MATHEMATICAL MODELING OF THIN LAYER DRYING CHARACTERISTICS AND PROXIMATE ANALYSIS OF TURKEY BERRY (*Solanum torvum*)

by

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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 18.73 g per hour in drip lock greenhouse active mode, 12.50 g per hour in UV polyethylene sheet greenhouse active mode,15.22 g per hour in drip lock sheet greenhouse passive mode, 11.84 g per hour in UV polyethylene sheet greenhouse passive mode and 10.65 g per hour 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, root mean square error, 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

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Introduction

Turkey berry is a plant with broad leaved shrub growing up to 5 m high shown in fig. 1. Turkey berry is scientifically called as *Solanum torvum*. It had originated from south of USA 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 were 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 greenhouse 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 PV 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.

Materials and methods

Experimental set-up

An Even span roof type greenhouse dryer have been designed and fabricated with 1.2×1.2 m^2 floor area and ceiling 1 m height. The structural frame of the greenhouse dryer is covered by UV polyethylene sheet and drip lock sheet as glazing material of 0.10 mm 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.

(a) (b)

Figure 2. Greenhouse dryers in; (a) passive mode and (b) active mode

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/m^2) with an accuracy of ±5%. A non-contact type infrared thermometer is used for temperature measurement up to 380 °C with an accuracy of ±1.5 °C.

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, $x_3 \ldots x_n$ are independent variables with uncertainty w_1, w_2, $w_3 \ldots w_n$. The result, R, is a dependent function of independent variables. The uncertainty in the result, R, is given by wR [13, 14]:

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

The uncertainties in the measured and calculated parameters of temperature is ±1.5 °C, solar radiation is 5%, mass of the product is 0.1%, and moisture ratio (MR) is 2%.

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 a. m. to 4 p. m. 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.

Mathematical modeling of drying curves

The MR is an important parameter to analyze and compare the performance of solar dryers. The MR is the ratio between mass of water to mass of solid in a sample [15]:

$$MR = \frac{M_{\text{int}} - M_{\text{eq}}}{M_{\text{in}} - M_{\text{eq}}} \tag{2}$$

where M_{int} is the instantaneous moisture content, M_{in} – the initial moisture content, and M_{eq} – the equilibrium moisture content.

The drying rate, Dr, is the ratio between the difference in moisture content and total hours taken for drying to reach the safe moisture content for preservation [15]:

$$Dr = \frac{M_{\text{i}} - M_{\text{f}}}{\text{Total hours of drying}} \tag{3}$$

where Dr [g/h] is the drying rate, M_{i} [g] – the initial moisture content, and M_{f} [g] – the final moisture content.

Drying curves were fitted to twelve thin layer drying models. The MATLAB R2019a was used to calculate the model constants and to fit the mathematical models. Non-linear regression analysis was carried out for the twelve models [15] presented in tab. 2. 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 eqs. (4)-(6):

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

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

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

where $MR_{\text{exp},i}$ is the experimental MR for i^{th} experiment, $MR_{\text{pre},i}$ – the predicted MR for i^{th} experiment, N – the total number of observations, and n – the total number of constants in the model.

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.

Results and discussion

Drying characteristics of Turkey berry

The variations of MR with time obtained using experimental data are shown in fig. 3 for Turkey berry. For Turkey berry the final MR of around 0.1 had been achieved in less than four days in drip lock greenhouse dryer under active mode (DLAM), five days in UV polyethylene greenhouse dryer under active mode (UVAM), five days in drip lock greenhouse dryer under passive mode (DLPM), six days in UV polyethylene greenhouse dryer under passive mode (UVPM), and seven 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 MR in drying decreases exponentially and in open Sun the rate of decrease of MR 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.

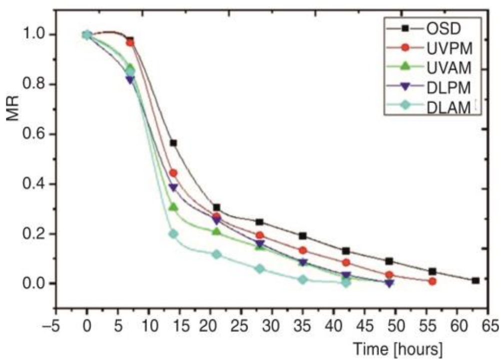

Figure 3. Variation of MR under open Sun drying, greenhouse drying using UV polyethylene and drip lock sheet as glazing material in passive and active mode

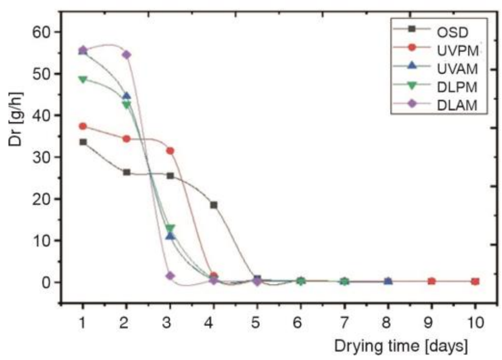

Figure 4. Variation of drying rate under open Sun drying, greenhouse drying using UV polyethylene and drip lock sheet as glazing material in passive and active mode

From the experimental results it is found that the drying rate of 18.73 g per hour is achieved in drip lock greenhouse active mode, 12.50 g per hour achieved in UV polyethylene sheet greenhouse active mode, 15.22 g per hour achieved in drip lock sheet greenhouse passive mode, 11.84 g per hour achieved in UV polyethylene sheet greenhouse passive mode, and 10.65 g per hour 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].

Model fitting of drying models

To describe the thin layer drying process of Turkey berry twelve drying models are fitted for the experimental values of MR and drying time [18]. The twelve models chosen to fit drying characteristics of Turkey berry is shown in tab. 1.

Table 1. Drying Models [19]

Model Name	Equation
Lewis model	$MR = \mathrm{e}^{-kt}$
Page model	$MR = \mathrm{e}^{-kt^n}$
Henderson and Pabis model	$MR = a\mathrm{e}^{-kt}$
Two term model	$MR = (a\mathrm{e}^{-k_0t}) + (b\mathrm{e}^{-k_1t})$
Logarithmic model	$MR = a\mathrm{e}^{-kt} + c$
Wang and Singh model	$MR = 1 + at + bt^2$
Two-term exponential model	$MR = a\mathrm{e}^{-kt} + (1 - a)\mathrm{e}^{-kat}$
Verma *et al.* model	$MR = a\mathrm{e}^{-kt} + (1 - a)\mathrm{e}^{-gt}$
Approximation of diffusion model	$MR = a\mathrm{e}^{-kt} + (1 - a)\mathrm{e}^{-kbt}$
Midilli-kucuk model	$MR = a\mathrm{e}^{-kt^n} + bt$
Prakash and Kumar	$MR = at^3 + bt^2 + ct + d$
Modified Henderson and Pabis mode	$MR = a\mathrm{e}^{-kt} + b\mathrm{e}^{-gt} + c\mathrm{e}^{-ht}$

For selecting the best model Regression analysis were carried out for twelve drying models. The creteria for the best drying model is the model having highest R^2 and the lowest SSE, RMSE, and χ^2 values. All the dryimg 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

$$\text{SSE} = 0.004227,\ R^2 = 0.99356,\ \text{RMSE} = 0.032506,\ \chi^2 = 0.007396$$

under UV polyethylene passive mode greenhouse dryer with the parameters

$$\text{SSE} = 0.001482,\ R^2 = 0.998742,\ \text{RMSE} = 0.02222829,\ \chi^2 = 0.001235$$

under UV polyethylene active mode with the parameters

$$\text{SSE} = 0.003934,\ R^2 = 0.996231,\ \text{RMSE} = 0.04435,\ \chi^2 = 0.005901$$

under drip lock greenhouse dryer passive mode with the parameters

$$\text{SSE} = 0.00207,\ R^2 = 0.997884,\ \text{RMSE} = 0.032169,\ \chi^2 = 0.004139,\ \text{and}$$

for drip lock greenhouse dryer under active mode with the parameters

$$\text{SSE} = 0.005004,\ R^2 = 0.995283,\ \text{RMSE} = 0.070738,\ \chi^2 = 0.020016.$$

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. 2. The experimental MR and predicted MR 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 greenhouse 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 2. 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 b = 152.6 c = 1.388 g = 0.6127 h = 0.06359 k = 0.619	0.004227	0.99356	0.032506	0.007396
UVPM	Modified Henderson and Pabis model	a = 2.722 b = –2.634 c = 0.9113 g = 3.306 h = 0.05832 k = 0.2888	0.001482	0.998742	0.02222829	0.001235
UVAM	Modified Henderson and Pabis model	a = 0.5922 b = –2.295 c = 2.702 g = 1.102 h = 0.2513 k = 0.05901	0.003934	0.996231	0.04435	0.005901
DLPM	Modified Henderson and Pabis model	a = 2.022 b = 1.06 c = –2.082 g = 0.07133 h = 3.285 k = 0.3483	0.00207	0.997884	0.032169	0.004139
DLAM	Modified Henderson and Pabis model	a = 1.838 b = 1.281 c = –2.122 g = 0.1421 h = 3.954 k = 0.2311	0.005004	0.995283	0.070738	0.020016

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. 3.

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.

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.

Table 3. Nutrition content of Turkey berry dried under various conditions

Nutrients	Open Sun drying	UV polyethylene greenhouse drying (Passive mode)	Driplock sheet greenhouse drying (Passive mode)	UV polyethylene greenhouse drying (Active mode)	Driplock sheet greenhouse drying (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 [mg/100g]	109	101	126	614	630
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

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.

Iron

The retention of iron is more in passive mode then in active mode. Still the iron content in drip lock greenhouse drying under active mode has higher value then 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.

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.

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.

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 figs. 5 and 6.

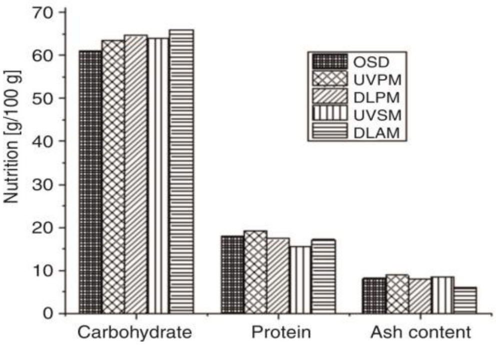

Figure 5. Variation of carbohydrate, protein, and ash content under open Sun drying and greenhouse drying (active and passive mode)

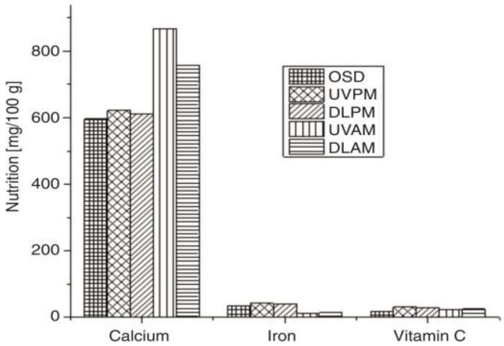

Figure 6. Variation of calcium, iron, and vitamin C content under open Sun drying and greenhouse drying (active and passive mode)

Conclusion

The experiments were conducted for drying Turkey berry under open Sun drying, UV polyethylene as glazing material, drip lock sheet as glazing matrial 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 per hour in drip lock greenhouse active mode, 12.50 g per hour in UV polyethylene sheet greenhouse active mode, 15.22 g per hour in drip lock sheet greenhouse passive mode, 11.84 g per hour in UV polyethylene sheet greenhouse passive mode and 10.65 g per hour 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.

Nomenclature

Dr – drying rate, [gh^{-1}]
M_{eq} – equilibrium moisture content, [kg]
M_i – initial moisture content, [kg]
M_{int} – instantaneous moisture content, [kg]
M_f – final moisture content, [kg]
N – total number of observations
n – total number of constants in the model
R^2 – coefficient of determination

Greek symbol

χ^2 – reduced chi square

Acronyms

DLPM – drip lock passive mode
DLAM – drip lock active mode
RMSE – root mean square error
SSE – sum square error
UVAM – UV active mode
UVPM – UV passive mode
MR – moisture ratio
OSD – open Sun drying

References

[1] Condori, M., Saravia, L., The Performance of Forced Convection Greenhouse Driers, *Renewable Energy, 13* (1998), 2, pp. 453-469
[2] Rai, A. K., *et al*., Experimental Study of Forced Convection Greenhouse Drying, *International Journal of Advanced Research in Engineering and Technology*, *4* (2013), 5, pp. 10-16
[3] Aliyu, A. B., Jibril, H., Utilization of Greenhouse Effect for Solar Drying of Cassava Chips, *International Journal of Physical Sciences*, *4* (2009), 11, pp. 615-622
[4] Lee, G. J., *et al*., Effects of Far-Infrared at Night on Quality of Sunlight Dried Red Pepper (*Capsicum annuum L*) in Plastic Houses, *Horticultural Science and Technology*, *32* (2014), 6, pp. 819-826
[5] Koyuncu, T., An Investigation on the Performance Improvement of Greenhouse – Type Agricultural Dryers, *Renewable Energy, 31* (2006), 7, pp. 1055-1071
[6] Jain, D., Tiwari, G. N., Effect of Greenhouse on Crop Drying Under Natural and Forced Convection I: Evaluation of Convective Mass Transfer Coefficient, *Energy Conversion and Management*, *45* (2004), 5, pp. 765-783
[7] Barnwal, P., Tiwari, G. N., Grape Drying by Using Hybrid Photovoltaic – Thermal (PV/T) Greenhouse Dryer: An Experimental Study, *Solar Energy*, *82* (2008), 12, pp. 1131-1144
[8] Sadodin, S., Kashani, T. T., Numerical Investigation of a Solar Greenhouse Tunnel Dryer for Drying of Copra, On-line first, https://arxiv.org/ftp/arxiv/papers/1102/1102.4522.pdf, 2011
[9] Sethi, V. P., Arora, S., Improvement in Greenhouse Solar Drying Using Inclined North Wall Reflection, *Solar Energy*, *83* (2009), 9, pp. 1472-1484
[10] Kumar, M., Forced Convection Greenhouse Papad Drying: An Experimental Study, *Journal of Engineering Science and Technology*, *8* (2013), 2, pp. 177-189
[11] Kumar, M., Effect of size on the Convective Heat and Mass Transfer Coefficients during Natural Convection Greenhouse Drying of Khoa – A Heat Desiccated Milk Product, *International Journal of Renewable Energy and Biofuels, 2014* (2014), ID961114
[12] Janjai, S., *et al*., Performance of a PV- Ventilated Greenhouse Dryer for Drying Bananas, *Asian Journal of Energy and Environment, 6* (2006), 2, pp. 133-138
[13] Aymen, E. L., Drying of Red Pepper Slicesin a Solar Green House Dryer and Under Open Sun: Experimental And Mathematical Investigations, *Innovative food science and emerging technologies, 52* (2019), Mar., pp. 262-270
[14] Vijayan, S., *et al*., Thin Layer Drying Characteristics of Curry Leaves (*Murraya koenigii*) in an Indirect Solar Dryer, *Thermal science, 21* (2017), Suppl. 2, pp. S359-S36
[15] Chauhan, P. S., *et al*., Drying Kinetics, Quality Assessment, and Economic Analysis of Bitter Gourd Flakes Drying inside Forced Convection Greenhouse Dryer, *Journal of Solar Energy Engineering, 140* (2018), 5, pp. 051001-051010
[16] Akoy, E. O. M., Experimental characterization and Modelling of Thin –Layer Drying of Mango Slices, *International Food Research Journal, 21* (2014), 5, pp. 1911-1917
[17] Vijayan, S., *et al*., Mathematical modeling and Performance Analysis of Thin Layer Drying of Bitter Gourd in Sensible Storage Based Indirect Solar Dryer, *Innovative Food Science and Emerging Technologies, 36* (2016), Aug., pp. 59-67
[18] Lewis, W. K., The Drying of Solid Materials, *Industrial Engineering Chemical Research, 13* (1921), 5, pp. 427-433
[19] Kumpavat, K. T., Sutar, P. P., Drying and Software Engineering, http://www.agrimoon.com
[20] Raquel, P., Guine, F., Drying of Foods and its Effects on Physical – Chemical, Sensorial and Nutritional Properties, *International Journal of food Engineering, 4* (2018), 2, pp. 93-100
[21] Subramani, S., *et al.*, Energy and Exergy Analysis of Greenhouse Drying of Ivy Gourd and Turkey Berry, *Thermal Science, 24* (2020), 1B, pp. 645-656

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