MATEC Web of Conferences **62**, 02007 (2016) DOI: 10.1051/matecconf/20166202007
ICCFE 2016

Empirical Modeling on Hot Air Drying of Fresh and Pre-treated Pineapples

Yardfon Tanongkankit [1,a], Kanjana Narkprasom[1], Nukrob Narkprasom[1]

[1]*Maejo University in Chiang Mai, Thailand*

Abstract. This research was aimed to study drying kinetics and determine empirical model of fresh pineapple and pre-treated pineapple with sucrose solution at different concentrations during drying. 3 mm thick samples were immersed into 30, 40 and 50 Brix of sucrose solution before hot air drying at temperatures of 60, 70 and 80°C. The empirical models to predict the drying kinetics were investigated. The results showed that the moisture content decreased when increasing the drying temperatures and times. Increase in sucrose concentration led to longer drying time. According to the statistical values of the highest coefficients (R^2), the lowest least of chi-square (χ^2) and root mean square error (RMSE), Logarithmic model was the best models for describing the drying behavior of soaked samples into 30, 40 and 50 Brix of sucrose solution.

1 Introduction

Pineapple (*Anana comosus*) is a tropical fruit belonging to the *Bromeliaceae* family, and originated from South America [1]. This fruit has been reported to be low in calories and a source of nutritional components such as fiber, mineral and antioxidants [1-2]. Pineapple is commonly consumed in a form of fresh product. Nevertheless, it has a short storage life approximately 5 days at 4°C and 1 day at 15°C [3]. Therefore, to extend its shelf life pineapple is usually dried.

Drying is a process to remove moisture content in products to a level at which deterioration from chemical reaction and microorganism are minimized. However, this method involving in high temperatures and times can cause changes in final quality of products when compared to the fresh fruit [4]. To avoid this problem, pre-drying treatments such as addition of sugars are needed for fruit drying in order to the improvement in texture and the stability of the color pigment during storage [5].

Pre-treatment with sugar solution has been claimed to be very effective for producing high quality dried fruits and vegetable. Since sugar especially non-reducing sugar does not react with amino acids or proteins to cause Maillard reaction, browning and loss of nutrition in products can be eliminated [5]. Giovanna [6] reported that immersing pineapple in 50 Brix of sucrose solution for 30 min protected the color of pineapple during drying at 70, 75 and 80°C.

The objective of this study was to determine kinetic dryings of fresh pineapple and pre-treated pineapple with sucrose solution. Empirical modeling for describing drying behavior of pineapples was also investigated.

2 Materials and Methods

[a] Corresponding author: yardfon@hotmail.com

2.1 Experimental material

Fresh pineapple cv. Nanglae were obtained from local market in Chiang Mai. An initial moisture content of pineapple was 80 ± 2% (d.b.), which was determined by drying the fresh pineapple in the electric thermal dryer at 105°C for 24 h until the weight was constant. Each run in the experiment was performed in triplicate.

2.2 Sample preparation

The fruits were hand peeled and sliced into a rectangular shape of 5×10 cm and 5 mm thickness. A batch each of 250 g of slices were pre-treated accordingly with sucrose osmosis method by immersing fresh slices into sucrose solution (Food grade of 98% purity) with concentration of 30, 40 and 50 Brix for 30 min. The samples were drained on a screen and reweighed.

2.3 Drying experiment

The prepared samples were dried in hot air dryer (Memmert, 500/108I, Germany). Approximately 250 g of the sample was placed as single layer on a perforated tray. The experiments were performed at temperature of 60, 70 and 80 °C. The samples were dried until a final moisture content of less than 18% (d.b.) was reached. During each experiment 3–5 g of the sample was taken out at various intervals to determine its moisture content. The moisture content of the sample was determined using a gravimetric method at 105 °C [7].

2.4 Mathematical modelling

The moisture ratio (MR) of the pineapple was defined as follows [8]:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

Where M_t, M_0 and M_e are the moisture content at any time of drying (kg water/kg dry mass), initial moisture content (kg water/ kg dry mass) and equilibrium moisture content, respectively. The experimental data at different thicknesses of paddy were fitted into 6 thin-layer drying models that commonly used in most food and biological materials (Table 1).

Table 1. Mathematical models applied the moisture ratio

Model name	Model equation	Reference
1. Lewis	$MR = \exp(-kt)$	[8]
2. Page	$MR = \exp(-kt^n)$	[9]
3. Modified Page	$MR = \exp(-kt)^n$	[9]
4.Wang and Singh	$MR = a\exp(-kt^n) + bt$	[10]
5.Handerson and Pabis	$MR = a.\exp(-kt)$	[11]
6.Logarithmic	$MR = a\exp(-kt) + c$	[12]

2.5 Correlation coefficients and error analyses

The determination of coefficients (R^2), reduced chi-square (χ^2) and root mean square error (RMSE) were used to evaluate the goodness fit. These parameters were calculated as follows:

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

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

Where N is the number of observations, z is the number of constants, $MR_{\exp}$ are the experimental and predicted moisture ratios, respectively.

2.6 Statistical analysis

The experiments were designed in complete random. The data were subjected to an analysis of variance (ANOVA) and are presented as mean values with standard deviations. Differences between mean values were established using Duncan's multiple range tests. Values were considered at a confidence level of 95%. All statistical analyses were performed using SPSS® software (version 17) (SPSS Inc., Chicago, IL). All experiments were performed in duplicate unless specified otherwise.

3 Results and Discussion

3.1. Drying kinetics of pineapples

Fig. 1 shows the drying curves of unpretreated and pre-treated with different sucrose concentration samples. The results showed that the drying rates at higher temperatures were higher than those at lower temperatures. This is due to drying at higher temperature led to higher moisture diffusivity values and larger driving force for heat/mass transfer than at lower temperatures. The equilibrium moisture content (EMC) and time needed to dry a sample to the desired moisture content of less than 0.18 g/g dry basis are listed in Table 2. EMC of the samples were in the range of 0.023-0.141 g/g dry basis. It was also observed that higher concentration of sucrose resulted in longer drying time.

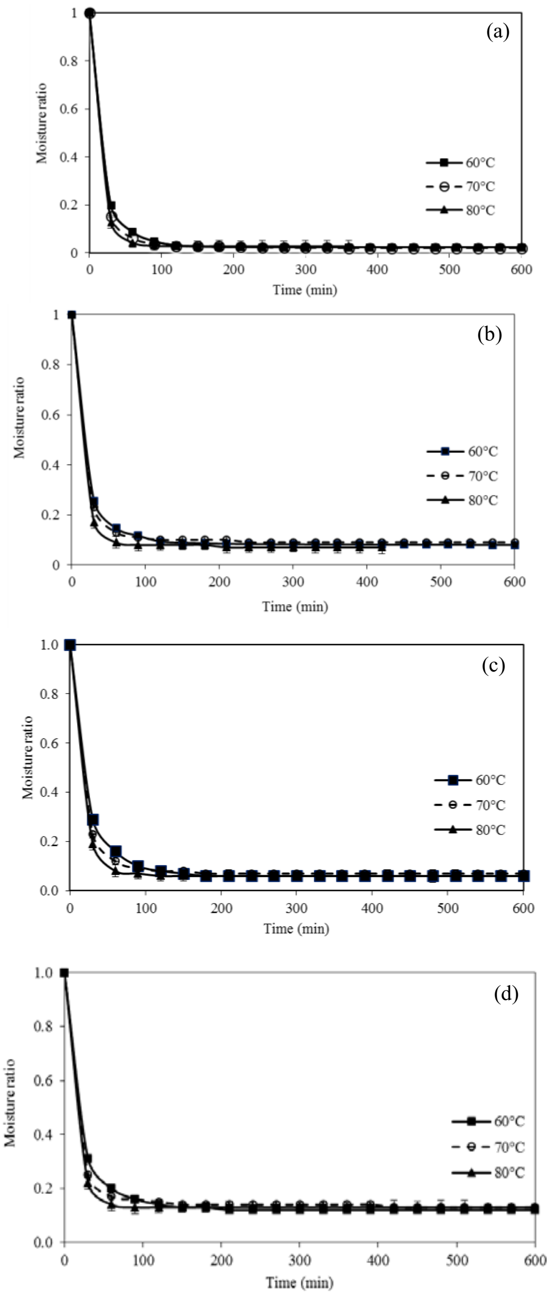

Figure 1. Drying curves of (a) unpretreated (b) pre-treated with 30 Brix of sucrose (c) pre-treated with 40 Brix of sucrose and (d) pre-treated with 50 Brix of sucrose samples during drying

Table 2. Time to dry samples to the final moisture content of less than 18% dry basis.

Drying temperature (°C)	Sucrose concentration (Brix)	Drying time (min)	Equilibrium moisture content (g/g d.b.)
60	0	300	0.023
	30	720	0.080
	40	690	0.089
	50	900	0.075
70	0	240	0.023
	30	540	0.093
	40	600	0.077
	50	810	0.122
80	0	210	0.028
	30	300	0.073
	40	390	0.066
	50	480	0.141

3.2. Empirical modeling of drying curves

Drying curves of the unpretreated and pre-treated pineapples under hot air at 60, 70 and 80°C were fitted with six different moisture ratio models shown in Table 1. The statistical results of the different models, including the drying model coefficients and the comparison criteria used to evaluate goodness of fit, namely, R^2, χ^2 and RSME, are summarized in Table 3. The R^2 values for the models were in the rage of 0.7507-0.9997. χ^2 values were varied between 0.0001 and 0.1081 and RMSE values between 0.122 and 0.981. By comparing the criteria values among four drying models, it can be seen that Logarithmic equation was the best descriptive model for all treatments, since it exhibited the highest average value of R^2, the lowest average values of χ^2 and RMSE. Thus, it was selected to represent the drying characteristics of pineapples.

Table 3. Statistical results obtained from different drying models.

Model	Sucrose concentration (Brix)	Temperature (°C)	Parameter	R^2	χ^2	RMSE
Newton	0	60	k = 0.0172	0.9691	0.0490	0.0668
		70	k = 0.0246	0.9536	0.0078	0.0834
		80	k = 0.0263	0.9908	0.0012	0.0325
	30	60	k = 0.0057	0.7507	0.0370	0.1884
		70	k = 0.0061	0.8451	0.0336	0.1775
		80	k = 0.0125	0.8573	0.0274	0.1578
	40	60	k = 0.0053	0.7770	0.0359	0.1855
		70	k = 0.0066	0.8565	0.0226	0.1468
		80	k = 0.0159	0.8029	0.0275	0.1597
	50	60	k = 0.0046	0.8731	0.0184	0.1334
		70	k = 0.0030	0.8528	0.0323	0.1764
		80	k = 0.0042	0.9028	0.0267	0.1587
Page	0	60	k = 0.0527, n = 0.7182	0.9888	0.0020	0.0403
		70	k = 0.1230, n = 0.5710	0.9870	0.0025	0.0442
		80	k = 0.0649, n = 0.7554	0.9967	0.0005	0.0196
	30	60	k = 0.3208, n = 0.2360	0.9880	0.0017	0.0391
		70	k = 0.3170, n = 0.2366	0.9919	0.0016	0.0379
		80	k = 0.3977, n = 0.2319	0.9932	0.0015	0.0349
	40	60	k = 0.2779, n = 0.2578	0.9879	0.0018	0.0405
		70	k = 0.0933, n = 0.4681	0.9730	0.0043	0.0627
		80	k = 0.3741, n = 0.2589	0.9870	0.0020	0.0414
	50	60	k = 0.0353, n = 0.6089	0.8958	0.0163	0.1234
		70	k = 0.1257, n = 0.3572	0.9739	0.0050	0.0679
		80	k = 0.1095, n = 0.3945	0.9800	0.0051	0.0672
Wang and Singh	0	60	k = 0.0108, n = 2.84×10^{-5}	0.9328	0.0188	0.1093
		70	k = 0.0137, n = 4.49×10^{-5}	0.9058	0.0316	0.1325
		80	k = 0.0209, n = 1.18×10^{-4}	0.9925	0.0014	0.0298
	30	60	k = 0.0039 n = 4.53×10^{-6}	0.8688	0.0331	0.1667
		70	k = 0.0065, n = 1.15×10^{-5}	0.8618	0.0318	0.1558
		80	k = 0.0093 n = 2.47×10^{-5}	0.9132	0.0317	0.1420
	40	60	k = 0.0040, n = 4.82×10^{-6}	0.8816	0.0306	0.1597
		70	k = 0.0048, n = 6.45×10^{-6}	0.9195	0.0170	0.1273
		80	k = 0.0077, n = 1.60×10^{-5}	0.8611	0.0184	0.1663
	50	60	k = 0.0032, n = 2.94×10^{-6}	0.9185	0.0170	0.1216
		70	k = 0.0033, n = 2.95×10^{-6}	0.9230	0.0213	0.1351
		80	k = 0.0077, n = 1.60×10^{-5}	0.9072	0.0334	0.1598
Logarithmic	0	60	k = 0.9172, a = 121.16, c = 0.2513	0.8735	0.0320	0.1527
		70	k = 1.0168, a = 158.43, c = 0.1637	0.9249	0.0207	0.1175
		80	k = 1.0356, a = 443.81, c = 0.1621	0.9271	0.0146	0.1032
	30	60	k = 0.7307, a = 0.0268, c = 0.2677	0.9998	0.0001	0.0053
		70	k = 0.6968, a = 0.0328, c = 0.3032	0.9997	0.0001	0.0106
		80	k = 0.7395, a = 0.0438, c = 0.1621	0.9991	0.0003	0.0151
	40	60	k = 0.7228, a = 0.0249, c = 0.2750	0.9998	0.0000	0.0053
		70	k = 0.7806, a = 0.0164, c = 0.2326	0.9981	0.0003	0.0167

		80	k = 0.7395, a = 0.0438, c = 0.1621	0.9991	0.0003	0.0151
	50	60	k = 0.8355, a = 0.0092, c = 0.2015	0.9922	0.0012	0.0330
		70	k = 0.7032, a = 0.0152, c = 0.3194	0.9968	0.0006	0.0237
		80	k = 0.6720, a = 0.0190, c = 0.3479	0.9962	0.0010	0.0291
Henderson and pabis	0	60	k = 0.9915, a = 0.0169	0.9696	0.0054	0.0662
		70	k = 0.9950, a = 0.0244	0.9538	0.0089	0.0832
		80	k = 0.9974, a = 0.0262	0.9027	0.0231	0.1373
	30	60	k = 0.7369, a = 0.0029	0.8584	0.0208	0.1385
		70	k = 0.8057, a = 0.0042	0.8854	0.0231	0.1423
		80	k = 0.9115, a = 0.0101	0.8742	0.0260	0.1459
	40	60	k = 0.7479, a = 0.0029	0.8707	0.0203	0.1363
		70	k = 0.8793, a = 0.0050	0.8870	0.0183	0.1288
		80	k = 0.9438, a = 0.0135	0.8149	0.0278	0.1543
	50	60	k = 0.9248, a = 0.0039	0.8875	0.0167	0.1250
		70	k = 0.7610, a = 0.0019	0.9082	0.0182	0.1301
		80	k = 0.8322, a = 0.0030	0.9298	0.0185	0.1277
Modified Page	0	60	k = 0.0166, n = 0.7182	0.9643	0.0092	0.0866
		70	k = 0.0254, n = 0.5710	0.9375	0.0170	0.1150
		80	k = 0.0267, n = 0.7554	0.9849	0.0025	0.0452
	30	60	k = 0.0081, n = 0.2360	0.8836	0.0871	0.2831
		70	k = 0.0077, n = 0.2366	0.8886	0.1402	0.3502
		80	k = 0.0187, n = 0.2319	0.8671	0.0846	0.2656
	40	60	k = 0.0069, n = 0.2578	0.8951	0.0925	0.2912
		70	k = 0.0063, n = 0.4681	0.9039	0.0487	0.2098
		80	k = 0.0224, n = 0.2589	0.8461	0.0537	0.0537
	50	60	k = 0.0041, n = 0.6089	0.9012	0.0314	0.1714
		70	k = 0.0030, n = 0.3572	0.9169	0.1074	0.3158
		80	k = 0.0036, n = 0.3945	0.9267	0.1081	0.3089

4 Conclusion

The experiments were performed to determine drying characteristics of unpretreated pineapple and pre-treated pineapple with sucrose solution at 30, 40 and 50 Brix. It was evidenced that higher drying temperature resulted in shorter drying time since moisture diffusivity values and larger driving force for heat and mass transfer were larger at higher drying temperatures Increase in sucrose concentration resulted in longer drying time. Different mathematical models were also determined with the drying behavior of pineapples. The results indicated that the Logarithmic model could present better predictions for the moisture transfer than others. Studies on physical and nutritional properties of the pineapple after pre-treatment and drying are suggested as a future work.

Acknowledgement

The authors express their sincere appreciation to Upper Northen Research Administration network for supporting the study financially and Faculty of Engineering and Agro-Industry, Maejo University for laboratory equipment.

References

1. S. W. Wijeratnam, Ref. Modul. Food Sci. Ency. Food Health **380-384** (2015)
2. D. I. S. da Silva, G. D. R. Nogueira, A. G. Duzzioni, M. A. S. Barrozo, *Indus. Crop. Product.* **50** (2013)
3. S. Chen, B. Mulgrew, and P. M. Grant, IEEE Trans. on Neural Network. **4** (1993)
4. M. K. Krokida, V. T. Karathanos, Z. B. Maroulis, D. Marinos-Kouris, J. Food Eng. **59** (2002).
5. G. E. Lombard, J. C. Oliveira, P. Fito, A. Andre´s, J. Food Eng. **85** (2008)
6. G. Cortellino, P. Pani, D. Torreggiani, *Procedia Food Sci.*, **1** (2011)
7. Association of Official Analytical Chemists (AOAC), *Official methods of analysis*, 15th ed., The Association of Official Analytical Chemists: Washington D.C (1995).
8. I. Ceylan, M. Aktas, H. Dogan, *Appl. Themal. Eng.* **27** (2007)
9. M. Rasouli, S. Seiiedlou, H. R. Ghasemzadeh, H. Nalbandi,. Austra. J. Agri. Eng. **2** (2011)
10. C. Y. Wang, R. P. Singh. ASAE, (1978)
11. M. A. Basunia, T. Abe, J. Food Eng. **47** (2001)
12. Z. Wang, J. Sun, X. Liao, F. Chen, G. Zhao, Food Res. Inter. **40** (2007)