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Mathematical Modelling of Thin Layer Dried Cashew Kernels

* Asiru, W.B.[1], Raji, A.O.[2], Igbeka, J.C.[2] and Elemo, G.N.[1]

ABSTRACT

In this paper mathematical models describing thin layer drying of cashew kernels in a batch dryer were presented. The range of drying air temperature was 70 – 110°C. The initial moisture content of the cashew kernels was 9.29% (d.b.) and the final moisture content was in the range of 3.5 to 4.6% dry-basis. Seven different thin layer mathematical drying models were compared according to their coefficients of determination (R^2) mean square error (MSE) and mean relative deviation modulus (P) to estimate drying curves. The effects of the drying air temperature and time on the drying model constants and coefficients were predicted by multiple regression analysis using linear and non-linear type models. The results have shown that among the models, the Page model was found to be the best for describing the drying behaviour of cashew kernels with R^2, MSE and P values of 0.9830, 0.00311 and 5.046 respectively.

Keywords: Modelling, cashew kernel, thin layer, drying, moisture loss.

Introduction

Cashew (*Anacardium occidentale*) is a tropical tree crop widely distributed throughout the tropics. The primary products of cashew nuts are kernels, which are used in confectionery, and CNSL, which is an important industrial raw material for resin manufacture (ITDG, 2002). Harvested cashew nut is processed into kernel by cleaning, soaking, steaming/roasting, shelling/cracking, separation, drying, peeling, grading, dehumidification and packaging.

Presently, cashew nut production has flourished with the current production level put as 30,000 metric tonnes. Despite all these, cashew is still a very important industrial and export cash crop yet to be fully exploited by Nigerian farmers and industrialists (Oluka, 2001; NEPC, 2004) having abandoned the industry after the discovery of petroleum.

1 Federal Institute of Industrial Research, Oshodi, PMB 21023, Ikeja, Lagos, Nigeria.
2 Department of Agric and Enviromental Engineering, University of Ibadan, Nigeria.
* corresponding author: bolaasiru@gmail.com

Cashew nut can be processed into kernel by two methods according to the type of heat treatment given to the nuts. These are (i) steaming where raw nuts are heated with steam and allowed to cool and dry for a day to make shelling easy and thus reduce breakage and (ii) roasting method where the cashew nuts are soaked in water to condition to a moisture content of 7 – 10% (Ohler, 1979; Oluka, 2001) then roasted in an oil bath at a controlled temperature of 180 – 185°C (Acland, 1977). Roasting the nuts releases the CNSL and the shell becomes brittle and easy to crack. Steaming method is more advantageous over roasting because the kernels produced are not scorched or brittled as their moisture content is about 10% while for roasting it is about 6% (Ohler, 1979). Also, steaming preserves phenolic constituents in the CNSL as roasting removes it by evaporation. These phenolic constituents are used in applications such as brake and clutch linings, adhesives, vanish, paint and epoxy resins.

Shelling of cashew nut and removal of testa from kernels are the two major operations in cashew nut processing. The shell of the roasted cashew nut is removed manually or with the help of gadgets. However, the most critical step in cashew processing is the removal of testa which requires that the shelled cashew kernels are dried in convective dryers for 6 to 8 h. This allows easy detachment of testa and then it is removed manually by special knives made of metal, bamboo or wood. Microbial stability in storage and industrial application or other processing require cashew kernel to have a moisture content of 5% w.b, so artificial drying became an important step of the industrial processing of cashew kernels. Dyring may impact product quality, yield and the entire process economics (Algood *et al.*, 1993; Palacios *et al.*, 2004).

Thin layer drying models for both semi-theoretical and empirical were used. The thin layer model considered for semi-theoretical are Henderson and Pabis model, Lewis model, the two term model, Page model and modified Page model. For empirical models, models considered are Wang and Singh model and Thompson model. All the models were used to describe drying process during drying of cashew kernels. The models were evaluated based on mean square error (MSE), correlation coefficient (R^2), and the mean relative deviation (P) modulus (Lomauro *et al.*, 1985; Madamba *et al.*, 1996; Palipane and Driscoll, 1994).

The aims of the present study are:

- To study the effect of drying temperature and time on the drying kinetics of the cashew kernel samples in a Mitchel batch dryer.
- To fit the drying curves with some mathmatical models.

Materials and Methods

The cashew nuts used for these experiments were collected from the University of Agriculture Abeokuta (UNNAB) cashew plantation. Cashew nut samples were steamed in an autoclave (Dixon Surgical Instrument LTD, Model 3T19T) at a pressure of 7.93 x 105 N/mm^2 and temperature of 121^{o}C for 30 min, and allowed to cool for 24 h (Raman *et al.* (2002). The nuts were shelled using FIIRO cashew nut sheller and the kernels separated from the shells. Whole kernels were separated from the broken and cracked ones. All whole kernels were put in sealed polythene and stored in a refrigerator set at 4^{o}C until used.

The kernels were dried in a batch dryer (heated air dryer, Model 008404/631) at a temperature range of 70^{o}C to 110^{o}C for 3 – 7 h. Drying of cashew kernels started with an initial moisture content of 9.29% (d.b.) and were dried to a final moisture content of 3.5 – 4.6% (d.b.) after 7 h.

Mathematical modelling

The thin layer drying model usually used in describing dying process in agricultural materials fall into three categories (Akpinar and Bicer, 2006), namely theoretical, semi-theoretical and empirical (Midilli *et al.*, 2002; Panchariya *et al.*, 2002). The first takes into account only internal resistance to moisture transfer while the other two considered only external resistance to moisture transfer between the air and product (Bruce, 1985; Parti, 1993; Ozedimir and Devres, 1999; Akpinar and Bicer, 2006). The most widely investigated is the Fick's second law of diffusion. Drying of many products such as rice (Ece and Cihan, 1993) and hazlenut (Dermitas *et al.*, 1998) has been successfully predicted using Fick's second law. Semi-theoretical models offer a compromise between theory and ease of use (Fortes and Okos, 1981). Simplifying general series solution of Fick's second law or its modification derived semi-theoretical models. However, they are only valid within the temperatute range for which they are developed. Among the semi-theoretical models used are Henderson and Pabis, Lewis, two term model, Page model and modified Page model. Emprical models derived a direct relationship between average moisture content and drying time. They neglect the fundamentals of the drying process and their parameters have no physical meaning. Therefore, they cannot give clear accurate view of the important processes occurring during drying although they may describe the drying curve for the conditions of the experiments (Ozdemir and Devres, 1999). Among them, the applicability of Wang and Singh and Thompson models have been commonly tested in the literature.

The model used are listed in Table1 below.

Table 1: Mathematical models used in this study

Model no.	Model name	Model
1	Henderson and Pabis	MR = aexp (-kt)
2	Lewis	MR = exp (-kt)
3	Two term model	MR = exp ($-kt^n$)
4	Page	
5	Modified Page	MR = exp $(-kt)^n$
6	Thompson	MR = aexp ($-k_1t$) + aexp ($-k_2t$)
7	Wang and Singh	MR = 1 + at + bt^2
		t = a (1n MR)+ b $(1n\ MR)^2$

Results and Discussions

Drying curves

Drying of the cashew kernels began with an initial moisture content of 9.29% (d.b.) and the kernels were dried to moisture content range of 3.5% to 4.6% using different temperatute of 70, 80, 90, 100 and 110°C for drying time of 3, 4, 5, 6 and 7 h. Variation of moisture content with drying time is presented in Figure 1 below.

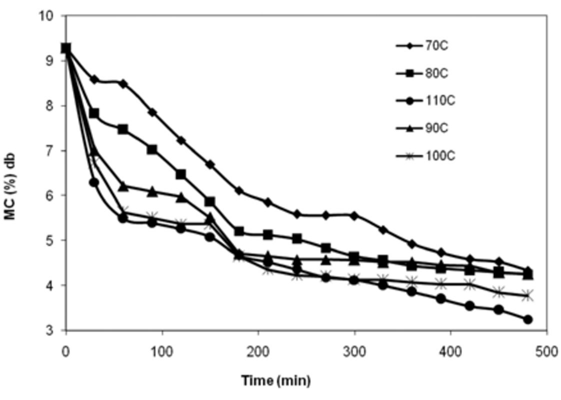

Fig. 1: Variation of moisture content with drying time

Temperature significantly affected drying of cashew kernels as shown in Figure 2. As temperature increased, drying became faster for a given period of time. During the first 180 min of drying, 63.2%, 80.3%, 90.5%, 93.5% and 75.5% of moisture were removed at drying air temperatures of 70°C, 80°C, 90°C, 100°C and 110°C respectively. Moisture removal at 110°C was lower than at 80°C, 90°C and 100°C after 180 min of drying due to formation of hard core at the surface of the kernel as a result of sudden removal of moisture from the kernel within 60 min (43%). Hardening of the kernel surface tends to slow down the rate of moisture removal. Similar high initial drying rates were reported by Palipane and Driscoll (1994) during Macadamia drying, Malamba *et al.* (1996) during garlic drying, Ozdemir (2003) during hazelnut drying and Hassan-Beygi *et al.* (2009) for walnut drying. As reported by many researchers, drying air temperature has been observed to be the single and most important factor affecting drying rates, hence it is concluded that higher drying air tempratures increase drying rate significantly. These observations were also reported by Tabil *et al.* (2003) for Purslane, Tabil *et al.* (2001) for echinacea roots, Ozdemir (2003) and Dermirtas *et al.* (1998) for hazlenuts, Crisp and Woods (1994) for rapeseed, Karatas and Battalbey (1991) for pistachio kernel, Umesh and Ramesh (2004) for cashew kernel drying and Hii *et al.* (2008) for cocoa drying.

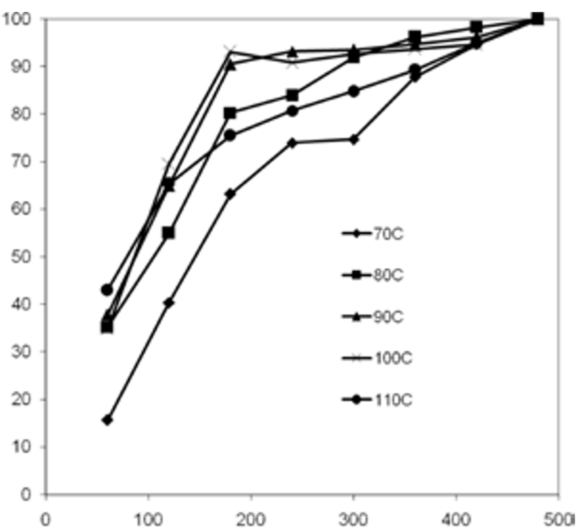

Fig. 2: Percentage of moisture removed during drying of cashew kernels

As expected, drying of cashew kernels took place in the falling rate period (Figure 3.) because the initial moisture content of 9.2% (d.b.) was already low at the beginning of drying. Almost all the drying of grains, nut products occur in the falling rate periods during drying or roasting (Suarez *et al.,* 1980a, b; Chinan, 1984; Syarief *et al.*, 1984; Parry, 1985; Moss and Otten, 1989; Karatas and Battalbey, 1991; Lebert and Bimbenet, 1991; Pathak *et al.*, 1991; Crisp and Woods, 1994; Palipane and Driscoll, 1994; Shivhare *et al.*, 1994; Dermitas *et al.*, 1998). The experimental results shown in Figures 1, 2 and 3 indicated that the drying air temperature has a significant effect on the evolution of the moisture content. Similar trends were reported by Akpinar and Bicer (2006) on strawberry drying; Hatamipor and Mowla (2003) during carrots drying.

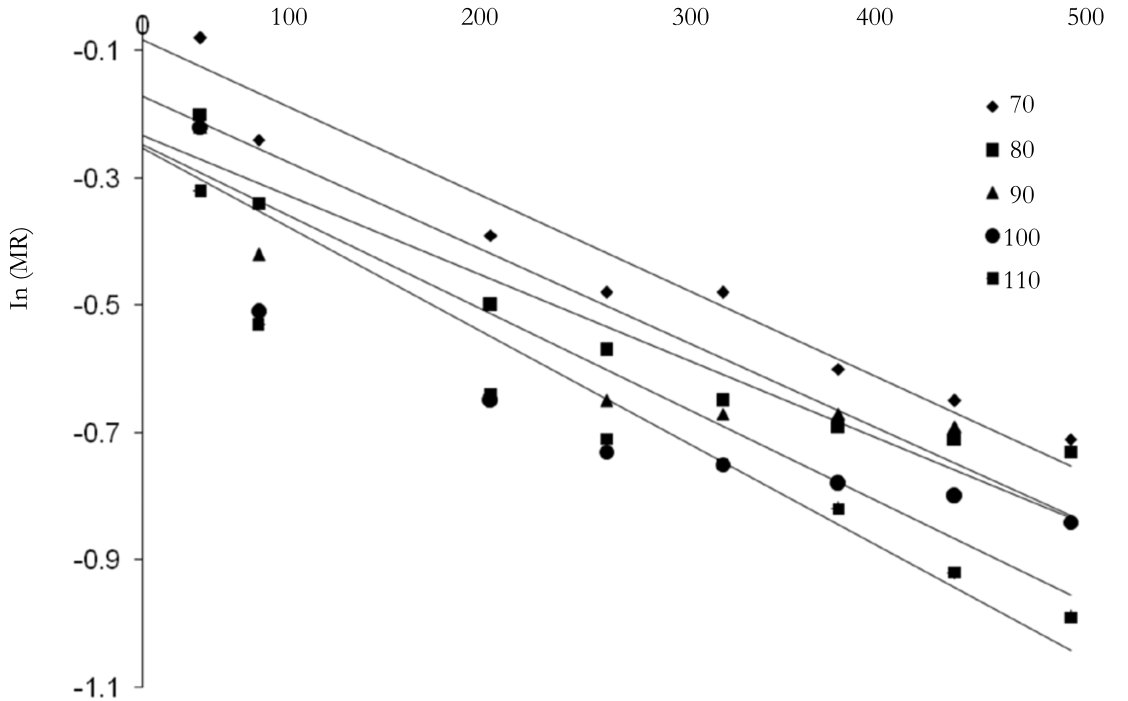

Fig. 3: Experimental and predicted ln (MR) versus time

Modeling of the thin layer drying characteristics

The data obtained on moisture content (d.b.) versus drying time were transformed to a dimensionless parameter called moisture ratio to enable the drying curve to be normalised. The moisture content at different drying temperature and time were converted to moisture ratio expression. The curve fitting computations were carried out on the seven models listed above in Table 1. The models were evaluated based on mean square error (MSE) and mean relative deviation modulus (P) (Ozemidir, 2003) as shown in Tables 2 and 3 below. Since a P value lower than 10% is recommended for the selection of models rather than R^2 for linear mathematical equations (Lamauro *et al.*, 1985; Chen and Morey, 1989; Madamba *et al.*, 1996).The Page model was the best descriptive model as shown in Table 2. The MSE and P values vary from 0.00025 – 0.00963 and 2.250 – 8.193 respectively. Hence the Page model gave better prediction than other models and best described the drying characteristics of cashew kernels. Although the fitting procedure showed that the results of the mentioned model could be used to model the drying behaviour of cashew kernel samples, it did not indicate the effect of drying air temperature and velocity. To account for the effect of the drying variables on the Page model constant k (s^{-1}) and coefficient n (dimensionless), the value of k and n were regressed against those of drying air temperature using multiple regression analysis. The multiple combinations of the parameters that gave the highest R-values were eventually included in the final model.

The selected Page model n and k values were related to drying temperature (T) using first degree polynomial:

$$n \text{ or } k = aT + b \qquad (4.9)$$

The result of the one-step regression procedure is:

$$N = -0.0101T + 1.561 \qquad (4.10)$$

$$K = 0.054T + 0.2379 \qquad (4.11)$$

The new model is now represented by equation 4.12 below

$$\log(-1n\ MR) = (-0.0101T + 1.561)\log t + \log(0.0054T + 0.2379) \qquad (4.12)$$

These expressions can be used to estimate the moisture ratio of cashew kernels at any time during the drying process with a high accuracy (R^2 = 0.9381). The consistency of the model and relationship between the coefficients and drying air temperature is evidently shown as illustrated in Figure 4. The accuracy of the established model was evaluated by comparing the computed moisture ratio in any particular drying conditions with the observed moisture ratio. The predicted data approximately banded around the straight line in Figure 5 which showed the suitability of the Page model in describing drying behaviour of cashew kernels.

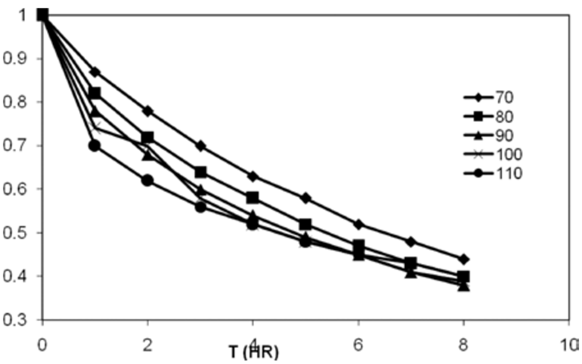

Fig. 4: Page model fitted to drying of cashew kernel

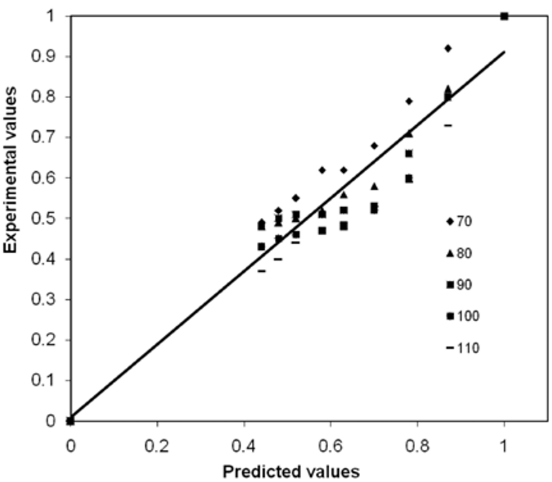

Fig. 5: Comparison of actual and predicted value by the Page model

Conclusion

Among these models, the Page model gave the best results and showed good agreement with the experimental data. When the effect of the drying air temperature on the constants and coefficients of the Page drying model was examined, the resulting model gave an R^2 of 0.9380, MSE of 0.00311 and P value of 5.046 for cashew kernels in the thin layer batch drying process. Thus, the Page drying model adequately describes the drying behaviour of cashew kernels dried in the thin layer.

Table 2: Curve fitting criteria for semi-theoretical thin layer drying models for cashew kernels

Models	T°C	R^2	MSE[a]	P (%)[b]
The Henderson & Pabis	70	0.9457	0.00383	3.940
MR = a exp (-kt)	80	0.8929	0.00200	2.010
	90	0.8031	0.00161	5.280
	100	0.8741	0.00350	10.00
	110	0.9530	0.00135	5.400
The Lewis	70	0.9173	0.00357	3.090
MR = exp (-kt)	80	0.8938	0.00559	11.27
	90	0.8751	0.00696	13.08
	100	0.6868	0.00998	16.42
	110	0.8245	0.00114	14.13
The Page	70	0.9436	0.00130	5.281
MR = exp ($-kt^n$)	80	0.9409	0.00963	4.780
	90	0.9530	0.00243	4.699
	100	0.8660	0.00195	8.193
	110	0.9755	0.00025	2.250
Modified Page model	70	0.9436	0.00130	5.281
MR = exp ($-kt^n$)	80	0.9409	0.00963	4.780
	90	0.9530	0.00243	4.699
	100	0.8997	0.00195	8.193
	110	0.9755	0.00025	2.250
The two-term	70	0.9457	0.00391	4.850
MR = a exp ($-k_1t$) + a exp ($-k_2t$)	80	0.8992	0.00342	3.444
	90	0.7031	0.00266	5.667
	100	0.8741	0.00375	10.45
	110	0.9530	0.00244	5.670

[a] Mean square error, [b] mean relative deviation modulus

Table 3: Curve fitting criteria for empirical thin layer drying models for cashew kernels

Models	T°C	R^2	MSE[a]	P (%)b
Wang & Singh	70	0.9858	0.00219	6.020
t = a (1n MR) + b $(1n\ Mr)^2$	80	0.9815	0.00144	70.96
	90	0.9647	0.00088	4.252
	100	0.9541	0.00344	18.59
	110	0.9541	0.00314	9.570
Thompson	70	0.9768	0.00256	14.96
MR = 1 + at + bt^2	80	0.9513	0.02689	21.29
	90	0.9094	0.04838	40.01
	100	0.9001	0.03713	20.32
	110	0.9855	0.00785	8.581

[a] Mean square error, [b] mean relative deviation modulus

References

Akpinar, E.K. and Bercer, Y. (2006). Mathematical modelling and experimental study on thin layer drying of strawberry. *International Journal of Food Engineering* Vol. 2, Issue 1.

Bruce, D.M. (1985). Exposed layer barley drying, three models fitted to new data up to 1500c. *Journal of Agricultural Engineering Research* 32: 337 – 347.

Crisp, J. and Woods, J.L. (1994). The drying properties of rapeseed. *Journal ofAgricultural Engineering Research* 57: 89 – 97.

Demirtas, C., Ayhan, T. and Kaygusuz, K. (1998). Drying behaviour of hazelnuts. *Journal of the Science of Food and Agriculture* 76: 559 – 564.

Ece, M.C. and Cihan, A. (1993). A liquid diffusion model for drying rough rice. *Transactions of American Society of Agricultural Engineers* 36: 837 – 840.

Fortes, M. and Okos, M.R. (1981). Non-equilibrium thermodynamics approach to heat and mass transfer in corn kernels. *Transactions of American Society of Agricultural Engineers* 22: 761 – 769.

Hassan-Beygi, S.R., Aghbashlo, M., Kianmehr, M.H. and Massah, J. (2009). Drying characteristics of walnut (*Juglans regia L.*) during convection drying. *Int. Agrophysics* 23: 129 – 135.

Hatamipour, M.S. and Mowla, D. (2003). Experimental investigation of drying behaviour of carrots in a fluidized bed with energy carrier. *Engineering Life Science* 3: 43 – 49.

Hii, C.L., Law, C.L. and Cloke, M. (2008). Modelling of thin layer drying kinetics of cocoa beans during artificial and natural drying. *Journal of Engineering Science and Technology* 3: (1) 1 – 10.

ITDG (2002). Cashew Nut Processing. Intermediate Technology Development Group http://www.itdg.org/html/technical, 1 – 7.

Karatas, S. and Battalbey, F.M. (1991). Determination of moisture diffusivity of pistation nut meat drying. *Lebensmitted Wissesschaft und Technologie* 24: 484 – 487.

Lebert, A. and Bimbenet, J.J. (1991). Drying Curves: A general process for their representation. In Drying' 91, (eds.) Mujumdar, A.S and Filkova, I. Hemisphere Publishing Company, USA., pp. 181 – 190.

Lomauro, C.J., Bakshi, A.S. and Labuza, T.P. (1985). Evaluation of food moisture isotherm equations: Part I: Fruit, vegetables and meat products. *Lebensmittel Wissenschaft ung Technologie* 18: 111 – 117.

Madamba, P.S., Driscoll, R.H. and Buckle, K.A. (1996). Thin layer drying characteristics of garlic slices. *Journal of Food Engineering* 29: 75 – 97.

Midilli, A., Kucuk, H. and Yapar, Z.A. (2002). New model for single-layer drying. *Drying Technology* 20 (7): 1503 – 1513.

Moss, J.R. and Otten, L. (1989). A relationship between colour development and moisture content during roasting of peanut. *Canadian Institute of Food Science and Technology Journal* 22: 34 – 39.

Ozdemir, M. (2003). Mathematical Modelling of Colour Changes and Chemical Parameters of Roasted Hazlenuts. PhD Thesis in the Department of Food Engineering, Institute of Science and Technology, Instanbul University, Turkey.

Ozedimir, M. and Devres, O. (1999). Turkish hazlenuts the properties and the effects of microbiology and chemical changes on the quality. *Food Review International* 15: 309 – 333.

Palipane, K.B. and Driscoll, R.H. (1994) Thin layer drying behaviour of macadamia in shell nuts and kernels. *Journal of Food Engineering* 23: 129 – 144.

Panchariya, P.C., Popovic, D. and Sharma, A.L. (2002). Thin-layer modelling of black tea drying process. *Journal of Food Engineering* 52: 349 – 357.

Parti, M. (1993). Selection of mathematical models for drying grains in thin layers. *Journal of Agricultural Engineering Research* 54: 339 – 352.

Parry, J.L. (1985). Mathematical modelling and computer simulation of heat and mass transfer in agricultural grain drying. *Journal of Agricultural Engineering Research* 32: 1 – 29.

Pathak, P.K., Agrawal, Y.C. and Singh, B.P.N. (1991) Thin layer model for rapeseed. *Transactions of American Society of Agricultural Engineers* 34: 2505 – 2508.

Raman, S.D., Pushpalatha, P.B. and Narayanankutt, M.C. (2002). Variation in processing qualities of cashew nuts in relation to damage by insect pests. *Journal of Tropical Agriculture* 40: 35 – 38.

Sahin, A.Z. and Dincer, I. (2005). Prediction of drying times for irregular shaped multi-dimensional moist solids. *Journal of Food Engineering* 71 (1): 119 – 126.

Shivhare, U.S., Raghavan, G.S.V. and Bosisio, R.G. (1994). Modelling the drying kinetic of maize in a microwave enviroment. *Journal of Agricultural Engineering Research* 57: 199 – 205.

Suarez, C., Viollaz, P. and Chirife, J. (1980). Kinetic of soybean drying: In Mujumdar, A.S. (ed.) *Drying '80*. Hemisphere Publishing Company, USA, pp. 251 – 255.

Syarief, A.M., Morey, R.V. and Custafson, R.J. (1984). Thin layer drying rates of sunflower seed. *Transactions American Society of Agricultural Engineers* 27: 195.

Tabil, L.G., Kashani Nejad, M. and Crerar, B. (2003). Drying characteristic of purslane. *American Society of Agricultural Engineers (ASAE) Meeting* Paper No. 036068. St. Joseph, Michigan. USA.

Tabil, L.G., Chang, J., Gensler, G., Shular, R., White, R., Roth, L. (2001) Drying characteristics of Echinacea roots and its effects on microbial load. ASAE paper No 016058. St. Joseph, MI. *American Society of Agricultural Engineers.*

Umesh, H.H. and Ramesh, M.N. (2004). Optimisation of processing conditions for infrared drying of cashew kernels with testa. *Journal of the Science of Food and Agriculture*. Vol 85 (5): pp. 865 – 867.