

MATHEMATICAL MODELING OF THIN LAYER DRYING CHARACTERISTICS AND PROXIMATE ANALYSIS OF TURKEY BERRY (SOLANUM TORVUM)

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In the present work the drying characteristics and proximate analysis of turkey berry (Solanum torvum) were analyzed under open sun drying and greenhouse drying with two different glazing materials (UV Polyethylene sheet and Drip lock sheet) under passive and active modes. The drying rate under different modes of drying are 18.73g/h in drip lock greenhouse active mode,12.50 g/h in UV polyethylene sheet greenhouse active mode,15.22 g/h in drip lock sheet greenhouse passive mode, 11.84 g/h in UV polyethylene sheet greenhouse passive mode and 10.65 g/h in open sun drying. Twelve mathematical models were chosen to determine the drying characteristics of Turkey berry. From the statistical analysis it is found that Modified Henderson and Pabis model is the best drying model describing thin layer drying characteristics of turkey berry in both open sun drying and greenhouse drying. The goodness of the fit achieved is based on the values of coefficient of determination(R^2), sum square error(SSE), root mean square error(RMSE) and reduced chi square (χ^2).From the proximate analysis of dried turkey berry it is found that more amount of carbohydrate is retained in UV polyethylene greenhouse dryer under passive mode. In drip lock greenhouse dryer under passive mode the retention of vitamins such as protein, vitamin C and ash content showed a positive sign. In drip lock greenhouse dryer under active mode the retention of calcium, iron and dietary fibre is found to be high. Finally it is observed that more amounts of nutrients are retained in greenhouse drying than in open sun drying.

Keywords: Active greenhouse drying, Drip lock sheet, Passive greenhouse drying, Proximate analysis, Statistical analysis, Turkey berry

1. Introduction

Turkey berry is a plant with broad leaved shrub growing up to 5m high shown in fig. 1. Turkey berry is scientifically called as *Solanum torvum*. It had originated from south of United States and then made its establishment in Asia and Africa. Turkey berry have a rich source of calcium, fat and iron. Because of its rich iron content it is used for treating anemia. Fresh or dried turkey berry is used to lower blood pressure and prevent heart attack. Turkey berry also prevent cancer due to its anti-bacterial and antifungal nature. Earlier turkey berry was used as a vegetable but now it is getting popular due to its medicinal benefits. The main drawback is it is not a long lived species. Therefore it is necessary to preserve turkey berry by drying process to utilize the benefits of it. Drying is done by removing the water vapour present in the product by the application of heat. This reduced the use of refrigerator for preservation and the storage volume of product after drying.



Figure 1. Pictorial view of Turkey berry(*Solanum torvum*)

One of the simplest method followed earlier in drying process is open sun drying where the products to be dried is lay down in open sun. The main drawback faced is the product dried in it had lot of contamination and poor quality of dried product. This paved the way for green house drying where the products are dried in a closed glazing greenhouse dryer. Productivity was increased by 87% in a double chamber forced convection greenhouse dryer with plastic cover glazing material for drying pepper [1]. A thermal model was developed for drying bitter melon in forced convection greenhouse drying with plastic film as glazing material and in open sun drying. The convective heat transfer coefficient is more under forced convection greenhouse drying [2]. A passive mode of greenhouse dryer was designed with transparent glass material for drying cassava chips. It was found that 30% drying time is reduced in greenhouse drying [3]. The effects of infrared irradiance at night time in a greenhouse dryer reduced the drying time and improved the quality of red pepper [4]. Two types of greenhouse models with polyethylene sheet as a glazing material for drying pepper were analyzed for drying pepper. The black coated surface and usage of chimney improved the performance of greenhouse dryer [5]. The convective mass transfer and humidity removal rate is more during the initial drying period of cabbage and peas under the open sun and greenhouse drying in passive and active mode [6]. A hybrid photovoltaic thermal greenhouse dryer was developed with two modules for drying grapes using UV stabilized polyethylene sheet. The heat transfer coefficient of module II is higher than module I [7].

A UV polyethylene film greenhouse tunnel drier reduced the moisture content of copra from 52.2% to 8% in 55 hours and the simulated results agreed with the experimental data [8]. The drying rate was improved by increasing the air temperature inside a greenhouse dryer with UV polyethylene glazing sheet and inclined north wall reflection at 23.56° in natural and forced convection mode [9]. Experimental data obtained in drying papad under forced greenhouse drying used regression analysis for determining Nusselt number constant [10]. The reduction in the size of khoa under forced convection greenhouse drying increased the convective heat and mass transfer coefficient [11]. Drying

time had been considerably reduced in drying banana under polycarbonate greenhouse dryer in active mode [12].

From the literature review it was found that drying characteristics of turkey berry are scarce and drip lock greenhouse drier glazing material was not used earlier. The objective of the present work is

- To investigate the drying characteristics of turkey berry.
- To fit the experimental values to twelve different models and
- To analyze the nutrition content of dried turkey berry under open sun drying and greenhouse drying with UV Polyethylene sheet and Drip lock sheet as glazing material.

2. Materials and Methods

2.1 Experimental setup

An Even span roof type greenhouse dryer have been designed and fabricated with 1.2 x1.2 m² floor area and ceiling 1m height. The structural frame of the greenhouse dryer is covered by UV polyethylene sheet and drip lock sheet as glazing material of 0.10mm thickness to trap the solar radiation under passive and active mode as shown in fig. 2. For enhancing the air movement in greenhouse dryer, an air vent is provided at the roof of the passive greenhouse dryer and a fan was used in active mode.

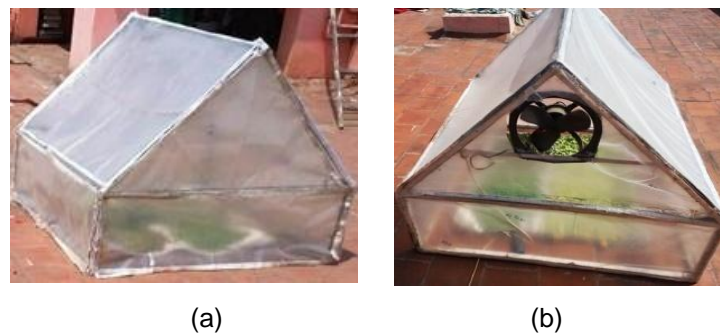


Figure 2. Greenhouse dryers in (a) Passive mode(b) Active mode

2.2 Instrumentation

Spray The initial moisture content of turkey berry was found out using HR83 Halogen moisture Analyzer. Solar radiation is measured using Solarimeter (range: 2000 W/m²) with an accuracy of $\pm 5\%$. A noncontact type infrared thermometer is used for temperature measurement up to 380°C with an accuracy of $\pm 1.5^\circ\text{C}$.

2.3 Uncertainty Analysis

The uncertainty in the measured parameters occurs due to in accuracy caused because of sensitivity, calibration, reading, etc. In the drying of Turkey berry there are some independent parameters like temperature, mass, time, etc. and some dependent parameters such as efficiency, drying rate etc. Let $x_1, x_2, x_3 \dots x_n$ are independent variables with uncertainty $w_1, w_2, w_3 \dots w_n$. The result R is a dependent function of independent variables. The uncertainty in the result R is given by w_R [13], [14] in Equation (1).

$$R = \left[\left(\frac{\partial R}{\partial x_1} w_1 \right)^2 + \left(\frac{\partial R}{\partial x_2} w_2 \right)^2 + \left(\frac{\partial R}{\partial x_3} w_3 \right)^2 + \dots + \left(\frac{\partial R}{\partial x_n} w_n \right)^2 \right]^{1/2} \quad (1)$$

The uncertainties in the measured and calculated parameters of Temperature is $\pm 1.5^\circ\text{C}$, Solar radiation is 5%, Mass of the product is 0.1% and Moisture ratio is 2%.

2.4 Experimental procedure

Greenhouse dryer was placed in East West orientation to have maximum exposure of solar radiation. Samples of one kg of turkey berry placed in trays in open sun drying, greenhouse drying under passive and active mode using UV polyethylene sheet and drip lock sheet as glazing material. Experiments were conducted in the month of March 2018 from 9 AM to 4 PM and the dried products were kept in air tight plastic sheets to prevent absorption of moisture from atmosphere during night time. Drying is carried out till the safe moisture content for preservation is achieved.

2.5 Mathematical modeling of drying curves

Moisture ratio (MR) is an important parameter to analyze and compare the performance of solar dryers. Moisture ratio is the ratio between mass of water to mass of solid in a sample [15]. It is given by Equation (2),

$$MR = \frac{(M_{int} - M_{eq})}{(M_{in} - M_{eq})} \quad (2)$$

Where M_{int} is instantaneous moisture content, M_{in} is initial moisture content and M_{eq} is equilibrium moisture content.

The drying rate is the ratio between the difference in moisture content and total hours taken for drying to reach the safe moisture content for preservation [15]. Drying rate is calculated as follows (3),

$$Dr = \left(\frac{M_i - M_f}{\text{Total hours of drying}} \right) \quad (3)$$

Where, Dr =Drying Rate (g/h), M_i =Initial moisture content (g) and M_f =Final moisture content (g).

Drying curves were fitted to twelve thin layer drying models. MATLAB R2019a was used to calculate the model constants and to fit the mathematical models. Nonlinear regression analysis was carried out for the twelve models[15]presented in table(4).The goodness of the fit for all the models depends on coefficient of determination (R^2),sum square error(SSE), root mean square error(RMSE) and reduced chi square(χ^2)[16].The model having the highest R^2 and the lowest SSE, RMSE and χ^2 is the main criteria for the goodness of fit[17]. The SSE, RMSE and χ^2 can be calculated from the equations (4), (5) and (6).

$$SSE = \frac{1}{N} \sum_{i=1}^n (MR_{exp,i} - MR_{pre,i})^2 \quad (4)$$

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

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

Where,

$MR_{exp,i}$ =Experimental moisture ratio for i^{th} experiment

$MR_{pre,i}$ =Predicted moisture ratio for i^{th} experiment

N =Total number of observations

n =Total number of constants in the model

2.6 Proximate analysis

Drying of vegetables will significantly affect the nutrition content. These changes happened due to pretreatment methods, drying temperature and storage methods. Some of the steps can be taken to minimize nutrition losses are reducing the drying time, maintaining minimum temperature and lower oxygen concentration during storage. In this present work the glazing material of UV polyethylene sheet and drip lock sheet were used to reduce the drying time and minimize the nutrition losses in dried turkey berry under passive and active mode.

3. Results and Discussion

3.1 Drying characteristics of turkey berry

The variations of moisture ratio with time obtained using experimental data are shown in fig. 3 for turkey berry. For turkey berry the final moisture ratio of around 0.1 had been achieved in less than 4 days in Drip lock greenhouse dryer under active mode (DLAM), 5 days in UV polyethylene greenhouse dryer under active mode (UVAM), 5 days in Drip lock greenhouse dryer under passive mode (DLPM), 6 days in UV polyethylene greenhouse dryer under passive mode (UVPM) and 7 days in Open sun drying(OSD). It can be seen from the fig. 3 that during initial period the rate of moisture removal is more and decreases as the time increases. This is due the evaporation of moisture from the surface initially and then the heat supplied is used for bringing the moisture from the inner part of the product to the surface. In general the moisture ratio in drying decreases exponentially and in open sun the rate of decrease of moisture ratio is slower than greenhouse drying. It is seen from the fig. 3 the drying process of turkey berry follow falling rate period. Drying rate mainly depends on the glazing material used and the air temperature inside the drier. Higher the heat transfer higher will be the drying rate. The variations of drying rate for each day for different sheets under passive mode, active mode and open sun drying are plotted in fig. 4.

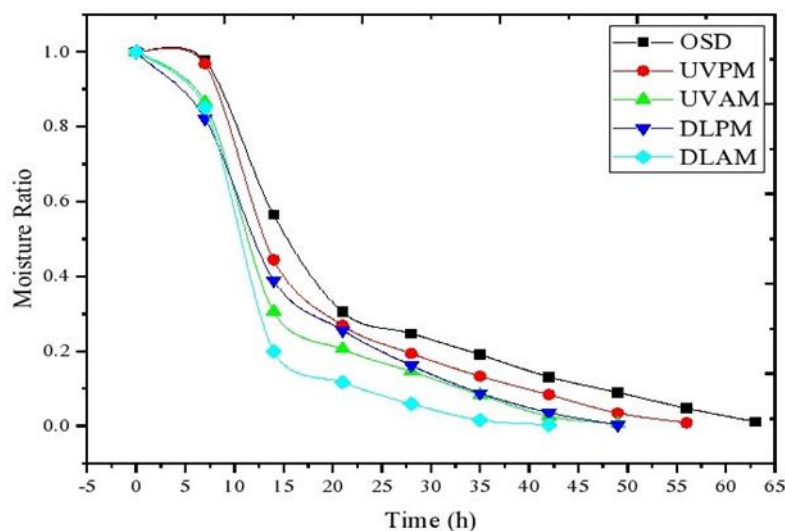


Figure 3. Variation of moisture ratio under open sun drying, Green house drying using UV Polyethylene and drip lock sheet as glazing material in Passive and Active mode

From the experimental results it is found that the drying rate of 18.73 g/his achieved in drip lock greenhouse active mode, 12.50 g/h achieved in UV polyethylene sheet greenhouse active mode, 15.22 g/h achieved in drip lock sheet greenhouse passive mode, 11.84 g/h achieved in UV polyethylene sheet greenhouse passive mode and 10.65 g/h achieved in open sun drying. The drying rate is found to be higher in drip lock greenhouse active mode dryer because of the more amount of heat transfer enhanced by the air movement by fan and due to increase in temperature inside the greenhouse dryer by the glazing material used. It is also seen that drying rate decreases continuously with time [13].

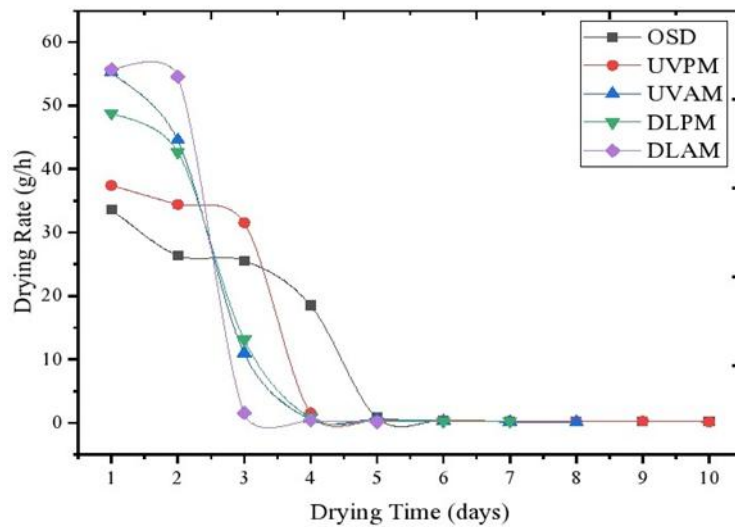


Figure 4. Variation of Drying rate under open sun drying, Green house drying using UV Polyethylene and drip lock sheet as glazing material in Passive and Active mode

3.2 Model fitting of drying models

To describe the thin layer drying process of turkeyberry twelve drying models are fitted for the experimental values of moisture ratio and drying time [18].The twelve models chosen to fit drying characteristics of turkey berry is shown in tab. 3.

Table 3. Drying Models [19]

Model Name	Equation
Lewis model	$MR = e^{-kt}$
Page model	$MR = e^{-kt^n}$
Henderson and Pabis model	$MR = a. e^{-kt}$
Two term model	$MR = (a. e^{-k_0 t}) + (b. e^{-k_1 t})$
Logarithmic model	$MR = a. e^{-kt} + c$
Wang and Singh model	$MR = 1 + at + bt^2$
Two- term exponential model	$MR = a. e^{-kt} + (1 - a) e^{-kat}$
Verma et al.model	$MR = a. e^{-kt} + (1 - a) e^{-gt}$

Approximation of diffusion model	$MR = a. e^{-kt} + (1 - a) e^{-kbt}$
Midilli- kucuk model	$MR = a. e^{-kt^n} + bt$
Prakash and Kumar	$MR = at^3 + bt^2 + ct + d$
Modified Henderson and Pabis mode	$MR = a. e^{-kt} + b. e^{-gt} + c. e^{-ht}$

For selecting the best model Regression analysis were carried out for twelve drying models. The criteria for the best drying model is the model having highest R^2 and the lowest SSE, RMSE and χ^2 values. All the drying model have good agreement with the experimental values. It is found that Modified Henderson and Pabis model is found to be the best model for drying turkey berry under open sun drying with the parameters SSE = 0.004227 , $R^2 = 0.99356$, RMSE = 0.032506, $\chi^2= 0.007396$, under UV polyethylene passive mode greenhouse dryer with the parameters SSE =0.001482 , $R^2 = 0.998742$, RMSE = 0.02222829, $\chi^2= 0.001235$, under UV polyethylene active mode with the parameters SSE = 0.003934 , $R^2 = 0.996231$, RMSE = 0.04435, $\chi^2= 0.005901$, under drip lock greenhouse dryer passive mode with the parameters SSE =0.00207 , $R^2 = 0.997884$, RMSE = 0.032169, $\chi^2= 0.004139$ and for drip lock greenhouse dryer under active mode with the parameters SSE = 0.005004 , $R^2 = 0.995283$, RMSE = 0.070738, $\chi^2= 0.020016$. It is found that Modified Henderson and Pabis model is the best drying model describing thin layer drying characteristics of turkey berry in both open sun drying and green house drying (tab. 4). The experimental moisture ratio and predicted moisture ratio were plotted graphically for the selected model. The predicted MR lies in line with the experimental MR for the selected model under open sun and green house drying, which clearly indicates the capability of selected drying model in describing the drying behavior of turkey berry under open sun and greenhouse drying.

Table 4. Best suited drying model under different modes of drying

Drying mode	Model	Model constants	SSE	R^2	RMSE	χ^2
OSD	Modified Henderson and Pabis model	a = -153	0.004227	0.99356	0.032506	0.007396
		b = 152.6				
		c = 1.388				
		g = 0.6127				
		h = 0.06359				
		k = 0.619				
UVPM	Modified Henderson and Pabis model	a =2.722	0.001482	0.998742	0.02222829	0.001235
		b = -2.634				
		c =0.9113				
		g = 3.306				
		h = 0.05832				
		k = 0.2888				

UVAM	Modified Henderson and Pabis model	a = 0.5922	0.003934	0.996231	0.04435	0.005901
		b = -2.295				
		c = 2.702				
		g = 1.102				
		h = 0.2513				
		k = 0.05901				
DLPM	Modified Henderson and Pabis model	a = 2.022	0.00207	0.997884	0.032169	0.004139
		b = 1.06				
		c = -2.082				
		g = 0.07133				
		h = 3.285				
		k = 0.3483				
DLAM	Modified Henderson and Pabis model	a = 1.838	0.005004	0.995283	0.070738	0.020016
		b = 1.281				
		c = -2.122				
		g = 0.1421				
		h = 3.954				
		k = 0.2311				

3.3 Proximate Analysis

The proximate analysis was carried out for turkey berry dried under open sun drying, greenhouse drying using UV polyethylene sheet and drip lock sheet as glazing material under passive and active mode. The nutrition content of dried turkey berry under different modes is shown in tab. 5.

3.3.1 Carbohydrate

Carbohydrate is one of the essential nutrients playing a vital role in human diet. Carbohydrate content in the product after drying indicates the amount of energy stored in it. The turkey berry dried under greenhouse drying gave a rich source of carbohydrate when compared to open sun drying.

Table 5. Nutrition content of Turkey berry dried under various conditions

Nutrients	Open Sun Drying	UV Polyethylene Greenhouse Drying	Driplock Sheet Greenhouse Drying	UV Polyethylene Greenhouse Drying	Driplock Sheet Greenhouse Drying
		(Passive Mode)	(Passive Mode)	(Active Mode)	(Active Mode)
Carbohydrate (g/100g)	48.52	76.58	69.62	71.4	74
Protein (g/100g)	12.95	14.87	16.12	14.1	13.1
Calcium	109	101	126	614	630

(mg/100g)					
Iron (mg/100g)	5.67	8.01	7.29	6.20	10.2
Vitamin C (mg/100g)	68	107	114	68.4	62.1
Dietary fibre (g/100g)	12.66	18.95	17.36	18.3	19.4
Ashcontent (g/100g)	6.19	6.27	8.13	6.30	6.70

3.3.2 Protein

The protein content in the active mode is slightly lower than the passive mode in both the glazing material. This is because the temperature inside the glazing material is high which affects the protein content directly.

3.3.3 Calcium

Generally the vegetables have a rich content of calcium. It is found that the retention of calcium is high under active mode in both the glazing material than in passive and open sun drying. Calcium is related to vegetable tissue firmness.

3.3.4 Iron

The retention of iron is more in passive mode than in active mode. Still the iron content in drip lock greenhouse drying under active mode has higher value than UV polyethylene sheet under active mode. The reduction of iron content in active mode greenhouse drying is due to effect of temperature and exposure of vegetables to atmosphere.

3.4.5 Vitamin C

Temperature and time are the two important parameters that affect vitamin C due to its sensibility to heat [20]. The retention of vitamin C in drip lock greenhouse drying under passive mode is more when compared to other modes.

3.4.6 Dietary fiber

Is a type of carbohydrate that cannot be broken down by our digestive enzymes. The presence of this will reduce the risk of diabetes and heart diseases. Drip lock greenhouse drying under active mode showed a rich level of dietary fiber when compared to other modes.

3.4.7 Ash content

Ash content indicates the mineral content in dried product after the removal of water and organic matter. It is found that it is higher in drip lock greenhouse drying under passive mode compared to other modes. The variation of nutrition content after drying under open sun drying and greenhouse drying for different modes is shown in fig. 5 and fig. 6

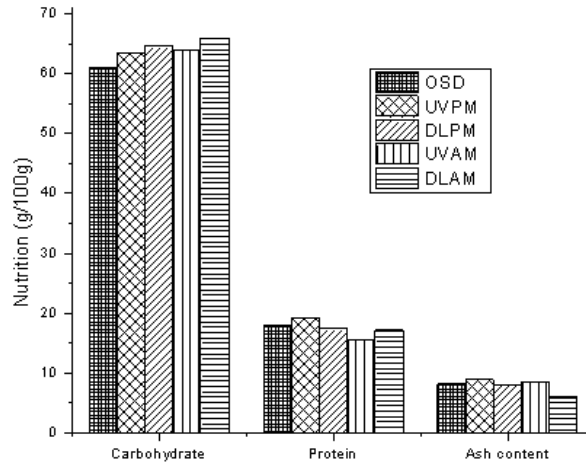


Figure 5. Variation of carbohydrate, protein and Ash content under open sun drying and Greenhouse drying (Active and Passive mode)

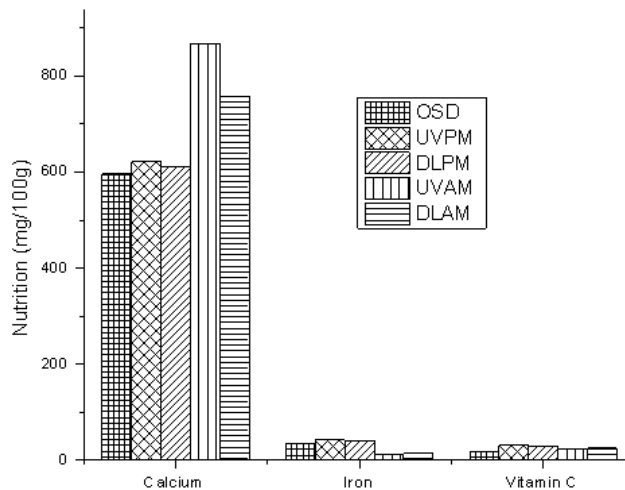


Figure 6. Variation of Calcium, Iron and Vitamin C content under open sun drying and Greenhouse drying (Active and Passive mode)

4. Conclusion

The experiments were conducted for drying turkey berry under open sun drying, UV polyethylene as glazing material, drip lock sheet as glazing material under passive and active mode [21]. The following conclusions were drawn from the results obtained.

- The drying rate under different modes of drying are 18.73 g/h in drip lock greenhouse active mode, 12.50 g/h in UV polyethylene sheet greenhouse active mode, 15.22 g/h in drip lock sheet greenhouse passive mode, 11.84 g/h in UV polyethylene sheet greenhouse passive mode and 10.65 g/h in sun drying. It is found that drip lock greenhouse active mode have a higher drying rate.
- From the statistical analysis it is found that Modified Henderson and Pabis model is the best drying model describing thin layer drying characteristics of turkey berry in both open sun drying and greenhouse drying. The best models are selected based on Highest R^2 and the lowest SSE, RMSE and χ^2 .

- From the proximate analysis of dried turkey berry it is found that more amount of carbohydrate is retained in UV polyethylene greenhouse dryer under passive mode. In drip lock greenhouse dryer under passive mode the retention of vitamins such as protein, vitamin C and ash content showed a positive sign. In drip lock greenhouse dryer under active mode the retention of calcium, iron and dietary fibre is found to be high. Finally it is observed that more amounts of nutrients are retained in greenhouse drying then in open sun drying. The quality of the dried turkey berry is also improved since the products dried under greenhouse dryer are free from contamination.

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Nomenclature

Dr – drying rate, [g/h]

M_{eq} – equilibrium moisture content, [kg]

M_i – initial moisture content, [kg]

M_{int} – instantaneous moisture content, [kg]

M_f - final moisture content, [kg]

Acronyms

DLPM – drip lock passive mode

DLAM – drip lock active mode

MR – moisture ratio

OSD – open sun drying

MR – moisture ratio

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