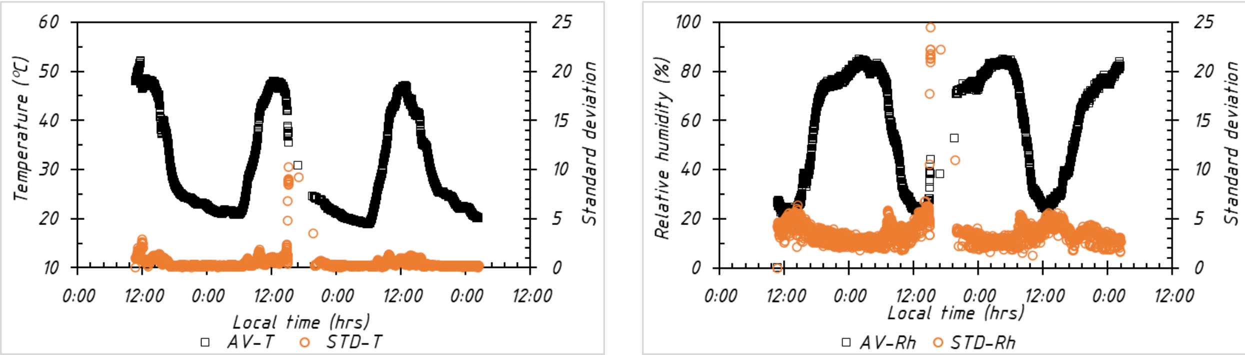


Fig. 5 – Sensor uniformity test from 3 to 6 August 2019 (a) temperature (b) relative humidity

In the DHT22 sensor uniformity test on August 4, the unstable temperature and relative humidity data readings (sensor 1 and sensor 2) lasted 16907 s. Therefore, the standard deviations of the temperature and relative humidity data at the time of measurement increased to 10.24 and 24.47, respectively. The instability of the temperature data measurements was marked by a decrease in the temperature readings of sensor 1 (from 44.40 °C to 23.90 °C) and sensor 2 (from 42.30 °C to 24.50 °C) within 618 s; the other sensors did not follow the same trend. As for the relative instability of the measurement of relative humidity data, it was marked by an increase in relative humidity readings by sensor 1 (from 43.60% to 68.70%) and sensor 2 (from 48.00% to 71.80%) within 618 s; the other sensors did not follow the same trend. Thereafter, all sensors were turned off for 16289 s. This incident was attributed to the power outage and the exhaustion of the backup power from the telemonitoring system before the power was restored. The measurements of temperature and relative humidity of all sensors returned to normal on their own at 19:41:28 pm after the power was restored.

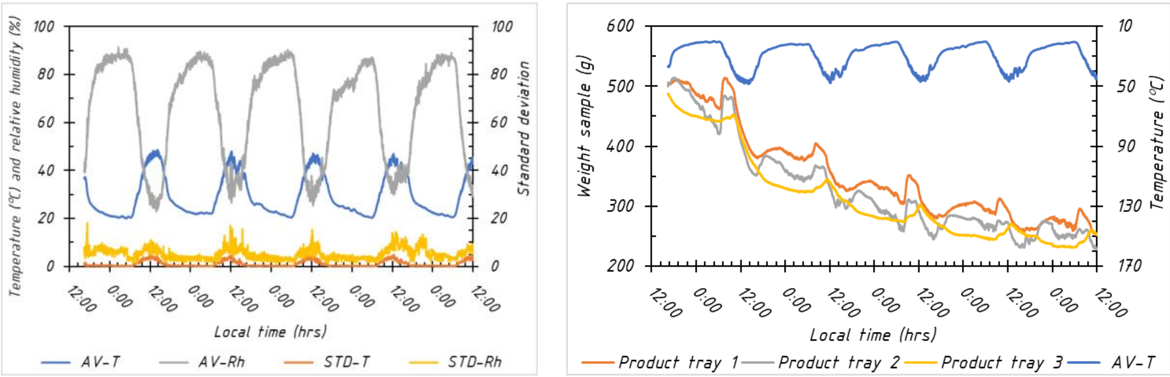


Fig. 6 – Testing solar dryer on 7 to 12 August 2019 (a) temperature and relative humidity (b) mass reduction

The average temperature and relative humidity readings of the DHT22 sensors following the standard deviations in the test using coffee products are presented in Figure 6a. The experiments were carried out from 7 August at 16:25:16 pm to 12 August at 11:59:38 am or for 115.57 h. A total of 6740 temperature and relative humidity readings were recorded, and they followed the patterns of the changes in temperature and relative humidity in the solar dryer. The percentages of NAN data for the temperature and relative humidity recorded from the seven sensors were 14.57%, 9.54%, 14.85%, 9.88%, 19.58%, 7.8%, and 12.66%. The highest, lowest, and average temperatures during the test were 48.57±4.9 °C, 20.00±0.00 °C and 29.30±1.06 °C, respectively. The highest, lowest, and average relative humidity during the test were 91.30%±18.10%, 22.94%±1.03% and 65.84%±5.33%, respectively. The performance test indicated that increasing the temperature increased the temperature measurement errors, and vice versa. Meanwhile, increasing the relative humidity decreased the errors from measuring relative humidity, and vice versa.

The decrease in product mass due to the evaporation of the moisture content in the test is presented in Figure 6b. Three trays with the same product of the same initial relative mass showed distinct differences in drying behaviour throughout the drying process. The percentage decrease in the mass of the dried product during the first stage of testing was 50.84%. In general, when the temperature in the solar dryer increased, the mass of the dried product decreased sharply. However, as the temperature decreased, the mass of the dried product increased. This result is in line with that of *Lakshmi et al.* (2019), who explained that it was caused by evaporation of moisture from the surface and the latter decrease in the rate of moisture removal was mainly due to the diffusion of moisture from the interior to the surface of the product.

With reference to Table 5, the results of the drying analysis, including the drying rate curve, characteristic drying curve, drying kinetic curves and drying curve of the semispherical solar dryer for arabica coffee beans are showed. The drying curve showed the change in profile in moisture content versus drying time (t). Figure 7a describes a reduction in moisture content (dry basis and wet basis). The drying rate with an average of 0.01 (g/g)/h and a maximum of 0.11 (g/g)/h, was calculated using Equation (5).

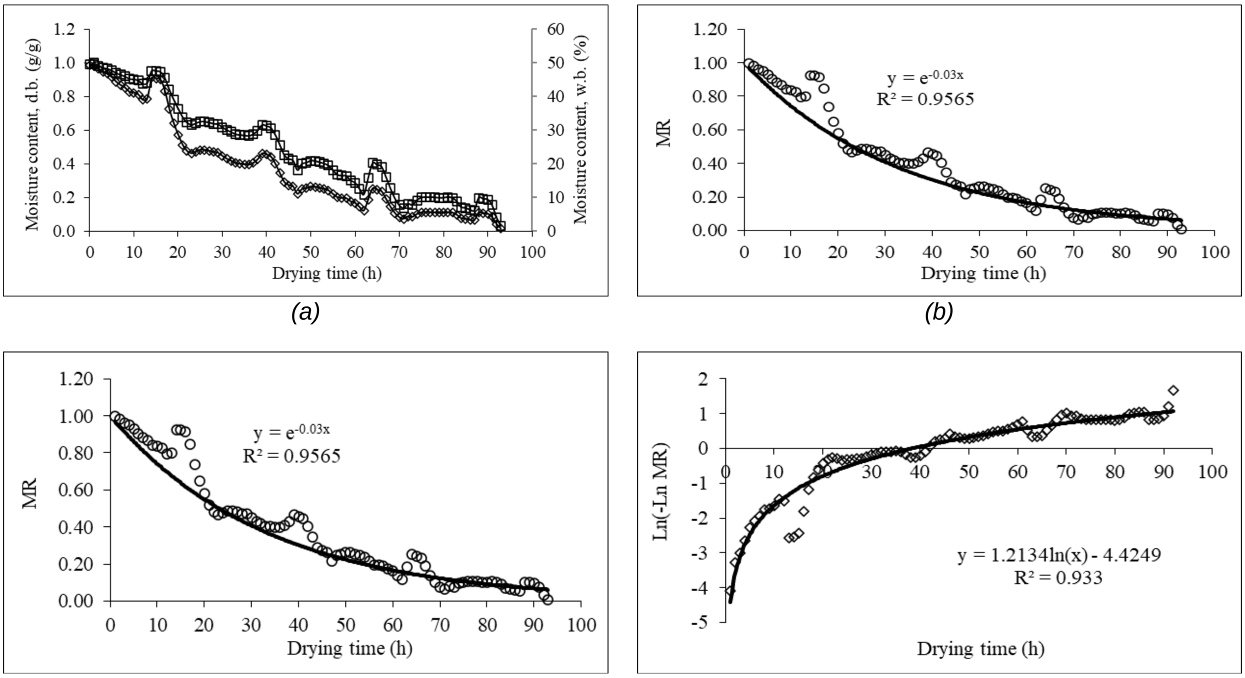


Fig. 7 – (a) Moisture content variation (b) Newton drying model (c) Page drying model (d) Henderson and Pabis drying model

Drying mathematical model curve of the semispherical solar dryer for arabica coffee beans are shown in Figure 7b until Figure 7d. Figure 7b shows Newton's model, which represents the correlation between the *MR* and drying time. Figure 7b shows that the exponential curve with k constant is 0.03. Figure 7c shows Page's model, which represent the correlation *ln (−ln MR)* with *t*, which is the curve of the logarithmic equation. Figure 7c shows that *n* constant is 1.2134 and the obtained value for *k* constant is 0.012. Figure 7d shows that a plot of *ln MR* versus drying time produced a straight line the intercept of which is *ln a* and the slope is *k* (0.0334) and the obtained value of *a* constant (1.242).

The results presented in Table 6 show that the Page drying model exhibited the highest value of R^2 (0.933) and the lowest values of *RMSE* (0.0581) and *MBE* (0.0034) compared to the Newton model and the Henderson and Pabis model. Accordingly, the Page model was selected to represent the drying mathematical model behaviour of arabica coffee beans. This selection is in accordance with the findings of *Fudholi et al.* (2014a), who reported that the Page model had a better fit in drying seaweeds than the Newton and Henderson and Pabis models. Also, it was reported that the Page model exhibited a better fit than other models in accurately simulating the drying curves of rapeseed, kiwi, okra, green beans, chili pepper, and others.

The performance characteristics of the semispherical solar dryer for arabica coffee beans, including *HUF* and *COP*, were calculated. The average *HUF* was 0.79. The average *COP* was 0.21, and the total *HUF* and *COP* was 1.

Table 6

Results of drying mathematical model analyses

Model	a	k	n	R^2	MBE	RMSE
Newton		0.03		0.8699	0.0066	0.0811
Page		0.012	1.2134	0.9596	0.0034	0.0581
Henderson and Pabis	1.242	0.0334		0.8854	0.0050	0.0706

CONCLUSIONS

A telemonitoring system as add-on equipment for solar dryers was realised using a low-cost IoT system, and the results of this work show its promising performance. The performance of a solar dryer unit when applied to product drying can be known in real time and online using the developed telemonitoring system. Solar dryer performance data can be logged and then accessed anytime and anywhere. The reduction in the moisture content of dried products can also be known online and in real time. Improving the performance of the proposed system requires an advanced and detailed understanding of the mechanism of the telemonitoring system. Such a requirement entails obtaining experimental results on the basis of real conditions and applying many types of product drying conditions. In sum, when a solar dryer is equipped with a telemonitoring system, it can be used as a high-performance technology system that can be considered intelligent technology. In this study a semi-spherical solar dryer was evaluated to dry Arabica coffee beans using kinetic curves. The Page model clearly showed a better fit to the experimental data compared to the Newton and Henderson–Pabis models. This model had the highest R^2 and the lowest *RMSE* and *MBE*. At the average ambient temperature of approximately 28 °C, the *HUF* and *COP* were 0.79 and 0.21, respectively. The semispherical solar dryer to dry Arabica coffee beans took 69 h to reduce the moisture content of the product from approximately 50% (w.b.) to 10% (w.b.).

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