Drying characteristics and energy requirement of drying cowpea leaves and jute mallow vegetables

G. P. Mutuli*, D. O. Mbuge

(Department of Environmental and Biosystems Engineering, University of Nairobi, Kenya)

Abstract: Thin layer drying of cowpea leaves (Vigna unguiculata) and jute mallow (Corchurus olitorious L) (African leafy vegetables) was studied at different temperatures (40°C -100°C) in a convective laboratory dryer. The study determined the drying characteristics of the vegetables, the maximum drying temperature and the drying energy requirements. Moisture content of the African leafy vegetables was determined on dry basis and the data were used to calculate moisture ratios and drying curves were plotted. The drying occurred in the falling rate period. The experimental data were fitted to fourteen thin layer drying models and the most appropriate drying model determined using correlation coefficient, mean square error and standard error of estimate. The model developed by Page showed good agreement with the data obtained from the experiments of this study because it consistently returned the required attributes from statistical analysis and its simplicity. The energy requirement of drying vegetables at the different temperatures was calculated. Cowpea leaves had a longer drying time of 304 min and a higher specific energy requirement of between 168 J/g at 100°C and 11.2 J/g at 40°C while jute mallow had a drying time of 256 min and an energy requirement of 155.3 J/g at 100°C and 10.6 J/g at 40°C respectively.

Keywords: Africa leafy vegetables, thin layer drying, moisture content, energy, modeling

Citation: Mutuli, G. P., and D. O. Mbuge. 2015. Drying characteristics and energy requirement of drying cowpea leaves and jute mallow vegetables. Agric Eng Int: CIGR Journal, 17(4):265-272.

1 Introduction

Africa leafy vegetables (ALVs) are plants in which the leafy parts, including the succulent stems, flowers and very young fruits, are used as a vegetable and are indigenous to the African communities. They are multi-functional crops providing food for humans and fodder for livestocks, e.g. cowpea leaves. They are of high nutritional value and have health benefits; jute mallow is rich in beta carotene, iron and aids in digestion. Drying of ALVs could be important in addressing post-harvest losses. This is an identified problem in sub-Saharan Africa.

Thin layer drying and preservation of African leafy vegetables has been studied. Seidu et al. (2012) studied the effects of solar drying on the nutritional content of selected indigenous leafy vegetables: *Xanthosoma sagittifolia, Moringa Oleifera, Talinum trangulare* and *Vernonia*. According to Ayua and Omware (2013), traditional sun drying (45%) and fermentation (35%) are methods for preserving the vegetables. However traditional sun drying methods often yield poor quality, since vegetables are not protected against dust, rain and wind, or even against insects, birds, rodents and domestic animals while being dried (Kiremire et al., 2010). Other methods include hydrating the vegetables through sprinkling with water but this can only prolong the vegetables' freshness for a short time (Ayua and Omware, 2013).

This study focuses on the drying of two vegetables: cowpea leaves and jute mallow. Cowpea leaves (*Vigna unguiculata*) which is highly fibrous and jute mallow (*Corchurus olitorious L.*) which breaks down into a pasty mass when cooked. These characteristics are representative of other ALVs in their respective groups. The main objective of this study was to investigate drying

Received date: 2015-06-04 Accepted date: 2015-09-21

***Corresponding author: Gibson Mutuli,** Department of Environmental and Biosystems Engineering, University of Nairobi, Kenya. Email: gibsonmutuli@yahoo.com.

characteristics of the stated ALVs in a convective dryer, with optimal energy consumption, specifically the study

(1) determined the drying characteristics of the ALVs;

(2) And the variation of energy requirement with temperature of drying jute mallow and cowpea leaves.

2 Materials and methods

2.1 Materials

The vegetables: jute mallow and cowpeas leaves were acquired fresh. They were prepared by plucking them from their stems manually and mixed appropriately ready for experimentation on the same day. The bruised, soiled, or imperfect leaves were all discarded and the remainder handled and preserved well to prevent moisture and nutrient loss.

2.2 Methodology

2.2.1 Drying experiment

The drying experiment was performed at Department of Environmental and Biosystems Engineering, University of Nairobi.

A calibrated standard laboratory dryer (Binder with air speed of 0.5 m/s and temperature 0-125℃ ±0.1℃) was switched on for an hour prior to its use, to ensure uniform heat distribution and required temperature is attained. 60 g of the prepared vegetables was weighed using a calibrated analytical laboratory scale (Sartorius with sensitivity 300 ±0.05 g) in triplicates on a clean and dry tray. The leaves were evenly spread and distributed on the trays before being put in the dryer. The continuous weighing method (Jayaraman, 2006) which involves determining the initial mass of the product and the bone dry mass after drying to constant weight was used to determine the drying rate. In the course of drying, the mass of the product was measured every between 10 to 20 min (depending on drying temperature) for the first one hour and every hour until the vegetables were observed to be dry and the mass was constant for two consecutive readings. The temperatures, 40°C, 50°C, 60°C, 70°C, 80°C, 90°C and 100°C were used in drying the product.

2.2.2 Determination of moisture content

The moisture content of the vegetables was determined on dry basis, kg/kg.

2.2.3 Modelling of drying curves

In thin layer drying, the moisture ratio is calculated as following Equation (1):

$$MR = \frac{M - M_e}{M_o - M_e} \quad (1)$$

Where:

M is the moisture content at time t (kg/kg, dry basis); M_o is the initial moisture content (kg/kg, dry basis); M_e is the equilibrium moisture content (kg/kg, dry basis); *MR* is moisture ratio (dimensionless).

The moisture contents for each sample were used to plot the drying curves. In order to estimate and select the appropriate drying model among different empirical models, mathematical modeling was carried out to describe the drying curve equation of the ALVs and to determine the parameters of the thin layer drying models by fitting experimental data to the model equation. The models in Table 1 were considered. Statistical test methods used to evaluate statistically the performance of the drying models were correlation coefficient (R^2), the mean square error (MSE), and the standard error estimate (SEE). The fitting was done using the non-linear regression function of SPSS 20: to establish the accuracy of the model for the thin layer drying process by comparing the predicted moisture ratio with experimental moisture ratio.

Table 1 Thin layer drying models

No.	Model name	Model
1	Lewis	$MR = \exp(-kt)$
2	Page	$MR = \exp(-kt^n)$
3	Modified Page	$MR = \exp[-(kt)^n]$
4	Henderson & Pabis	$MR = a\exp(-kt)$
5	Logarithmic	$MR = a\exp(-kt) + c$
6	Two Term	$MR = a\exp(k_o t) + b\exp(-k_1 t)$
7	Two Term Exponential	$MR = a\exp(-kt) + (1-a)\exp(kat)$
8	Wang & Singh	$MR = 1 + at + bt^2$
9	Approximation of diffusion	$MR = a\exp(-kt) + (1-a)\ \exp(-kbt)$
10	Verma et al.	$MR = a\exp(-kt) + (1-a)\exp(-gt)$
11	Modified Henderson & Pabis	$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$
12	Simplified Fick's Diffusion	$MR = a\exp[-c(t/l^2)$
13	Modified Page II	$MR = \exp[-k(t/l^2)^n$
14	Midilli & Kucuk	$MR = a\exp(-kt^n) + bt$

Source: Wang, et al. 2007, Akpınar and Bicer 2003

2.2.4 Correlation coefficient (R^2)

The correlation coefficient, R was used to test the linear relation between measured and estimated values, which can be calculated from the Equation (2):

$$R^2 = \frac{\sum_{i=1}^{N}(MRi - MR_{pre\ i}) * (MRi - MR_{exp\ i})}{\sqrt{([\sum_{i=1}^{N}(MRi - MR_{pre\ i})^2] * [(MRi - MR_{exp\ i})^2])}} \quad (2)$$

2.2.5 Standard error of estimate

It is given as Equation (3):

$$SEE = \sqrt{\frac{\sum_{i=1}^{e}(MR_{prev\ i} - MR_{\exp\ i})^2}{e - P}}) \quad (3)$$

Where *e* is the number of experimental points and *p* the number of regression parameters.

2.2.6 Mean square error (MSE) Equation (4):

$$MSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{prev\ i} - MR_{\exp i}\right)^2\right] \quad (4)$$

Where R^2 is called the coefficient of determination; *MR* exp,i stands for the experimental moisture ratio found in any measurement; *MR* prev i is the predicted moisture ratio for this measurement; *N* is the total number of observations.

2.3 Energy requirement determination

The dryer energy consumption and the energy required for the drying of vegetables was calculated using Equation (5) (Koyuncu et al., 2007; Aghbashlo et al., 2008; Motevali et al., 2011).

$$Et = A\upsilon\rho a Ca\Delta TDt \quad (5)$$

Where: E_t is the total energy in each drying phase, kJ; *A* is the cross sectional area of the holder, 0.0314 m^2; ρa is the air density, kg/m^3; ΔT is the temperature differences, ℃; *Dt* is the total time for drying each sample, h; and *Ca* is the specific heat of air, kJ/kg/^{o}C); υ is the air velocity, m/s. Energy consumption for drying 1 g of fresh vegetable was obtained using Equation (6)**:**

$$E\,g = \frac{Et}{Wo} \quad (6)$$

Where, *E g* is the required specific energy, kJ/g; *Wo* is the primary mass of sample, g

3 Results and discussion

3.1 Drying curves

Drying data was represented as moisture ratio against drying time. The moisture ratio was calculated from vegetable moisture content on dry basis (d.b.). See Figure 1 and Figure 2 please.

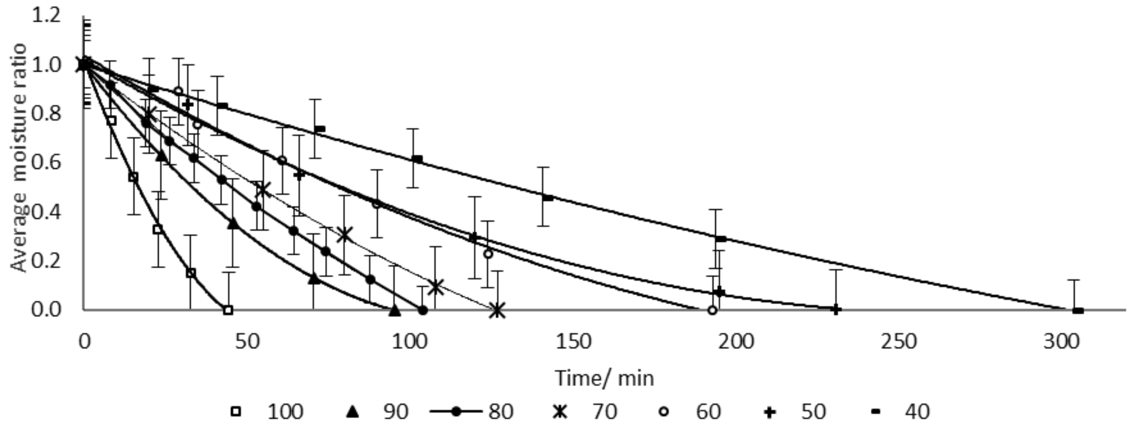

Figure 1 Showing cowpea leaves drying curves at different temperatures

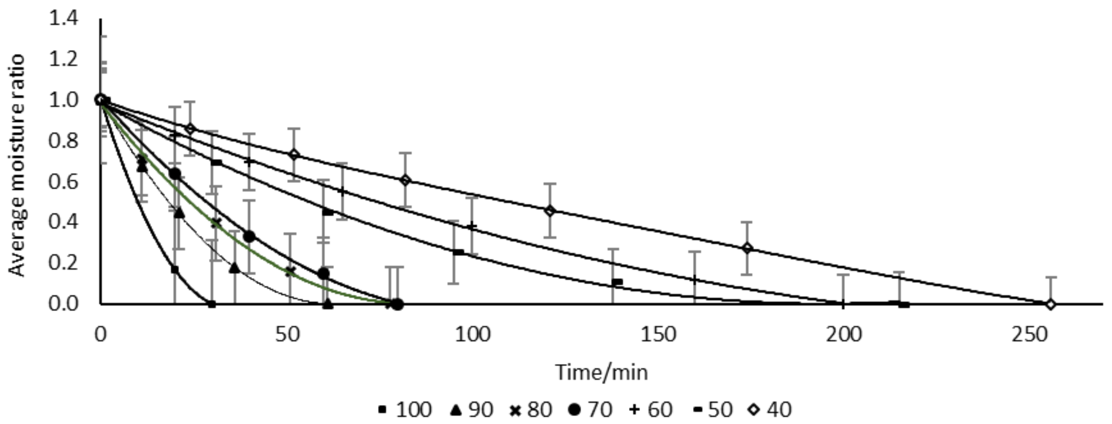

Figure 2 Jute mallow drying curves at different temperatures

From Figure 1 and Figure 2, the drying characteristics of the cowpeas leaves and jute mallow vegetable at temperatures 40°C to 100°C adopt a decay curve model. All the drying processes occurred in falling rate drying period, from the initial to the final moisture content at the stated drying conditions. Similar trend has been reported for thin layer drying of potato by Akpinar, (2003). The effect of drying air temperature is apparent: higher drying temperatures generally translated into decreasingly shorter drying times as expected.

Observed from Figure 1 and Figure 2, is that jute mallow has shorter drying time than cowpeas leaves. The longest drying time was at 40°C, cowpea leaves took 304 min and jute mallow 256 min, shortest drying time was at 100°C, cowpeas leaves took 44 min and jute mallow 30 min. Jute mallow could have taken shorter since it has a lower average moisture content of 0.738 d.b. compared to cowpea leaves with an average moisture content of 0.8 d.b.

The graphs in Figure 1 and Figure 2 were modelled as decay curves. Curve fitting values and the equation coefficients were obtained as is shown in Table 2 and Table 3.

Table 2 Summary cowpeas leaves drying curve parameters at different temperatures

Temperature, °C	R^2 Value	Coefficients	
		Time,min	Decay constant
100	0.759	-0.139	2.921
90	0.772	-0.065	2.697
80	0.631	-0.047	2.411
70	0.681	-0.043	2.481
60	0.793	-0.033	2.443
50	0.775	-0.025	2.386
40	0.761	-0.020	2.121

Table 3 Summary jute mallow drying curve parameters at different temperatures

Temperature, ^{O}C	R^2 Value	Coefficients	
		Time, min	Decay constant
100	0.803	-0.210	2.826
90	0.871	-0.112	2.481
80	0.830	-0.082	2.452
70	0.749	-0.076	2.361
60	0.756	-0.029	2.229
50	0.874	-0.031	2.227
40	0.740	-0.023	2.194

From Table 2 and Table 3 there is a general trend of decrease in the decay constant value and time coefficient with temperature decrease. This correlates the decrease in drying rates with the decrease in temperature. This shows that the constants are temperature dependent.

The results in Table 2 and Table 3 can be fitted into Equation (7) below:

$$MR = k\ exp^{-wt} \qquad (7)$$

Where, *MR* represents the average moisture ratio; *k* is the decay constant coefficient; *w* is the drying time coefficient; *t* is the drying time.

3.2 Modelling of drying curves:

The drying curves were modelled against thin layer models (Table 1). Modelling was done for temperatures 100°C to 40°C for cowpea leaves and jute mallow respectively. The moisture ratio data was fitted into model equations in Table 1 and statistical analysis on the data done using MS office excel 2013 and SPSS 20.

Table 4 and Table 5 represent the number of times the model equation returns Highest R^2 and lowest SEE, MSE results

Table 4 Comparison of fitted models by their best fit frequency for Cowpeas leaves

	Page	Lewis	Henderson & Pabis	Modified page
R^2	5	3	0	0
SEE	5	3	0	0
MSE	5	3	0	0

Table 5 Comparison of fitted models by their best fit frequency for jute mallow

	Page	Lewis	Henderson & Pabis	Modified page
R^2	4	2	0	2
SEE	4	2	0	2
MSE	4	2	0	2

These models exhibited a very close relationship of the statistical characteristics high values of R^2 and low values of SEE and MSE. Studies by Gunhan et al. (2005), Román et al. (2011) show similar trends. Gunhan et al. (2005) studied drying of bay leaves and close relationship was obtained between page, modified page and modified page II.

The most appropriate model would exhibit the following characteristics; returns the highest R2 value and lowest SEE and MSE values.

In this study page model was chosen because it consistently returns the required attributes from statistical analysis as observed in Table 4 and Table 5, and its simplicity. Fitting of this model was done by plotting empirical and expected moisture ratio values and drying curves for jute mallow and cowpeas leaves at 50°C (Figure 3, Figure 4, Figure 5 and Figure 6). Note that the temperature was arbitrarily considered.

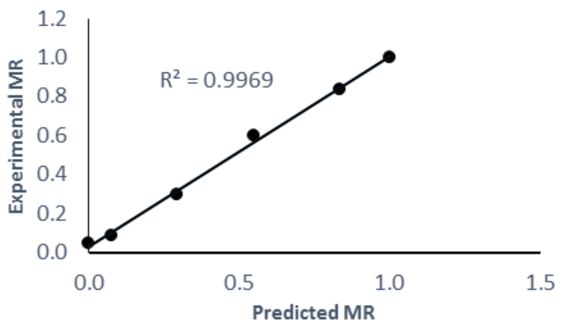

Figure 3 Experimental and predicted moisture ratio fitting at 50°C for cowpeas leaves

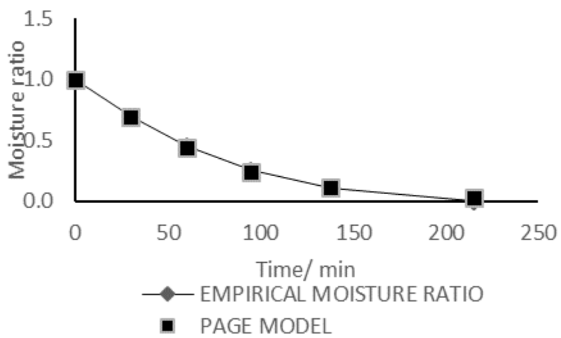

Figure 4 Cowpeas drying curve at 50°C

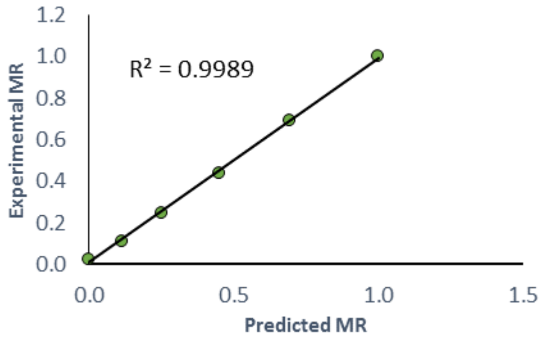

Figure 5 Experimental and predicted moisture ratio fitting at 50°C for jute mallow

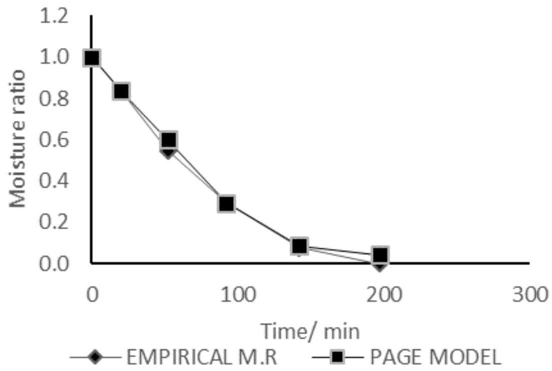

Figure 6 Jute mallow drying curve at 50°C

Figure 3, Figure 4, Figure 5 and Figure 6 show the fitting of page model for both cowpea leaves and jute mallow vegetables. The R^2 value for Figure 3, Figure 4 and Figure 5 show good fit for expected and empirical moisture ratio relation for the page model for both vegetables. The drying curves plotted in Figure 4, Figure 5 and 6 also show a close relationship between the experimental and model curves.

3.3 Energy requirement:

- Area of the drying tray 0.0315 m^2
- Dryer air velocity was 0.5 m/s

The calculated specific energy requirement was plotted at different temperatures as shown in figures 7 and 8. Both Figures 7 and 8 exhibit similar trends of energy requirement variation with temperature. With lower temperatures, lower energy is required in drying of the vegetables as expected. The thermal efficiency diminishes as drying air temperature increases, resulting in an increase of energy consumption in function of increasing drying air temperature. Similar trend of results on drying curves and energy requirement have been obtained in work done by researchers: Franz Roman et al. (2011) and Milovan et al. (2011) respectively.

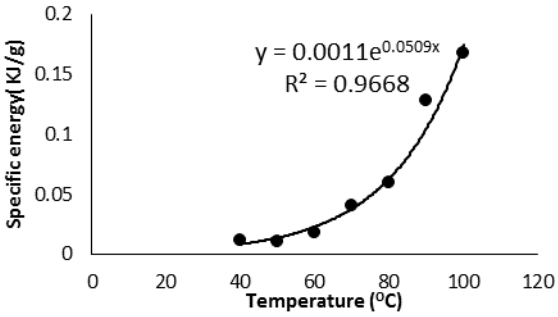

Figure 7 Trend of specific energy required to dry cowpeas leaves with different temperatures

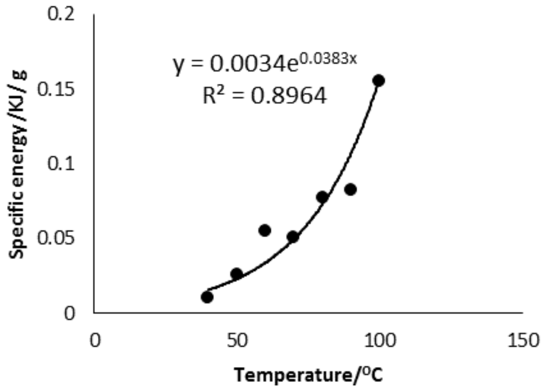

Figure 8 Trend of specific energy required to dry jute mallow with different temperatures

With reference to Equation 5, determination of the energy required to dry the vegetables had temperature and drying time as variables. A relationship between specific energy, the drying time and temperature was developed using multiple regression analysis. Specific energy to dry 1 g of the vegetable was considered, heat losses could not be determined and an assumption of negligible heat loss was made.

The coefficients fit in a regression Equation (8);

$$E_t = A + B_1 t + B_2 T \qquad (8)$$

Where, E_t is the total energy in kJ; *A* is the constant; *B1*, *B2* are time and temperature coefficients respectively; *t* and *T* are time and temperature variables respectively.

Table 6 represents a summary of energy requirement curves. The coefficient of temperature is higher than that of time which signifies that drying temperature affects the energy requirement more compared to drying time. Comparing the two vegetables, the coefficients for cowpea leaves are higher than for jute mallow and hence their energy requirements. The differences in their energy requirements are attributed to the differences in the moisture contents: cowpeas leaves being higher than jute mallow.

Table 6 summary of energy requirement curves

Vegetable	R^2 Value	Coefficients		
		Constant	Time, min	Temperature, °C
Cowpeas leaves	0.960	-581.480	1.034	6.880
Jute mallow	0.907	-224.493	0.362	3.462

4 Conclusions

The drying of both vegetables occurred in the falling rate with drying time decreasing with the increase in temperature. Jute mallow had a shorter drying time than cowpeas leaves. This was due to the difference in moisture content of the vegetables. Among the drying models, the model developed by Page showed good agreement with the data obtained from the experiments of the present study. It may be concluded that the model developed by Page adequately explained the drying behaviour of the ALVs studied at a temperature range of 100°C to 40°C for both jute mallow and cowpeas leaves.

The energy consumption in vegetable processing was a function temperature and time. Generally the energy consumption increased with the increase in temperature. The relationship between temperature, time and energy showed that the latter is affected more by temperature than processing time. Jute mallow had a lower energy requirement than cowpeas leaves due to processing time and moisture content levels. It could be concluded that non-fibrous ALVs non-fibrous ALVs have a shorter processing time and lower energy requirement than fibrous.

References

Aghbashlo, M., M. Kianmehr, and H. Samimi Akhijahani. 2008. Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thin-layer drying of Berberis Fruit (Berberidaceae). *Energy Conservation and Management*., 49(10): 2865-2871.

Akpınar, E. K., and Y. Bicer. 2003. Modelling and experimental study on drying of apple slices in a convective cyclone dryer. *Journal of Food Process Engineering*, 26(6):515- 541

Akpınar, E., A. Midilli, and Y. Bicer. 2003. Single layer drying behaviour of potato slice in a convective cyclone dryer and mathematical modelling. *Energy Conversion and Management*, 44(10):1689-1705.

Ayua, E., and J. Omware. 2013. Assessment of processing methods and preservation of African leafy vegetables in Siaya County, Kenya. *Global Journal of Biology Agriculture and Health Sciences.*, 2(2):46-48.

Román, F., and O. Hensel. 2011. Effect of air temperature and relative humidity on the thin-layer drying of celery leaves (Apium graveolens var. secalinum). *Agric Eng. Int: CIGR Journal*, 13(2).

Tuncay, G., V. Demir, E. Hancioglu, and A. Hepbasli. Mathematical modelling of drying of bay leaves. *Energy Conversion and Management*, 46 (2005):1667-1679.

Jayaraman, K. S., and D. K. D. Gupta. 2006. Drying of fruits and vegetables. In *Handbook of industrial drying*, ed. by Arun S.

Kiremire, B., E. Musinguzi, and F. Lukwago. 2010. Effects of vegetables drying techniques on Nutrient Content: A case study of South Western Uganda. African. *Journal for Food Agriculture, Nutrition and Development*, 10(5): 2587-2600

Koyuncu, T., Y. Pinar, and F. Lule. 2007. Convective drying characteristics of azarole red (Crataegus monogyna) and yellow (Crataegus aronia Bosc.) Fruits. *Journal of. Food Engineering*., 78(4): 1471–1475.

Milovan, Ž., R. Sveto, M. Radojka, P. Dragan, N. Miloš, and K. Nada. 2011. Effect of temperature on the physical changes and drying kinetics in plum (Prunus Domestica L.) Požegača Variety. *Chemical Industry and Chemical Engineering Quarterly.*, 17(3): 283-289.

Motevali, A., S. Minaei, and M. H. Khoshtagaza. 2011. Evaluation of energy consumption in different drying methods. *Energy Conservation and Management*., 52(2): 1192-1199.

Seidu, J. M., E. Y. H. Bobobee, W. K. J. Kwenin, R. Frimpong, S. D. Kubge, W. J. Tevor, and A. A. Mahama. 2012. Preservation of indigenous vegetables by solar drying.

ARPN Journal of Agricultural and Biological Science, 7(6).

Wang, W., G. Chen, and A. S. Mujumdar. 2007. Physical interpretation of solids drying: an overview on mathematical modelling research. *Drying Technology*, *25*(4):659-668.