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Study of the Drying Kinetics of Lemon Grass

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Abstract: Problem statement: The thin- layer drying experiments were conducted to examine the effect of drying air temperature and humidity on the drying kinetics. **Approach:** A model to estimate the drying behavior of Lemon grass was developed). **Results:** Four different thin-layer drying models were compared with respect to their coefficient of determination (R^2), Mean Bias Error (MBE) and Root Mean Square Error (RMSE). The one with highest (R^2) and lowest (MBE) and (RMSE) was selected to better estimate the drying curves. Three temperatures (35, 45 and 55°C) and three humidities (30, 40 and 50%) were investigated with a fixed air velocity of 1 m sec^{-1}. **Conclusion/Recommendation:** The increase in the drying air temperature increased the drying process and decreased the Equilibrium Moisture Content (EMC) of Lemon grass. The drying process decreased as the air humidity increases. The effect was less than that of the temperature. The EMC have high values with high relative humidity.

Key words: Drying, lemon grass, air temperature, air humidity, mathematical modeling

INTRODUCTION

Lemon grass is widely used as a herb in Asian (particularly Khmer, Thai, Lao, Sri Lankan, Vietnamese) and Caribbean cooking. It is commonly used in teas, soups and curries. It is also suitable for poultry, fish and seafood. It is often used as a tea in African countries (Togo). The wide varieties of dehydrated foods and the interesting concern for meeting quality specifications and energy conservation, emphasize the need for a thorough understanding of the drying process. Conventional air-drying is the most frequently used dehydration operation in food and chemical industry. In this case, the drying kinetic is greatly affected by air temperature and material characteristic dimension, while other process factors exert negligible influence[1,2]. Optimization of the drying operation must answer two essential imperatives that are the restricted consumption of the necessary energy and the safeguard of the biologic quality of the dried products[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]. The objectives of this study were to determine the effects of drying air temperature and air humidity on the drying behavior of Lemon grass and to propose mathematical model for the drying curves.

MATERIALS AND METHODS

Mathematical models: Semi-theoretical thin layer drying models were used widely in the analysis of drying characteristics[1,5-9]. For this study, four models were tested, as shown in Table 1.

The Moisture Ratio (MR) can be calculated as:

$$MR = (M-Me)/(Mo-Me) \qquad (1)$$

The amount of moisture in a product is designated on the basis of weight of water[14]:

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

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Table 1: Mathematical models applied to the drying curves

Model name	Model	References
Newton	MR = exp (-kt)	[10]
Page	MR = exp ($-kt^n$)	[11]
Modified Page	MR = exp ($-(kt)^n$)	[12]
Henderson and Pabis	MR = a exp (-kt)	[13]

Drying experiments: The variables of the experiments were drying air temperature and air humidity. Three drying air temperatures (35, 45 and 55°C) and three relative humilities (30, 40 and 50% RH) were applied. Air velocity was kept constant at (1 m sec^{-1}) for all experiments. The experiments were carried out in Constant Temperature and Humidity Chamber (Model TH-1-180-L. JEIO TECH Co., Ltd, KOREA). Temperature and humidity ranges are (-40 to 150°C) and (10-98%RH), respectively. Analytical semi-microbalance, Model GR-200, A and D Company, limited, Japan, (sensitivity 0.1mg) was used. The weight data of the drying material was recorded on personal computer at 30-second intervals, using the data acquisition software (RsCOM Version 2.40). A convective oven (Venticell, MMM, Medcener) was used to determine the initial and the final moisture content according to the method described in the Handbook of food analytical chemistry[15]. 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. For this study, fresh Lemon grass was collected from the farm of Faculty of Science and Technology (University Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia).

RESULTS AND DISCUSSION

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. Consequently, the most suitable model was selected to best describe the drying behavior of lemon grass. The values of the coefficient of determination (R^2), Mean Bias Error (MBE) and Root Mean Square Error (RMSE) were used to determine the goodness or the quality of the fit[1,7,16]:

$$MBE = \frac{1}{N}\sum_{i=1}^{N} \left(MR_{pre,i} - MR_{exp,i}\right)^2 \quad (3)$$

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

Table 2: Initial and final moisture content

	Initial (decimal db)	Final (decimal db)
Max.	11.3251	0.5959
Min	7.2615	0.2927
Aver.	9.2937	0.4443

Table 3: Newton's equation parameters and the results of the statistical computations for drying of lemon grass

Model	T	RH%	k	R^2	MBE	RMSE
Newton	35	(30-50)	0.002744	0.995524	0.000157	0.012522
	45	(30-50)	0.003405	0.994386	0.000155	0.012449
	55	(30-50)	0.004926	0.997326	0.000124	0.011135

A set of 12 experiments was conducted to develop a drying model to simulate the drying curves of the lemon grass calyxes. The average initial and final moisture content of lemon grass was 9.2937 and 0.4443 (g water per g dry matter), respectively as shown in Table 2.

The values of R^2, MBE, RMSE and the parameters a, n and the constant k, for the different models were listed in Table 3-6. The highest value of R^2 and lowest value of MBE and RMSE indicated the goodness of the fit. All the models showed high values for R^2 ranged between (0.985326-0.997326) and low values for MBE (0.000124-0.000296) and RMSE (0.011135-0.017209). Moreover, these models can estimate the drying curves or the moisture content of the lemon grass during the dehydration processes adequately. These tables illustrate the effect of the drying air temperature and air humidity on the modeling of the moisture content versus drying time.

However, among the four models, the Newton model resulted in the highest values of R^2 (average 0.995745) and the lowest values of MBE (average 0.000145) and RMSE (average 0.012035).This indicated the good fit of Newton model compared to other models as shown in Table 7.

It was observed that the main factor influencing drying kinetics is the drying air temperature. Thus, a higher drying air temperature produced a higher drying rate and consequently the moisture ratio decreased. The drying process was accelerated by increasing the temperature of the drying air from 35-55°C. Figure 1a-c and 2a-c show examples of the effect of temperature on the drying processes. This effect was clearly observed during the first period of drying process. The drying time required to dry at temperature 35°C was as much as times that of temperature 55°C (at constant RH). For instant, the time required to reach 0.2 moisture content is about 550 minutes at temperature 35°C and 30%RH, compared to only 200 minutes at temperature 55°C, 30%RH (as shown in Fig. 1a and 2a, respectively). This is due to the fact that, drying at high temperature led to

Table 4: Page's equation parameters and the results of the statistical computations for drying of lemon grass

Model	T	RH%	k	n	R^2	MBE	RMSE
Page	35	(30-50)	0.004257	0.930268	0.994874	0.000183	0.013530
	45	(30-50)	0.005910	0.942216	0.996196	0.000190	0.013790
	55	(30-50)	0.002412	0.980768	0.990105	0.000258	0.016065

Table 5: Modified Page's equation parameters and the results of the statistical computations for drying of lemon grass

Model	T	RH%	k	n	R^2	MBE	RMSE
Modified page	35	(30-50)	0.068607	0.041576	0.992008	0.000230	0.015190
	45	(30-50)	0.046321	0.366718	0.994385	0.000196	0.013844
	55	(30-50)	0.063260	0.080959	0.985326	0.000296	0.017209

Table 6: Henderson and Pabis's equation parameters and the results of the statistical computations for drying of lemon grass

Model	T	RH%	a	k	R^2	MBE	RMSE
Hendersonand Pabis	35	(30-50)	0.944385	0.002470	0.992343	0.000210	0.014497
	45	(30-50)	0.973848	0.003872	0.995485	0.000225	0.015011
	55	(30-50)	1.052093	0.005638	0.989220	0.000268	0.016386

Table 7: The results of the statistical computations on the models equations and the values of constants for drying of lemon grass

Model	a	k	n	R^2	MBE	RMSE
Newton		0.003691		0.995745	0.000145	0.012035
Page		0.004193	0.951084	0.993725	0.000210	0.014461
Modified page		0.059396	0.163084	0.990573	0.000240	0.015414
Henderson and pabis	0.990108	0.003993		0.992349	0.000234	0.015298

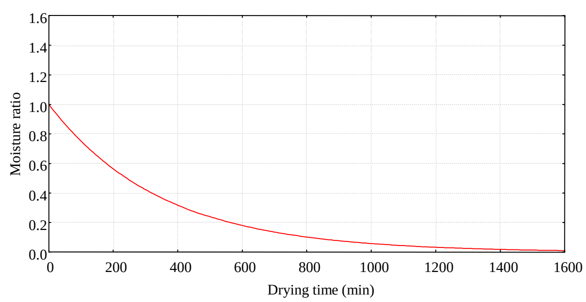

Fig. 1a: Drying time curve of lemon grass at temperature 35°C, (RH 30%)

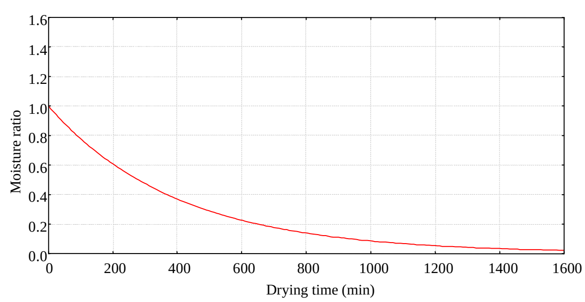

Fig. 1b: Drying time curve of lemon grass at temperature 35°C, (RH40%)

high moisture diffusivity and also provided a large water vapor pressure deficit, which is one of the driving forces for drying[17,18]. However, the drying is observed in the falling rate period only for the range of the

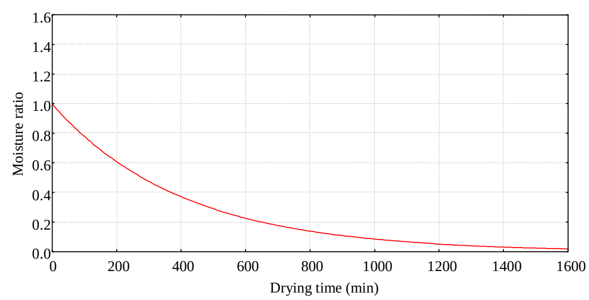

Fig. 1c: Drying time curve of lemon grass at temperature 35°C, (RH50%)

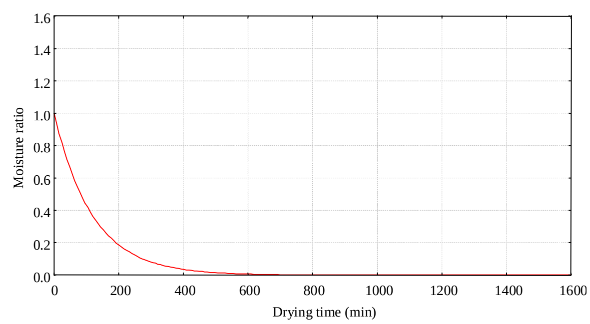

Fig. 2a: Drying time curve of lemon grass at temperature 55°C, (RH30%)

temperatures applied. As drying air humidity increased from 30-50% showed less effect than that of drying air temperatures. This agreed with the works of many

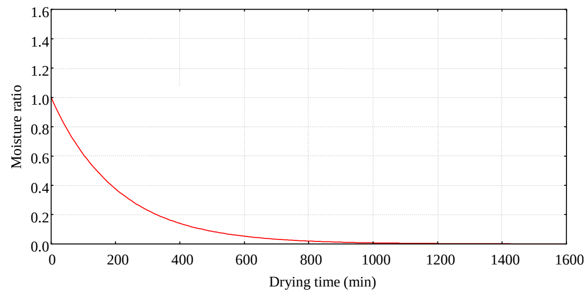

Fig. 2b: Drying time curve of lemon grass at temperature 55°C, (RH40%)

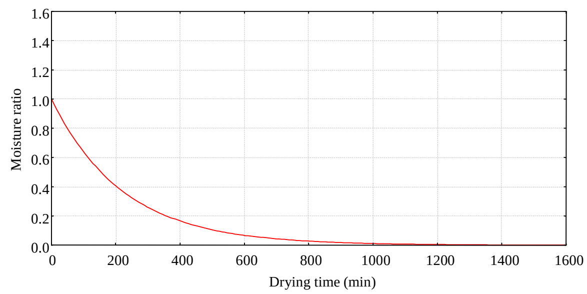

Fig. 2c: Drying time curve of lemon grass at temperature 55°C, (RH50%)

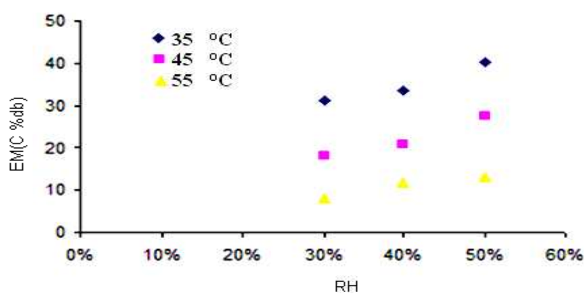

Fig. 3a: The relationship between the EMC and RH%

authors[1]. Figure 1a-c show the effect of increasing air humidity at temperature (35°C). Figure 2a-c show the effect of increasing air humidity at temperature 55°C. It is clear that, there was a slight decrease in the drying processes as the humidity was increased from 30-50%, (at low temperature, 35°C). This effect was negligible as the temperature was increased to (55°C). The Equilibrium Moisture Content (EMC) was obviously of high values when the RH was increased. In contrast, equilibrium moisture content was of low value with high temperatures. Figure 3a and b show the relationship between the EMC, RH and temperature. To validate the developed model, the experimental data

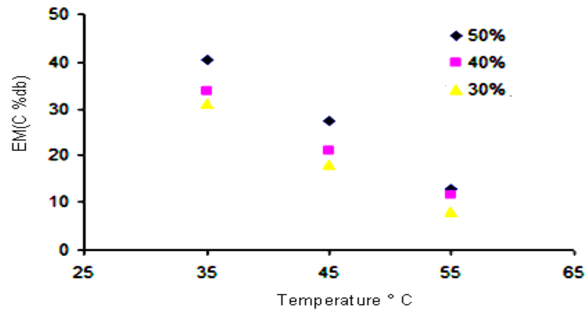

Fig. 3b: The relationship between the EMC and temperature

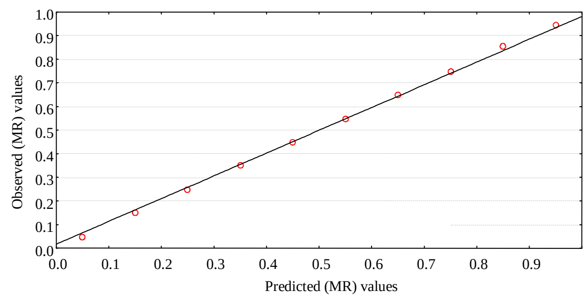

Fig. 4a: Observed moisture content versus predicted moisture content for lemon grass modeling at temperature 35°C (RH30%)

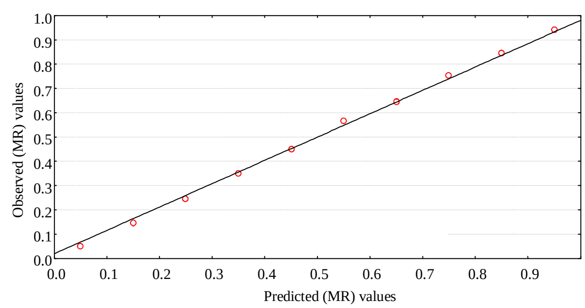

Fig. 4b: Observed moisture content versus predicted moisture content for lemon grass modeling at temperature 35°C (RH40%)

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 the lemon grass during the drying processes. Figure 4a-c, show the observed moisture content versus predicted moisture content at 35°C and (30, 40, 50% RH, respectively). Figure 5a-c, show the plotting of the observed moisture content against the predicted values

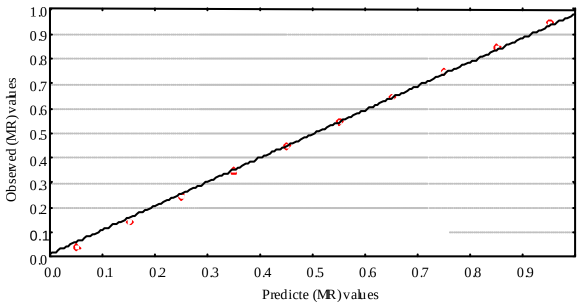

Fig. 4c: Observed moisture content versus predicted moisture content for lemon grass modeling at temperature 35°C (RH50%)

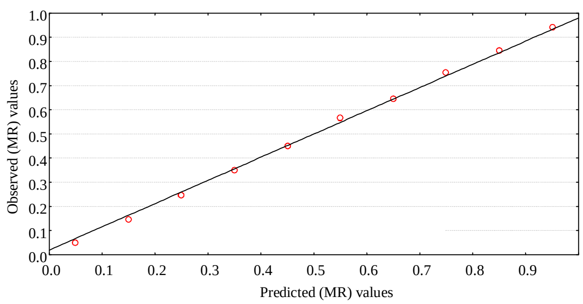

Fig. 5a: Observed moisture content versus predicted moisture content for lemon grass modeling at temperature 55°C (RH30%)

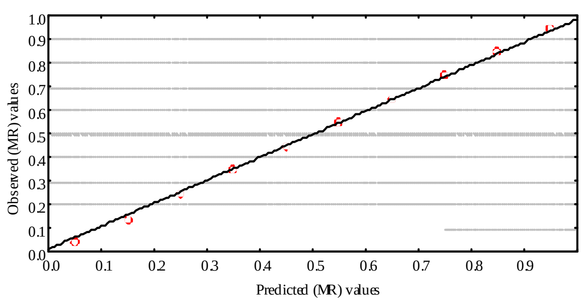

Fig. 5b: Observed moisture content versus predicted moisture content for lemon grass modeling at temperature 55°C (RH40%)

at 55°C and (30, 40 and 50% RH, respectively). This indicated the suitability of the developed model to describe the drying behavior of the lemon grass. The results obtained and the values for the parameters a, n and the constant k, calculated were agreed and within the range for agricultural products, found by different authors[1,5,6,8,19].

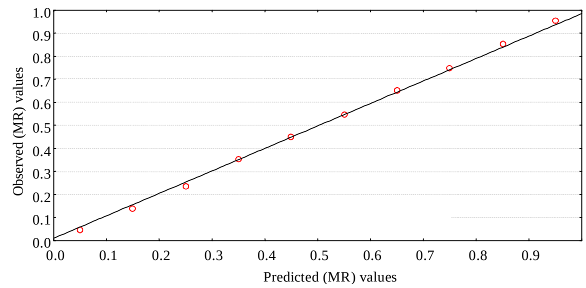

Fig. 5c: Observed moisture content versus predicted moisture content for lemon grass modeling at temperature 55°C (RH50%)

CONCLUSION

Experiments were carried out to study the effect of drying air temperature and air humidity on the drying characteristics of lemon grass and to develop a model to estimate the drying curves. The drying kinetics was effected mainly by the drying air temperatures. The temperature was found to control the drying rate and thus the drying times. The increase in the drying air temperature increased the drying process, at constant RH. Moreover, the reverse was observed with the less effect for relative humidity, at constant temperature. The EMC was found to have a linear relation with RH and inverse relation with temperature. The results were represented in a graphical representation and statistical analysis was done to find out the best-fit model for the drying curves. The entire models were showed a good fit to the drying data. However, the Newton model was showed a better fit to the experimental data among other models. In addition, it represents the drying behavior of lemon grass adequately.

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