Original Research Article

THIN LAYER MODELLING OF INDIRECT AND MIXED MODE ON-FARM DRYING OF SELECTED VEGETABLES

ABSTRACT

The thin layer drying characteristics of tomato and okra slices dried using mixed mode on-farm solar dryer, indirect mode on-farm solar dryer and open sun drying. The tomato and okra slices dried faster when dried under the mixed mode on-farm solar dryer. Drying time reduced considerably using the on-farm solar dryers. The drying data were fitted into Lewis, Henderson and Pabis, and page equations. The Page model (R^2=0.9365, 0.9623; X^2= 0.0067, 0.0000579; RMSE= 0.0086, 0.0020 and MBE= -0.008, -0.002) gave the best prediction for the mixed mode drying and indirect mode drying of tomato slices respectively. In the same vein Page model (R^2=0.9202, 0.933o; X^2= 0.00091, 0.000730; RMSE= 0.0265, 0.0244 and MBE= -0.0088, -0.0074) gave the best prediction for the mixed mode drying and indirect mode drying of okra slices respectively. Effective moisture diffusivity of tomato slices varied between -7.4724 X 10^{-08} and -1.6439 X 10^{-07} while that of okra varied between -3.12 X 10^{-07} and -8.08 X 10^{-07}. The indirect mode dryer gave final dried tomato and okra.

Key words: Drying, Characteristics, Tomato, Okra, mixed mode dryer, indirect mode dryer.

1. Introduction

Fresh vegetables are highly appreciated both from economic and nutritional source of view, owing to the presence of important minerals and vitamins (Adegunwa *et al*., 2011). Vegetables of all type are rich in carotenoids, ascorbic acids which are known to have high antioxidant capacity. Vegetables in general are highly seasonal in nature, at peak season they often cause market glut while at off season they become scarce and expensive.

Man has been using drying of food materials as a means of preservation since from time immemorial. This "art of living" depends mainly on energy from the sun (Hayashi, 1989). Conventionally, on the farm, vegetables are dried by spreading fresh products on mats, tarred roads or cemented floors. However, this method is time consuming and results in final dried vegetable products with deteriorated quality (FAO, 2012). Mahesh K. *et al.*, (2016) also reported that conventional open sun drying are trapped with some severe draw backs in terms of quality, accuracy, economy, handling and capacity which causes loss of the products in the drying process, the loss is estimated to be 30-40% of total production in developing countries. According to them, the best alternative to overcome the challenges of traditional drying methods is the development of solar dryers. According to (Eke, 2013), over 50% saving in drying time could be achieved using solar dryers instead of open sun drying.

Visavale (2012) classified solar dryers based on the mode of drying as direct, indirect and mixed dryers. Direct dryers is similar to open sun drying except that products are covered under a glass while in indirect dryers, atmospheric air is heated in a collector, and then the hot air flows to the drying chamber where products are placed. Moreover, mixed dryers combines the futures of both direct and indirect mode dryers (Balasuadhakar *et al.*, 2016). However, according to (Mahesh K. *et al.*, 2016), indirect mode forced convection dryers have is superior in drying speed and quality drying.

Diane *et al.*, (2010) came up with an assertion, that nutrients in vegetables are degraded as a result of exposure to direct sun light during open sun drying and mixed mode drying. This is attributed to the fact that, carotenoids and other micro nutrients in vegetables are highly sensitive to light and oxidation. As a result indirect mode dryer can

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greatly reduce drying time of agricultural products without a significant degradation of the inherent qualities of the products. Based on these findings this present study is aimed at indirect and mixed mode drying of some selected (tomato and okra) vegetables on the farm. The objectives of this study are therefore to look at the drying characteristics and drying time required to reduce tomato and okra slices to safe moisture content during drying using an indirect mode and a mixed mode drying methods and to fit these data obtained to some generally accepted drying models for agricultural materials.

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2. Materials and Methods

2.1 Materials

Freshly harvested tomato (Roman VF) and Okra (Ex- Borno) were used for the experiment. The tomato and okra were sourced from a local market in Zaria metropolis, Nigeria. To ensure uniformity of physical characteristics, the tomatoes were carefully sorted out to an average of 80mm length and 50mm diameter while the okra pods were sorted out to an average of 100mm length and 25mm diameter. The sorted vegetables were washed and allowed to drain, after which they were stored in a refrigerator at a temperature of 6˚C and 8˚C until drying experiment which was done within 24h. Prior to the drying time the products were kept at room temperature for 6h to maintain thermal equilibrium. Initial moisture content of the samples were determined using an oven at 105˚C for 24h. Initial moisture content of tomatoes and okra was 94% and 86% (w.b) respectively. 5mm and 10mm samples of tomatoes and okra were prepared using a kitchen knife. To achieve uniformity in size and shape, sliced sample were obtained from the central region of the products. Each slice of the samples were subjected to drying under three drying method viz a viz mixed mode solar drying (MSD), indirect mode solar drying (ISD) and open sun drying (OSD).

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During each run, sample slices were placed in a single layer on trays arranged in the drying chambers of the solar dryers. The monitored parameters in the drying study include; sample weight, sample temperature, temperature and relative humidity (ambient, drying chamber, inlet and outlet of collector and drying chamber), and air velocity inside the drying chamber. The drying process was concluded when samples reached moisture content of 8% and 7% (w.b) for tomatoes and okra respectively. These moisture contents were chosen as safe moisture contents and for uniformity.

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2.2 Tomato and okra drying process

Six (6) different tests were performed under similar drying conditions. Tomato slices MSD, ISD and OSD and also okra slices MSD, ISD and OSD. There were 18 distinct experiment runs. About 1kg ±5g of tomato and okra slices were used for each of the runs. At the beginnings of each drying run, change in weight was recorded at 1h intervals. The drying test was concluded when there was no noticeable change in weight for two consecutive readings. The drying tests were repeated three times and the average was recorded.

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2.3 Drying methods

Figures 1a and 1b are the pictorial views of the mixed mode and indirect mode on-farm solar dryers used for the drying process. Products to be dried are spread on the trays within the drying chamber. In the mixed mode dryer, products to be dried are subject to direct solar radiation as well as heat from the collector area. In the case of the indirect mode dryer, products to be dried are enclosed in a cabinet. Therefore, products here are only subjected to heat from the collector area. Ambient air is blown over the collector with the aid of an axial fan placed at the end of the collector. Heated air from the collector area then blows over the products to be dried.

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Figure 1a: Mixed mode on-farm solar dryer. **Figure 1b: Indirect mode on-farm solar dryer.**

2.4 Color analysis

Tomato and Okra slices were photographed at standard color temperature of 5500k under closely monitored conditions using a light box (Sanoto Box 16 x 12 in) and a Panasonic digital LUMIX TS7 camera, using a standard procedure described by (Avinash et al., 2019). Computer aided software (Adobe Photoshop 7) was then employed to measure the corresponding coordinates. L* coordinate ranged from 0 (black) to 100 (white), a*coordinate ranged from green (-a) to red (+a) and b* coordinate from blue (-b) to yellow (+b). The reading was performed on the pericarp of the sliced surface of the dried tomato while dried okra was grounded into powder before taking the readings. For the readings to be statistically viable, triplicated measurement where taken and means of the three readings were recorded.

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2.5 Modelling of drying curves

Thin layer drying models have gained wide acceptance in designing new, simulating existing systems and for analytical drying purposes. Many researchers have used the exponential drying models (Newton (Lewis), Henderson and Pabis, Page, logarithmic, Parabolic and Wang and Singh models in describing the drying behaviour of the food materials. These equations are derived from simplifying the general series of fick's 2nd law of diffusion. Newton (Lewis) model a simple exponential model is the solution of Fick's law, with the assumptions of diffusion based moisture migration, negligible shrinkage, constant diffusion coefficients and temperature. This is one of the simplest models in describing movement of moisture in food products. It has been successfully used in describing the drying characteristics of strawberry (El-Beltagy et al. 2007), Grape seeds (Roberts et al., 2008), and Red chili (Hossain et al. 2007),

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$$MR = e^{(-kt)} \qquad (1)$$

Henderson and Pabis model is the first term solution of the general series of fick's second law that have been used to successfully describe the drying characteristics of mango and cassava (Koua et al. 2009) and African breadfruit seed (Shittu and Raji 2011).

$$MR = ae^{(-kt)} \qquad (2)$$

Page model is an empirical modification of the Lewis model to eliminate the shortcomings associated with the Lewis model. This is done by the introduction of a dimensionless empirical constant (n) to the time term. Doymaz (2007) used the model to successfully describe the drying characteristics of tomato, and that of barberries was successfully achieved by (Aghbashlo et al. 2009).

$$MR = e(-kt^n) \qquad (3)$$

In the proposed models discussed earlier, a, b, c and n are drying coefficients and k is the drying constant given in (/min). Table 1 shows the drying models;

Table 1: Mathematical models fitted to various fruits and vegetables

s/no	Model	Model Equation	References
1	Newton (Lewis)	$\mathrm{MR} = \mathrm{e}^{(-\mathrm{kt})}$	El-Beltagy et al. 2007, Roberts et al. 2008, Hossain et al. 2007.
2	Henderson and Pabis	$\mathrm{MR} = \mathrm{ae}^{(-\mathrm{kt})}$	Koua et al. 2009, Shittu and Raji 2011
3	Page model	$\mathrm{MR} = \mathrm{e}(-\mathrm{kt}^{\mathrm{n}})$	Doymaz 2007, Aghbashlo et al. 2009

R^2 which is the coefficient of determination was used to determine the suitability of each of the drying model. Other statistical tools (Chi square X^2, root mean square RMSE and mean bias error MBE) were also employed to determine goodness of fit. R^2 value must be highest while X^2, RMSE and MBE values lowest for quality fit (Workneh and Moruf 2013).

$$X2 = \frac{\sum_{i=1}^{N}(MR_{(exp,i)} - MR_{(pred,i)})^2}{N-Z} \quad (4)$$

$$MBE = \left\{\frac{1}{N}\sum_{i=1}^{N}\left((MR_{(pred,i)} - MR_{(exp,i)}\right)\right\} \quad (5)$$

$$RMSE = \left\{\frac{1}{N}\sum_{i=1}^{N}\left((MR_{(exp,i)} - MR_{(pred,i)}\right)^2\right\}^{\frac{1}{2}} \quad (6)$$

2.6 Determination of effective moisture diffusivity

Transport of moisture during the drying process was described using the fick's law of diffusion model. Though the effective moisture diffusivity is not the best equation to fit the drying data, it has the ability to provide a description of the average diffusion coefficient for the entire drying process. Solution to the equation developed by (Crank 1975) can be written in logarithmic form for long period drying as (Workneh and Moruf 2013);

$$MR = \frac{8}{\pi^2} exp\left[\frac{D_{eff}}{4L^2}\pi^2 t\right] \quad (7)$$

Where; D_{eff} is reference moisture diffusivity (m^2/s), t is drying time (s) and L is half the thickness of sample (m). A plot of Ln (MR) against time at different temperature gives the effective moisture diffusivity as the slope.

$$\text{Slope} = \frac{D_{eff}}{4L^2}\pi^2 \quad (8)$$

2.7 Determination of activation energy

Arrhenius equation is used to predict the dependence of effective moisture diffusivity on different drying temperature. This equation is expressed as (Workneh and Moruf 2013);

$$D_{eff} = D_0 exp\left(-\frac{E_a}{R(T+273.15)}\right) \quad (9)$$

Where; Do is the maximum diffusion coefficient at infinite temperature in (m^2/s), E_a is the activation energy in (kJ/mol), R is the universal gas constant (kJ/mol K) and T is temperature (°C). The slope from a plot of Ln (D_{eff}) against $\left(-\frac{1}{R(T+273.15)}\right)$ is E_a.

3. Results and Discussion

3.1 Drying curves for Tomato and Okra slices

The relationship between drying time and dimensionless moisture content of tomato slices subjected to indirect mode solar drying, mixed mode solar drying and open sun drying is given in figure 2. It is worthy to note that moisture contents decreased continually with drying time. As depicted in the data presented, the time required to reduce tomato slices to 7.2% ranged from 52h to 58h in the mixed mode solar dryer and 72h to 79h in indirect mode solar dryer but it took as much as 147h for tomato slices under open sun to attain the same moisture content of 7.2%. A gradual drying was observed in the moisture content in this study which is in agreement with the previous findings (Perumal, 2007; Eke, 2016; Wishmore and Padmawatti, 2016). Generally instantaneous moisture content of tomato slices decreased faster in the mixed mode on-farm solar dryer than the indirect mode on-farm solar dryer especially for slices on the first tray. This is as a result of faster moisture diffusion from the centre point of the tomato slices to the surface triggered by higher heat energy at the entry point of the drying chamber when compared to other positions in the drying chamber.

Tomato slices experienced both constant and falling drying rate periods (Figure 2). The constant drying rate lasted for 44h in the first tray of the mixed mode dryer while in the open sun it lasted for a period of about 84h. Mixed mode drying is found to be more effective in drying of tomato slices; this is because the tomato slices here are subjected to both direct solar radiation and conventional heat from the collector. (Perumal, 2007; Aravidh, 2015) observed that solar cabinet dryer dries tomato slices faster than open sun drying.

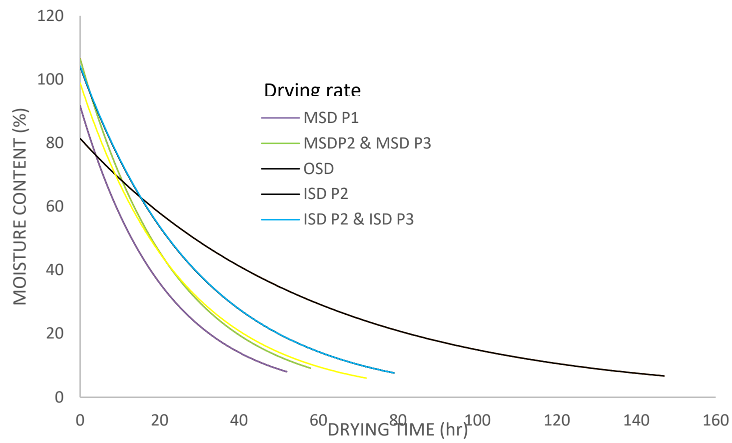

Fig 2. Drying rate of Tomato slices under MSD, ISD and OSD

Drying time was reduced by 64.63% and 60.54 % when tomato slices were dried in the mixed mode on-farm solar dryer. Time was also reduced by 51.02% and 46.26% (Table 2). In general, the time required to reduce the moisture content to any given level is dependent on the drying conditions, and this is highest when the tomato slices were dried in tray 1 of the mixed mode on-farm solar dryer.

Table 2 Effect of different drying methods and drying tray position on drying time of tomato slices

Drying treatment /Tray Position	**Time (h)**	**Percentage reduction in time (%)**
OSD	147	0
Mixed mode on-farm solar dryer		
P1	52	64.63
P2	58	60.54
P3	58	60.54
Indirect mode on-farm solar dryer		
P1	72	51.02
P2	79	46.26
P3	79	46.26

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Figure 4 shows the relationship between dimensionless moisture content and drying time of Okra slices subjected to mixed mode on-farm solar dryer, indirect mode on-farm solar dryer and open sun. Generally, moisture content decreased with increasing drying time as can be seen on the drying curve of all the okra slices. The time taken to reduce okra slices to 6.5% ranged from 34h to 52h in the mixed mode on-farm solar dryer and from 55h to 58h in the indirect mode on-farm solar dryer. It took okra slices under open sun 127h to reach similar moisture content of 6.5%.

Just like tomato slices, Okra slices also both constant and falling rate drying periods. The constant rate drying period lasted for about 12h in the first tray of the mixed mode dryer while a highest constant rate period of 52h was experienced by Okra slices in open sun. The mixed mode on-farm solar dryer was found to be more effective in

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drying Okra slices. However subjecting Okra slices to indirect mode on-farm solar dryer gives final dried products of better quality, this is line with results obtained by (Wankhade et al., 2013).

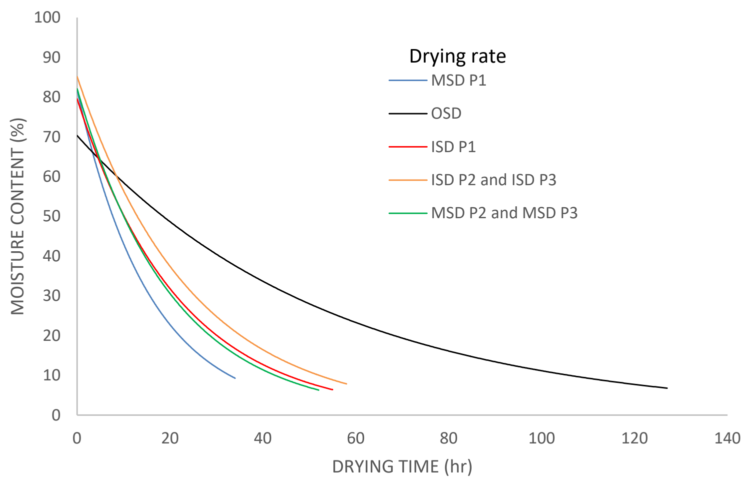

Fig 3. **Drying rate of Okra slices under MSD, ISD and OSD**

Drying time was greatly reduced by 73.23% to 59.06% when okra slices were subjected to mixed mode on-farm solar dryer. In the same vein, Okra slices in the indirect mode dryer experienced a reduction in drying time of 56.69% to 54.33%. Drying is a complex process involving both mass and heat transfer. The heat is transferred to the drying product to evaporate liquid while mass is transferred as liquid or vapour (Visavale, 2012). The drying of agricultural products is a non- linear process that depends on some external variables such as temperature, humidity, air velocity and some internal variables that has to do with physical propertied of the products such as surface area, porosity etc. The mixed mode dryer in this case has a better supply of these external variables, hence having the ability to greatly reduce the drying time when compared to the indirect solar dryer.

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Table 3 Effect of different drying methods and drying tray position on drying time of okra slices

Drying treatment /Tray Position	Time (h)	Percentage reduction in time (%)
OSD	127	0
Mixed mode on-farm solar dryer		
P1	34	73.23
P2	52	59.06
P3	52	59.06
Indirect mode on-farm solar dryer		
P1	55	56.69
P2	58	54.33
P3	58	54.33

3.2 Modeling of Drying Curves

The experimental data were fitted with six drying models, this is indicated in table 4. The results obtained for the non-linear regression of the models including the criteria for selecting the goodness of fit, precisely, coefficient of determination (R^2), reduced chi-square (X^2), root mean square error (RMSE), mean bias error (MBE) and the constants of these equations are presented in tables 4 and 5. 0.6543 to 0.9796, 5.79E-05 to 1.565, 0.007 to 0.3893 and -0.447 to -0.002 are the range of values for R^2, X^2, RMSE and MBE respectively for tomato slices. 0.4425 to 0.94e of values for 61, 1.0E-05 to 1.738, 8.6E-04 and -0.431 to -8.6E-04 are the range of values for R^2, X^2, RMSE and MBE respectively for okra slices. The selection of the best model for predicting the drying characteristics of the tomato and okra slices is based on the model with highest R^2 and lowest of X^2, RMSE and MBE values.

Considering the mixed mode dried tomato, Page model with overall R^2 value (0.979) is higher than that of Lewis (0.748) and Henderson and Pabis models (0.935). Thus Page model best fitted the drying curve of tomato slices under mixed mode on-farm solar dryer. More so considering indirect mode dried tomato, Page model with overall R^2 value (0.962) is higher than that of Lewis (0.804) and that of Henderson and Pabis (0.912). Thus page model best describes the drying curve of tomato slices under indirect mode on-farm solar dryer. Considering the model with lowest X^2, RMSE and MBE for both drying conditions, page model also had the lowest values.

Taking a look at mixed mode dried okra, Page model with overall R^2 value (0.920) is higher than that of Lewis (0.747) and that of Henderson and Pabis (0.907). Hence, Page model best describes the drying curve of okra slices in mixed mode on-farm solar dryer. Meanwhile for okra slices in indirect mode dryer, Page model with overall R^2 value (0.933) is higher than that of Lewis (0.789) and that of Henderson and Pabis (0.914).

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Table 4 Statistical results obtained in the modeling of the drying data

Crop	Model	Drying Condition	R^2	CHI	RMSE	MBE
Tomato	Lewis	MSDP1	0.654	0.108	0.120	-0.083
		MSDP2	0.743	0.028	0.159	-0.152
		MSDP3	0.748	0.278	0.389	-0.152
		ISDP1	0.729	0.212	0.364	-0.132
		ISDP2	0.794	0.106	0.087	-0.109
		ISDP3	0.804	0.336	0.155	-0.185
		OSD	0.831	0.091	0.060	-0.080
	Henderson and Pabis	MSDP1	0.935	1.549	0.415	-0.391
		MSDP2	0.817	1.245	0.336	-0.321
		MSDP3	0.826	1.261	0.338	-0.323
		ISDP1	0.912	1.577	0.379	-0.361
		ISDP2	0.826	1.099	0.280	-0.270
		ISDP3	0.847	1.150	0.287	-0.276
		OSD	0.939	1.565	0.250	-0.447
	Page	MSDP1	0.937	0.001	8.6E -03	-0.008
		MSDP2	0.926	0.003	0.012	-0.017
		MSDP3	0.929	0.001	0.009	-0.009
		ISDP1	0.962	5.8E -05	0.002	-0.002
		ISDP2	0.941	0.003	0.015	-0.014
		ISDP3	0.942	0.003	0.014	-0.013
		OSD	0.979	0.001	0.007	-0.007
Okra	Lewis	MSDP1	0.443	0.061	0.229	-0.087
		MSDP2	0.760	0.104	0.305	-0.102
		MSDP3	0.747	0.101	0.299	-0.099
		ISDP1	0.621	0.083	0.288	-0.113

		ISDP2	0.729	0.127	0.339	-0.103
		ISDP3	0.734	0.129	0.343	-0.104
		OSD	0.788	0.115	0.332	-0.072
	Henderson and Pabis	MSDP1	0.869	1.738	1.114	-0.431
		MSDP2	0.902	1.324	1.014	-0.338
		MSDP3	0.907	1.388	1.039	-0.346
		ISDP1	0.914	1.589	1.128	-0.357
		ISDP2	0.894	1.516	1.114	-0.336
		ISDP3	0.889	1.486	1.103	-0.332
		OSD	0.870	0.441	0.635	-0/132
	Page	MSDP1	0.901	0.003	0.056	-0.012
		MSDP2	0.918	1E -05	8.6E -04	-8.6E -04
		MSDP3	0.920	9.1E –O4	0.027	-0.009
		ISDP1	0.924	4.0E -04	0.018	-0.006
		ISDP2	0.933	0.028	0.152	0.046
		ISDP3	0.933	7.3E -04	0.024	-0.007
		OSD	0.946	0.187	0.414	0.086

Table 5 Equation constants for the drying models

Crop	**Model**	**Drying Condition**	**n**	**a**	**k**
Tomato	Lewis	MSDP1			0.0935
		MSDP2			0.0807
		MSDP3			0.0804
		ISDP1			0.0748
		ISDP2			0.0477
		ISDP3			0.0661
		OSD			0.0379
	Henderson and Pabis	MSDP1		0.0858	0.0649
		MSDP2		0.3640	0.0648
		MSDP3		0.3545	0.0642
		ISDP1		0.2023	0.0547
		ISDP2		0.4815	0.0569
		ISDP3		0.4568	0.0557
		OSD		0.1896	0.0295
	Page	MSDP1	0.9265		0.0746
		MSDP2	1.1680		0.0255
		MSDP3	1.1690		0.0254
		ISDP1	1.1167		0.0297
		ISDP2	1.2772		0.0137
		ISDP3	1.3008		0.0125
		OSD	0.9750		0.0290
Okra	Lewis	MSDP1			0.1216
		MSDP2			0.1051
		MSDP3			0.1036
		ISDP1			0.0959
		ISDP2			0.0815

	ISDP3			0.0819
	OSD			0.0436
Henderson and Pabis	MSDP1		0.0345	0.0784
	MSDP2		0.1874	0.0797
	MSDP3		0.1649	0.0775
	ISDP1		0.0408	0.0659
	ISDP2		0.1572	0.0603
	ISDP3		0.168	0.0611
	OSD		0.2115	0.0346
Page	MSDP1	0.9235		0.0992
	MSDP2	1.0345		0.0597
	MSDP3	1.0279		0.0604
	ISDP1	0.9796		0.0664
	ISDP2	1.0235		0.0480
	ISDP3	1.0287		0.0473
	OSD	0.8928		0.0478

Based on this results, the Page model has been selected as the suitable model to predict the drying characteristics of tomato and okra slices in mixed mode and indirect mode on-farm solar dryers for fruits and vegetables.

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A close comparison between the experimental and predicted moisture ratios of both tomato and okra slices using page model for mixed mode and indirect mode on-farm solar dryers is indicated in figures 4 and 5. All figures indicate conformity between predicted and experimental moisture ratios. This shows the suitability of page model in predicting the drying characteristics of tomato and okra slices. The use of page model to predict the drying characteristics tomatoes is similar to thin layer drying of tomatoes (Doymaz, 2007) and barberries (Aghbashlo et al., 2009).

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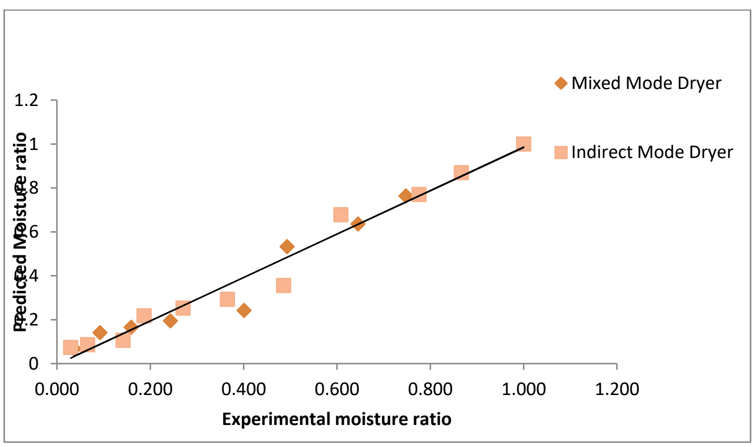

Figure 4. Experimental and predicted moisture ratio for tomato slices under mixed mode and indirect mode dryers.

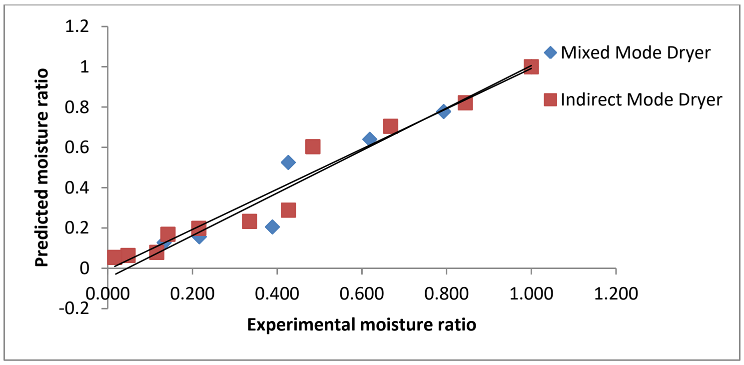

Figure 5. Experimental and predicted moisture ratio for okra slices under mixed mode and indirect mode dryers.

3.3 Effective moisture diffusivity

The effective moisture diffusivity coefficient ($D_{eff)}$ was calculated using the method of slopes as shown in eq. (8). The slopes of the graphs of Ln (MR) versus time were determined (Workneth et al., 2013). The values of D_{eff} of tomato samples varied between -7.4724 X 10^{-08} and -1.6439 X 10^{-07}. The D_{eff} values obtained for open sun drying was the least (-7.4724 X 10^{-08}) and that of while that of the mixed mode dryer was highest (1.6439 X 10^{-07}) which indicates that D_{eff} is a function of temperature. The values of D_{eff} of okra samples varied between -3.12 X 10^{-07} and -8.08 X 10^{-07}. The D_{eff} values obtained for open sun drying was the least (-7.4724 X 10^{-08} and -3.12 X 10^{-07} for tomato and okra respectively), and that of while that of the mixed mode dryer was highest (1.6439 X 10^{-07} and -8.08 X 10^{-07} for tomato and okra respectively) which indicates that D_{eff} is a function of temperature. Moisture transport within a product during drying is predominantly by diffusion. Here the drying temperature has a significant effect on mass transfer of moisture, since the higher the temperatures encountered by products, the faster the rate of diffusion of moisture from the internal region to the surface. Therefore the mixed mode dryer results in higher moisture diffusion than open sun or the indirect mode dryer. The effective moisture diffusivity obtained for tomatoes and okra is similar to that obtained for apples (Goyal et al., 2008), tomatoes dried at 45–75°C (Akanbi et al,, 20060); 1.49 and 5.59 × 10–9 m2/s and for kale (Mwithiga and Olwal, 2005), 2.22 × 10–10 to 4.69 × 10–10 m2/s.

3.4 Colour of fresh and dried tomato slices

The changes in colour of MSD dried, ISD dried and OSD dried, tomato and okra samples are presented in Table 6. There was colour change in all the samples observed, this indicates that drying has a significant effect on the colour of dried fruits and vegetables. This colour changes are mainly due to direct exposure of the products to solar radiation or due to some changes in the chemical properties of the dried products, especially changes in some carotenoid content and oxidation of chlorophyll pigment of greens. The amounts of sugar, amino acids as well as time of processing have also been reported to affect the colour of dried Tomato by causing formation of brown pigments (Perumal, 2007). After drying an increase in darkness i.e decrease in L* of Tomato was observed for all the drying method when compared to the fresh samples of Tomato. This indicates that there was a general darkening in all the dried sample. However this darkening is more in OSD (L*=40.27) than in MSD (L*=41.93) and MSD is darker than ISD (L*=47.13). An a*/b* value is commonly used to report the colour quality of Tomato (brightness of red) as reported by (Perumal, 2007). The experimental a*/b* of Tomato for MSD is 0.76, for ISD is 1.03 and for OSD is 0.41. Indicating more brightness in ISD followed by MSD and the darkest been OSD. This result is similar to the colour parameters obtained by (Perumal, 2007) and (Soner and Kamil, 2013). After drying an increase in brightness that is increase in L* value of dried okra was observed for all the drying method when compared to fresh sample of okra. This indicates that there was a general lightening (fading effect) in all the dried samples. However this lightening is more pronounced in OSD followed by MSD then ISD. An increase in a* and b* value observed in dried okra samples indicates that dried Okra samples were more brownish as compared to fresh Okra samples, this is as a result of oxidation of ascorbic acid found in fresh okra during the drying process . This browning effect is more pronounced in OSD followed by MSD then ISD. The colour coordinates observed for dried Okra in MSD, ISD and OSD are (L*=35.30, a*=7.30, b*=10.50), (L*=32.72, a*=4.64, b*=8.38) and (L*=37.47, a*=7.93, b*=16.10).

Table 6 Dried Sample Colour Values of MSD, ISD and OSD

Drying method	Crop	L*	a*	b*	a*/b*
Fresh	Tomato	49.45	15.58	14.90	1.05
MSD	Tomato	41.93	13.80	18.27	0.76
ISD	Tomato	47.13	27.00	26.20	1.03
OSD	Tomato	40.27	7.83	19.13	0.41
Fresh	Okra	30.60	-5.5	8.90	-0.62
MSD	Okra	35.30	7.30	10.50	0.70
ISD	Okra	32.72	4.64	8.38	0.55
OSD	Okra	37.47	7.93	16.10	0.49

Conclusion

Drying characteristics of tomato and okra slices was investigated under a mixed mode on-farm solar dryer, indirect mode on-farm solar dryer and open sun drying. Drying time was significantly reduced in the mixed mode on-farm solar dryer than in the indirect mode on-farm solar dryer. In this report both tomato and okra slices went through both constant and falling rate. The mixed mode dryer reduced the drying time of tomato by 64.63% and that of okra by 73.23%. the indirect mode dryer reduced the drying time of tomato by 51.02% and that of okra by 56.69%.

Page model gave the best fit to predict the mixed mode and the indirect mode on-farm solar drying of tomato and okra slices. The drying rate and effective moisture diffusivity increased when mixed mode dryer was used instead of indirect mode dryer. The reduction in drying time and quality colour retention makes the mixed mode and indirect mode on-farm solar dryers a good option for drying of tomato and okra on the farm.

Nomenclature

MSD P1 : 1st tray from bottom in drying chamber of the mixed mode dryer
MSD P2 : 3rd tray from bottom in the drying chamber of the mixed mode dryer
MSD P3 : 5th tray from bottom in the drying chamber of the mixed mode dryer
ISD P1 : 1st tray from bottom in drying chamber of the indirect mode dryer
ISD P2 : 3rd tray from bottom in the drying chamber of the indirect mode dryer
ISD P3 : 5th tray from bottom in the drying chamber of the indirect mode dryer
OSD : Open sun drying

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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