JOURNAL OF AGROBIOTECHNOLOGY 2021, VOL 12(1S):112-123
e-ISSN: 2180-1983
http://dx.doi.org/10.37231/jab.2021.12.1S.276
https://journal.unisza.edu.my/agrobiotechnology/index.php/agrobiotechnology/index

The Influence of Drying Temperatures and Methods on the Drying Characteristics of 'IkanBakar' Paste

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ABSTRACT

Drying is one of the popular preservation methods in food products. This work was done to investigate the influence of the drying temperatures and methods on the drying characteristics of 'ikanbakar' paste. The 'ikanbakar' paste was dried by using oven drying and vacuum drying methods at temperatures of 50°C, 60°C and 70°C. The drying rate was estimated from the moisture content and drying time data. The drying curve showed the falling rate period as the drying rate decreased with increasing time. For colour analysis of the paste, the L* values from the oven drying method were lower than those from the vacuum drying method, ranging from 7.4210 to 7.2752. This showed that the colour of paste from oven drying was darker than vacuum drying. The mathematical models used to describe the drying curve of 'ikanbakar' paste were Lewis, Page, Two-term, and Midilliet. al. model. The performance of these models was evaluated by comparing their root mean square error (RSME) and chi-square (X^2) values, and it was found that the most suitable model was the Two-term model. There were insignificant differences between the effective moisture diffusivity (D_{eff}) values for the 'ikanbakar' paste in both drying methods.

Keywords: Drying characteristics, mathematical modelling, 'ikanbakar' paste, colour, effective diffusivity

INTRODUCTION

Drying is famous in the food industry for preserving food products by increasing the shelf life of the products. Drying is a process that can decrease the amount of moisture content and the presence of microorganisms in food products during storage. One of the famous methods used today for drying food products is hot air drying, which also known as a convective hot air drying. This method showed the effect on the speediness, the weight and volume decreases, producing high capacity, and cutting down cost of packing, storage and transportation (Naderinezhad et al., 2016). Therefore, to maintain the quality of the products, the drying process is used to inhibit the growth and multiplication of bacteria (Doymaz, 2011). Other than that, vacuum drying is also being used in food industry nowadays. The advantage of vacuum drying is it is very for efficient heat sensitive products. For food products, it will become valuable because it does not degrade the quality of the product by damaging with heat. Besides, the vacuum drying tends to work faster than other drying method as the average drying temperature is low (Parikh, 2015).

‘IkanBakar’ paste is quite popular in Malaysia. According to The Spruce Eats by (Veneracion, 2019), the ‘ikanbakar’ is known as charcoal-grilled fish in Malaysia and Indonesia. The fish is flavoured with a spice paste and then covered in banana leaves before being placed on the hot grill (Veneracion, 2019). The ‘ikanbakar’ paste contains a high amount of moisture content. Higher amounts of water content may cause the growth of microbes and finally make the food easy to deteriorate.

Several research have already been conducted regarding the drying process on food products such as tomato paste (Sramek et al., 2015), okra (Doymaz, 2005), oyster mushrooms (Tulek, 2011)and Thai red curry paste (Inchuen et al., 2010).Doymaz (2005) conducted an experiment of drying okrain a laboratory scale hot-air dryer. The drying temperatures were 50°C, 60°C and 70°C. After drying process, the moisture content decreased to 15±0.3% w.b. and the sample was cooled for 10 minutes and kept in air glass jars. Increasing drying temperature resulted in an increase of drying rate, thus the drying time decreased. Doymaz concluded that the times taken decreased as higher temperatures were used during the process and the Page model was chosen as the suitable mathematical model that describes the drying curve of the sample rather than the simple exponential model (Doymaz, 2005).

Tulek (2011)used oyster mushroom as the sample for the drying experiment. The oyster mushroomswere dried in a cabinet laboratory type dryer at different temperatures which were 50°C, 60°C and 70°C. The air velocity of the dryer was constant at $0.2ms^{-1}$ and the measured relative humidity was 19% to 21%. The drying rate decreased continuously with time and with decreasing moisture content. As drying time increased, the amount of moisture content in the sample decreased. Then, the drying time which needs to reduce the moisture content is depend on the drying temperature. Hence, an increase in drying temperature can reduce the drying time. For mathematical model, the most suitable model is Midilli model because it yielded the highest R^2 values for all drying temperature among 7 other models which are Lewis, Page, Modified Page, Henderson and Pabis, Logarithmic, Two-term, and Midilli et.al. model (Tulek, 2011).

The aims of this study are to evaluate the effect of drying temperatures and methods on the colour changes and moisture content of dried ‘ikanbakar’ paste, then, to calculate the effective moisture diffusivity for the drying process of the ikanbakar paste. Additionally, the suitable mathematical drying model that can describes the drying curve of the paste also will be determined. To increase the shelf life of the food products in paste form, the moisture content need to be removed or lowered. Thus, it could increase the availability of the products in market or store at home in longer time than in its original form which is paste.

MATERIALS AND METHODS

Sample

The sample of ‘ikanbakar’ paste from Adabi’s brand was purchased from Matt Mart market in Besut, Terengganu. This paste was stored at dry place and under room temperature before further analysis.

Drying procedure

An oven dryer was used to dry the ‘ikanbakar’ paste operated at air temperature of 50°C, 60°C, and 70°C. The amount of paste used for each temperature was 60g. First, the oven dryer (Memmert Oven, Germany) was preheated to the desired drying temperatures which are 50°C, 60°C, and 70°C. Then, the ‘ikanbakar’ pastes that were already spread on the stainless-steel mesh tray were placed into the oven dryer. The moisture loss was calculated by weighing in an electronic weighing balance at specific time intervals. The samples were weighed at every 15 minutes during the 1 hour of drying and every 30 minutes for another 2 hours. After that, the sample was put into the oven dryer as soon as possible. The drying was continued until they reached the equilibrium moisture content (after 24 hours). After that, the steps were repeated using vacuum dryer (Memmert Vacuum Dryer, Germany). The operating pressure was 200mbar for each drying temperature (Sramek et al., 2015).

Determination of moisture content

After drying, the sample was weighed to calculate the amount of moisture content. The differences of weight of sample before drying and after drying were calculated to determine the moisture content in the sample. Moisture ratio is the ratio of the moisture content in the samples. The moisture ratio during this analysis was calculated using following equation:

$$MR = (M - M_e)/(M_0 - M_e) \quad \textbf{Eqn. 1}$$

where M is the moisture content at any time, M_0 is the initial moisture content, and M_e is equilibrium moisture content and can be neglected or assume as zero. The drying rates were calculated using the Eqn. 2:

$$\text{Drying rate} = (\quad M_t - \quad)/dt \quad \textbf{Eqn. 2}$$

where and M_t are moisture content at t and moisture content at t+dt, respectively, and t is drying time in minute.

Determination of colour

Colour measurement was performed using chromameter Konica Minolta, Model CR-400 for each sample before and after drying for every 30 minutes until 180 minutes. The colour meter was calibrated before starting the analysis, against a standard calibration plate of a white surface (Inchuen et al., 2010).

Statistical analysis

The data collection of drying rate and colour measurement was carried out in triplicate for each temperature and the average value was used. All of the data obtained in this study was analysed and tested using Solver in Microsoft Office Excel and analysis of variance (ANOVA) in SPSS software. The effective moisture diffusivity D was calculated using this equation:

$$D = - \frac{k}{\quad} \quad \textbf{Eqn. 3}$$

where k_1 is the slop of the graph and L is the half thickness of the sample slab (m).

Mathematical modelling for drying curves

There are several mathematical models available in the literature that can be used to describe the drying curve of the ‘ikanbakar’ paste. Table 1 shows the selected models that were used to describe the drying curves of the ‘ikanbakar’ paste. Nonlinear least-squares curve fitting analysis was performed to evaluate the constant parameters in each model using Solveranalysis tool in Microsoft Office Excel.

Table 1: Selected single layer drying models for describing ‘ikanbakar’ paste drying data

Model name	Model	References
Lewis	$MR=exp(-kt)$	Macedo et al.(2020)
Page	$MR=exp(-kt^n)$	Giri& Prasad(2007)
Two-term	$MR=aexp(-k_0t)+(b)exp(-k_1t)$	Mahjoorian et al.(2016)
Midili et. al.	$MR=aexp(-kt^n)+bt$	Drier et al.(2020)

where the a, b, k, k_0 and n are the constant parameters

RESULTS AND DISCUSSION

Moisture content

Moisture content is the amount of water left inside the 'ikanbakar' paste after drying process. The effect of three temperatures on the drying curve of 'ikanbakar' paste is shown in Fig 1 and 2.

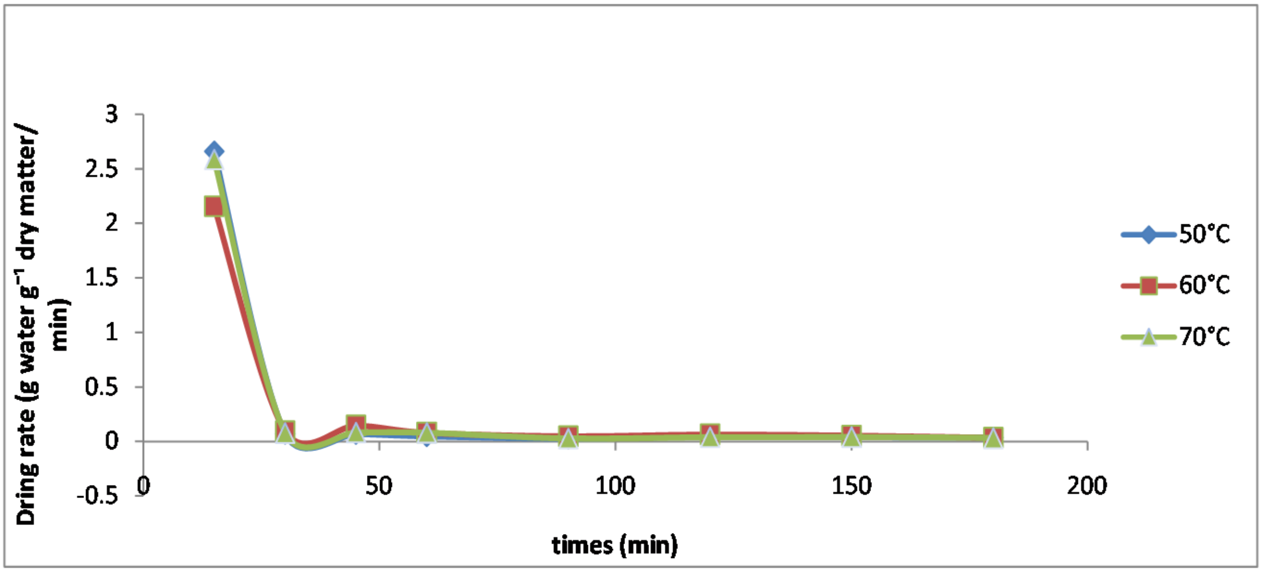

Fig1: Drying curve of 'ikanbakar' paste at different temperature using oven dryer

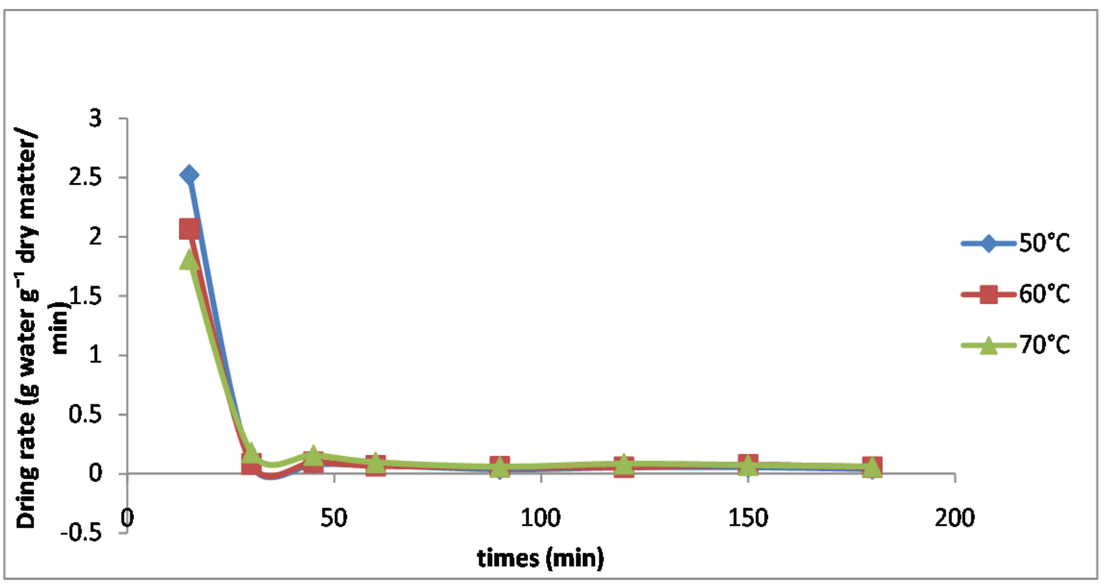

Fig2: Drying curve of 'ikanbakar' paste at different temperature using vacuum dryer

It is obvious that the drying rate was decreased by time. The calculated drying rate of the 'ikanbakar' paste was 2.6610, 2.1584, and 2.5871 g water g^{-1}dry matter/min in the earlier drying time, which is at 15 min. However, at the final stages of drying time, the drying rate was decreased to the value of 0.0361, 0.0353, 0.0334 g water g^{-1} dry matter/min at 50°C, 60°C and 70°C of oven drying method, respectively. The decrease in drying rate was influenced by the drying times. If the drying rate increases, the amount of moisture that is removed from the sample also increases (Tekin et al., 2017).

For the vacuum drying method, the drying rate of 'ikanbakar' paste at 15 min was 2.5240, 2.0663, and 1.8106 g water g^{-1} dry matter/min while the drying rate at final stages was 0.0398, 0.0565 and 0.0602 g water g^{-1} dry matter/min at 50°C, 60°C and 70°C. Both graphs showed that all the drying of 'ikanbakar' paste takes place in the falling rate period which is due to diffusion controlled mechanism inside the paste, and there is no constant rate period. No constant rate period during hot-air drying may be caused by the surface of the products dried rapidly and causing 'case hardening', where the free moisture movement is resisted (Zhao et al., 2014). The lack of a constant rate period can be caused by the changes in the internal moisture and surface changes due to the sample shrinkage during the process of drying (Naderinezhad et al., 2016).

According to Torki-Harchegani et al.(2016), in the falling rate period, the molecular diffusion was controlling the water migration from the interior product to the surface of the product, and the water moves from zones with higher moisture content to zones with lower moisture content. This called a phenomenon that explained by the second law of thermodynamics (Torki-Harchegani et al., 2015, 2016)

Drying rate is decreased when the drying time increases due to the reduction of mass transfer from the interior to the surface of the sample (Tekin et al., 2017). From the result, the drying rates of temperature 50°C, 60°C and 70°C at 15min from the oven dryer were higher than those from the vacuum dryer. The difference in initial drying rate at 70°C can be clearly seen between oven and vacuum drying compared to the other drying temperature. The advantages of vacuum drying are that it can lower the boiling point temperature of water and increase the rate of evaporation (Cheenkachorn et al., 2012). Thus, the rate of evaporation of drying methods can influence the drying rate.The effective moisture diffusivity of 'ikanbakar' paste was obtained from the gradient of the graph of ln(MR) versus drying time.

Table 2: Result of k and D_{eff} values for oven and vacuum drying methods

Temperature/method	k (min^{-1})	D_{eff} (m^{2}s^{-1})	R^2
Oven drying			
50°C	-0.0157	1.0191 x 10^{-05}	0.8147
60°C	-0.0154	9.9964 x 10^{-06}	0.9015
70°C	-0.0160	1.0386 x 10^{-05}	0.8361
Vacuum drying			
50°C	-0.0165	1.0710 x 10^{-05}	0.8684
60°C	-0.0147	9.5420 x 10^{-06}	0.8865
70°C	-0.0146	9.4771 x 10^{-06}	0.9275

The D values from oven drying method have almost the same values for the drying temperature 50°C and 60°C, and it only slightly increased at 70°C. In oven drying, the molecules of water are loosely bound to the food materials at high temperature, thus needing less energy to remove than at lower temperature (Touil et al., 2014). According to Doymaz(2011), the increase of D was affected by the increase in heat transfer potential between sample and drying air. Therefore, it can raise the evaporation of water from the product (Doymaz, 2011). High temperature also reduced water viscosity and subsequently resistance to fluid out-flow diffusion. This phenomenon causes water molecules to diffuse more easily in product capillaries, thus increasing moisture diffusivity value (Torki-Harchegani et al., 2016).

Colour properties

Table 3: Colour properties for each L*, a* and b* for oven drying and vacuum drying

Drying method	Colour		
	L*	a*	b*
Oven drying			
50°C	7.4210 ± 2.8622[b]	8.5252 ± 1.4998[b]	6.2490 ± 2.1568[ab]
60°C	7.1290 ± 2.4566[b]	8.3910 ± 1.9903[bc]	6.0767 ± 2.9367[ab]
70°C	7.2752 ± 3.6724[b]	8.3762 ± 1.3343[bc]	5.8571 ± 1.9364[ab]
Vacuum drying			
50°C	11.3771 ± 1.6092[a]	7.3171 ± 2.4752[ac]	5.6238 ± 2.6043[ab]
60°C	8.2176 ± 2.2669[b]	9.4443 ± 2.0034[b]	7.1505 ± 2.7355[a]
70°C	11.0924 ± 2.1995[a]	6.8462 ± 1.0710[a]	4.9181 ± 0.8947[a]

Means (± standard deviation) with different superscripts in each column are significantly different ($P<0.005$).

Table 3 displays the result of colour properties for drying process of 'ikanbakar' paste. The chromameter shows the three values which are L*, a* and b*. L* value measures the lightness, a* measures red when positive and green when negative, and b* measures yellow when positive and blue when negative (Deng et al., 2018).The L* value is in the range of 7.1290 to 11.3771, while a* value in the range of 6.8462 to 9.4443, and b* value in the range of 4.9181 to 7.1505. The value of L*, a* and b* were affected by the drying method. The L* value from the oven drying method were lower than the value from the vacuum drying method. The lower the L* value is the darker the sample becomes. Therefore, the dried 'ikanbakar' paste from oven drying is darker than vacuum drying. The darker and redder of the sample indicates that the sample browned more while less yellow colour could indicate that pigment destruction occurred (Inchuen et al., 2010). Colour influences the choices and preferences of consumers and also one of the important quality attributes of food (Deng et al., 2018). From the result, the colour of 'ikanbakar' paste at temperature 50°C and 70°C from vacuum drying is less dark and less redness than oven drying. This is due to the L* values from the vacuum drying were higher and a* values from the vacuum drying were lower than those from the oven drying method.

Modelling

The drying curves obtained from the moisture content of 'ikanbakar' paste versus time, were fitted to four different mathematical models which are Lewis, Page, Two-term and Midili et. al. The results in Table 4 and 5 show the values of RMSE and X^2 of the four types of models for oven and vacuum drying, respectively.

Table 4: The values of RMSE and X^2 of four models from oven drying

Models/temperature	RMSE	X^2
Lewis		
50°C	0.0760	0.0058
60°C	0.0286	0.0008
70°C	0.0614	0.0038
Page		
50°C	0.0413	0.0017
60°C	0.0267	0.0007
70°C	0.0318	0.0010

Two-term		
50°C	0.0285	0.0008
60°C	0.0241	0.0006
70°C	0.0226	0.0005
Midilli et. al.		
50°C	0.3620	0.1310
60°C	0.4266	0.1820
70°C	0.3671	0.1348

Table 5: The values of RMSE and X^2 of four models from vacuum drying

Models/temperature	RMSE	X^2
Lewis		
50°C	0.0383	0.0015
60°C	0.0538	0.0029
70°C	0.0576	0.0033
Page		
50°C	0.0359	0.0013
60°C	0.0464	0.0022
70°C	0.0337	0.0011
Two-term		
50°C	0.0382	0.0015
60°C	0.0378	0.0014
70°C	0.033276	0.0011
Midilli et. al.		
50°C	0.4655	0.2167
60°C	0.4180	0.1747
70°C	0.5163	0.2665

From the result, the Two-term model has the smallest values of RMSE and X^2 among the four models. According to Tulek(2011), the reduced chi-square (X^2) and root mean square error (RMSE) can be used to determine the most suitable model. It is better if the calculated reduced X^2 values are close to zero (Tulek, 2011).

Table 6: Result of fitting Two-term model for oven drying method

Model/ Parameters	50°C	60°C	70°C
Two-term model			
a	0.3865	0.4755	0.4039
k_0	0.0098	0.0113	0.0108
b	0.3865	0.4754	0.4039
k_1	0.0098	0.0113	0.0108
RMSE	0.0285	0.0241	0.0226
X^2	0.0008	0.0006	0.0005

Table 7: Result of fitting Two-term model for vacuum drying method

Model/ Parameters	50°C	60°C	70°C
Two-term model			
a	0.5050	0.4426	0.5700
k_0	0.0106	0.0097	0.0110
b	0.5050	0.4426	0.5700
k_1	0.0106	0.0097	0.0110
RMSE	0.0382	0.0378	0.0333
X^2	0.0015	0.0014	0.0011

Overall, the Two-term model can be used to evaluate the drying curve for both oven drying and vacuum drying methods. Although the values of RMSE and X^2 from vacuum drying method was only slightly higher than those from oven drying method. Table 6 and 7 present the obtained parameters of the Two-term model from the fitting analysis. While Fig. 3, 4 and 5show the fitting model of the experimental data at temperatures of 50°C, 60°C, and 70°C for the oven drying method.

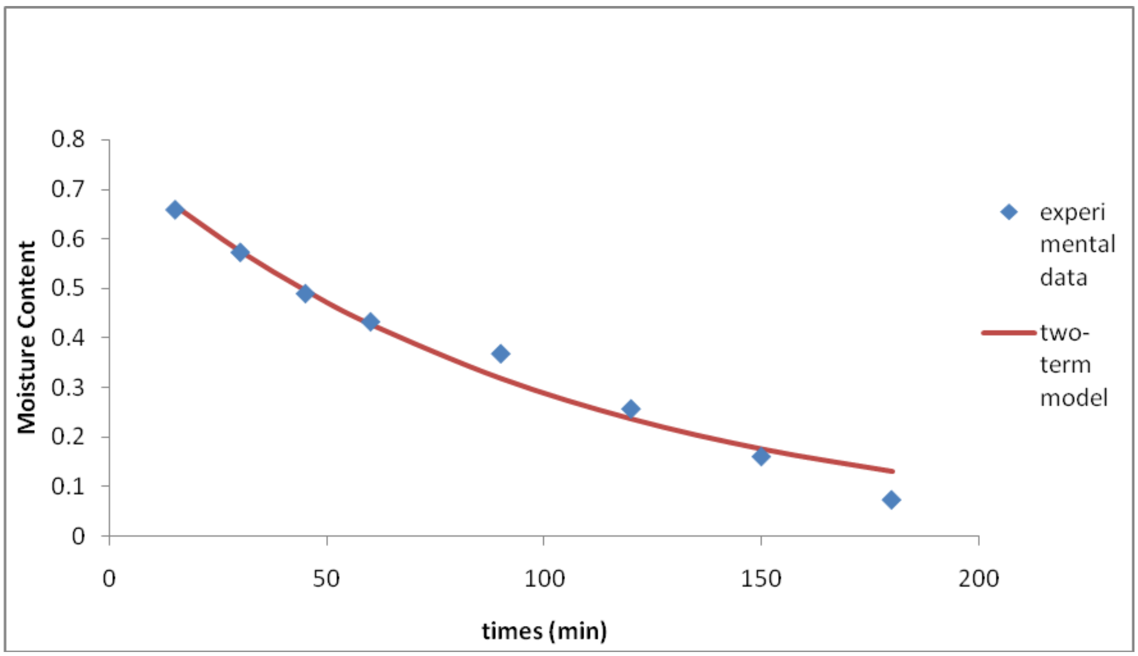

Fig3: Graph of moisture content of experimental data and Two-term model versus time at 50°C

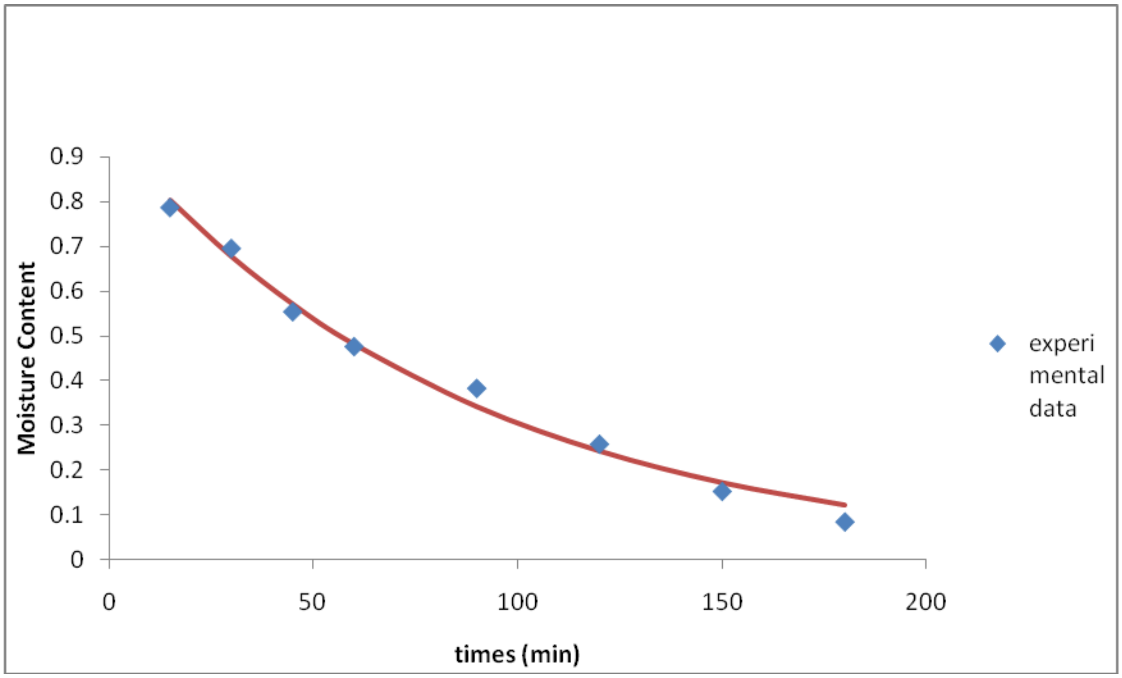

Fig4: Graph of moisture content of experimental data and Two-term model versus times at 60°C

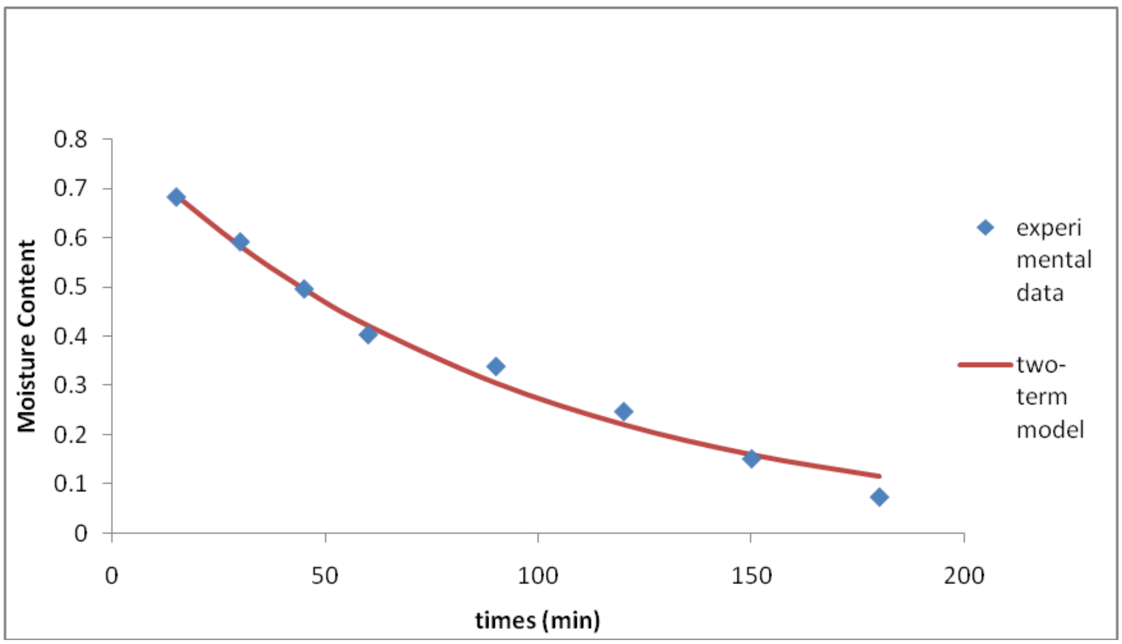

Fig5: Graph of moisture content of experimental data and Two-term model versus times at 70°C

CONCLUSION

Drying characteristics of 'ikanbakar' paste were investigated in oven drying and vacuum drying methods at temperature 50°C, 60°C, and 70°C. The drying rate decreased as the time increased. Low value of drying rate showed that the amount of moisture content after drying decreased. The drying rate of 'ikanbakar' paste for 50°C, 60°C and 70°C showed the falling rate period.The values of effective moisture diffusivity(D) for oven drying at 50°C, 60°C and 70°C were almost the same. The D value at 70°C from vacuum drying method was the lowest value which is around 9.477 x 10^{-06} m^2s^{-1}. The darkness of the 'ikanbakar' paste depended on the values of L*. The colour of paste from oven drying was darker than that of the vacuum drying since its L* value was low. In order to describe the drying curves of 'ikanbakar' paste, four mathematical models were compared based on their values of RMSE and chi-square (X^2). Thus, the most suitable drying model was Two-term model which has the lowest values of the RMSE and chi-square.

ACKNOWLEDGMENTS

The author is very appreciative to the supervisor, Mr Mohd Tarmizan bin Ibrahim for his guidance, suggestions and contributions, and also laboratory staffs, family, and friends for their cooperation in order to finish this work.

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How to cite this paper:
Che Ku Azman, C.K.N.A.M. & Ibrahim, M.T. (2021). The Influence of Drying Temperatures and Methods on the Drying Characteristics of 'IkanBakar' Paste. *Journal of Agrobiotechnology, 12*(1S), 112-123

APPENDIX

Table 8: Moisture content for each temperature for oven drying method

Time(min)	50°C	60°C	70°C
Initial moisture (g)	60.50	60.09	60.51
0	3.87	2.88	3.69
15	0.66	0.79	0.68
30	0.57	0.70	0.59
45	0.49	0.56	0.50
60	0.43	0.48	0.40
90	0.37	0.38	0.34
120	0.26	0.26	0.25
150	0.16	0.15	0.15
180	0.07	0.08	0.07

Table 9: Moisture content for each temperature for vacuum drying method

Time(min)	50°C	60°C	70°C
Initial moisture (g)	60.26	60.29	60.26
0	3.94	2.58	2.59
15	0.84	0.78	0.97
30	0.74	0.66	0.81
45	0.63	0.58	0.67
60	0.54	0.52	0.59
90	0.45	0.41	0.48
120	0.31	0.31	0.33
150	0.17	0.18	0.20
180	0.07	0.08	0.10