Thin-Layer Drying Characteristics of Banana Slices in a Force Convection Indirect Solar Drying

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Abstract:- An experimental study was performed to determine the thin layer drying characteristics of banana slices in a force convection indirect solar drying. The system consists of two main parts: heat collector and the food drying cabinet. Heat collector absorbing maximum solar radiation by and provides heated air flow to the cabinet via two fans at the air inlet/outlet. The air temperature at the inlet of the cabinet under both natural and forced air velocities was about 62.8˚c. During the experiments, the cabinet was loaded with 426g of banana slices having an initial moisture content of 80%. Eight different thin layer drying models were compared with respect to their coefficient of determination (r^2), reduced chi-square (x^2) and root mean square error (RMSE) was selected to better estimate the drying curves. The performance of these models was investigated by non-linear regression analysis using statistica computer program. The entire models were showed a good fit to the drying data. However, the (wang and singh) drying model was showed a better fit to the experiment data among other models.

*Key-Words:*drying characteristics, drying model, force convection, indirect solar dryer

1 Introduction

Fruits and vegetables play an important role in human diet and nutrition as sources of vitamins and minerals. Overall post-harvest losses of fruit and vegetables in developing countries are estimated at about 20–50% of the production. Drying is one of the widely used preservation methods. It is used for improving food stability, since it decreases considerably the water activity of the material, reduces microbiological activity and minimizes physical, chemical changes during its storage period, lighter weight, less storage space, lower packing and transportation costs and encapsulates original flavor. Dried products have almost unlimited shelf life in proper packages and substantially lower transportation, handling and storage costs compared to products of other preservation methods[1-2].

Banana is one of the important tropical fruit in the world. The ripe fruit contains many of the necessary elements that are essential for a balanced diet. Banana contains fat, natural sugars, protein, potassium and vitamins A, B complex and C. Banana is a climacteric fruit with soft texture and it becomes more vulnerable to be spoiled due to high moisture content in banana, it is wounded and contaminated during handling and transportation and quality is deteriorated at high temperature and relative humidity [3].

Thin layer equations describe the drying phenomena in a unified way, regardless of the controlling mechanism. They have been used to estimate drying times of several products and to generalize drying curves. In the development of thin layer drying models for agricultural products, generally the moisture content of the material at any time after it has been subjected to a constant relative humidity and temperature conditions is measured and correlated to the drying parameters [4]. Several thin layer equations available in the literature for explaining drying behavior of agricultural products have been used for sweet potato slices, for garlic slices, for

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pistachio, for grape, for rough rice, for black tea, for banana and for prickly pear peel [5].

The objectives of this study were to determine the thin layer drying characteristics of banana slices in a force convection indirect solar drying and to propose mathematical model for the drying curves.

2 Experiment Set Up

The Force convection indirect solar drying has been designed and fabricated, as shown in the Figure 1. The system is an indirect forced circulation solar dying thermal. The system consists of two main parts as heat collector and the food cabinet. The food cabinet was made by ply wood which was paint with black color and sealed well by using silicone sealant, Figure 2. The air flows through compartment made by polystyrene at each top and bottom part of the food cabinet. It was used to let the smoother air flow in/out of the food cabinet, i.e. reduce turbulence flow happened. Two aluminums foil flexible (2m), the longer tube was attached to the heat collector into the bottom part of food cabinet. A shorter tube was fixed onto the top part of the food cabinet, which acts as the intermediate of air flow from heat collector to food cabinet.

Fig. 1 Picture of indirect forced circulation solar drying thermal system.

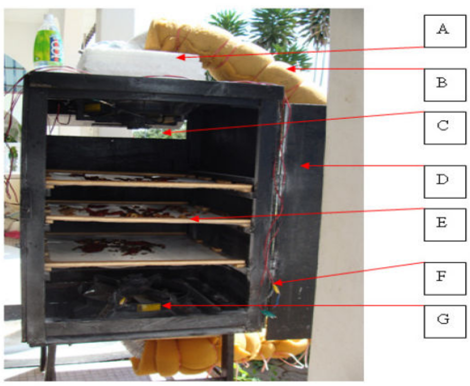

Fig. 2 Picture of food cabinet, A) Air flow compartment, B) Aluminum foil flexible, C) Moisture outlet, D) Door, E) Food Tray, F) Wires connecting to fans, G) Dc fan

There were three trays of area (550 x 550) mm^2 of each tray. The tray was made by aluminum net for food placing. The distance from the bottom fan to the bottom tray was about 150mm, and a distance of 200mm among each tray. Fans of 7.2 watts were located at top and bottom part of the food cabinet to drive the desired air flow inside the system. In total, the height of the cabinet was1200mm and width 600mm with overall volume of food storage region was $0.288m^3$. The food located inside the cabinet was to avoid direct exposure of the solar radiation so that the discoloration and hygiene dried food produced.

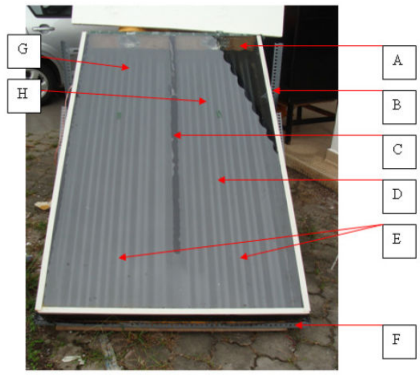

Fig. 3 Picture of heat collector on supporting structure, A) Aluminum foil connecting frame, B) Aluminum angle, C) Air flow divider, D) Clear glass, E) Two zinc sheets, F) Supporting structure, G) Air flow inlet compartment of heat collector, H) Air flow outlet compartment of heat collector.

The heat collector (Figure 3) has two pieces of curvy zinc sheet (1770x470) mm^2 allocated behind the transparent cover (clear glass) of area $1.8m^2$. Those sheets act as the heat absorber plate painted in black color to maximize the heat absorption from the solar radiation. 5 mm thick of transparent cover acted as green house and increased the temperature of air inside the heat collector. A gap of 150mm, between the glass and the absorber surface for air circulation inside the heat collector, was made. The heat collector was sealed by silicone sealant and placed on the heat collector supporting structure at the tilt angle of 23.5° degree with respect with the horizontal plane to maximize the exposure of solar radiation.

3 Materials and Methods

Semi-theoretical thin layer drying models were used widely in the analysis of drying characteristics [6-10].

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For this study, eight models were tested, as shown in Table 1.

Table 1: Mathematical models applied to the drying curves

Model	Model name	Equation	Reference
1	Lewis or Newton	$MR = \exp(-kt)$	12
2	Page	$MR = \exp(-kt^{n})$	13
3	Modified Page	$MR = \exp(-(kt)^{n})$	14
4	Henderson and Pabis	$MR = a\exp(-kt)$	15
5	Logarithmic	$MR = a\exp(-kt) + c$	16
6	Two-term	$MR = a\exp(-k_0 t) + b\exp(-k_1 t)$	17
7	Two term exponential	$MR = a\exp(-kt) + (1-a)\exp(-kat$	18
8	Wang and Singh	$MR = 1 + at + bt^2$	19

The Moisture Ratio (MR) can be calculated as:

MR = (M-Me)/ (Mo-Me) [1]

The amount of moisture in a product is designated on the basis of weight of water [7,10]:

$$\%\, MC_{db} = \frac{W_w}{W_d}(100\,\%)$$ [2]

In these experiments, the solar drying thermal system was loaded with very ripe banana slices (total weight of 426g) of equal thickness 5mm which having initial moisture content of 80%. The fan speed inside the cabinet was 4.23m/min throughout the experiments .The products were equally distributed on three trays in the cabinet equally. During the experiments, the trays were swap to each other to get uniformity of product drying of each tray every one hour. All product dried in the solar dryer were compare with the product dried under open sun drying method. All parameters were measured for nine hours from 9 am to 5 pm.

The drying processes were continued until there was no significant decrease of the product moisture content with increasing the drying time. This moisture contents were taken as the value of equilibrium moisture content. Banana slices was tested to perform this study.

4 Results and Discussions

A statistical software package was used in the analysis of the raw data obtained from the drying experiments. The values of the parameters a, n and the constant k for the models were determined. The correlation coefficient (R^2) was the primary criterion for selecting the best equation to describe the drying curve equation. In addition to (R^2), the reduced chi-square (X^2) as the mean square of the deviations between the experimental and calculated values for the models and the root mean square error analysis (RMSE) were used to determine the goodness of the fit. Higher values of (R^2) and lower values of chi-square (X^2) and RMSE indicate better goodness of fit model was selected to best describe the drying behavior of Banana slices[7-9,19-22]. These can be calculated as

$$R^2 = \frac{\sum_{i=1}^{n}(MR_i \quad MR_{pre;i}) \cdot \sum_{i=1}^{n}(MR_i \quad MR_{exp;i})}{\sqrt{\left[\sum_{i=1}^{n}(MR_i \quad MR_{pre;i})^2\right] \cdot \left[\sum_{i=1}^{n}(MR_i \quad MR_{exp;i})^2\right]}} \quad (3)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_{exp;i} \quad MR_{pre;i})^2}{N \quad n}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre;i} \quad MR_{exp;i})^2\right]^{1=2}$$ [4,5]

Where MRexp,i is the ith experimentally observed moisture ratio, MRpre,i the ith predicted moisture ratio, N the number of observations and n the number constants.

Drying experiments were performed for banana slices in indirect forced solar drying at different trays in the cabinet and in open sun drying. Three experiments was applied in the cabinet by dividing it into three trays, top, middle and bottom, and the forth experiment was done under open sun drying. The objective of these experiments is to choose the best curve among the four types which let us know which one gives the maximum evaporation of the moisture content with minimum amount of time. Figure 4 shows the moisture ratio relation of the banana slices in indirect forced solar drying for the three trays and open sun drying against the time.

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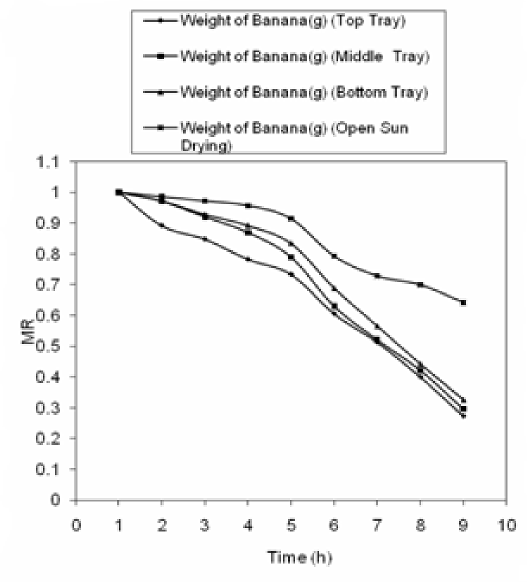

Fig.4 Moisture ratio versus Time (h) curves

As can be seen from Figure 4, the best moisture ratio is on the top tray comparing from other trays and open sun drying. For example, after 5 drying hour's time, MR in the top tray (0.733), middle tray (0.7894), bottom tray (0.8333) and open sun drying (0.91394). So the minimum value of the MR (0.733) which related to the top tray.

A set of 8 mathematical drying models in Table 1 was conducted to develop a drying model to simulate the drying curves of the banana slices in indirect forced solar dryer. These models can be used for predicting of change of moisture content with time. The values of R^2, X^2, RMSE and the parameters a, b, c. n and the drying constant k, k_0, k_1 for the different models (for top tray) was listed in Table 2. The highest value of R^2 and the lowest value of X^2 and RMSE indicated the goodness of the fit. All the models showed high values for R^2 ranged between (0.8461291-0.9938108) and low values for X^2 (1.04659*10^-3 - 2.39254*10^-4) and RMSE (0.0894042-0.013641351). Moreover, these models can estimate the drying curves or the moisture content of the banana slices in indirect forced solar drying during the dehydration processes adequately.

However, among the eight mathematical drying models, the Wang and Singh model resulted in the highest values of R^2 (0.9938108) and the lowest values of X^2 (2.39254*10^-4) and RMSE (0.013641351). This indicated that the good fit of Wang and Singh model compared to other models as shown in Table2. Figures 5-7 show the Wang and Singh model drying curve for top, middle, and bottom tray, respectively. To validate the developed model, the experimental data were plotted against the predicted values. The results showed smooth and good scatter of the data points around the fitted line. This confirms the goodness of the developed model to estimate the moisture content of banana slices in a force convection indirect solar drying. Figures 8-10 show the observed moisture content versus predicted moisture content for top, middle, and bottom tray, respectively.

Table 2: Thin layer drying models results (top tray)

Model	R^2	X^2	RMSE	a	b	c	k	k_0	k_1	n
Newton	0.8461291	7.19104*10^-3	0.0894042				-0.91356			
Page	0.9842469	1.04659*10^-3	0.0285295				-0.14868			1.98628
Modified Page	0.9842469	1.04659*10^-3	0.02853				-0.14868			1.98625
Henderson and Pabis	0.9274247	4.82289*10^-3	0.0612463	1.18462			-0.122748			
Logarithmic	0.9774471	1.74983*10^-3	0.034155	17.214		-16.103	-0.005165			
Two-term model	0.9274247	6.7518*10^-3	0.061245399	0.591865	0.592758			-0.122833	-0.122666	
Wang and Singh	0.9938108	2.39254*10^-4	0.013641351	-0.03109	-0.00551					
two-term exponential model	0.9661937	2.24705*10^-3	0.041805595	2.10859			-0.189464			

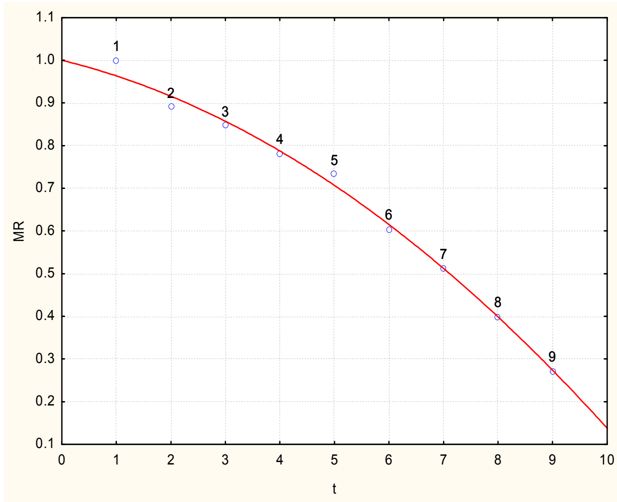

Fig. 5 Wang and Singh model drying curve (Top tray).

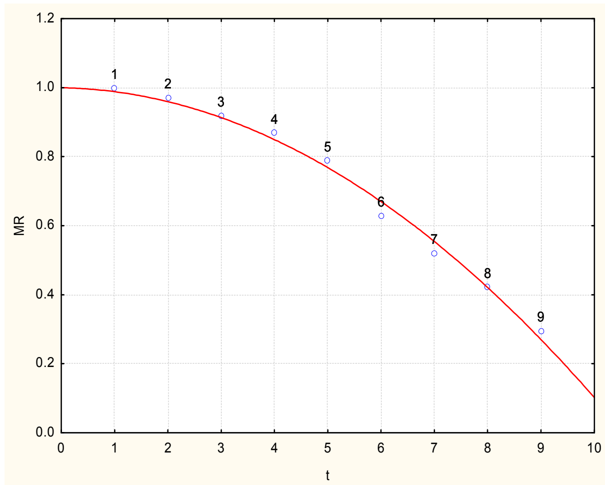

Fig. 6 Wang and Singh model drying curve (Middle tray).

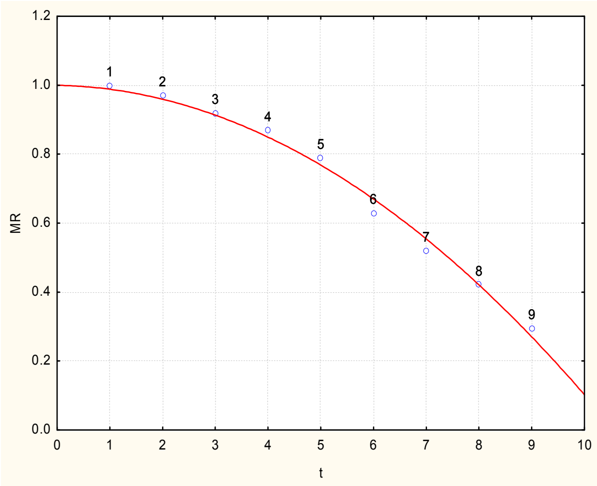

Fig. 7 Wang and Singh model drying curve (Bottom tray)

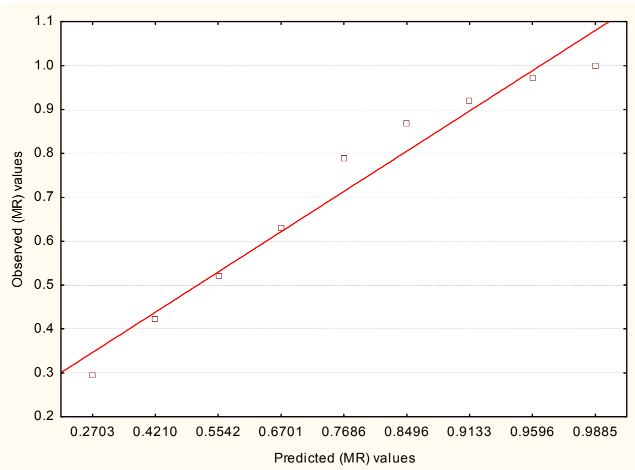

Fig. 8 Wang and Singh model (Top tray), Observed moisture content versus predicted moisture ratio for banana slice

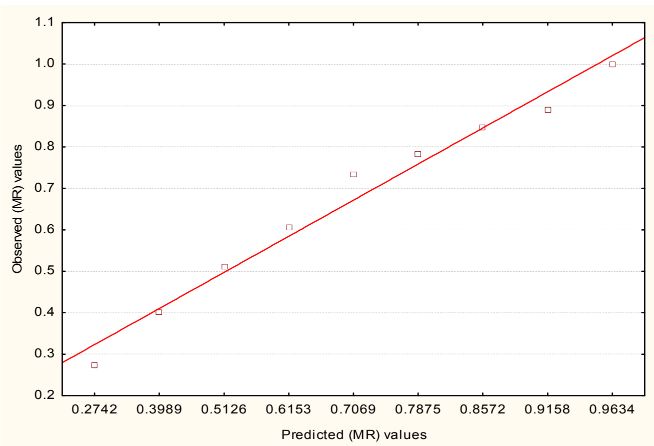

Fig. 9 Wang and Singh model (Middle tray), Observed moisture content versus predicted moisture ratio for banana slice.

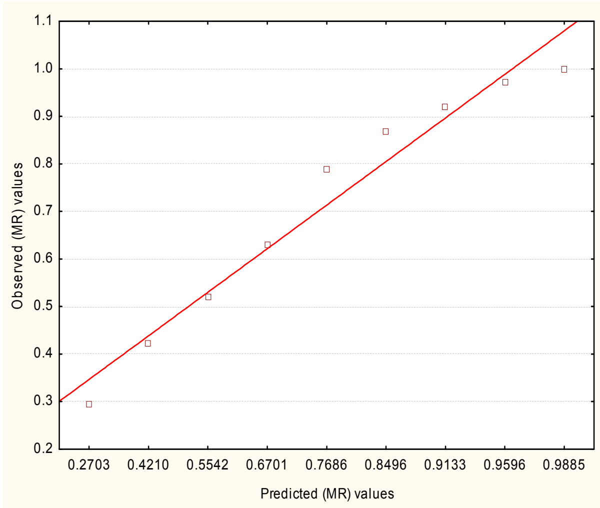

Fig. 10 Wang and Singh model (Bottom tray), Observed moisture content versus predicted moisture ratio for banana slice.

5 Conclusion

In the present study, drying behavior of the banana slices was investigated under force convection indirect solar drying. Wang and Singh model had high a correlation coefficient (R^2)and low chi-square(X^2) and root mean square error (RMSE) values was found to be adequate in describing the thin layer drying characteristics of banana slices in a force convection indirect solar drying.

References:

[1] Hakan Okyay Menges and Can Ertekin, "Thin layer drying model for treated and untreated Stanley plums," Energy Conversion and Management 47 (2006): 2337–2348.

[2] A. Arabhosseini , W. Huisman, A. van Boxtel and J. Muller, "Modeling of thin layer drying of tarragon (Artemisia dracunculus L.)," industrial crops and products 2 9 (2009): 53–59.

[3] B.M.A. Amer, M.A. Hossain and K. Gottschalk, "Design and performance evaluation of a new hybrid solar dryer for banana," Energy Conversion and Management 51 (2010): 813–820. 2010.

[4] Midilli, A., H. Kucuk and Z. Yapar, 2002. A new model for single layer drying. Dry. Technol., 20: 1503-1513.

[5] Kamil Sacilik, Rahmi Keskin and Ahmet Konuralp Elicin, "Mathematical modelling of solar tunnel drying of thin layer organic tomato," Journal of Food Engineering 73 (2006): 231–238.

[6] Adnan Midilli and Haydar Kucuk, "Mathematical modeling of thin layer drying of pistachio by using

ISBN: 978-960-474-274-5

solar energy," Energy Conversion and Management 44 (2003): 1111–1122.
[7] Kamenan Blaise Koua, Wanignon Ferdinand Fassinou, Prosper Gbaha and Siaka Toure, "Mathematical modelling of the thin layer solar drying of banana, mango and cassava," Energy 34 (2009): 1594–1602.
[8] E. Kavak Akpinar and Y. Bicer, "Mathematical modelling of thin layer drying process of long green pepper in solar dryer and under open sun," Energy Conversion and Management 49 (2008): 1367–1375.
[9] Zhengfu Wang, Junhong Sun, Fang Chen, Xiaojun Liao and Xiao Song Hu. "Mathematical Modeling on Thin Layer Microwave Drying of Apple pomace with and without hot air pre-drying," Journal of Food Engineering 80 (2006): 536–544.
[10] I.E. Saeed, K. Sopian and Z. Zainol Abidin, "Drying characteristics of Roselle (1): Mathematical Modeling and Drying Experiments,"Thesis, National University of Malaysia, UKM 43600 Bangi, S.D.E., Malaysia. [Online].Available: http://www.cigrjournal.org/index.php/Ejounral/article/viewFile/1161/1117. [Accessed: February.15, 2010].
[11] Mujumdar AS. Handbook of industrial drying. New York: Marcel Dekker; 1987.
[12] Diamante LM, Munro PA. Mathematical modelling of thin layer solar drying of sweet potato slices. Sol Energy 51(1993): 271–6.
[13] White GM, Bridges TC, Gewer OJ, Ross IJ. Seed coat devage in thin layer drying of soybeans as affected by drying conditions. ASAE Paper No. 3052. St. Joseph (MI): ASAE; 1978.
[14] Zhang Q, Litchfield JB. An optimization of intermittent corn drying in a laboratory scale thin layer dryer. Dry Technol 9 (1991): 383–95.
[15] Yagcioglu A, Degirmencioglu A, Cagatay F. Drying characteristic of laurel leaves under different conditions. In: Bascetincelik A, editor. Proceedings of the seventh international congress on agricultural mechanization and energy. Adana, Turkey: Faculty of agriculture, Cukurova University; 1999. p. 565–9.
[16] Henderson SM. Progress in developing the thin layer drying equation. Trans ASAE 1974:1167–72.
[17] Sharaf-Eldeen YI, Blaisdell JL, Hamdy MY. A model for ear corn drying. Trans ASAE 1980; 23:1261–71.
[18] Wang CY, Singh RP. A single layer drying equation for rough rice. Paper No. 78-3001. St. Joseph (MI): Am Soc Agr Eng; 1978
[19] C. Ertekin and O. Yaldiz, "Drying of Eggplant and Selection of a Suitable Thin Layer Drying Model," Journal of Food Engineering 63 (2003): 349–359.
[20] D.G. Praveen Kumar, H. Umesh Hebbar and M.N. Ramesh, "Suitability of Thin Layer Models for Infrared–Hot Air-Drying of Onion Slices," LWT 39 (2005): 700–705.
[21] Zhengfu Wang, et al., "Mathematical modeling on hot air drying of thin layer apple pomace," Food Research International.40 (2007): 39–46.
[22] Ebru Kavak Akpinar, Yasar Bicer and Cengiz Yildiz, "Thin layer drying of red pepper," Journal of Food Engineering 59 (2003): 99–104.
[23] Mustafa Ibrahim, K. Sopian and W.R.W. Daud, "Study of the Drying Kinetics of Lemon Grass," American Journal of Applied Sciences 6 (6) (2009): 1070-1075.