EVALUATION OF THIN LAYER DRYING MODELS FOR SIMULATING DRYING KINETICS OF JACKFRUIT SLICES IN A SOLAR GREENHOUSE DRYER

Ronoh EK*, Ndirangu SN, Kiburi FG, Kipsang MJ, Rutto EJ
Agricultural and Biosystems Engineering Department, Jomo Kenyatta University of Agriculture and Technology, P.O. Box 62000-00200, Nairobi, Kenya
*Corresponding author, Email: ronoh@jkuat.ac.ke

Abstract

Thin layer drying models are important tools in describing drying kinetics and improving the drying process of various agricultural produce. Reliance solely on experimental drying practices without mathematical considerations of the drying kinetics can significantly affect the design of efficient dryers. Simulation of the drying process in dryers by means of mathematical models can help in understanding the drying kinetics as well as in selection of optimal operating conditions of dryers. This study was therefore undertaken to evaluate thin layer drying models for simulating drying kinetics of jackfruit slices in a solar greenhouse dryer. The experimental work involved monitoring air temperature and relative humidity in the dryer, moisture changes of jackfruit slices during drying and eventually mathematical modeling of the drying process. The pulp took 19 hours to reach its equilibrium moisture content of 4.52% dry basis (db) from an initial moisture content of 257.92% (db). In the first four hours, a fast drying rate was observed which thereafter slowed down. Generally, the drying rate increased with increase in temperature and decreased with increase in relative humidity. Four widely used thin layer drying models (Newton, Page, Modified Page, and Henderson and Pabis) were fitted to the experimental data and the best model was selected based on the coefficient of determination (R^2), root mean square error (RMSE) and chi-square (χ^2). The Page model was found to best explain the prediction of thin layer drying of jackfruit slices, based on the highest value of R^2 and the lowest values of RMSE and χ^2. Overall, the results obtained proved that the Page model is an efficient thin layer model that could be used in enhancing dryer design and processing of jackfruit slices.

Keywords: Thin layer drying, Page model, solar greenhouse dryer, jackfruit slices

Introduction

Jackfruit (*Artocarpus heterophyllus Lam.*) is an exotic fruit that rarely grows in all parts of the world. It is believed to have originated from rainforest of the western Ghast of India and later spread to other parts of India. It is mainly grown in tropical regions of the world (Ranasinghe *et al.,* 2019). It does well in well-drained soil and fails to flourish in waterlogged areas. Its propagation is through seeds which have a shelf life of only one month. The jackfruit tree matures after four years and can keep producing fruits for over 100 years. It is majorly of two varieties, namely firm flesh and soft flesh. Jackfruit is rich in energy, dietary fiber, minerals and vitamins, and hence is potentially valuable as human and animal food (Swami *et al.,* 2012). One jack tree bares up to 700 fruits per year, with one fruit weighing up to 35 kg or 80 pounds.

Jackfruit is one of the rare fruits grown and known in Kenya. It is grown in some parts of Elgeyo Marakwet County, Muranga County, western parts of Kenya and Taita Taveta

County. The fruit is very perishable, and therefore requires immediate preservation. After harvesting, the fruits remain fresh for between 3 to 10 days. After harvesting, large quantities of ripe jackfruits undergo rapid deterioration due to lack of proper knowledge on postharvest practices (Ranasinghe *et al.,* 2019). The amount of jackfruits that spoils during the harvesting season can be minimized by drying it into jackfruit leather to increase its shelf life as well as its availability during off-season (Chowdhury *et al*., 2011).

Drying is one of the easiest and more affordable way of reducing postharvest wastes of fruits (Ndirangu *et al.,* 2018). It is a classical method of food preservation, which involves the removal of moisture through the application of heat to the product (Sangamithra *et al.,* 2014). After drying, the jackfruit has leather appearance and it can therefore be cooked in place of meat to be used by vegetarians; it is also commonly directly eaten as a snack. The abundance of solar energy is making a noticeable impact in the lives of rural people due to the potential of tapping this energy for drying of agricultural produce using numerous dryer designs (Sangamithra *et al.,* 2014).

Thin layer drying is a widely used method for determining the drying kinetics of agricultural produce. It involves simultaneous heat and mass transfer operations. During these operations, the material is fully exposed to drying conditions of temperature and hot air, thus improving the drying process (Onwude *et al.,* 2016). The most important aspects of thin layer drying technology are the mathematical modeling of the drying process and the equipment design which can enable the selection of the most suitable operating conditions.

According to Onwude *et al*. (2016), dependence purely on experimental drying practices, without mathematical considerations of the drying kinetics, can significantly affect the efficiency of dryers, increase the cost of production, and reduce the quality of the dried product. Thus, the use of mathematical models in estimating the drying kinetics, the behaviour, and the energy needed in the drying of agricultural and food products becomes indispensable (Onwude *et al.,* 2016; Murthy and Manohar, 2012). Mathematical modeling using thin layer drying models has been studied in drying of various agricultural produce such as green pepper (Akpinar *et al.,* 2003), cocoa (Hii *et al*., 2009), tomato slices (Oyerinde, 2016), pineapple (Olanipekun *et al.,* 2015), banana (Da Silva *et al.,* 2014), chili (Tunde-Akintunde, 2011), amaranth (Ronoh *et al.,* 2009), among others.. The models fall into three categories namely theoretical, semi-theoretical and empirical (Chowdhury *et al*., 2011; Hii *et al*., 2009). Semi-theoretical models offer a compromise between theory and ease of application. Examples of semi-theoretical models are Newton model (El-Beltagy *et al*., 2007), Page model (Akoy, 2014), Modified Page model (Yaldiz *et al*., 2001), Henderson and Pabis model (Akpinar *et al*., 2003), Logarithmic model (Yaldiz and Ertekin, 2007), two-term model (Togrul and Pehlivan, 2004), two-term exponential model (Akpinar *et al*., 2003), Verma model (Verma *et al*., 1985), Midilli-Kucuk model (Midilli *et al*., 2002), among others. These models are often employed to describe the drying behaviour of various agricultural produce as they are most useful to dryer engineers and designers (Brooker *et al.,* 1992). However, they are only valid within the applied drying conditions (Onwude *et al.,* 2016).

Although limited studies have been conducted on thin layer drying of jackfruit (especially leather), further studies are necessary on mathematical modelling of jackfruit slices (from ripe and mature fruits) drying with respect to specific dryer type and conditions.

Dried jackfruit slices can be preserved for later use or made into jackfruit chips and hence providing a potential part of the solution for tropical countries facing food insecurity problems. Further, the widely used mathematical models can be utilized to describe the thin layer drying behaviour of jackfruit slices under different drying systems (Chowdhury *et al*., 2011). Based on these reasons, this study was conducted to evaluate the thin layer drying models for simulating drying kinetics of jackfruit slices in a solar greenhouse dryer.

Methodology

Experimental solar greenhouse dryer

The solar greenhouse dryer used in this study is shown in Figure 1. The dryer measured 8 m long, 4 m wide and 2.6 m high. The dryer was rectangular in shape with a galvanized steel framework. It was installed in an east-west orientation (longer axis) as it is the preferred orientation for latitudes less than 40^o in order to capture maximum solar radiation (Dragicevic, 2011; IEA-SHC, 1998). The floor of the greenhouse dryer was constructed using concrete and painted black to help increase the effectiveness of converting light into heat (Arun *et al.,* 2014). Ultraviolet (UV) polythene film of 200 microns was used to cover the greenhouse dryer. It is important to use UV-stabilized films as the UV radiations from the sun cause adverse effects on the organoleptic properties of the drying produce (Sangamithra *et al.,* 2014). Two metallic drying trays were fabricated with two levels of drying and food-grade plastic mesh screen to hold the produce in place during drying. The drying trays measured 6 m long by 1 m wide with a spacing between the two levels being 0.3 m.

Figure 1 Experimental solar greenhouse dryer

The study was conducted at the Department of Agricultural and Biosystems Engineering, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya. JKUAT is located in Juja (37.05°E, 1.19°S latitude and an altitude of 1550 m above the sea level). The mean annual temperature of Juja is 18.9°C with mean annual maximum and minimum temperatures of 26.1°C and 13.6°C, respectively. The relative humidity ranges from 15% to 80%. The region generally experiences bimodal rainfall pattern with cold, rainy seasons occurring between April and

August, and October and December each year, the rest of the period being dry and hot.

Samples of freshly harvested jackfruits were collected from Murang'a County, Kenya. The pulp from the jackfruit was picked up and extracted from the seeds manually. The pulp obtained was cut into slices of 3 mm thickness (Akpinar and Bicer, 2008) and evenly spread in thin layers on the drying trays (Figure 2). Uniform jackfruit slice samples of 791 g were prepared and taken to the experimental solar dryer. Weights of the samples were recorded periodically at intervals of one hour until equilibrium moisture content was attained. Initial moisture content was determined using the constant temperature oven method. Weight measurements were carried out using a high precision balance (HZT-A 200, China) with a precision of ±0.01 g. Temperature and relative humidity were recorded using DHT22 sensors which are laboratory calibrated with a measurement range of -40^{o}C to 125^{o}C (±0.2) for temperature and 0% to 100% (±5%) for relative humidity. The sensors were programmed to record data in Arduino Mega (ATmega2560, Italy) microcontroller equipped with 8 GB microSD card for data storage. The drying experiments were conducted between the months of May and July 2019.

Figure 2 Samples of fresh ripe jackfruit (left) and jackfruit slices spread on drying trays (right)

Drying characteristics of jackfruit slices

The percentage moisture content on dry basis, M_{db}, at any given drying time t was determined using Eq. 1, where m_i is the initial weight of sample before drying and m_t is the weight of sample at time t. The relation between moisture content and drying time was based on the Newton model of thin layer drying for the material under varying relative humidity as in solar drying (Uluko *et al.,* 2006).

$$M_{db} = \frac{m_i - m_t}{m_t} \times 100 \qquad (1)$$

The drying rate of jackfruit slices was calculated based on the weight of water removed per unit time per unit weight of dry matter. The drying rate was taken to be approximately proportional to the difference in moisture content between the product dried and equilibrium moisture content at the drying air state. The instantaneous drying rate was computed using Eq. 2 (Amer *et al.,* 2003; Omid *et al.,* 2006), where DR is the drying rate, dM is change in mass, dt is change in time, t_{i-1} is the drying time preceding a given instantaneous drying time t_i, m_{i-1} is the sample mass preceding a given instantaneous sample mass m_i and m_d is the final dried sample mass.

$$DR = \frac{dM}{dt} = \frac{(m_{i-1} - m_i)}{m_d\,(t_{i-1} - t_i)} \qquad (2)$$

The data for moisture content of jackfruit slices was used to compute the moisture ratio at different drying time as shown in Eq. 3, which is based on the theory of thin layer drying (Uluko *et al.,* 2006). In the equation, MR is the moisture ratio, M is the dry basis moisture content at any time t, M_o is the initial dry basis moisture content of the sample and M_e is the equilibrium moisture content.

$$MR = \frac{M - M_e}{M_o - M_e} \quad (3)$$

Prediction accuracy of thin layer drying models

The drying kinetics of food is a complex phenomenon and requires simple representations to predict the drying behaviour and for optimizing the drying parameters. For mathematical modelling, the widely used thin layer drying models in Table 1 were tested to select the best model for describing the drying behaviour of jackfruit slices in a solar greenhouse dryer. The selection of the most appropriate model for describing the drying behaviour of various agricultural produce does not depend on the number of constants or coefficients; rather, it depends on various statistical indicators (Onwude *et al.,* 2016).

Table 1: Mathematical models commonly used to describe the drying kinetics

S/No.	Model*	Model name	References
1.	$MR = \exp(-kt)$	Newton	Yaldiz *et al*. (2001)
2.	$MR = \exp(-kt^n)$	Page	Abalone *et al*. (2006)
3.	$MR = \exp[-(kt)^n]$	Modified Page	Omid *et al*. (2006)
4.	$MR = a\exp(-kt)$	Henderson and Pabis	Chhninman (1984)

**a* and *n* are drying coefficients, *t* is drying time (hours) and *k* is drying constant (per hour)

Modeling the drying behaviour of different agricultural produce often requires the statistical indicators or methods of regression and correlation analyses. These analyses were carried out using MS Excel 2016™. The coefficient of determination (R^2), reduced chi-square (χ^2) and root mean square error (RMSE) were used to determine the quality of the fit. The higher the value of R^2 or rather nearness to one ($R^2 \cong 1$) and the lower the values of χ^2 and RMSE, the better the goodness of fit (Kucuk *et al.,* 2014; Doymaz, 2004; Yaldiz *et al*., 2001). These parameters were calculated using Eqs. 4, 5 and 6, where $MR_{exp,i}$ is the experimental moisture ratio, $MR_{pre,i}$ is the predicted moisture ratio, $MR_{exp,avg}$ is the average experimental moisture ratio, $MR_{pre,avg}$ is the average predicted moisture ratio, i indicates subsequent experimental data, N and n_c are the number of observations and constants found in the respective model, respectively (Sarsavadia *et al.,* 1999).

$$R^2 = \left[\frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{pre,avg}\right)^2}{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{\exp,avg}\right)^2}\right] \quad (4)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N - n_c} \quad (5)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2\right]^{1/2} \quad .. (6)$$

Results and discussion

Thin layer drying characteristics of jackfruit slices

The variation of drying conditions (viz., temperature and relative humidity) in a solar greenhouse dryer and outdoors is shown in Figure 3. Temperatures inside the solar dryer were higher than the corresponding outdoor values throughout the drying period. The maximum and minimum temperatures inside the dryer were 63.7°C and 31°C, respectively. The corresponding maximum and minimum temperatures outdoors were 39°C and 25°C, respectively. Further, the maximum and minimum relative humidity values inside the dryer were 32% and 5%, respectively. The corresponding maximum and minimum relative humidity values outdoors were 95% and 48%, respectively. High temperatures recorded in the dryer compared to outdoors can be attributed to the solar energy harnessed through the cover material. A combination of high temperature and low relative humidity in the dryer can impressively increase the ability of the air to dry agricultural materials (Kiburi *et al.,* 2017; Ronoh *et al.,* 2012; Ozbek and Dadali, 2007).

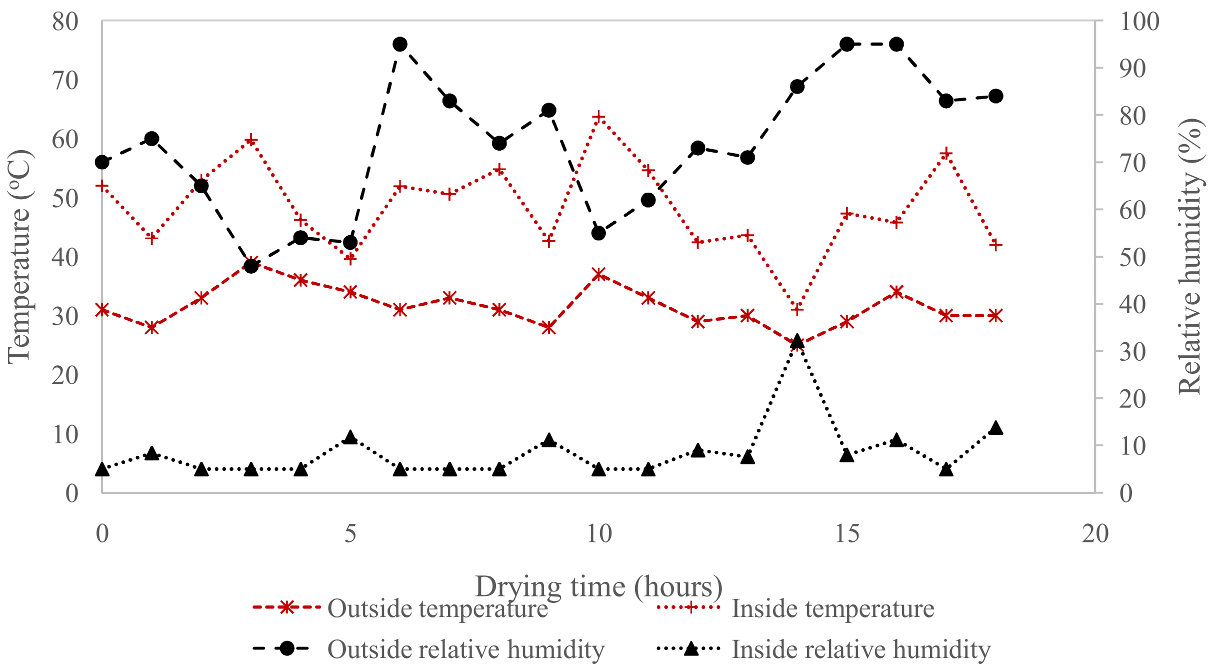

Figure 3: Variation of temperature and relative humidity in the dryer and outdoors

Jackfruit slices were dried from an initial moisture content of 257.92% (db) to a final moisture content of 4.52% (db) in the solar greenhouse dryer. Variations of moisture content and drying rate with time for jackfruit slices dried in the solar greenhouse dryer are presented in Figure 4. Generally, the results show that jackfruit slices had fast rates of moisture loss within the first four hours before slowing down. Based on the trend of drying rates, experimental work showed that the drying process could be divided into three periods that are: a short primary increasing, a fairly constant and a falling drying rate periods. However, the falling rate period clearly dominated the drying process of jackfruit slices, which indicates that the drying process of jackfruit slices was mainly controlled by diffusion mechanisms. This observation of continuous decrease in drying rate with decreasing moisture content or increasing drying time are in agreement with observations of other researchers for various agricultural produce (Kiburi *et al.,* 2017; Olanipekun *et al.,* 2015; Ronoh *et al.,* 2012; Chowdhury *et al*., 2011). As seen in the figure, drying of jackfruit slices occurred during the falling rate period which is enormously influenced by the drying temperature. Similar results regarding the diffusion mechanism as the dominant controlling mechanism of the drying process of most agricultural produce have been reported extensively in the literature (Onwude *et al.,* 2016). Jackfruit contains high amounts of moisture which reduces rapidly due to transpiration resulting in the loss of cell turgor. This behaviour is consistent with drying of most biological materials and confirms to similar observations by Abalone *et al.* (2006) and Basunia and Abe (2001).

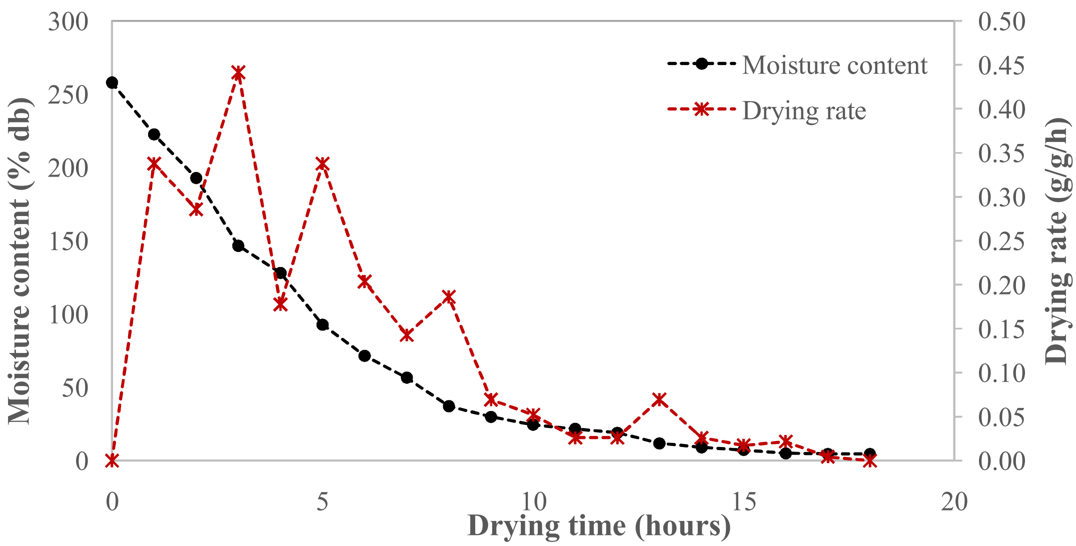

Figure 4: Drying curve and drying rate of jackfruit slices dried in a solar greenhouse dryer

Evaluation of thin layer drying models

The parameters and comparison criteria for the thin layer drying models fitted to the experimental drying data of jackfruit slices are presented in Table 2. The four models generally showed a good fit with R^2 ranging from 0.9256 to 0.9923, RMSE from 0.0002 to 0.0141 and χ^2 from 0.0032 to 0.0280. However, the Page model had the highest value of R^2 and the lowest values of RMSE and χ^2 compared to the other three models. Accordingly, the Page model was selected to best characterize the thin layer drying of jackfruit slices. Similar results for best prediction by the Page model have been reported during thin layer drying studies of various food materials, including tomato slices (Oyerinde, 2016), pineapple (Olanipekun *et al.,* 2015), banana (Da Silva *et al.,* 2014), chili (Tunde-Akintunde, 2011), amaranth (Ronoh *et al.,* 2009), green bean (Yaldiz and Ertekin, 2007) and rapeseed (Duc *et al.,* 2011).

A comparison of the predicted and experimental moisture ratio (MR) is presented in Figure 5. It can be clearly seen from the figure that the trend of the Page model prediction is very close to the experimental MR compared to the other three models. This is explained by its accuracy (highest R^2 and lowest values of RMSE and χ^2) in terms of predicting the thin layer drying behaviour of jackfruit slices under study. Under-prediction of MR is generally noticed for the Henderson and Pabis model and the Newton model during the drying period. Also noticeable is the over-prediction of MR by the Modified Page model during the latter stages of drying ($t > 4$ hours).

Table 2 Model parameters and comparison criteria for predicting drying of jackfruit slices

Model	Coefficients and constants	R^2	RMSE	χ^2
Newton	$k = 0.2967$	0.9256	0.0078	0.0209
Page	$k = 0.1304$, $n = 1.3018$	**0.9923**	**0.0002**	**0.0032**
Modified Page	$k = 0.1304$, $n = 1.3018$	0.9895	0.0061	0.0184
Henderson and Pabis	$k = 0.3445$, $a = 1$	0.9346	0.0141	0.0280

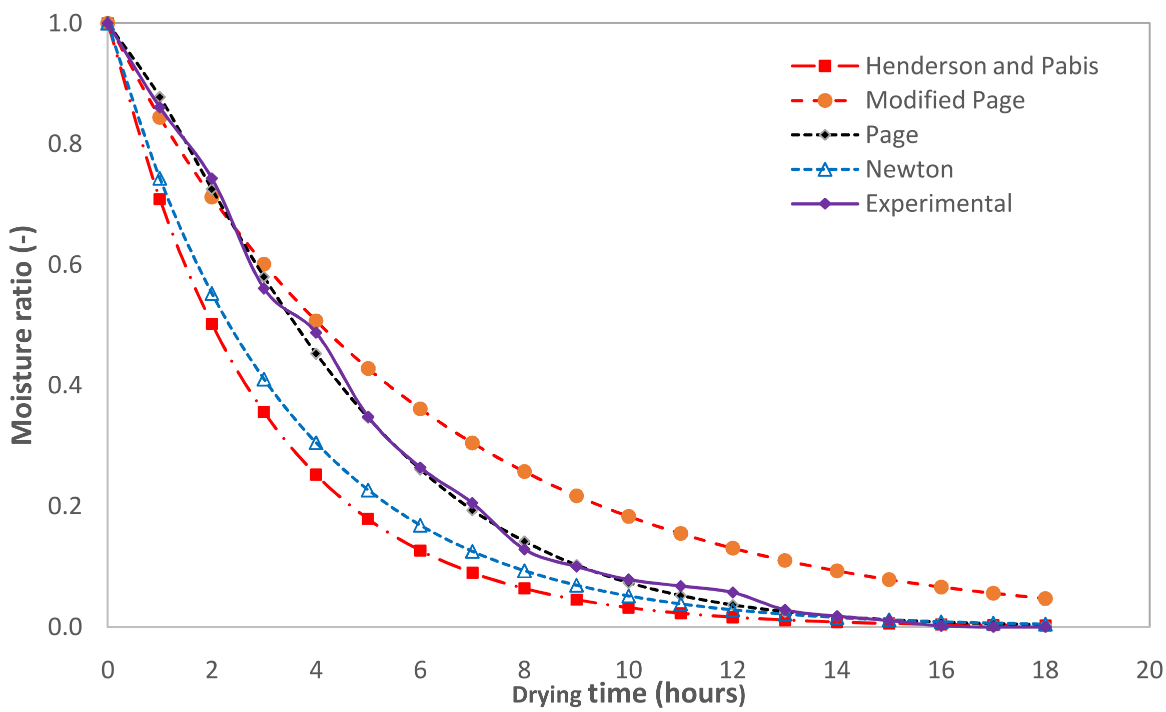

Figure 5: Comparison between predicted and actual moisture ratios of jackfruit slices

Conclusions

Evaluation of thin layer drying models for predicting drying behaviour of jackfruit slices in a solar greenhouse dryer was carried out. It was established that jackfruit slices dried from an initial moisture content of 257.92% (db) to a final moisture content of 4.52% (db) within 19 hours. A faster drying rate was observed in the first four hours compared to the subsequent drying duration. Optimum temperature is recommended during the drying process for the production of high quality jackfruit slices. Four commonly used thin layer drying models (Newton, Page, Modified Page, and Henderson and Pabis) were selected from literature and fitted to the experimental data. The acceptability of the model was based on how close to one the value for the coefficient of determination (R^2) was and how low the values for chi-square (χ^2) and root mean square error (RMSE) were. Based on the results and statistical indicators, Page model was selected to best characterize thin layer drying of jackfruit slices since it had the highest value of R^2 (0.9923) and the lowest values of RMSE (0.0002) and χ^2 (0.0032). Overall, thin layer modeling approach is an essential tool in estimating the drying kinetics from the experimental data, describing the drying behaviour, improving the drying process and eventually minimizing the total energy requirement.

Acknowledgements
The authors are very grateful to the Department of Agricultural and Biosystems Engineering, Jomo Kenyatta University of Agriculture and Technology (JKUAT) for the financial support and facilities used during the research.

References

Abalone, R., Cassinera, A., Gastón, A. and Lara, M.A. (2006). Thin layer drying of amaranth seeds. Biosystems Engineering, 93(2), 179-188.

Akoy, E.O. (2014). Experimental characterization and modeling of thin-layer drying of mango slices. International Food Research Journal, 21(5), 1911-1917.

Akpinar, E.K. and Bicer, Y. (2008). Mathematical modeling of thin layer drying process of long green pepper in solar dryer and under open sun. Energy Conversion and Management, 49(6), 1367-1375.

Akpinar, E.K., Bicer, Y. and Yildiz, C. (2003). Thin layer drying of red pepper. Journal of Food Engineering, 59, 99-104.

Amer, B.M.A., Morcos, M.A. and Sabbah, M.A. (2003). New method for the determination of drying rates of fig fruits depending on empirical data under conditions suiting solar drying. The International Conference of New methods Means and Technologies for Applications of Agricultural Products. Institute of Agricultural Engineering LUA Raudondvaris, Lithuania, September 2003.

Arun, S., Velmurugan, K. and Kumar, V.K. (2014). Optimization and comparison studies of solar tunnel greenhouse dryer coupled with and without biomass backup heater. International Journal of Innovative Science and Modern Engineering, 2(11), 41-47.

Basunia, M.A. and Abe, T. (2001). Thin-layer solar drying characteristics of rough rice under natural convection. Journal of Food Engineering, 47(4), 295-301.

Brooker, D.B., Bakker-Arkema, F.W. and Hall, C.W. (1992). Drying and storage of grains and oilseeds. The AVI Publishing Company, Westport, Conn., USA.

Chhninman, M.S. (1984). Evaluation of selected mathematical models for describing thin layer drying of in-shell pecans. Transactions of the ASAE, 27, 610-615.

Chowdhury, M.M.I., Bala, B.K. and Haque, M.A. (2011). Mathematical modeling of thin-layer drying of jackfruit leather. Journal of Food Processing and Preservation, 35(6), 797-805.

Da Silva, W.P., Silva, C.M.D.P.S, Gama F.J.A. and Gomes, J.P. (2014). Mathematical models to describe thin-layer drying and to determine drying rate of whole bananas. Journal of the Saudi Society of Agricultural Sciences, 13(1), 67-74.

Doymaz, I. (2004). Drying kinetics of white mulberry. Journal of Food Engineering, 61(3): 341-346.

Dragicevic, S.M. (2011). Determining the optimum orientation of a greenhouse on the basis of the total solar radiation availability. Thermal Science, 15(1), 215-221.

Duc, L.A., Han, J.W. and Keum, D.H. (2011). Thin layer drying characteristics of rapeseed (*Brassica napus L.*). Journal of Stored Products Research, 47(1), 32-38.

El-Beltagy, A., Gamea, G.R., Essa, A.H.A. (2007). Solar drying characteristics of strawberry. Journal of Food Engineering, 78, 456-464.

Hii, C.L., Law, C.L. and Cloke, M. (2009). Modeling using a new thin layer drying model and product quality of cocoa. Journal of Food Engineering, 90(2), 191-198.

International Energy Agency Solar Heating and Cooling (IEA-SHC) (1998). IEA-SHC programme, solar air systems. Available at (accessed on 3rd October 2019): http://www.iea-shc.org.

Kiburi, F.G., Mutwiwa, U.N., Ronoh, E.K., Chemain, N. and Yegon, H.K. (2017). Evaluating the performance of dehumidified solar dryer in drying of pumpkin slices (*Cucurbita pepo*). African Journal of Horticultural Science, 11, 72-81.

Kucuk, H., Midilli, A., Kilic, A. and Dincer, I. (2014). A review on thin-layer drying-curve equations. Drying Technology, 32(7), 757-773.

Midilli, A., Kucuk, H. and Yapar, Z. (2002). A new model for single layer drying. Drying Technology, 20(7), 1503-1513.

Murthy, T.P.K. Manohar, B. (2012). Microwave-drying of mango ginger (*Curcuma amada Roxb*): Prediction of drying kinetics by mathematical modeling and artificial neural network. International Journal of Food Science and Technology, 47(6), 1229-1236.

Ndirangu, S.N., Kanali, C.L., Mutwiwa, U.N., Kituu, G.M. and Ronoh, E.K. (2018). Analysis of designs and performance of existing greenhouse solar dryers in Kenya. Journal of Postharvest Technology, 6(1), 27-35.

Olanipekun, B.F., Tunde-Akintunde, T.Y., Oyelade, O.J., Adebis, M.G. and Adenaya, T.A. (2015). Mathematical modeling of thin-layer pineapple drying. Journal of Food Processing and Preservation, 39(6), 1431-1441.

Omid, M., Yadollahinia, A.R. and Rafiee, S. (2006). A thin-layer drying model for paddy dryer. Proceedings of the International conference on Innovations in Food and Bioprocess Technologies, 12th - 14th December, AIT, Pathumthani, Thailand.

Onwude, D.I., Hasim, N., Janius, R.B., Nawi, N.M. and Abdan, K. (2016). Modeling the thin-layer drying of fruits and vegetables: A review. Comprehensive Reviews in Food Science and Food Safety, 15(3), 599-618.

Oyerinde, A.S. (2016). Modelling of thin layer drying kinetics of tomato (*Lycopersicon esculentum Mill*) slices under direct sun and air assisted solar dryer. International Journal of Engineering and Applied Sciences, 3(5), 41-46.

Ozbek, B. and Dadali, G. (2007). Thin-layer drying characteristics and modelling of mint leaves. Journal of Food Engineering, 83(4), 541-549.

Ranasinghe, R.A.S.N., Maduwanthi, S.D.T. and Marapana, R.A.U.J. (2019). Nutritional and health benefits of jackfruit (*Artocarpus heterophyllus* Lam.): A review. International Journal of Food Science, 1-12.

Ronoh, E.K., Kanali, C.L., Mailutha, J.T. and Shitanda, D. (2012). Evaluation of solar-energy dryer systems on drying behaviour and quality attributes of amaranth grains. International Journal of Energy Science, 2(5), 189-194.

Ronoh, E.K., Kanali, C.L., Mailutha, J.T., Shitanda, D. (2009). Modelling thin layer drying of amaranth seeds under open sun and natural convection solar tent dryer. Agricultural Engineering International: the CIGR Ejournal. Manuscript 1420. Vol. XI. November, 2009.

Sangamithra, A., Swamy, G.J., Prema, R.S., Priyavarshini, R., Chandrasekar, V. and Sasikala, S. (2014). An overview of a polyhouse dryer. Sustainable Energy Reviews, 40, 902-910.

Sarsavadia, P.N., Sawhney, R.L., Pangavhane, D.R. and Singh, S.P. (1999). Drying behaviour of brined onion slices. Journal of Food Engineering, 40(3), 219-226.

Swami, S.B., Thakor, N.J., Haldankar, P.M. and Kalse, S.B. (2012). Jackfruit and its many functional components as related to human health: A review. Comprehensive Reviews in Food Science and Food Safety, 11(6), 565-576.

Togrul, I.T. and Pehlivan, D. (2004). Modeling of thin layer drying of some fruits under open-air sun drying process. Journal of Food Engineering, 65(3), 413-425.

Tunde-Akintunde, T.Y. (2011). Mathematical modeling of sun and solar drying of chilli pepper. Renewable Energy, 36(8), 2139-2145.

Uluko, H., Kanali, C.L., Mailutha, J.T. and Shitanda, D. (2006). A finite element model for the analysis of temperature and moisture distribution in a solar grain dryer. The Kenya Journal of Mechanical Engineering, 2(1), 47-56.

Verma, L.R., Bucklin, R.A., Endan, J.B., Wratten and F.T. (1985). Effects of drying air parameters on rice drying models. Transactions of the ASAE, 28(1), 296-301.

Yaldiz, O. and Ertekin, C. (2007). Thin layer solar drying of some vegetables. Drying Technology, 19(3-4), 583-597.

Yaldiz, O., Ertekin, C. and Uzun, H.B. (2001). Mathematical modelling of thin layer solar drying of sultana grapes. Energy, 26(5), 457-465.

Blank Page