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Thin Layer Drying Kinetics of Solar-Dried *Amaranthus hybridus* and *Xanthosoma sagittifolium* Leaves

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Abstract: The aim of the study was to model the solar drying characteristics of the leaves of *Amaranthus hybridus* and *Xanthosoma sagittifolium* dried in thin layers. Fresh leaves were obtained from Centre for Biodiversity Utilisation and Development (CBUD) farms, trimmed into strips of 0.3×3 cm and loaded into cabinet solar dryers up to a 5 mm layer. Drying was monitored and moisture loss determined by loss in weight of samples at hourly interval. Drying data were fitted to five thin layer models, namely; Newton's, Page's, Modified Page, Handerson and Pabis and Logarithmic Models by Non-linear Regression Analysis, the effective diffusivity was also determined for the two leafy vegetables. All five models showed a good fit between observed and predicted values with Page's Model resulting in the highest r^2 and lowest RMSE and χ^2 and hence the best model to describe the solar-drying characteristics of the two vegetables.

Key words: Drying curves, effective moisture diffusivity, leafy vegetables, mathematical modelling, solar drying

INTRODUCTION

Leafy vegetables have gained commercial importance and form an essential part of the Ghanaian diet, providing vitamins and micro-nutrients. As a result of their high moisture and short shelf life, there is the need to process them into stabilized forms with controlled water activity (Driscoll, 2004) that can store for longer periods (Jayaraman and Das Gupta, 2006) and so are available all year round (Mudambi *et al*., 2006). Drying presents one of the most effective methods of food preservation. The process broadly describes the thermal removal of moisture from a product to yield a solid product (Mujumdar, 2006). It is a dual process of heat transfer to the product from the heating source and the mass transfer of moisture from the interior of the product to its surface and from the surface to the surrounding environment (Okos *et al*., 2007) and therefore the rate at which drying proceeds depends primarily on the rate at which these two processes proceed (Mujumdar, 2006).

Drying method and the physical and biochemical changes that occur during drying seem to affect the quality properties of the dehydrated product. The proper handling of these reactions ensures that the dried product has a high nutritional value as well as a significantly extended shelf life. It is therefore essential to model and study the drying characteristics of food products in order to predict suitable drying conditions as part of process control (Nasser *et al*., 2006) and in the design and manufacture of dryers.

The study aimed at observing the drying characteristics of solar-dried *Amaranthus* and *Xanthosoma* sp. leaves in thin layers using five analytical models in order to ascertain the model which best describes these drying characteristics.

MATERIALS AND METHODS

Drying experiments: Fresh fully mature and edible *Amaranthus* sp. (months) and *Xanthosoma* sp. () leaves were obtained from the Centre for Biodiversity Utilisation and Development (CBUD) farms at the Prisons Camp Amanfrom, Kumasi. The leaves were detached from their stalks and inedible parts removed. The leaves were washed and trimmed into thin strips of dimension (0.3×3 cm), spread evenly on drying trays and loaded into a solar cabinet dryer (made of wood with glass windows, schematic in Fig. 1) at a density of 1.5 kg/m^2, in a single layer of 5 mm. Moisture loss during drying was determined by measuring the loss in weight of samples at hourly interval and at the beginning and end of drying, representative samples taken for moisture content

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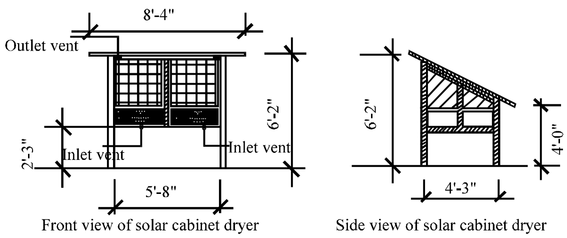

Fig. 1: Schematics of solar cabinet dryer

Table 1: Mathematical models

Models	Names	References
MR = exp (-kt)	Newton	Liu and Bakker-Arkema (1997)
MR = exp ($-kt^y$)	Page's	Doymaz (2005)
MR = exp $(-kt)^y$	Modified Page's	Waewsak *et al.* (2006)
MR = a exp (-kt)	Henderson and Pabis	Waewsak *et al.* (2006)
MR = a exp (-kt) + c	Logarithmic	Yaldiz *et al.* (2001)

determination (AOAC, 1990). The leaves with initial moisture (wb) content 85.8 and 82.7% were dried to a final moisture content of 8.5 and 8.9% for *Amaranthus* and *Xanthosoma* sp. leaves, respectively. Average drying temperatures over the period of drying in the dryers were 49.8°C (RH 31.3%) and 48.7°C (RH 32.8) (Thermohygrometer, Hanna HI 91610) for *Amaranthus* and *Xanthosoma* sp., respectively. In order to reduce the incidence of moisture reabsorption, drying was discontinued at sundown (30.1°C, RH 47.5% and 30.8°C RH 46.3% for *Amaranthus* and *Xanthosoma* sp., respectively) and the products sealed air-tight in polypropylene bags overnight and drying continued the next morning (ambient 24.9°C, RH 69.8%).

Model fitting of drying data: Drying data was fitted to the Newton's, Page's, Modified Page, Handerson and Pabis and Logarithmic models by Non-linear Regression Analysis (STATGRAPHICS Centurion, 15.1) and coefficient of correlation and goodness of fit of predicted to experimental data determined. The moisture ratio was simplified as M/M_0 because the relative humidity of the inlet air could not be controlled and M_e is very small compared to M_0. Mathematical models shown in Table 1. The reduced chi square was calculated as:

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

Effective moisture diffusivity: During drying, a general diffusion transport mechanism in which the rate of moisture movement is described by an effective diffusivity value, D_{eff} is often assumed regardless of which mechanism is really involved in moisture movement. In this approach, Fick's diffusion equation is used to explain the effective diffusivity. Parameters required in this approach are only sample dimensions and the effective diffusion coefficient. This method is very practical and convenient in describing moisture content change during processing. In using Fick's equation, the leaves used were assumed as slabs and all assumptions for slab-shaped objects proposed by Crank (1975) observed. The effective diffusivity was calculated by a linearised version (Sacilik, 2007; Sobukola *et al.*, 2007; Wang *et al.*, 2007):

$$\text{In}(MR) = \text{In}\left(\frac{8}{\pi^2}\right) - \left(\frac{D_{eff} \times \pi^2}{4L^2} \times t\right) \quad (2)$$

Where:

D_{eff} = The effective diffusivity ($m^2 \sec^{-1}$)

L = Half the thickness of the slab (m)

RESULTS AND DISCUSSION

Drying curves: The drying curves for the two leafy vegetables show a sample heat-up period where there is little or no drying. This may probably have been due to low temperatures at the beginning of the drying process and not actually a sample heat-up period that characterises most drying processes.

The drying curves (Fig. 2) show an elbowing along the curve which indicates the period between the discontinuation and resumption of drying. The curves show a very short constant rate period as is observed in the drying of most food products (Hallstrom *et al.*, 2006) and a longer falling rate period, a phenomenon characteristic of food products with water activity <1 (Driscoll, 2004). This occurrence demonstrates that diffusion is the dominant physical mechanism governing the removal of moisture from the samples. Similar observations were made by Rosello *et al.* (1997) for green beans, Gupta *et al.* (2002) for red chilli and Doymaz (2005), for okra.

Mathematical modelling: The r^2, RMSE and reduced Chi-square values for Amaranthus and Xanthosoma leaves for the chosen models are shown (Table 2). The appropriateness of a model for describing the drying characteristics of samples was based on its r^2, RMSE and reduced Chi-square. The higher the r^2 values and lower the reduced χ^2 and RMSE values, the better the goodness of fit (Ozdemir and Devres, 1999; Ertekin and Yaldiz, 2004; Demir *et al.*, 2004; Erenturk *et al.*, 2004; Togrul and Pehlivan, 2003).

All five models showed very good fit with $r^2>0.9$ (Table 2). For the two samples studied, the Page Model resulted in the highest r^2 values and corresponding least

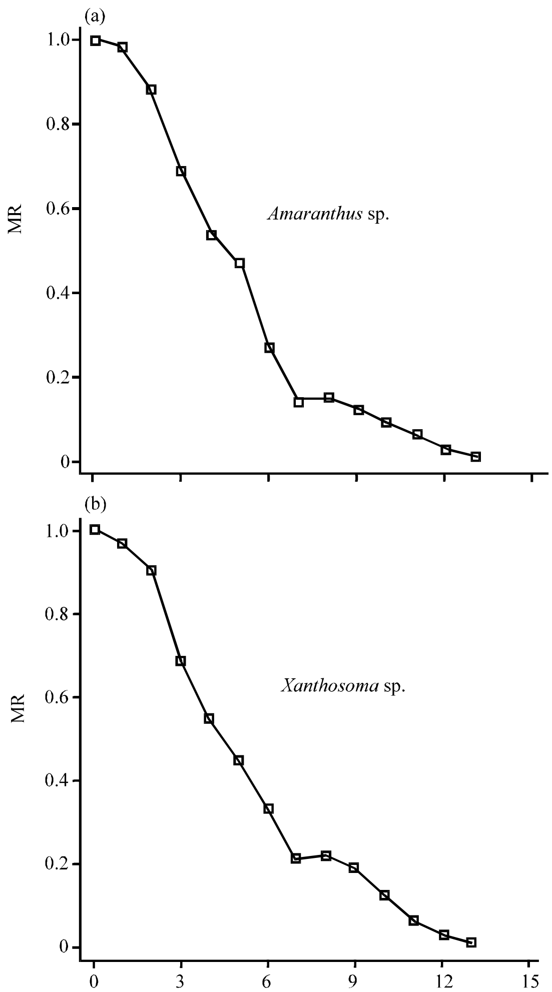

Fig. 2: Drying curves for a) *Amaranthus* and b) *Xanthosoma* sp.

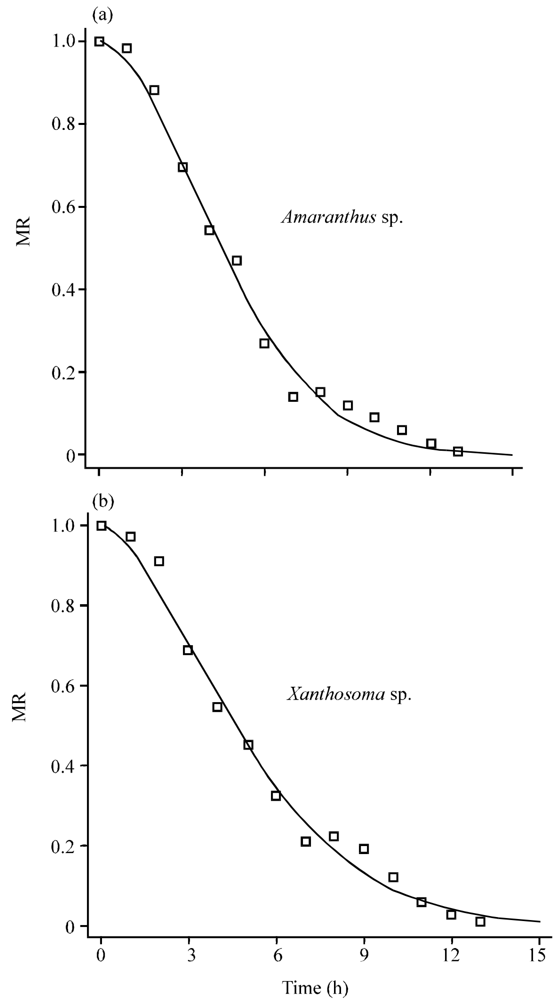

Fig. 3: Fitted drying curve for leafy vegetables using Page's Model. a) *Amaranthus*; b) *Xanthosoma* sp.

Table 2: Models and their respective r^2, RMSE and χ^2 for *Amaranthus* and *Xanthosoma* sp. leaves

	Leafy vegetable					
	Amaranthus sp.			*Xanthosoma* sp.		
Models	r^2	RMSE	χ^2	r^2	RMSE	χ^2
MR = exp (-kt)	0.9236	0.1017	0.0100	0.9343	0.0914	0.0084
MR = exp (-kt^y)	0.9917	0.0349	0.0012	0.9905	0.0363	0.0013
MR = exp (-kt)^y	0.9236	0.1058	0.0100	0.9343	0.0951	0.0091
MR = a exp (-kt)	0.9483	0.0870	0.0070	0.9573	0.0767	0.0058
MR = a exp (-kt) + c	0.9699	0.0693	0.0046	0.9791	0.0561	0.0033

values for RMSE and reduced Chi-square whilst the Newton and Modified Page's Models gave the lowest r^2 and highest RMSE and reduced Chi-square. The high r^2 for the Page Model is an indication that it best describes the thin layer solar drying characteristics of the two leafy vegetables and fitted curve for the model is shown in Fig. 3. Similar findings detailed by Doymaz (2005) were for okra, Kajuna *et al*. (2001) for thin layer drying of diced cassava roots and Madamba *et al*. (1996) for garlic slices (Fig. 4 and 5).

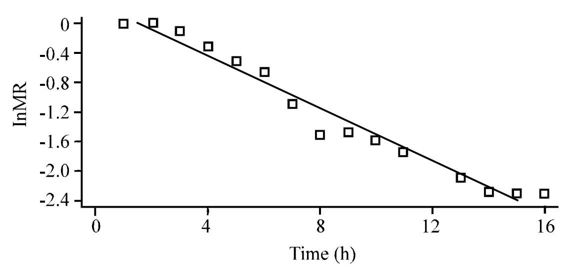

Fig. 4: Linear relationship between ln MR and drying time for *Amaranthus* sp.

Effective moisture diffusivity calculation: A plot of ln (MR) against time, t gives a line with slope:

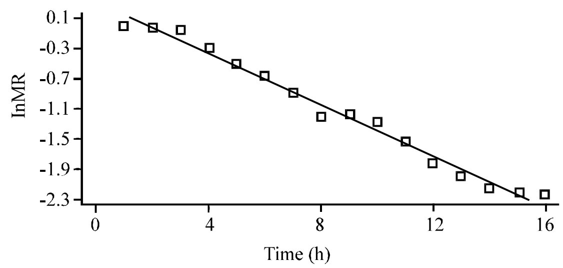

Fig. 5: Linear relationship between ln MR and drying time for *Xanthosoma* sp.

Table 3: Effective diffusivity, slope, reduced χ^2 and co-efficient of determination for the leafy vegetables

Leafy vegetable	Slope	D_{eff} x10^{-9} m^2 sec^{-1}	χ^2	r^2
Amaranthus sp.	0.1766	1.95	0.0200	0.9700
Xanthosoma sp.	0.1682	2.09	0.0086	0.9859

$$\text{Slope} = \frac{\pi^2 D_{eff}}{4L^2}$$

The slope, effective diffusivity values (D_{eff}), the corresponding values of coefficients of determination r^2 and the reduced Chi-square (χ^2) for the two indigenous leafy vegetables are presented (Table 3).

The effective diffusivity, D_{eff} for the two leafy vegetables are comparable to 6.4×10^{-9} m^{2}sec^{-1} as obtained by Saravacos and Charm (1962) for drying carrots at 64°C and 1.2×10^{-9} to 5.9×10^{-9} m^{2}sec^{-1} by Bimbenet *et al.* (1985) for carrots dried between 30 and 70°C. Again it was within the range of 3.8×10^{-10} to 1.2×10^{-9} m^{2}sec^{-1} for drying green pepper at 60-80°C (Kiranoudis *et al.*, 1992) and 6.03×10^{-9} to 3.15×10^{-8} m^{2}sec^{-1} for vegetable wastes in a temperature range of 50-150°C (Lopez *et al.*, 2000). At higher drying temperatures, the effective diffusivity is expected to be higher, especially with an increase in the drying air velocity (Park *et al.*, 2002; Akgun and Doymaz, 2005, Ozbek and Dadali, 2007).

CONCLUSION

The results show that the change in moisture ratio over time for solar drying the two leafy vegetables can be best described by the Page's Model. Under similar drying conditions, the model is appropriate for simulating the outcome of drying these vegetables during process control. Effective moisture diffusivity ranged between 1.9×10^{-9} and 2.1×10^{-9} m^{2}sec^{-1} for the two leafy vegetables.

NOMENCLATURE

a, b, c, k, y = Constants in models
D_{eff} = Effective diffusivity (m^2 sec^{-1})
L = Half-thickness of slab (m)
MR = Moisture Ratio
M = Moisture content
Mo = Initial moisture content
N = Number of observation
r^2 = Coefficient of determination
t = Drying time (min)
z = Number of constants
exp = Experimental
pre = Predicted

REFERENCES

AOAC, 1990. Official Methods of Analysis. 15th Edn., Association of Official Analytical Chemists, Washington, DC., USA.

Akgun, N.A. and I. Doymaz, 2005. Modeling of olive cake thin-layer drying process. J. Food Engin., 68: 455-461.

Bimbenet, J.J., J.D. Daudin and E. Wolf, 1985. Air Drying Kinetics of Biological Materials. In: Drying 85, Mujumdar, A.S. (Ed.). Hemisphere, New York, USA., pp: 178-185.

Crank, J., 1975. Mathematics of Diffusion. Claredon Press, Oxford, UK.

Demir, V., T. Gunhan, A.K. Yagcioglu and A. Degirmencioglu, 2004. Mathematical modeling and the determination of some quality parameters of air-dried bay leaves. Biosyst. Eng., 88: 325-335.

Doymaz, I., 2005. Drying characteristics and kinetics of Okra. J. Food Eng., 69: 275-279.

Driscoll, R., 2004. Food Dehydration. In: Food Processing, Principles and Applications, Smith, S.J. and H.H Yiu (Eds.). Blackwell Publishers, USA., pp: 30-42.

Erenturk, S., M.S. Gulaboglu and S. Gultekin, 2004. The thin layer drying characteristics of rosehip. Biosyst. Eng., 89: 159-166.

Ertekin, C. and O. Yaldiz, 2004. Drying of eggplant and selection of a suitable thin layer drying model. J. Food Eng., 63: 349-359.

Gupta, P., J. Ahmed, U.S. Shivhare and G.S.V. Raghavan, 2002. Drying characteristics of Red Chilli. Drying Technol. Int. J., 20: 1975-1987.

Hallstrom, B., V. Gekas, I. Sjoholm and A.M. Romulus, 2006. Mass Transfer in Food, In: Handbook of Food Engineering, Heldman, D.R. and D.B. Lund (Eds.). CRC Press, Taylor and Francis Group, USA.

Jayaraman, K.S. and D.K. Das Gupta, 2006. Drying of Fruits and Vegetables. In: Handbook of Industrial Drying, Mujumdar, A.S. (Ed.). CRC Press, Boca Raton, FL.

Kajuna, S.T.A.R., V.C.K. Silayo, A. Mkenda and P.J.J. Makungu, 2001. Thin layer drying of diced cassava roots. Afr. J. Sci. Technol., 2: 94-100.

Kiranoudis, C.T., Z.B. Maroulis and D. Marinos-Kouris, 1992. Model selection in air drying of foods. Drying Technol. Int. J., 103: 1097-1106.

Liu, Q. and F.W. Bakker-Arkema, 1997. Stochastic modeling of grain drying: Part 2. Model development. J. Agric. Engin. Res., 66: 275-280.

Lopez, A., A. Iguaz, A. Esnoz and P. Virseda, 2000. Thin-layer drying behaviour of vegetable wastes from wholesale market. Drying Technol., 18: 995-1006.

Madamba, P.S., R.H. Driscoll and K.A. Buckle, 1996. The thin layer drying characteristic of garlic slices. J. Food Eng., 29: 75-97.

Mudambi, S.R., S.M. Rao and M.V. Rajagopal, 2006. Food Science. 2nd Edn., New Age International Publishers Limited, New Delhi, India.

Mujumdar, A.S., 2006. Principles, Classification and Selection of Dryers. In: Handbook of Industrial Drying, Mujumdar, A.S. (Ed.). Taylor and Francis Group, LLC, USA.

Nasser, H., M. Sayyad and A. Oladegaragoze, 2006. Mathematical modeling of thin layer drying kinetics of apple slices. Proceedings of the 13th World Congress of Food Science and Technology, September 17-21, 2006, Nantes, France.

Okos, M.R, O. Campanella, G. Narsimhan, R.K. Singh and A.C. Weitnauer, 2007. Food Dehydration. In: Handbook of Food Engineering, Heldman, D.R. and D.B. Lund (Eds.). CRC Press, Taylor and Francis Group, Boca Raton, USA., pp: 601-743.

Ozbek, B. and G. Dadali, 2007. Thin-layer drying characteristics and modelling of mint leaves undergoing microwave treatment. Int. J. Food Engin., 83: 541-549.

Ozdemir, M. and Y.O. Devres, 1999. The thin layer drying characteristics of hazelnuts during roasting. J. Food Eng., 42: 225-233.

Park, K.J., Z. Vohnikova and F.P.R. Brod, 2002. Evaluation of drying parameters and desorption isotherms of garden mint leaves (*Mentha crispa* L.). J. Food Eng., 51: 193-199.

Rosello, C., S. Simal, N. Sanjuan and A. Mulet, 1997. Non isotropic mass transfer model for green bean drying. J. Agric. Food Chem., 45: 337-342.

Sacilik, K., 2007. Effect of drying methods on thin-layer drying characteristics of hull-less seed pumpkin (*Cucurbita pepo* L.). J. Food Engin., 79: 23-30.

Saravacos, G.D. and S.E. Charm, 1962. A study of the mechanism of vegetable and fruit dehydration. Food Technol. Int. J., 16: 78-81.

Sobukola, O.P., O.U. Dairo, L.O. Sanni, A.V. Odunewu and B.O. Fafiolu, 2007. Thin layer drying process of some leafy vegetables under open sun. Food Sci. Technol. Int., 13: 35-40.

Togrul, I.T. and D. Pehlivan, 2003. Modeling of drying kinetics of single apricot. J. Food Eng., 58: 23-32.

Waewsak, J., S. Chindaruksa and C. Punlek, 2006. A mathematical modeling study of hot air drying for some agricultural products. Thammasat Int. J. Sci. Technol., 11: 14-20.

Wang, Z., J. Sun, F. Chen, X. Liao and X. Hu, 2007. Mathematical modeling on thin layer microwave drying of apple pumice with and without hot-air pre drying. J. Food Engin., 80: 536-544.

Yaldiz, O., C. Ertekin and H.I. Uzun, 2001. Mathematical modeling of thin layer solar drying of sultana grapes. Energy, 26: 457-465.