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RENEWABLE SOLAR ENERGY SYSTEMS FOR SUSTAINABLE DRYING OF BANANA (MUSA ACUMINATA) PEEL BIOMASS.

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ABSTRACT

Huge amount of banana peel biomass are generated annually which are excellent sources of bioenergy, biofuels and other value-added products. The initial moisture content of banana peel is about 70%, which leads to deterioration and limits the efficiency of conversion processes. Solar energy is abundant, free and renewable, so the solar drying of banana peel was investigated. Drying kinetics of banana peel in passive and active solar dryers was compared with that of direct sunlight. Mathematical and artificial neural network (ANN) modelling methods were applied to describe the rate of drying of the peel. The banana peel dried fastest in the active dryer followed by the passive dryer, then direct sunlight. The peels dried in the falling rate period. The Verma, Midilli-Kucuk and Weibull models best described the peel drying kinetics in direct sunlight, passive and active solar dryers, respectively. Feed-forward multilayer perception ANNs having (4-3-1) network topologies best fitted the drying data. The estimated diffusivities of moisture in the peel were 7.835×10^{-11}, 9.59×10^{-11} and 1.952×10^{-10} $m^2\ s^{-1}$ during its drying in direct sunlight, passive and active solar dryers, respectively. Renewable solar energy can sustainably remove moisture from banana peel biomass.

Keywords: ANN Modelling, Banana peel, drying kinetics, mathematical modelling, solar dryer, thin layer

1. INTRODUCTION

The direct consumption and processing of banana generate a huge quantity of peels which can cause the problems of waste disposal and pollution of the surroundings [1]. Peels constituted about 30-40% of the global production of banana fruit of about 113.9 million tons in 2017 [2-4]. However, the peel, being a lignocellulosic material, can be transformed to bioenergy and biofuels via processes such as torrefaction, pyrolysis, gasification, direct combustion and anaerobic digestion [5-7]. Besides, banana peel is an excellent source of alkali, biosorbent, biofertilizer, cellulose nanofibers, pectin, dietary fiber and animal feeds [8-11]. The moisture present in fresh banana peel is as high as 72% [5], this can lead to the decay of the material during storage. This high moisture content also limits the efficiency of processes such as pyrolysis, gasification and combustion [12-14]. Hence, it's essential to dry the peels before they are stored or utilized in these processes. In addition, a drying step is required in the production of animal feeds, briquettes, dietary fiber and adsorbents from banana peels [15-18]. Besides, drying will generally decrease the cost of packaging and transporting the banana peel biomass.

The energy from the sun, which is abundant, clean, free and renewable, can be utilized for drying both agricultural products and their residues. The energy from the sun can be directly used in the conventional open sun (direct sunlight) or solar drying. In open sun drying, materials are exposed to rodents, insects and dust, the process depends on weather and takes relatively long time. Conversely, though the solar drying method also depends on weather, it uses equipment, the solar dryer, which shields materials from dust, rainfall, insects and rodents. Also, drying time can be shorter in the solar dryer because the temperature can be higher than the ambient [19). Besides, the rate of drying of a material can be enhanced in a forced convection (active) solar dryer, which has a fan that has the capacity to increase the drying air velocity, compared to a natural convection (passive) solar dryer that lacks such component [20].

The solar drying of biomass is a sustainable way of processing biomass using the renewable energy from the sun without any emission of pollutants to the environment during the drying process whereas mechanical dryers powered by electricity generated from the combustion of non-renewable fossil fuels contribute to environmental pollution especially the emission of the greenhouse gas carbon dioxide which is responsible for global warming and climate change. Moreover, the utilization of abundant, free and renewable solar energy from the sun for drying biomass can considerably reduce the overall processing cost of the biomass, drying being an energy intensive process.

The drying characteristics including the drying rates of biomass are essential for the design of solar dryers for the drying of the biomass. The drying kinetics of agricultural residue biomass have not been thoroughly investigated. Notably, the open sun, passive solar and active solar drying of banana peel biomass has not been previously reported.

Drying is a very complex and nonlinear process consisting of coupled mass and heat transfer mechanisms, so models are required to understand, design, optimize and control this process. The drying behavior of biological materials can be described by thin layer drying mathematical models [21]; these are mathematical models that can be used to predict drying rates. These mathematical models have been used to describe the drying rates of agricultural products [19, 21-24]; they have also been used to describe the drying kinetics of agricultural residue biomass [25-27].

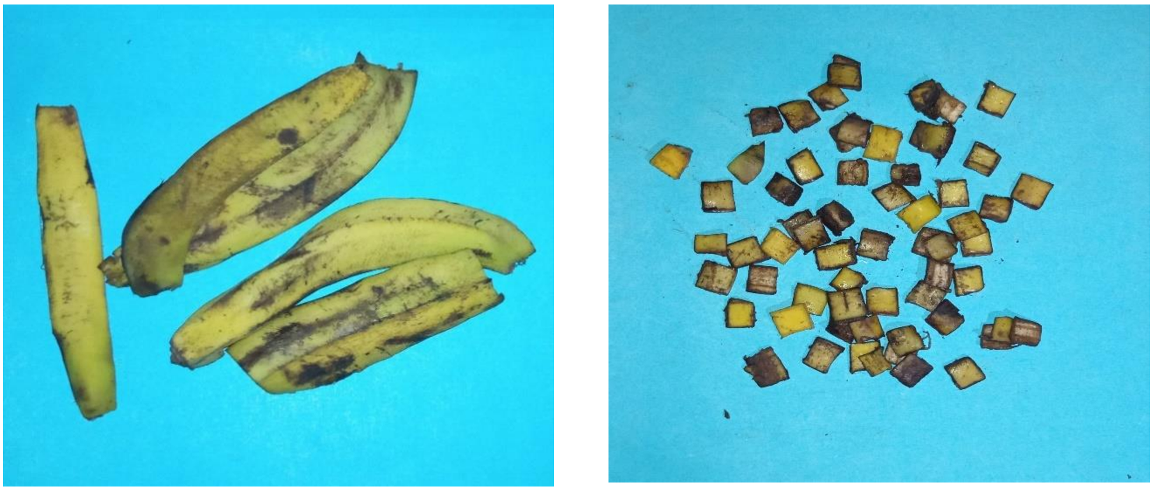
Artificial neural network (ANN) is a type of artificial intelligence approach to modelling, a form of black-box modelling, which can handle the nonlinearities of complex processes without the need for mathematical relationships. The ANN models are nonparametric regression models which are characterized by high flexibility, good tolerance for noisy data, ability to learn from experimental data, high generalization capability and the ability to handle several variables with unknown interactions [28]. They have been previously used successfully in the prediction of the drying kinetics of agricultural produce [28, 29].

In this study, passive and active direct solar dryers were evaluated for the drying of banana peels biomass; the drying rates and effective moisture diffusivities were determined. Several thin layer drying mathematical models were investigated to determine the one which best described the rate of drying of the peel. In addition, ANN modeling was applied to the drying data to illustrate the applicability of this modelling approach to the peel biomass drying operation.

2. MATERIALS AND METHODS

2.1. Peel Preparation

Ripe bananas were purchased from a fruit market. The peel was separated from the pulp and sliced into 1 cm x 1 cm pieces. The thickness of the peel was 2 mm. Figure 1 shows images of the banana peel biomass.



(a) **(b)**

Figure 1. Images of banana peels biomass (a) peels separated from pulp (b) peel slices

2.2. Experimental Apparatus (Solar Dryers)

The direct passive solar dryer used in this study has a metallic frame and drying surface with glass covers. Air flows into its drying chamber through a wire mesh and flows out via a chimney at the top of the dryer. Figure 2a and Figure 2b show the isometric view and image of this dryer, respectively.

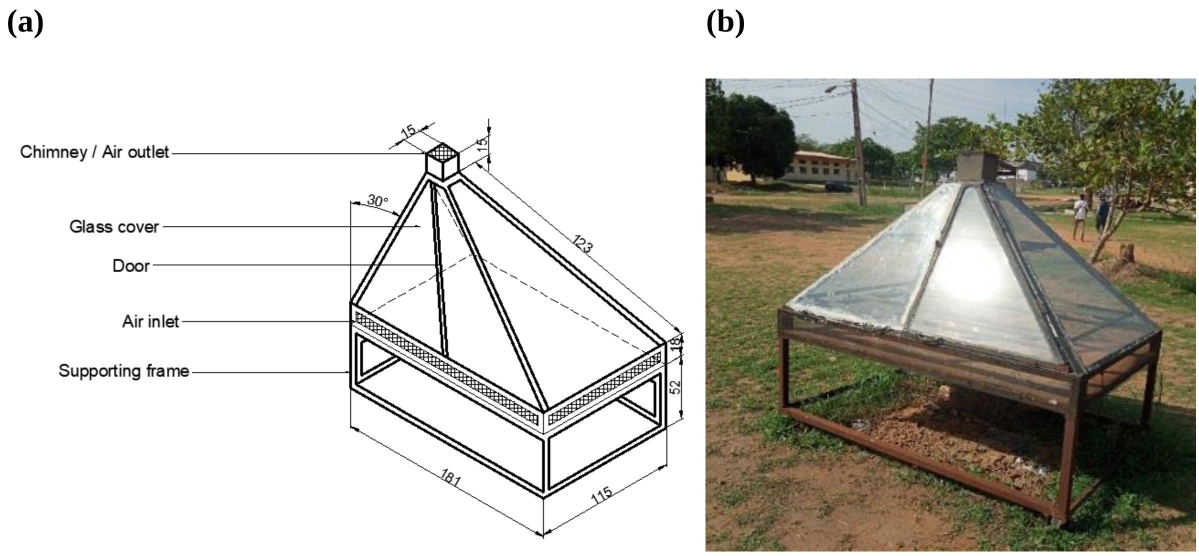


Figure 2. Passive dryer (a) isometric representation (b) image

The isometric representation and image of the direct active solar dryer are shown in Figure 3a and Figure 3b, respectively. This dryer has a polished metallic drying surface for improved absorption of the sun radiation. It has a glass cover through which the sun radiation penetrates into the dryer and black metallic doors with vents via which air exits the drying chamber. Forced convention of air into the dryer is achieved through a fan (DC Brushless, model AFC1212DE, Delta Electronics, China) which is powered by a solar panel (ROY monocrystalline solar panel, China) connected to it via a lead battery that ensures that power is available to the fan even when the intensity of the sun radiation goes down. The mass of banana peel slices were measured using a digital weighing balance (model ZH-8256, 0.01 – 1000 g, Zhi Heng Jewelry Scale, China) with an accuracy of 0.01 g. An Environmental meter (model HHEM-SD1, Omega Technologies, Taiwan) was used to measure the relative humidity, temperature and velocity of the drying air.

(a) **(b)**

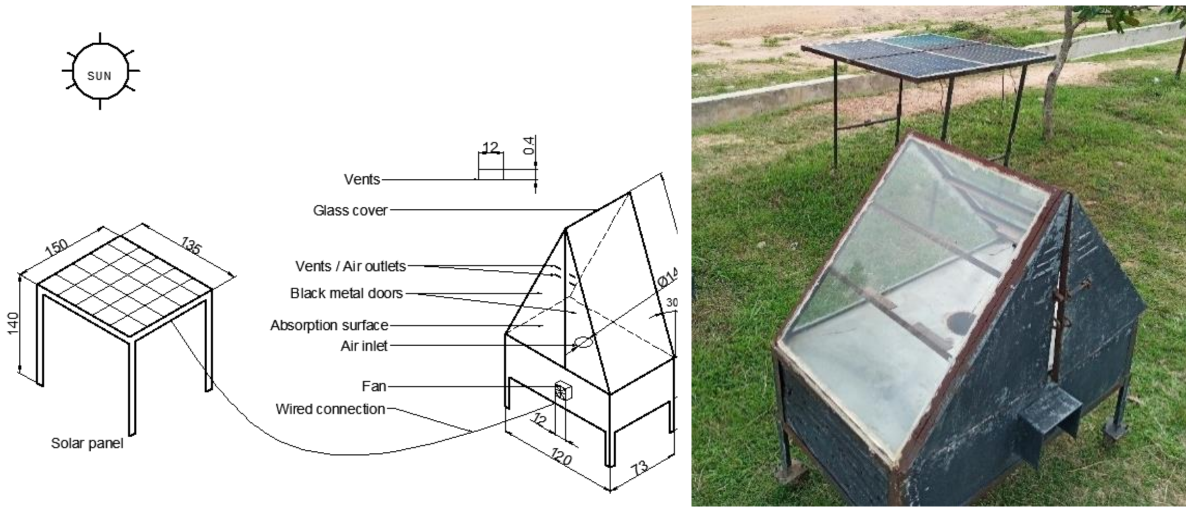


Figure 3. The direct active solar dryer (a) isometric representation (b) image

2.3. Experimental Procedure

Equal amounts (4.0 g) of banana peel slices were evenly spread in drying pans and then separately placed at the same time in open sun, passive and active solar dryers. The mass of the peel slices were measured and recorded at an interval of 30 minutes until constant mass was achieved. The ambient air temperature, humidity and velocity as well as those of the solar dryers were also measured along with the mass of the peels at the same time interval. Experiments were carried out in the month of April, 2021, between 11:30 am and 6 pm; they were carried out in triplicates.

2.4. Mathematical Modelling of Drying Kinetics

The moisture in the banana peel at time t, M_t (g water/ g dry matter) is defined as:

$$M_t = \frac{x_t - x_d}{x_d} \quad (1)$$

where x_t (g) and x_d (g) are the mass of peel slices at any time t and absolute dried mass of peel slices, respectively. The drying rates of the peel slices were calculated from equation (2):

$$D_R = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

The dimensionless moisture ratio (MR) was calculated using equation (3):

$$MR = \frac{M_t - M_e}{M_i - M_e} \tag{3}$$

where M_i is the initial moisture in the peel and M_e is the moisture in it at equilibrium. For a lengthy drying time, the values of M_e are insignificant relative to M_t and M_i, so equation (3) reduces to:

$$MR = \frac{M_t}{M_i} \tag{4}$$

The empirical mathematical models investigated to describe the rate of drying of banana peel were:

Midilli-kucuk:	$MR = a\,exp(-kt^n) + bt$	(5)
Page:	$MR = exp(-kt^n)$	(6)
Logarithmic:	$MR = a\,exp(-kt) + c$	(7)
Two-term:	$MR = a\,exp(-k_o t) + b\,exp(-k_1 t)$	(8)
Wang and Singh:	$MR = 1 + at + bt^2$	(9)
Approximation of diffusion:	$MR = a\,exp(-kt) + (1-a)\,exp(-kbt)$	(10)
Modified Henderson and Pabis:	$MR = a\,exp(-kt) + b\,exp(-gt) + c\,exp(-ht)$	(11)
Modified Page:	$MR = exp(-(kt)^n)$	(12)
Henderson and Pabis:	$MR = a\,exp(-kt)$	(13)
Two-term exponential:	$MR = a\,exp(kt) + (1-a)\,exp(-kat)$	(14)
Verma *et al*:	$MR = a\,exp(-kt) + (1-a)\,exp(-gt)$	(15)
Weibull *et al*:	$MR = a - b\,exp(-kt^n)$	(16)
Newton:	$MR = exp(-kt)$	(17)

where *a, b, c, g, h, n* are empirical constants; *k*, k_o and k_1 are drying constants; *t*, is drying time and MR, is moisture ratio. The curve fitting tool of MATLAB version 9.1 (Mathworks, Inc., Natick, Massachusetts) was employed to fit the moisture ratio obtained from experimental data to the models using non-linear least squares regression technique. Model constants and their coefficients of determination (R^2) were estimated and reported by the curve fitting tool while other parameters used to decide how well the model matched the data namely the root mean square error (RMSE), sum of square error (SSE) and chi-square (χ^2) were obtained through MATLAB computation of equations (18), (19) and (20), respectively. The MATLAB scripts for the curve fitting have been reported earlier [30]. The model with the highest R^2 and the smallest SSE, RMSE and χ^2 was chosen as the model that best described the peel drying behaviour [19].

$$SSE = \frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2 \tag{18}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2\right]^{\frac{1}{2}} \tag{19}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N - z} \tag{20}$$

where $MR_{exp,i}$ and $MR_{pre,i}$ are the ith experimental and predicted moisture ratio, respectively; N is the number of observations and z is the number of constants.

2.5. Determination of the Effective Moisture Diffusivity

The Fick's equation for diffusion can be employed to depict the characteristics of biomaterials in the falling rate period of drying. In terms of MR, the Fick's law is expressed as:

$$\frac{d(MR)}{dt} = D_{eff}\frac{\mathrm{d}^2(\mathrm{MR})}{\mathrm{dx}^2} \tag{21}$$

where x (m) is spatial dimension and D_{eff} is effective moisture diffusivity (m^2 s^{-1}). When Equation (21) is solved for bodies with slab geometry, MR is expressed as [31] (Crank, 1975):

$$MR = \frac{8}{\pi^2}\sum_{i-0}^{\infty}\frac{1}{(2i+1)^2}exp\left[\frac{-(2i+1)^2 D_{eff}\pi^2 t}{4L^2}\right] \tag{22}$$

where L is half of the depth of the slab/peel (m) and t is the peel drying time (s). For amply long drying time equation (22) is simplified to:

$$MR = \frac{8}{\pi^2} \, exp\left[\frac{-D_{eff}\pi^2 t}{4L^2}\right] \tag{23}$$

Equation (23) can be expressed as:

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{D_{eff}\pi^2 t}{4L^2}\right) \tag{24}$$

The diffusivity is calculated from the slope (S_1) of the plot of $\ln(MR)$ against drying time:

$$S_1 = \frac{D_{eff}\pi^2}{4L^2} \tag{25}$$

2.6. Artificial Neural Network Development

The Multilayer Perceptron (MLP) ANN with a feedforward-backpropagation structure using Levenberg-Marquardt training algorithm has been reported to best describe the drying rates of vegetables and fruits [29]; so this approach was employed in this study. The number of nodes in the input layer is determined by the number of independent variables while the number of neurons in the output layer is determined by the number of dependent variables [32]. In this study there were one dependent variable (the moisture ratio) and four independent variables (time, temperature, air-velocity and humidity), so one neuron was allocated to the output layer and four nodes to the input layer as shown in Figure 4. However, the number of hidden layers and their neurons were varied by trial and error until the desired prediction accuracy was achieved. To select the best network topology two evaluation factors were used: the highest value of correlation coefficient (R), and the least mean squared of errors (MSE). The neurons of the hidden layers possess a log-sigmoid transfer function while the neurons of the output layer have a linear transfer function for approximating the networks outputs, however, the nodes of the input layer do not make use of any transfer functions. The neural network toolbox of MATLAB version 9.1 (Mathworks, Inc, 2016) was used to perform the ANN modelling of the drying process. The MATLAB scripts for the ANN modelling have been reported earlier [30].

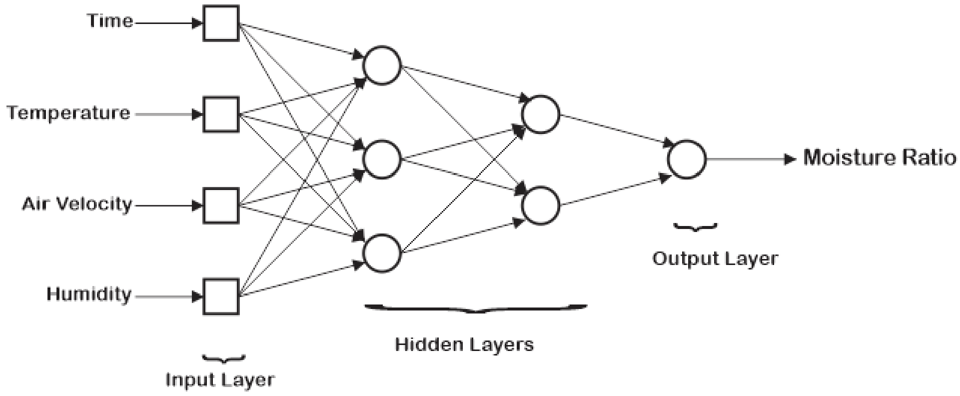


Figure 4. Feedforward-backpropagation ANN structure used for the drying process

3. RESULTS AND DISCUSSION

3.1. Solar Drying Characteristics of Banana Peel Biomass

Figure 5 shows the plot of ambient, passive solar dryer and active solar dryer temperatures versus the drying time; the temperatures in the solar dryers were higher than those of their immediate surroundings, with the active dryer having temperatures higher than those of the passive dryer. Higher temperatures and air velocity of the active solar dryer contributed to the higher drying rates of banana peel biomass observed in this dryer [33, 34].

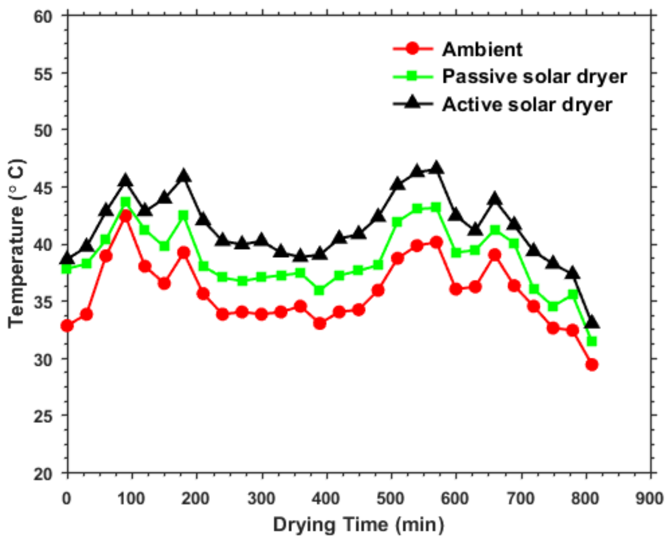


Figure 5. Plot of temperature against drying time

Figure 6a and Figure 6b show the drying behavior of banana peels in open sun, passive and active solar dryers. As indicated in these curves, the peel drying occurred predominantly in the falling rate period. This implies that moisture diffusion through the peel, from the inner part to its surface, controlled the drying rate of the peel [19]. Shorter drying times were achieved in the solar dryers, with the active and passive solar drying of banana peel taking 210 and 330 minutes, respectively compared to 450 minutes required for open sun drying.

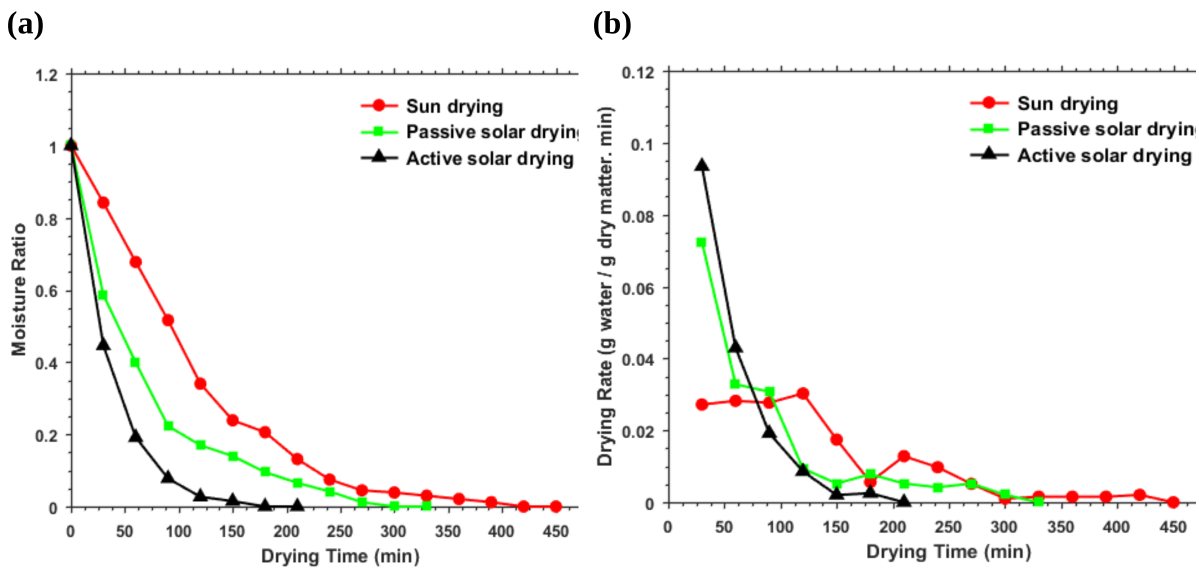


Figure 6. Plot of (a) moisture ratio against drying time (b) drying rate against drying time

Diffusivities of moisture in the peel slices were 7.835×10^{-11}, 9.59×10^{-11} and 1.952×10^{-10} $m^2 s^{-1}$ during their drying in open sun, passive and active solar dryers, respectively. These measured diffusivities are close to those of other agricultural materials [35].

3.2. Modelling of Banana Peel Biomass Drying Kinetics

3.2.1. Thin layer mathematical modelling

Table 1, Table 2 and Table 3 show the statistical parameters as well as the values of the model constants obtained after the experimental drying data for the open sun and solar drying of banana peel were fitted to the thirteen thin layer drying mathematical models investigated for the drying kinetics of banana peel in this study.

It was observed that the Verma *et al*, Page, Modified Page, Midilli-Kucuk and Weibull *et al* models had the highest R^2 of 0.9984 for open sun drying, as shown in Table 1. Conversely, the Verma *et al* model reported the least SSE (0.0001586) and RMSE (0.012593) relative to the other models, hence, it was considered to best represent the open sun drying behavior of banana peel. The Verma *et al* model also well depicted the open sun drying behavior of parsley leaves and figs in previous studies [36, 37]. The Midilli-Kucuk model best explained the passive solar drying of banana peel having reported the highest R^2 of 0.9975 and the least SSE (0.0002135) and RMSE (0.014612), as shown in Table 2. The Midilli-Kucuk has been reported to well describe the drying kinetics of the passive solar drying of orange skin paste biomass [38]. Lastly, the Weibull *et al*, Verma *et al*, Logarithmic, Page, Modified Page, Midilli-Kucuk, and Modified Henderson and Pabis, models reported the highest R^2 of 0.9999 for the active solar drying as evidenced in Table 3, but the Weibull *et al* model reported the least SSE (5.83E-06) and RMSE (0.0024141). The Weibull *et al* model most accurately represented the active solar drying of banana peel having reported the least errors among all models with the highest R^2. The moisture ratio predicted by each of the best models were plotted against the moisture ratio obtained directly from the experiments, as shown in Figure 7. It is seen that the moisture ratios predicted by the Verma *et al*, Midilli-Kucuk and Weibull *et al* models agreed well with the moisture ratio obtained from the open sun, passive solar and active solar drying data, respectively.

Table 1**.** Constants and statistical parameters of thin layer mathematical models for open sun drying of banana peel

Model	Model Constants	R^2	SSE	RMSE	χ^2
Midilli-Kucuk	a = 0.9989; k = 0.001806; n = 1.322; b = 7.563e-06	0.9984	0.00016466	0.012832	0.00022454
Page	k = 0.001886; n = 1.312	0.9984	0.00016609	0.012888	0.00019165
Logarithmic	a = 1.103; k = 0.007987; c = -0.05757	0.9921	0.00080235	0.028326	0.02832600
Two-term	a = 0.004119; k_o = 0.00698; b = 0.9793; k_1 = 0.00865	0.9801	0.00201480	0.044886	0.00274740
Wang and Singh	a = -0.006067; b = 9.104e-06	0.9900	0.00101200	0.031812	0.00116770
Approximation of diffusion	a = 0.002938; k = 0.008762; b = 0.9995	0.9826	0.00175640	0.041910	0.00219550
Modified Henderson and Pabis	a = -0.4699; k = 1.732; b = 0.271; g = 0.2578; c = 1.198; h = 0.01034	0.9952	0.00048558	0.022036	0.0008093
Modified Page	k = 0.008383; n = 1.312	0.9984	0.00016609	0.012888	0.00019165

Henderson and Pabis	a = 1.065; k = 0.009266	0.9870	0.00131600	0.036276	0.00151840
Two-term exponential	a = 0.0003216; k = 27.22	0.9826	0.00176080	0.041962	0.00203170
Verma *et al.*	a = -2.018; k = 0.01944; g = 0.01407	0.9984	0.00015860	0.012593	0.00019824
Weibull *et al.*	a = 0.003576, b = -0.9951; k = 0.001779; n = 1.326	0.9984	0.00016413	0.012811	0.00022382
Newton	k = 0.008758	0.9826	0.00175640	0.041910	0.00188190

Table 2**:** Constants and statistical parameters of thin layer mathematical models for passive solar drying of banana peel

Model	Model Constants	R^2	SSE	RMSE	χ^2
Midilli-Kucuk	a = 1.001; k = 0.03244; n = 0.8255; b = -6.075e-05	0.9975	0.00021350	0.014612	0.00033550
Page	k = 0.02784; n = 0.8658	0.9972	0.00024262	0.015576	0.00029654
Logarithmic	a = 0.9654; k = 0.01615; c = 0.02091	0.9949	0.00043733	0.020913	0.00060133
Two-term	a = 0.7121; k_o = 0.01192; b = 0.2875; k_1 = 0.03762	0.9972	0.00023713	0.015399	0.00037264
Wang and Singh	a = -0.00924; b = 2.08e-05	0.9099	0.00767610	0.087613	0.00938190
Approximation of diffusion	a = 0.2878; k = 0.03767; b = 0.3165	0.9972	0.00023714	0.015399	0.00032607
Modified Henderson and Pabis	a = 0.02863; k = 10.39; b = 0.2529; g = 0.03488; c = 0.718; h = 0.01203	0.9972	0.00023628	0.015371	0.00051981
Modified Page	k = 0.01598; n = 0.8658	0.9972	0.00024262	0.015576	0.00029654
Henderson and Pabis	a = 0.9779; k = 0.01502	0.9936	0.00054605	0.023368	0.00066740
Two-term exponential	a = 0.335; k = 0.03429	0.9972	0.00023887	0.015455	0.00029195

Verma *et al*.	a = 0.7116; k = 0.01192; g = 0.0376	0.9972	0.00023714	0.015399	0.00032607
Weibull *et al*.	a = -0.01998, b = -1.021 k = 0.03222, n = 0.8214	0.9974	0.00022047	0.014848	0.00034646
Newton	k = 0.01536	0.9930	0.00059750	0.024444	0.00065725

Table 3. Constants and statistical parameters of thin layer mathematical models for active solar drying of banana peel

Model	Model Constants	R^2	SSE	RMSE	χ^2
Midilli-Kucuk	a = 0.9999; k = 0.02344; n = 1.04; b = -2.275e-05	0.9999	5.99E-06	0.0024469	1.40E-05
Page	k = 0.02241; n = 1.053	0.9999	8.88E-06	0.0029795	1.24E-05
Logarithmic	a = 1.01; k = 0.02684; c = -0.008871	0.9999	1.18E-05	0.0034293	2.06E-05
Two-term	a = 0.502; k_o = 0.02722; b = 0.5001; k_1 = 0.02793	0.9997	3.54E-05	0.0059461	8.25E-05
Wang and Singh	a = -0.01597; b = 6.007e-05	0.9544	0.0052251	0.072285	0.0073152
Approximation of diffusion	a = 0.1263; k = 0.02782; b = 0.9875	0.9997	3.61E-05	0.0060058	6.31E-05
Modified Henderson and Pabis	a = -0.07216; k = 1.742; b = 0.2168; g = 0.02857; c = 0.8551; h = 0.02923	0.9999	1.29E-05	0.0035959	9.05E-05
Modified Page	k = 0.0271; n = 1.053	0.9999	8.80E-06	0.0029662	1.23E-05
Henderson and Pabis	a = 1.002; k = 0.02757	0.9997	3.52E-05	0.0059346	4.93E-05
Two-term exponential	a = 0.007441; k = 3.675	0.9996	4.17E-05	0.0064606	5.84E-05
Verma et al.	a = -0.09597; k = 0.01272; g = 0.02552	0.9999	7.19E-06	0.0026812	1.26E-05
Weibull et al.	a = -0.004284; b = -1.004;	0.9999	5.83E-06	0.0024141	1.36E-05

	k = 0.02367; n = 1.035				
Newton	k = 0.02751	0.9997	3.61E-05	0.0060044	4.21E-05

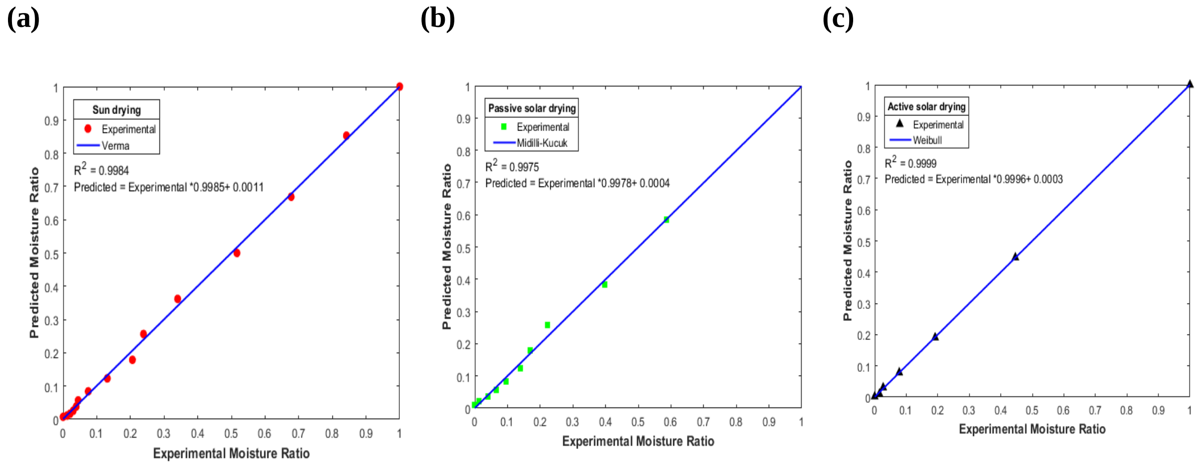


Figure 7**:** Comparison of experimental and predicted moisture ratio by selected mathematical models for (a) sun drying (b) passive solar drying (c) active solar drying, of banana peel slices

3.2.2. Artificial neural network modeling

Table 4 shows the effect of number of hidden layers and neurons on the accuracy of ANN modelling of the open sun and solar drying kinetics of banana peel. The single-hidden layer network with 3 neurons in the hidden-layer stood out as the ANN with the best performance, reporting the highest correlation coefficient (0.99959, 0.99577, 0.99814) and minimum MSE (1.5002E-04, 7.6301E-04, 4.6421E-04) for the open sun, passive and active solar drying of banana peel, respectively. Figure 8 shows that the predicted outputs of the selected ANN model well fitted the experimental data.

Table 4**.** Monitoring the effect of the number of hidden layers and neurons on the accuracy of ANNs in predicting the drying behavior of banana peel slices

Number of neurons in hidden layers			Open Sun Drying		Passive Solar Drying		Active Solar Drying	
Layer 1	Layer 2	Layer 3	R	MSE	R	MSE	R	MSE
10	_____	_____	0.92695	0.0181	0.9666	0.0067	0.89446	0.0258
5	5	_____	0.99350	0.0033	0.97505	0.0064	0.82846	0.0490
4	3	3	0.95961	0.0084	0.98927	0.0021	0.9759	0.0065
5	_____	_____	0.96750	0.0079	0.9803	0.0062	0.93107	0.0334
3	2	_____	0.99619	0.0014	0.95361	0.0628	0.9690	0.0095
2	2	1	0.89839	0.0204	0.94604	0.0140	0.90986	0.0198
3	_____	_____	0.99959	1.5002E-04	0.99577	7.6301E-04	0.99814	4.6421E-04
2	1	_____	0.97819	0.0047	0.67257	0.4656	0.90986	0.0198
1	1	1	0.90765	0.0200	0.86489	0.0477	0.29496	0.1417

(a) **(b)** **(c)**

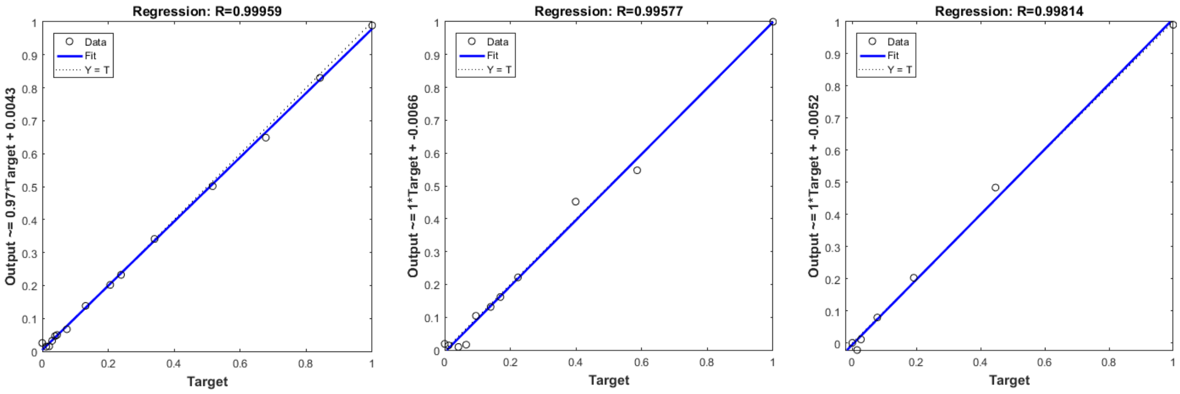


Figure 8. Predicted moisture ratio by the selected ANN model versus experimental (target) values for (a) open sun drying (b) passive solar drying (c) active solar drying of banana peel slices

3.2.3. Comparison of mathematical and ANN modelling

In order to compare the modelling techniques, the coefficient of determination (R^2) of the selected ANN models were calculated from the sample correlation coefficient (R) reported between their corresponding target and output data. The comparison between the selected mathematical and ANN models that best described the drying behavior of banana peel, for the drying methods considered is presented in Table **Error! Reference source not found.**. The ANN model achieved a better fitting (R^2 = 0.9992; MSE = 0.0001500) than the mathematical model (R^2 = 0.9984; MSE = 0.0001586) for the open sun drying process. However, the mathematical models better explained the passive and active solar drying processes with (R^2 = 0.9975; MSE = 0.0002135) and (R^2 = 0.9999; MSE = 0.0000058) respectively compared to the ANN model with parameters (R^2 = 0.9916; MSE = 0.0007630) and (R^2 = 0.9963; MSE = 0.0004642), respectively. These results imply that the ANN model may not yield a better result than the mathematical model in terms of accuracy, however it is superior to the mathematical model in generalization ability [28]. Besides, the mathematical models could only describe the moisture ratio as a function of time, whereas the ANN model predicted the effect of time, temperature, air velocity and humidity on the moisture ratio.

Table 5. Comparison of modelling techniques for the drying of banana peel slices

Drying Method	ANN Model			Mathematical Model	
	R	R^2	MSE	R^2	MSE
Open Sun Drying	0.99959	0.9992	0.0001500	0.9984	0.0001586
Passive Solar Drying	0.99577	0.9916	0.0007630	0.9975	0.0002135
Active Solar Drying	0.99814	0.9963	0.0004642	0.9999	0.0000058

4. CONCLUSION

The active solar dryer dried banana peel biomass faster compared to the passive solar dryer and direct sunlight. Peel drying occurred primarily in the falling rate period. The diffusivities of moisture in the peel measured for the direct sunlight and solar drying of banana peel ranged between 7.835×10^{-11} and 1.952×10^{-10} m^2 s^{-1}. The Verma, Midilli-Kucuk and Weibull thin layer drying mathematical models best described the drying rates of banana peel in direct sunlight, passive and active solar dryers, respectively. The feed-forward multilayer perception ANNs having (4-3-1) network topologies best fitted the drying data. The ANN model described the open sun drying process better than the mathematical model while the mathematical models better explained the passive and active solar drying processes. Renewable solar energy drying systems can be sustainably utilized for drying banana peel biomass before it is stored or further processed, especially in regions of high sun radiation. The active solar dryer is recommended for the sustainable drying of biomass at an enhanced rate.

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