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Thin layer mathematical modelling of white maize in a mobile solar-biomass hybrid dryer

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Abstract: Performance of a tractor mounted solar-biomass hybrid dryer which utilise combined energy of solar and biomass was investigated. Drying behaviour of maize grains in the dryer was also investigated using 10 thin-layer mathematical models. The models were compared based on coefficient of determination (R^2) and root mean square error (RMSE) values between experimental and predicted moisture ratios. Moisture content (MC) of grains in the dryer reduced from 19 ± 0.86% to 13 ± 0.4% (w.b.) in 5 h, compared to grains dried in open-sun which reached same MC in 15 hours. This resulted in average drying rate of 1.2 $\%\cdot h^{-1}$ compared to 0.4 $\%\cdot h^{-1}$ for grains dried in the open-sun leading to net savings in drying time of 67%. Overall mean temperature, 41.93 ± 2.7 °C in the dryer was 15.3 °C higher than the ambient temperature. Midilli Kucuk model was best to describe the thin-layer drying kinetics of maize in the dryer. It showed a good fit between the predicted and experimental data. The effective moisture diffusivity of grains dried in the dryer ranged between 1.45×10^{-11}–3.10×10^{-11} $m^2 \cdot s^{-1}$. An activation energy of 96.83 $kJ \cdot mol^{-1}$ was determined based on the Arrhenius-type equation.

Keywords: drying rate; coefficient of determination; drying kinetics; effective moisture diffusivity; activation energy

Maize (*Zea-mays*) is widely grown throughout the world and serves as raw material for many industries for the production of animal feed, food materials and some beverages. In Ghana, it is the most cultivated crop with production across all the 16 regions in the country and is by far, the most consumed staple crop contributing significantly to consumer diets with estimated per capita consumption of 43.8 kg (MOFA 2011). However, post-harvest losses related to improper and/or untimely drying is the most important constraint that limits maize production in Ghana. Togrul and Pehlivan (2004) reported that, significant percentage of post-harvest losses and aflatoxins contamination are related to untimely drying of foodstuffs such as cereal grains, pulses, tubers, meat and fish among others.

To reduce the loss of grains through timely drying, electrical and diesel-powered mechanised dryers are prefered since they are faster and provide better quality dried product. However, they are expensive and require substantial quantities of fuel or electricity to operate, resulting in high drying cost (Tonui et. al. 2014). This makes the cost of owning and operating mechanised drying systems economically unattractive and less patronised in developing countries according to Kaaya and Kyamukangire (2010). This has resulted in the continuous dependent on the traditional open-sun drying of grains by smallholder farmers in Africa and other developing countries who usually produce on farmlands less than 2 ha. Though open sun drying is weather dependent, labour intensive, unhygienic and time consuming, it is the most common and the cheapest method of drying farm produce in sub-Sahara Africa according to Amer et al. (2010).

In the absence of an equally cheaper but cleaner and convenient drying system for the smallholder farmer, Tonui et. al. (2014) recommend solar dryers

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as an alternative drying technology. It is eco-friendly and economically feasible to smallholder farmers and has the potential to replace open-sun drying. Solar dryers provide better drying option with higher drying efficiency that leads to lower dying time and produce dried grains of higher quality than grains dried in the open-sun. The application of solar dryers is however limited, they can only be used during the daytime when there is adequate solar radiation. Prolong drying with solar dryers during poor weather condition can affect the quality of the dried product. For commercial grain producers, this factor limits their ability to patronise solar dryers for drying grains. According to Geramitcioski and Mitrevski (2011), this shortfall can be addressed with a hybrid system which integrates a conventional solar dryer with a back-up heating system. Solar hybrid drying systems allows continuous drying irrespective of the weather. This continuity and reliability are important to commercial grain producers to satisfy their markets.

Experimental evaluation on the performance of solar hybrid dryers with biomass burner or other heating systems have shown to be better compared to conventional solar and open-sun drying methods (Amer et al. 2010). However, to successfully transfer knowledge acquired from these experimental set-ups into industrial or commercial applications, mathematical modelling of the drying kinetics of the crop is important. This allows dryer operators to choose the most suitable conditions for drying a crop in a specific dryer. Moreover, mathematical models are important tools used to optimize operating parameters and to predict performance of a drying system (Nag and Dash 2016). Many empirical and semi-empirical thin layer drying models have been developed to describe the drying kinetics of different materials in different drying systems (Doymaz and Ismail 2011; Suherman et al. 2012; Hussein et al. 2016). Research into mathematical modelling of thin layer drying kinetics of maize in conventional solar dryers under force and natural convection have been reported by Agbossou et al. (2016) and Simate (2001). Studies into thin layer drying kinetics of maize in solar hybrid drying systems are critical to support the potential commercialisation of solar drying technologies. This study was carried out using different thin layer drying models to evaluate the drying kinetics of white maize in a 1-tonne capacity tractor mountable solar-biomass hybrid dryer in Ghana. The effect of drying temperature on the effective moisture diffusivity in maize grains was also determined in this study.

MATERIAL AND METHODS

Description and operation of the mobile solar biomass hybrid dryer (MSBHD). The developed MSBHD (Figure 1) consists of three major parts, namely; drying chamber, solar PV systems and biomass furnace. The parts all fabricated together as a single unit and can be hitched to a tractor and moved from place to place to provide drying services in a local farming community. This is similar to the operational concept of mobile mechanical threshers largely used by smallholder maize farmers for threshing/shelling legumes and grains in Ghana. The design capacity of the dryer is approximately 1 000 kg of maize per batch.

Figure 1. Developed mobile solar biomass hybrid dryer with Solar PV system
1 – solar PV system; 2 – furnace with enclosed heat exchanger and chimney; 3 – drying chamber with drying racks; 4 – insert of trays with maize in the dryer and logging device

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The drying chamber has an overall dimension of 3 × 1.8 × 1.9 m and is designed as a greenhouse tent dryer with the roof and all sides covered with a 0.03 m thickness UV-protected transparent acrylic sheet. The drying chamber is divided longitudinally into two with each half made up of three sections and each mirror section represented by seven drying levels/racks (L_1, L_2, L_3....L_7). Each level accommodates six movable drying trays, 3 on each side and each tray is dimensioned 0.9 × 0.8 × 0.05 m. For this study, four levels of 24 trays (12 on each side) was used as shown in Figure 1. The trays are made of wood and the base fixed with perforated plastic mesh to hold the drying grain. The movable trays sit on mild steel angle line frame and are spaced to allow for smooth flow of drying air on top and beneath the product preventing the need to stir during drying. The acrylic sheets on both sides of the drying chamber is framed on mild steel flat bars that allows it slide open for easy access to the trays for loading and off-loading during drying.

The hybrid dryer is integrated with a furnace (0.95 m × 0.95 m × 1 m) enclosed with a cross-flow heat exchanger. Biomass feedstock such maize cobs are burnt in the furnace to provide clean hot air as illustrated in Figure 2 that is channelled into the drying chamber using a blower. This ensures the drying process continue during periods of no sunshine or cloudy weather. An installed PV system with a backup battery ensures possible operation of the dryer in communities with no access to electricity or at night, cloudy and/or rainy periods.

Maize variety. A local white maize variety known as 'Obaatanpa' was obtained from the KNUST Agricultural Research Station farm for the experiment. The initial moisture content was determined using ISO 6540-1980 method for determining moisture content of maize. 8 g of ground maize was put in the oven at 130 °C for 4 hours. Three replicate samples were used for the determination of moisture content and an initial average of 19.0 ± 0.86% wb (23.46% db) was recorded.

Experimental procedure and treatment. The experiment was conducted on a day the weather was cloudy with recorded ambient temperatures staying below 30 °C during the drying period of 7 hours. The drying experiment was conducted using four levels (L_1–L_4) of the hybrid dryer and drying in the open-sun served as control treatment. The dryer was allowed to run for at least 1 h before the commencement of drying for it to reach steady state condition. A total of 420 kg of maize at an initial MC of 19% was used for the drying experiment. About 20 kg of maize grains were uniformly spread on each of the six drying trays at each level (L_1–L_4) with each tray filled in thin layer to a depth of 0.025 m. The six filled trays at each level served as replicate set-up. Similar quantity of 20 kg maize grains at same MC of 19% was set-up in triplicate as a control set-up and dried using the open-sun.

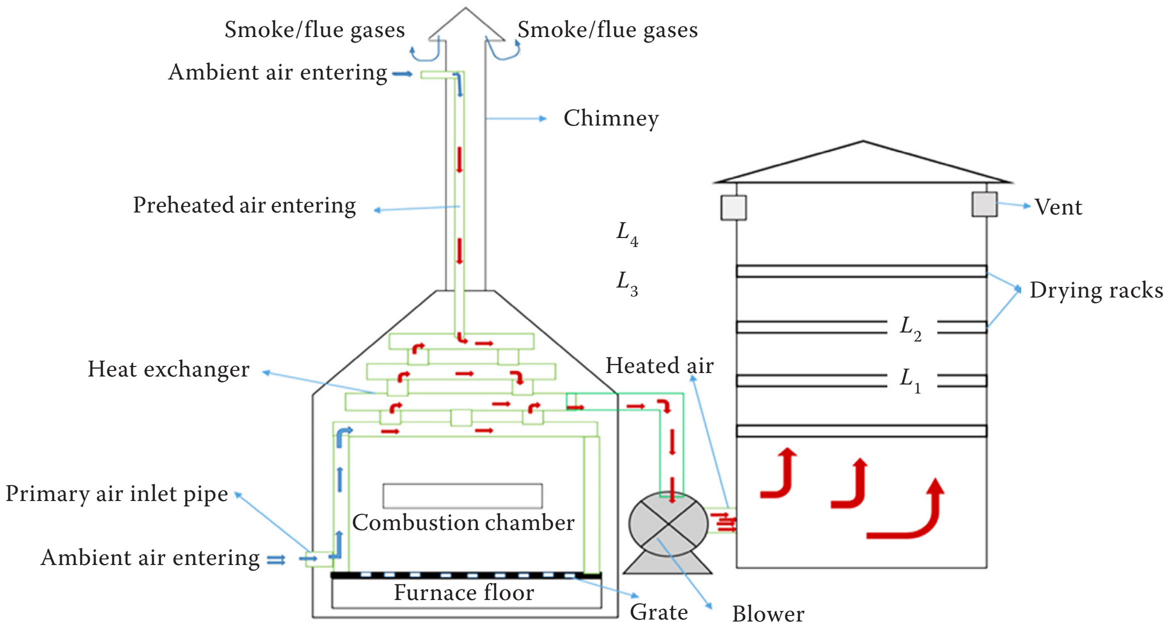

Figure 2. Schematic view of the hybrid dryer showing the flow direction of hot air

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The MC of maize grains during the drying experiment was concurrently monitored hourly with a pre-calibrated moisture meter (Dicky-John mini GAC, USA; plus moisture analyser with accuracy of ± 0.1%). Maize grains were sampled at different positions on each of the six trays at each level and mixed thoroughly before the MC reading was taken and recorded. Three measurements were taken at each period and the means calculated for analysis. Same procedure was repeated for grains dried in the open-sun. Temperature and relative humidity (rh) conditions at all levels in the hybrid dryer and ambient were also monitored and logged with a TinyTag data logger (model TGP-4017; Gemini Data Loggers, UK).

Experimental set-up. The experimental design for this study was a Randomized Complete Block Design (RCBD) with the vertical drying levels serving as the blocks and the six trays at each level as replicates. Key parameters monitored were MC of maize (maize drying rate), temperature and rh in the MSBHD and the ambient formed the basis for the thin layer drying kinetics modelling in the newly developed hybrid dryer using experimental models.

Thin layer mathematical modelling. The moisture ratio (MR) calculated from the MC of maize grains during the drying experiment were fitted to 10 common thin-layer drying models (Table 1). The moisture ratio of maize during the experiment at any given time was calculated using Equation (1):

$$MR = \frac{M_t - M_e}{M_o - M_e} \tag{1}$$

where: MR – moisture ratio; M_t – the moisture content on dry basis at any drying time; M_e – the equilibrium moisture content on dry basis; M_o – the initial moisture content on dry basis.

For long drying period, M_e values are relatively small as compared to M_t and M_o (Hussein et al. 2016). Equation (1) is therefore simplified to Equation (2):

$$MR = \frac{M_t}{M_o} \tag{2}$$

Model fitting. The fitness of experimental data to the thin-layer drying models was evaluated using statistical parameters such as the root mean square error (RMSE) and coefficient of determination (R^2) which were calculated using Equations (3) and (4) respectively. For better fitting procedures, Ertekin and Firat (2017) reported that, higher R^2 and lower RMSE values should be obtained. Regression analysis was done using MATLAB (version R2015a) statistical computer program.

$$RMSE = \left[\frac{\sum_{i=1}^{N} \left(MR_{pre,i} - MR_{exp,i} \right)^2}{N} \right]^{0.5} \tag{3}$$

where: $MR_{pre,i}$ – the predicted moisture ratio; $MR_{exp,i}$ – the experimental moisture ratio; N – the number of observations/readings.

$$R^2 = 1 - \frac{residual\ SS}{corrected\ total\ SS}^{0.5} \tag{4}$$

where: R^2 – coefficient of determination; SS – sum of squares.

Table 1. Mathematical models applied for the thin-layer drying curves

Model	Equation	Reference
Newton	$MR = \exp(-kt)$	Doymaz and Ismail (2011)
Two-term	$MR = a \times \exp(-k_1 t) + b \times \exp(-k_2 t)$	Zenoozian et al. (2008)
Page	$MR = \exp(-kt^n)$	Jangam et al. (2008)
Henderson and Pabis	$MR = a \times \exp(-kt)$	Koua et al. (2009)
Logarithmic	$MR = a \times \exp(-kt) + b$	Doymaz and Ismail (2010)
Wang and Singh	$MR = 1 + at + bt^2$	Bal et al. (2010)
Weibull	$MR = \exp(-t/a)^b$	Vega-Galvez et al. (2010)
Two-Term Exponential	$MR = a \times \exp(-kt) + (1-a) \times \exp(-kat)$	Erbay and Icier (2009)
Midilli kucuk	$MR = a \times \exp(-kt^n) + bt$	Doymaz (2008)
Modofied Page	$MR = \exp[-(kt)^n]$	Lemus-Mondaca et al. (2009)

MR – moisture ratio; k, k_1, k_2 – drying constants; a, b, n – model parameters

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Moisture diffusivity and activation energy. Maize dried in the hybrid dryer followed the falling rate drying period and as such, Fick's equation of diffusion, Equation (5) was used to calculate the effective diffusivity (D_{eff}) ($m^2 \cdot s^{-1}$)

$$MR = A_1 \exp\left(-\frac{\pi^2 D_{eff} t}{A_2}\right) \tag{5}$$

where: A_1 and A_2 – geometric constants.

For an infinite slab, A_1 and A_2 are $8 \cdot \pi^{-1}$ and $4L^2$ respectively. Where, L is half the thickness (in meters) of the sample. With a simple arrangement, Equation (6) is obtained from Equation (5). This shows that, the In(MR) varies linearly with "t" at a slope of "k", which is the drying constant. Equation (7) was used to calculate the effective moisture diffusivity at the different drying levels in the newly developed hybrid dryer.

$$\text{In}(MR) = \text{In}\left(\frac{8}{\pi}\right) - kt \tag{6}$$

where:

$$k = \frac{\pi^2 D_{eff}}{4L^2} \tag{7}$$

The Arrhenius-type equation, Equation (8), was used to describe the relationship between effective moisture diffusivity and drying temperature.

$$D_{eff} = D_0 \exp\left[-\frac{E_a}{R(T + 273.15)}\right] \tag{8}$$

where: Deff – the effective diffusivity (m2·s–1); R – the gas constant (8.3143 kJ·mol⁻1 K); D0 – the pre-exponential factor of the equation (m2·s–1); T – the average temperature exhibited at different drying levels (°C).

The activation energy was determined from the gradient of the plot of In(Deff) vs 1/(T+273.15).

RESULTS AND DISCUSSION

Effect of drying temperature on moisture content variation vs. time. Maize at an initial average moisture content of 19 ± 0.86% (w.b.) was used for this experiment. Variation in grain moisture with time at the different drying levels (L1–L4) was influenced by drying temperature (Figure 3) which varied in an increasing order from the bottom (L1) across the upper levels (L2, L3 and L4). Over the drying period of 7 h, a mean temperature (TL4) of 44.04 ± 8.51 °C was recorded at L4. Similar variations in temperature were observed for L3, L2 and L1 in the dryer with mean temperatures of 43.0 ± 8.2 °C, 42.71 ± 7.94 °C and 37.98 ± 5.78 °C, respectively. Comparatively, average ambient temperature (26.68 ± 1.3 °C) was 15.25 °C lower than the overall mean temperature (41.93 ± 2.7 °C) observed inside the dryer.

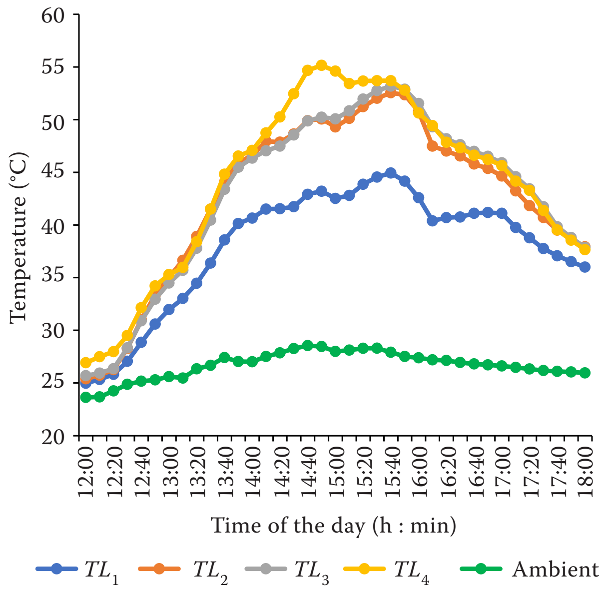

Figure 3. Temperature variation in dryer vs. ambient over drying time

TL_1–TL_4 – drying air temperature at, L_1, L_2, L_3 and L_4 in the dryer

The high temperature recorded in the dryer compared to the ambient temperature was due to the transparent material (perspex) that was used to overlay the drying chamber. Tonui et al. (2014) reported that, perspex material allows absorption of solar energy due to direct solar insolation and is able to prevent heat from escaping by acting as a heat trap for infrared (thermal) radiation thereby confining the heated air. According to Akowuah et al. (2018), the increasing trend in temperature from L1 to L4 in the dryer could also be attributed to the air density differences due to buoyancy effect which caused stratification of hot and cooler air. The additional heat from burning of maize cobs in the biomass furnace also contributed to the high temperature trend in the dryer compared to the ambient temperature agreeing with the findings of Kaaya and Kyamuhangire (2010). Similar results were observed by Agbossou et al. (2016) for maize drying in a solar tunnel dryer.

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Results as shown in Figure 4 illustrates a direct correlation between temperature effect across the levels (L1 to L4) on moisture loss over time. With relatively higher temperature at L4, grains at L4 reached a final MC of 13% in 3 h followed by grains at L3 in 4 h, L2 in 5 h and L1 in 7 h. Comparably, grains dried in the open sun reached same MC of 13% after 15 h of drying. On average, it took 5 h to dry maize grains from 19 ± 0.86% to 13 ± 0.4% MC (w.b.) in the hybrid dryer resulting in an average drying rate of 1.2%·h–1 compared to 0.4 %·h–1 for grains dried in the open-sun. This demonstrates the hybrid dryer as a better option to dry grains faster in a cleaner and hygenic environment compared to grains dried in the open-sun. Net savings in drying time of 67% was achieved by using the hybrid dryer compared to open-sun drying.

The reduction in total drying was due to relatively high temperatures observed in the dryer thereby increasing the available energy required for the evaporation of moisture from the grains. Achint et al. (2017) made similar observations in the drying of corn in a solar cabinet dryer.

Fitting of drying curves. Based on the multivariate regression analysis of the data in MATLAB, the Midilli kucuk model was selected as the best model to predict the drying process of maize in the dryer (Table 2). It recorded the highest R2 and the lowest RMSE values. In a similar work by Agbossou et al. (2016), the Midilli kucuk model was found as the best model of 14 different models fitted to predict the thin layer drying behaviour of yellow dent maize grains at different drying levels in a Hohenheim tunnel dryer.

Validation of the selected model was established by comparison of the experimental data for each drying curve with the values predicted by the Midilli kucuk model. The results are presented in Figure 5. The Midilli Kucuk model provided satisfactorily good conformity between experimental and predicted moisture ratios as the predicted data generally banded around a straight line as shown in Figure 6. According to Hussein et al. (2016), this shows the suitability of the model and validates the accuracy of the model in describing the drying kinetics of maize grains in the mobile hybrid dryer.

Effective diffusivity. Drying of the grains mainly occured in the falling rate period which involved moisture removal from the maize grains by the diffusion process where moisture from inside was transported towards the surface of the grains. This mechanism of diffusion is best described by Fick's second law

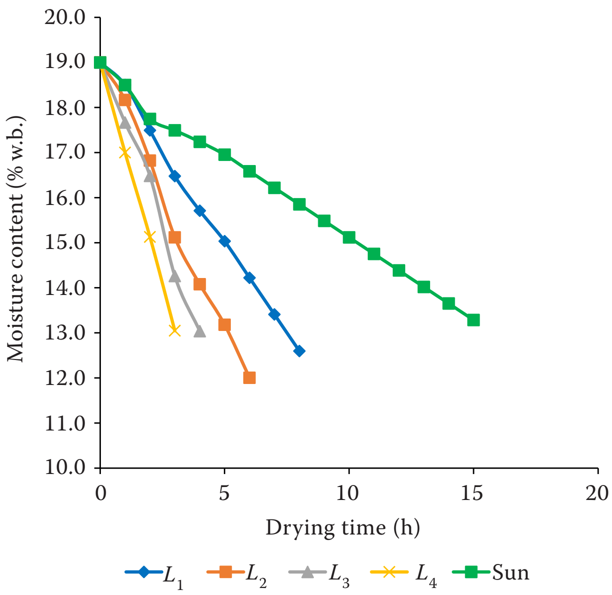

Figure 4. Variation in moisture content *vs* drying time

L_1–L_4 – the drying levels

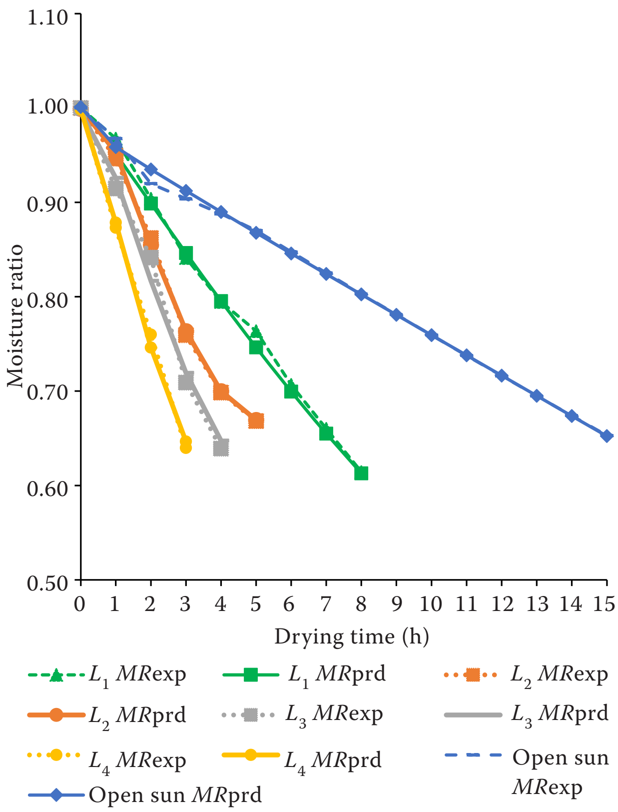

Figure 5. Comparison of predicted moisture ratios (*MR*prd) by Midilli kucuk model and experimental moisture ratios (*MR*exp) with time for maize dried in the dryer and open-sun

L_1–L_4 – the drying levels

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Table 2. Estimated parameters and model comparison of thin-layer drying of maize in the solar-hybrid dryer vs open-sun

Level/temp (°C)	Model	Parameter	RMSE	R^2
L_1(37.98 °C)	Newton	k = 0.0583	0.0129	0.9909
	Two-term	a = 3.629 k_1 = –0.0763 b = –2.62 k_2 = –0.08292	0.0128	0.9944
	Page's	k = 0.04749 n = 1.123	0.0095	0.9956
	Henderson and Pabis	k = 0.0611 a = 1.015	0.0111	0.9941
	Logarithmic	k = 0.0271 a = 2.019 b = –0.1688	0.0104	0.9956
	Wang and Singh	a = –0.05105 b = 0.000327	0.0102	0.995
	Weibull	a = 3.605 b = 0.2102	0.0138	0.9909
	Two term Exponential	k = 0.05831 a = 0.9948	0.0138	0.9909
	Midilli kucuk	**k = 0.0506 a = 1.005 b= 0.0081 n = 1.102**	**0.0110**	**0.9958**
	Modified Page	k = 0.06606 n= 1.121	0.0118	0.9881
L_2 (42.71 °C)	Newton	k = 0.08352	0.0191	0.9801
	Two-term	a = 2.71 k_1 = –0.01193 b = –1.708 k_2 = 0.02218	0.0326	0.9767
	Page's	k = 0.07336 n = 1.099	0.0197	0.9831
	Henderson and Pabis	k = 0.08727 a = 1.013	0.0197	0.9830
	Logarithmic	k = 0.09539 a = 0.9436 b = 0.07006	0.0227	0.9831
	Wang and Singh	a = –0.08031 b= 0.002298	0.0209	0.9809
	Weibull	a = 14.25 b = 1.19	0.0213	0.9801
	Two term Exponential	k = 0.08352 a = 0.9987	0.0213	0.9801
	Midilli kucuk	**k = 0.1395 a = 0.9991 b = 0.0844 n = 1.431**	**0.0051**	**0.9994**
	Modified Page	k = 0.09291 n = 1.1	0.0197	0.9831
L_3 (43.00 °C)	Newton	k = 0.104	0.0198	0.9840
	Two-term	a = 2.158 k_1 = –0.04642 b = –1.16 k_2 = –0.00593	0.0331	0.9821
	Page's	k = 0.09763 n = 1.049	0.0216	0.9847
	Henderson and Pabis	k = 0.1061 a = 1.007	0.0217	0.9846
	Logarithmic	k = 0.1159 a = 0.9416 b = 0.06637	0.0250	0.9846
	Wang and Singh	a = –0.1027 b = 0.004348	0.0216	0.9847
	Weibull	a = 14.11 b = 1.468	0.0221	0.9840
	Two term Exponential	k = 0.1042 a = 0.9625	0.0221	0.9840
	Midilli kucuk	**k = 0.1473 a = 0.9959 b = 0.0664 n = 1.351**	**0.0221**	**0.9920**
	Modified Page	k = 1.089 n = 1.049	0.0216	0.9847
L_4 (44.04 °C)	Newton	k = 0.1318	0.0251	0.9794
	Two-term	a = 1.386 k_1 = –0.1285 b = –0.3971 k_2 = –0.1285	0.0383	0.9808
	Page's	k = 0.1571 n = 0.8597	0.0223	0.9870
	Henderson and Pabis	k = 0.128 a = 0.9879	0.0270	0.9809
	Logarithmic	k = 0.2716 a = 0.6235 b = 0.3837	0.0201	0.9920
	Wang and Singh	a = –0.1527 b = 0.01258	0.0137	0.9951
	Weibull	a = 17.09 b = 2.253	0.0281	0.9794
	Two term Exponential	k = 0.4841 a = 0.1856	0.0203	0.9892
	Midilli kucuk	**k = 0.209 a = 0.9982 b = 0.06856 n = 1.241**	**0.0131**	**0.9978**
	Modified Page	k = 0.1162 n = 0.8597	0.0223	0.9870

RMSE – root-mean-square error; R^2 – coefficient of determination

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Table 2. to be continued

Level/temp (°C)	Model	Parameter	RMSE	R^2
Open-sun (26.7°C)	Newton	k = 0.02811	0.0094	0.9922
	Two-term	a = 0.9882 k_1 = –0.02597 b = –5.77E–05k_2 = 0.3947	0.0084	0.995
	Page's	k = 0.03049 n = 0.9653	0.0123	0.9927
	Henderson and Pabis	k = 0.02731 a = 0.9924	0.0089	0.9935
	Logarithmic	k = 0.0123 a = 1.983 b = –0.9964	0.0086	0.9944
	Wang and Singh	a = –0.02768 b = 0.000316	0.0099	0.9919
	Weibull	a = 23.49 b = 0.66	0.0097	0.9922
	Two term Exponential	k = 0.03248 a = 0.6403	0.0097	0.9922
	Midilli kucuk	**k = 0.0228 a = 1.0 b = –0.0209 n = 0.1835**	**0.0071**	**0.9964**
	Modified Page	k = 0.04716 n = 0.6248	0.0123	0.9436

Highlighted rows represent selected model; L_1–L_4 – the drying levels; RMSE – root mean square error; R^2 coefficient of determination; a, b, k, k_1, k_2, n – models parameters; E – exponential notation

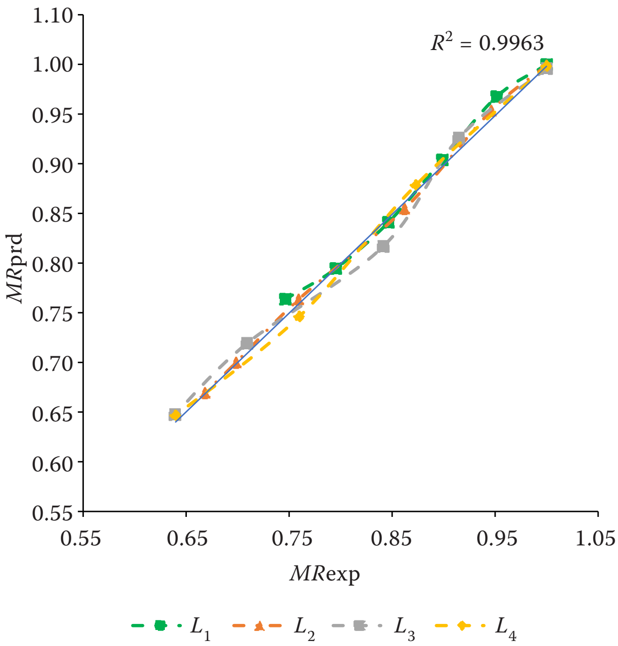

Figure 6. Variation of predicted moisture ratio (*MR*prd) and experimental moisture ratio (*MR*exp) with time for maize in the dryer

L_1–L_4 – the drying levels

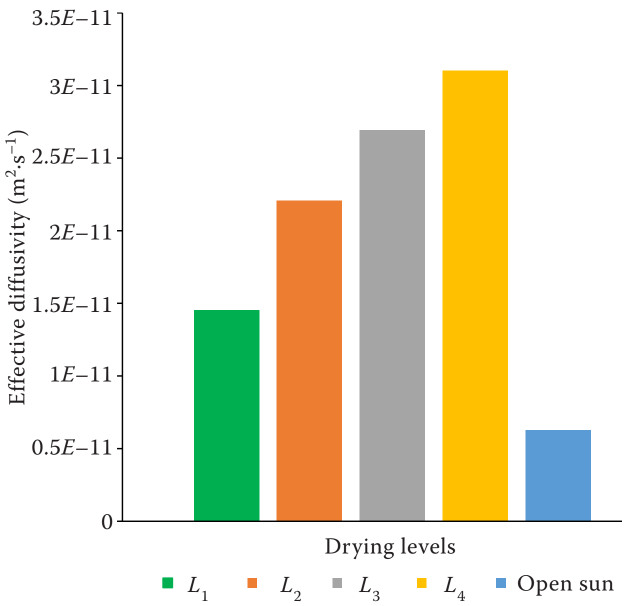

Figure 7. Variations in effective moisture diffusivity at different drying levels in the dryer vs. open-sun

L_1–L_4 – the drying levels; E – exponential notation

of diffusion. Effective moisture diffusivity, which is a result of this phenomenon, is affected by temperature. According to Hussein et al. (2016), the higher the drying temperature, the higher the rate at which diffusion of moisture from the internal regions to the surface occurs. The effective moisture diffusivity (Deff) (Figure 7) increased across the levels with values of 1.45 × 10^{-1}1 m2·s–1 and 3.10 × 10^{-1}1 m2·s–1 recorded for grains dried at L1 and L4 respectfully. Samples dried in the open-sun experienced the least Deff of 6.28 × 10^{-1}2 m2·s–1 during the study.

The higher moisture diffusivity recorded in the dryer compared to the open-sun is due to the high drying temperatures observed in the hybrid dryer which resulted in an increased vibrational motion of water molecules in the maize grains resulting in a high moisture gradient and mass transfer between the grains and the drying air. The Deff determined for maize grains in this study fall within the accept-

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able range (10–[12] to 10–8 m2·s–1) for drying biological materials as reported by Doymaz (2010).

Activation energy. The Arrhenius equation was used to determine the activation energy from the study. A plot of In (Deff) against (T+273.15)–1 yields a slope of –ER–1 and an intercept of In(Do). The activation energy of maize dried in the mobile hybrid dryer was determined as 96.83 kJ·mol–1. This is within the accepted limit for most agricultural food crops (12.7–110 kJ·mol–1) as reported by Kara and Doymaz (2014).

CONCLUSION

In this study, a newly developed tractor mountable solar-biomass hybrid dryer was used to dry 480 kg of white maize from 19 to 13% MC. An overall average drying temperature (41.93 ± 2.7 °C) inside the dryer was 15.25 °C more than the average ambient temperature (26.68 ± 1.3 °C). This resulted in a shorter drying time of 5 h for grains in the hybrid dryer to reach the final MC of 13% compared to grains dried in the open-sun which reached same final MC in 15 hours. A net savings in drying time of 67% was therefore archived using the hybrid dryer. The drying rate of maize dried in the hybrid dryer was higher, 1.2%·h–1 compared to 0.4 %·h–1 for grains dried in the open-sun. The Arrhenius equation was successful to predict that, the effective moisture diffusivity was dependent on the drying temperature. The recorded values across the levels ranged between 1.45 × 10^{-1}1 m2·s–1 and 3.10 × 10^{-1}1 m2·s–1. An activation energy of 96.83 kJ·mol–1 was determined in the study and all drying processes occurred in the falling rate period. The Midilli kucuk model was selected as the best model which described the thin-layer drying kinetics of maize in the newly developed hybrid dryer. It recorded the highest R2 and the lowest RMSE values of 0.01 and 0.9980, 0.01 and 0.9974, 0.02 and 0.9920, and 0.01 and 0.9978 across L_1, L2, L3 and L4, respectively in the mobile drying system.

Overall, the newly developed mobile solar hybrid dryer is effective in drying maize grains with many benefits including shorter drying time, protected drying environment and increased throughput particularly during periods of cloudy weather.

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