International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

Mathematical Modeling of Thin Layer Drying Characteristic of Macadamia Nuts Varieties in Different Drying Environment

Simon N. Njuguna*,
Directorate of intellectual property Management and Industry Liaison,
Jomo Kenyatta University of Agriculture and Technology (JKUAT,
Nairobi, Kenya

Dr. Stephen Ondimu,
Agricultural and Biosystems Engineering Department,
JKUAT University,
Nairobi, Kenya

Prof. Glaston M. Kenji ,
Department of food science and nutrition,
JKUAT University,
Nairobi, Kenya

***Abstract*—Thin layer drying studies of macadamia nuts (*Macadamia integrifolia*) were carried out in a Solar Tent dryer, oven dryer and a combination of Solar Tent dyer and microwave oven, Solar Tent dryer and oven dryer and finally oven dryer at temperature of 50 and 60°C. Two varieties of Macadamia nuts; KRG-15 and MRG-20 were used in this study. Eight different thin layer-drying models were compared according to R^2, X^2 and RMSE in order to determine the model of best fit for the different drying environment. As per the result, the most predominant models of best fit were Approximation of diffusion and Modified Handerson and Pabis model**

Keywords—Thin layer, Macadamia, soalr tent dryer, oven dryer,

I. INTRODUCTION

Macadamia nuts grown in Kenya originated from Australia.U.S.A is the leading world producer of the nuts, followed by Australia, Kenya and South Africa [1]. Although this nut is found in the family of Proteaceae which has four species, only Macadamia. Integrifolia and Macadamia. tetraphylla L. and their hybrid are of commercial importance. These species are cultivated for their edible nuts in Kenya and are grown in Meru, Machakos, Murang'a, Kiambu, Kirinyaga, Bungoma and Embu [1].
There are four varieties of macadamia nuts that are economically viable in Kenya :- MRG-20, KRG-15, KMB-3 and EMB-1[1]. It is estimated that over 100,000 small scale rural producers grow macadamia nuts alongside 500 large scale farmers and company farms in Kenya [2] [3]. These are then processed and sold for their edible nuts. 83% of this processed product is sold to America and Japan [3].

Drying is among the oldest methods used to preserve food. Food is preserved by removal of sufficient moisture level so as to prevent biochemical and microbial activities which lead to spoilage [4]. Because of low moisture content, foods can be stored over a long period since spoilage organisms cannot grow. In the course of drying, Physical and biochemical (Viz., lipid oxidation, Maillard reaction, etc.) changes are observed [5].

There are several drying methods that have been used for drying of macadamia nuts. These include; the use of heat pump [6], microwave assist [7], Hot air assisted Radio frequency [8] , Hot air drying and greenhouse drying [9].Many studies carried out using these dryers were conducted in thin layer. This type of drying has been described using mathematical model, which fall into three groups, namely theoretical, semi-theoretical and empirical [4]. Of the three groups, Semi-theoretical thin layer drying model is the commonly used [4].

There is little information in the literature on the drying characteristic of various varieties of macadamia nuts, dried using a combination of different dryers There is therefore need to study the drying characteristic in the effect of combination of dryers and the varieties of macadamia nuts. Hence, the objective of the present study are:

- To study the relevance of thin layer mathematical models to the drying varieties on nuts and the drying environment
- To determine the best drying models

II. MATERIAL AND METHOD

A. Introduction

This study was conducted at Jomo Kenyatta University of Agriculture and Technology (JKUAT) in Juja, Kenya at the school of Bio-systems and Environmental Engineering. It is at a latitude of 37 07 E, longitude of, 1 09 S, and with an altitude of 1416 m above sea level.

B. Dryers used in the study

i. Solar Tent Drying

The nuts were placed in trays 1, 2, 3 and 4 in the drying chamber C as shown in Fig. 1. The temperatures and relative humidity were recorded using four *Hobo Onset MX1101* data logger. Two drying pans of KRG-15 nuts were placed in each tray. The drying pans contained 0.7 Kg. of nuts. These were randomly distributed. The weights were

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

recorded after every 60 minutes, averagely, until the nuts reached a moisture content of 3% (d.b). The air velocity was set at 3 ms^{-1}. This procedure was repeated using MRG-20.

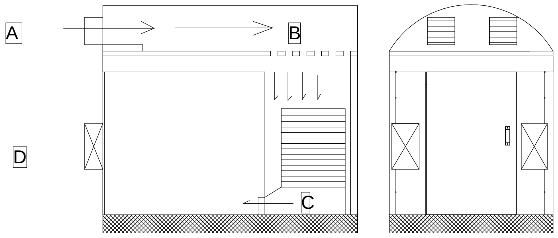

Figure 1: Tent Dryer

A-Air inlets, B-black mild steel plate collector, C-drying chamber and D- exhaust fan

ii. Oven drying

KRG-15 and MRG-20 nuts were placed in an oven dryer set at 50˚C. Three drying pans of each varieties were placed in the two drying levels. The nuts were weighed after every 60 minutes until they attained a moisture content of 3% (d.b). This experiment was repeated using a temperature of 60˚C.

iii. Combined oven drying at 50 and 60˚C

Nuts were placed in an oven set at 50˚C and dried up to a moisture content of 5% (d.b). The oven was then set at 60˚C and nuts dried up to a moisture content of 3% (d.b). The weight was recorded after every 60 minutes

iv. Combined Solar Tent and oven drying

Nuts of each varieties were place in a Solar Tent Dryer and dried up to a moisture content of 5% (d.b). These were then taken to an oven dryer set at 60˚C and nuts dried up to a moisture content of 3% (d.b). The weight was recorded after every 60 minutes

v. Combined solar Tent and Microwave oven drying

Nuts were placed in a Solar Tent Dryer and dried up to a moisture content of 5% (d.b). These were then taken to a microwave oven set at 140W and dried up to a moisture content of 3% (d.b). The weight was recorded after every 60 minutes

C. Sample Preparation

Two macadamia nut varieties (MRG-20 and KRG-15) Grown in Embu, Kenya were used in this study. The nuts were dehusked immediately after harvesting and the transported to Juja in Nylon bags. These were air dried in a shade to a moisture content of 10-12.5 (d.b) for a period of two weeks.

D. Experimental set up

Hot air Drying studies were carried out at drying air temperatures of 50 and 60 while in tent dryer shown in figure 1, carried out at a constant air flow rate of 3.2 m/s. Triplicate samples of macadamia nuts of known weight in thin layer, were used for each drying experiment and the drying process was monitored by weighing the samples at an average time interval of 60 minutes till a moisture content of about 3 (d.b.)

For the dryer combination, the nuts were dried to an average moisture content of 5 (d.b) in both a hot air drying at 50°C and tent dryer and transferred to oven at 60°C, and microwave oven. All this was done at an average interval of 60 minutes until a moisture content of about 3 (d.b).

E. Data collection

The samples were placed in an electric conventional oven for a 24-hour period to determine the initial moisture content at a temperature of 105°C. The moisture content for the subsequent stages were determined based on weight of water in the samples. The dry basis (d.b) was calculated using equation:

$$M_{db} = \frac{W_o - W_d}{W_d} \qquad (1)$$

Where $M_{d.b}$ represent Moisture in dry basis while W_o is the initial weight of the sample before drying while W_d is the weight of the sample after twenty-four hours of drying.

F. Mathematical modelling of drying curves

Moisture ratio, MR, is one of the important criteria to determine the drying characteristics of agricultural product. MR can be determined according to external conditions. If the relative humidity of the drying air is constant during the drying process, then the moisture equilibrium is constant too. In this respect, MR is determined as in Eq. ()

$$MR = \frac{M - M_e}{M_i - M_e} = \exp(-kt^n) \qquad (2)$$

In the case of continuous fluctuation of relative, then the value of M_e continues vary hence MR is determined as in Eq. (3) [10]

$$MR = \frac{M}{M_i} = \exp(-kt^n) \qquad (3)$$

In the drying of agricultural products, there are three categories of thin layer drying approaches. These include Theoretical, Semi-Theoretical and Empirical approach. Theoretical approach tends to give a good understanding of the transportation process whereas the empirical approach a goodness of fit to the experimental data.[11]

Statistical parameters such as the correlation coefficient (R^2), reduced chi-square (X^2) and the root mean square error (RMSE) were evaluated as:

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

$$R^2 = 1 - \left(\frac{\sum_{i=1}^{N} \left(MR_{pred,i} - MR_{\exp,i} \right)^2}{\sum_{i=1}^{N} \left(\overline{MR_{pred}} - MR_{pred,i} \right)^2} \right) \quad (4)$$

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

$$RMSE = \sum_{i=1}^{N} \sqrt{\frac{(MR_{\exp,} - MR_{pred,})^2}{N}} \quad (6)$$

Table 1: Drying Kinetic Model

S/N	MODEL	EQUATION
(1)	Newton	MR = exp(−kt)
(2)	Page	MR = exp (−ktn)
(3)	log	MR = aexp(−kt) + c
(4)	Wang and Singh	MR = 1 + at + bt 2
(5)	midilli	MR = aexp (−ktn) + bt
(6)	Approximation of diffusion	MR= aexp (−ktn) + (1− a) exp(−kbt)
(7)	Two term	MR=aexp(-kt) +bexp(-gt)
(8)	Modified Handerson and Pabis	MR=aexp(-kt) +bexp(-gt) +cexp(-pt)

A. *Drying Models*

The experimental data was fitted with eight thin-layer drying models as in *Table 1*. The Statistical results Obtained from the non-linear regression of the models are presented in *Table 2*, which include Sum of square error (SSD), the correlation coefficient (R^2), chi-square (X^2) and the root mean square error (RMSE) for both KRG-15 and MRG-20 in the different drying environment. The parameter values are shown in *Table 3*

G. *Analysis of model*

The correlation coefficient (R^2), chi-square (X^2) and the root mean square error (RMSE) obtained from equation (**Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**) respectively, were used to evaluate the goodness of fit mathematical models shown in Table *1* to the experimental data. The goodness of fit was determined by a higher value of R^2 and a lower value of both X^2 and RMSE. [12]

III. RESULTS AND DISCUSSION

Table 2: Coefficient of Determination R^2, Chi-square(X^2) and root mean square error (RMSE) value of the different models

Dryer type	Variety Model	KRG-15 SSD	KRG-15 R sq.	KRG-15 Chi sq.	KRG-15 RSME	MRG-20 SSD	MRG-20 Rsq.	MRG-20 Chi sq.	MRG-20 RSME
Solar Tent dryer	(1)	0.0538	0.9585	0.0030	0.0532	0.0694	0.9447	0.0039	0.0604
	(2)	0.0052	0.9906	0.0003	0.0165	0.0069	0.9869	0.0004	0.0191
	(3)	0.0018	0.9967	0.0001	0.0098	0.0023	0.9957	0.0001	0.0109
	(4)	1.2337	0.6598	0.0726	0.2548				
	(5)	0.0017	0.9969	0.0001	0.0095	0.0022	0.9958	0.0001	0.0107
	(6)	0.0015	0.9972	0.0001	0.0089	0.0028	0.9949	0.0002	0.0120
	(7)	0.0167	0.9697	0.0011	0.0296	0.0211	0.9602	0.0014	0.0333
	(8)	0.0015	0.9972	0.0001	0.0089	0.0021	0.9961	0.0002	0.0104
Oven at 50 degrees	(1)	0.0369	0.9877	0.0016	0.0392	0.0379	0.9747	0.0017	0.0406
	(2)	0.0056	0.9955	0.0003	0.0152	0.0082	0.9937	0.0004	0.0188
	(3)	0.0113	0.9909	0.0005	0.0217	0.0143	0.9849	0.0007	0.0249
	(4)	2.7155	0.6996	0.1234	0.3364	3.3017	0.8375	0.1099	0.3087
	(5)	0.0055	0.9955	0.0003	0.0152	0.0082	0.9938	0.0004	0.0188
	(6)	0.0035	0.9972	0.0002	0.0120	0.0016	0.9973	0.0001	0.0082
	(7)	0.0113	0.9910	0.0006	0.0217	0.0124	0.9891	0.0007	0.0232
	(8)	0.0043	0.9965	0.0002	0.0134	0.0066	0.9942	0.0004	0.0170
Oven at 60 degrees	(1)	0.1197	0.9594	0.0060	0.0755	0.1553	0.9438	0.0078	0.0860
	(2)	0.0048	0.9951	0.0003	0.0152	0.0055	0.9938	0.0003	0.0162
	(3)	0.0107	0.9889	0.0006	0.0226	0.0138	0.9844	0.0008	0.0257
	(4)	4.6028	0.5078	0.2423	0.4682	9.7980	0.6158	0.0975	0.2969
	(5)	0.0122	0.9875	0.0007	0.0241	0.0223	0.9941	0.0013	0.0326
	(6)	0.0022	0.9978	0.0001	0.0101	0.0025	0.9972	0.0001	0.0109
	(7)	0.0262	0.9743	0.0015	0.0353	0.0287	0.9689	0.0017	0.0369
	(8)	0.0024	0.9976	0.0002	0.0106	0.0028	0.9968	0.0002	0.0116
Solar Tent dryer-oven at 60	(1)	0.0668	0.9641	0.0027	0.0507	0.1964	0.8830	0.0079	0.0869
	(2)	0.0194	0.9795	0.0008	0.0273	0.0828	0.9043	0.0035	0.0564
	(3)	0.0246	0.9738	0.0011	0.0308	0.1008	0.8833	0.0044	0.0623
	(4)	6.1391	#DIV/0!	0.2558	0.4859	6.8396	#DIV/0!	0.2850	0.5129
	(5)	0.0193	0.9795	0.0009	0.0272	0.0816	0.9057	0.0037	0.0560
	(6)	0.0155	0.9835	0.0007	0.0244	0.0549	0.9369	0.0025	0.0459
	(7)	0.0300	0.9683	0.0014	0.0340	0.0717	0.9171	0.0033	0.0525
	(8)	0.0173	0.9816	0.0009	0.0258	0.0671	0.9225	0.0027	0.0508

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

o ven 50-60 degrees	(1)	0.0414	0.9836	0.0013	0.0354	0.8391	0.9561	0.0262	0.1595
	(2)	0.0265	0.9858	0.0009	0.0284	0.7655	0.9568	0.0247	0.1523
	(3)	0.0210	0.9887	0.0007	0.0252	0.8035	0.9610	0.0268	0.1560
	(4)	12.9700	#DIV/0!	0.4184	0.6269	13.2319	#DIV/0!	0.4268	0.6332
	(5)	0.0201	0.9892	0.0007	0.0247	0.7716	0.9589	0.0266	0.1529
	(6)	0.0214	0.9885	0.0007	0.0255	0.0282	0.9851	0.0010	0.0292
	(7)	0.0335	0.9825	0.0012	0.0319	0.0288	0.9848	0.0010	0.0295
	(8)	0.0222	0.9881	0.0008	0.0259	0.0285	0.9850	0.0011	0.0294
Solar Tent dryer-MW	(1)	0.0451	0.9657	0.0027	0.0500	0.0640	0.9304	0.0038	0.0596
	(2)	0.0033	0.9942	0.0002	0.0135	0.0418	0.9407	0.0026	0.0482
	(3)	0.0027	0.9951	0.0002	0.0123	0.0464	0.9342	0.0031	0.0508
	(4)	0.0112	0.9848	0.0007	0.0249	6.8396	#DIV/0!	0.2850	0.5129
	(5)	0.0112	0.9848	0.0008	0.0249	0.0418	0.9408	0.0030	0.0482
	(6)	0.0019	0.9966	0.0001	0.0102	0.0405	0.9432	0.0029	0.0472
	(7)	0.0126	0.9778	0.0009	0.0264	0.0433	0.9387	0.0031	0.0490
	(8)	0.0021	0.9962	0.0002	0.0109	0.0405	0.9426	0.0034	0.0474

Table 3: Parameter value of the different models

Dryer type	Model	a	b	c	k	n	g	p
Solar Tent dryer	(1)				0.0009			
	(2)				0.0082	0.6644		
	(3)	0.6239		0.3653	0.0021			
	(4)	0	0					
	(5)	0.9993	0.0001		0.003	0.8657		
	(6)	0.3878	0.0335		0.0582	0.0487		
	(7)	0.8702	0.1298		0.0007		0.5773	
	(8)	0.0223	0.3763	0.6011	0.4603		0	0.002
Oven at 50°C	(1)				0.0013			
	(2)				0.005	0.7937		
	(3)	0.8438		0.1177	0.0016			
	(4)	0	0					
	(5)	1.004	0		0.0052	0.789		
	(6)	0.494	1034.9097		0	1.7085		
	(7)	0.8913	0.1087		0.0011		0.5773	
	(8)	0	0.7883	0.2166	0.4603		0.001	0.0065
Oven at 60°C	(1)				0.002			
	(2)				0.0253	0.6015		
	(3)	0.7844		0.1634	0.0032			
	(4)	0	0					
	(5)	0.9408	0.0001		0.0034	0.946		
	(6)	0.5672	0.0539		0.0579	0.4325		
	(7)	0.7265	0.2735		0.0014		0.5773	
	(8)	0.1316	0.2581	0.6103	0.5194		0.0004	0.0033
Solar Tent dryer-oven at 60°C	(1)				0.0007			
	(2)				0.0043	0.7377		
	(3)	0.7258		0.2435	0.0011			
	(4)	0	0					
	(5)	1.0049	0		0.0043	0.7376		
	(6)	0.5663	2706.0676		0	1.7555		
	(7)	0.8931	0.1069		0.0006		0.5773	
	(8)	0	0.7717	0.2346	0.4603		0.0005	0.0038
oven 50-60 °C	(1)				0.001			
	(2)				0.0024	0.8741		
	(3)	0.8925		0.1071	0.0013			
	(4)	0	0					
	(5)	0.988	0		0.0009	1.0385		
	(6)	0.903	0		0.0015	0.9716		
	(7)	0.9472	0.0528		0.0009		0.5773	
	(8)	0.0442	0.0978	0.8842	0.4603		0	0.0012
Solar Tent dryer-MW	(1)				0.0008			
	(2)				0.0077	0.674		
	(3)	0.6451		0.3394	0.0019			
	(4)	-0.0005	0					
	(5)	1.0109	0.0001		0.0066	0.7537		
	(6)	0.7029	0.6678		0.0039	0.7044		
	(7)	0.8706	0.1294		0.0007		0.5773	
	(8)	0.0459	0.3228	0.6339	0.4603		0	0.0017

For the tent dryer, data fitted the best with Approximation of diffusion, Log, Midilli and Modified Handerson and Pabis model; the values for R^2, X^2, and RMSE were of (0.9972-0.9957), (0.0001-0.0002), and (0.0089-0.0012), respectively for both KRG-15 and MRG-20.For Oven drying at 50°C, the data fitted with Page, midilli, Approximation of diffusion and Modified Handerson and Pabis model, with the values for R^2, X^2, and RMSE were of (0.9972-0.9937), (0.0001-0.0004), and (0.0120-0.0188), for both varieties. For oven drying at 60C, the data fitted with Page, Approximation of diffusion and Modified Handerson and Pabis model, with the values for R^2, X^2, and RMSE were of (0.9978-0.9938), (0.0001-0.0003), and (0.0101-0.170) respectively for both varieties. For combination of Solar Tent dryer and oven drying at 60C, the data fitted with Approximation of diffusion and Modified Handerson and Pabis model, with the values for R^2, X^2, and RMSE for KRG-15 were of (0.9835-0.9816), (0.0007-0.0009), and (0.0244-0.0258) respectively while for MRG-20 were (0.9369-0.923), (0.0025-0.0027), and (0.0459-0.508). For combination of 50 and60C, the data fitted with Log, Midilli, Approximation of diffusion and Modified Handerson and Pabis model for KRG-15 while for MRG-20, the data fitted with Approximation of diffusion, two term and Modified Handerson and Pabis model. And finally, for the combination of both Solar Tent dryer and microwave oven, the data fitted with Log, Page, Approximation of diffusion and Modified Handerson and Pabis model for KRG-15, while for MRG-20, the data fitted with Page, Approximation of diffusion and Modified Handerson and Pabis model. These agrees with the fitted models for drying of macadamia nuts using convective drying [11], [13].

IV. CONCLUSIONS

The use of semi empirical drying model sufficient describes the drying characteristics of macadamia nuts of the two varieties under solar tent dryer, Hot air/ Oven drying at 50°C and 60°C and combined drying using microwave oven and oven drying at 60°C. This gives a useful tool for engineering purposes in the prediction of drying behavior of macadamia nuts. The most predominant models of best fit were Approximation of diffusion and Modified Handerson and Pabis model. These models adequately described the thin layer drying behavior of the two varieties of macadamia under the six different drying condition.

ACKNOWLEDGEMENT

I acknowledge the support by National Commission for Science, Technology and Innovation of the Republic of Kenya and Jomo Kenyatta University of Agriculture and Technology, who funded the study. I also want to recognize the Technical assistance at Practical training Centre (PTC) by Benson Kagiri and Mrs. Susan W. Ng'ang'a for her Technical support

REFERENCES

[1] N. O. Ondabu, L. A. Wasilwa, and G. W. Watani, "Adaptability of Kenyan macadamia selections and Hawaiian varieties in four agro-ecological zones," African Crop Sci. Conf. Proc., vol. 8, pp. 391–394, 2007.

[2] K. I. Network, "Macadamia Nut Farming and Production in Kenya,"2016.[Online].Available: https://www.investinkenya.co.ke/main/view_article/188.

[3] J. N. Mbaka, L. S. Wamocho, L. Turoop, and M. M. Waiganjo, "The incidence and distribution of Phytophthora cinnamomi Rands on macadamia in Kenya," J. Anim. Plant Sci., vol. 4, no. 1, pp. 289–297, 2009.

[4] J. O. Ojediran and A. O. Raji, "Thin layer drying of millet and effect of temperature on drying characteristics," International Food Research Journal, 2010. .

[5] M. M. Kamwere, C. L. Kanali, U. N. Mutwiwa, and G. M. Kituu, "Thin Layer Drying Characteristics of Stinging Nettle (Urticadioica L .) in a Solar Tunnel Dryer," Int. J. Eng. Res. Technol., vol. 4, no. 12, pp. 428–434, 2015.

[6] C. Borompichaichartkul, N. Chinprahast, S. Devahastin, L. Wiset, N. Poomsa-Ad, and T. Ratchapo, "Multistage heat pump drying of macadamia nut under modified atmosphere," Int. Food Res. J., vol. 20, no. 5, pp. 2199–2203, 2013.

[7] N. Poomsa- and L. Wiset, "Macadamia Drying by Microwave Dryer combined with Hot Air," pp. 36–40.

[8] Y. Wang, L. Zhang, J. Johnson, M. Gao, J. Tang, J. R. Powers, and S. Wang, "Developing Hot Air-Assisted Radio Frequency Drying for In-shell Macadamia Nuts," Food Bioprocess Technol., vol. 7, no. 1, pp. 278–288, 2014.

[9] C. Phusampao, "Performance of a greenhouse solar dryer for drying macadamia nuts," Green Energy …, vol. 5, no. 6, pp. 1155–1161, 2014.

[10] S. Kumar, "Review of Mathematical Modelling of Thin Layer Drying Process," Int. J. Curr. Eng. Sci. Res. o, vol. 2, no. 11, pp. 96–107, 2015.

[11] C. Phusampao, P. Pankeaw, W. Nilnont, and S. Janjai, "Thin layer drying of macadamia nut," pp. 50–58.

[12] Z. Guan and X. J. , Xiuzhi Wang , Min Li, "Mathematical Modeling on Hot Air Drying of Thin Layer Fresh Tilapia Fillets," Polish J. Food Nutr. Sci., vol. 63, no. 1, pp. 49–54, 2013.

[13] D. Zare, M. Ranjbaran, M. Niakousari, and M. Javidi, "Thin Layer Drying and Equilibrium Moisture Content Equations for Canola (Brassica napus L.)," Iran Agric. Res., vol. 30, no. 1, 2012.