The Pharma Innovation Journal 2023; 12(12): 3642-3650

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(12): 3642-3650

www.thepharmajournal.com
Received: 01-09-2023
Accepted: 04-10-2023

Drying characteristics and mathematical modelling of blanched turmeric rhizomes (*var*. Salem) influenced by drying temperature and blanching time

Ravina Parmar, Brijesh Khanpara, Nirav Joshi and Mukesh Dabhi

Ravina Parmar
Ph.D. Scholar, Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Anand Agricultural University, Godhra, Gujarat, India

Brijesh Khanpara
Ph.D. Scholar, Department of Farm Machinery and Power Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University Junagadh, Gujarat, India

Nirav Joshi
Assistant Professor, College of Food Technology, SDAU, Sardarkrushinagar, Gujarat, India

Mukesh Dabhi
Professor and Head, Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh, Gujarat, India

Corresponding Author:
Ravina Parmar
Ph.D. Scholar, Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Anand Agricultural University, Godhra, Gujarat, India

Abstract

Blanching and drying are two major post-harvest operations which influence the quality characteristics of turmeric (*Curcuma longa*). The objective of this study was to find the effect of four different blanching times (15, 30, 45 and 60 min) and tray drying of turmeric rhizomes (var. Salem) at three different drying temperatures (60, 70 and 80 °C) by forced air circulation. It was found that the blanching time and drying temperature significantly affected the drying time of the turmeric rhizomes. The drying process of turmeric rhizomes occurred in a falling rate period. The mathematical modelling was analysed for all twelve treatment combinations by fitting the different mathematical models based on the drying coefficient (k), root mean square error (RMSE), coefficient of regression (R^2) and the sum of chi-square (χ^2). The non-linear regression analysis was carried out on the experimental data of moisture ratio and drying time. The turmeric rhizomes blanched at 60 min and dried at 80 °C had the highest drying coefficient and the lowest drying time. The drying time of turmeric rhizomes was decreased with the increase in blanching time and drying temperature. The effective diffusivity increased as the blanching time and drying temperature increased. The effective moisture diffusivity varied from 4.68×10^{-9} to 14.77×10^{-9} m^2/s. The activation energy of turmeric rhizome was also found to increase with an increase in the blanching time. For the goodness of fit, the best suitable model for the dried turmeric rhizomes was found to be the Midilli model with the highest regression coefficient and the lowest root mean square error.

Keywords: Mathematical modelling, activation energy, effective moisture diffusivity, model fitting, moisture ratio

1. Introduction

Spices occupy an essential part of agricultural commodities being used as seasoning or condiment and for medicinal purposes. Since ancient times, India has been renowned as the "*Spice Bowl of the World*", because it cultivates a vast range of high-quality spices. Turmeric is an ancient medicinal spice derived from the rhizomes of *Curcuma longa*, a ginger family (*Zingiberaceae*) member, is also referred as "*Indian Saffron*". India is a leading producer and exporter of turmeric in the world. Turmeric (*Curcuma longa*) rhizome is a widely used food flavouring, colouring and spice additive in South-East Asian countries. Apart from flavouring food, turmeric, also known as "*Kitchen Queen*", has long been used in traditional medicine as a home remedy for a variety of ailments (Rathaur *et al*., 2012) [1]. Turmeric is known to contain a significant amount of natural antioxidants and bioactive components. Turmeric has health-promoting properties, such as anti-oxidant activities and anti-carcinogenic, being responsible for preventing cancer and cardiovascular diseases. The primary mode of international trade involves dried rhizomes due to their direct applicability as a spice and their utilization in the production of turmeric oleoresin and oil (Chumroenphat *et al*., 2021) [2].

Turmeric undergoes a comprehensive post-harvest processing sequence, including curing, drying, polishing, colouring, and rhizome grinding, before becoming a stable commodity in the market. In India, a prevalent practice involves boiling turmeric rhizomes in water or alkaline water before drying to enhance or retain colour. Boiling, a step in the post-harvest process, not only eliminates the vitality of fresh rhizomes but also eliminates raw odours, reduces drying time, and yields a uniformly coloured product. Blanching and drying are pivotal post-harvest procedures significantly shaping the quality attributes of turmeric. In India, steam boiling, especially through pressure boiling, has gained popularity as a preferred alternative to traditional water boiling, offering enhanced time and energy efficiency by preventing water vapour from escaping into the atmosphere and ensuring uniform steam distribution within the vessel. Drying stands out as a crucial technique in the realm of long-term food preservation, playing a pivotal role in preventing the growth of spoilage microorganisms, slowing enzyme activity, and mitigating moisture-related deterioration reactions. While sun drying remains the most widely used method for drying turmeric rhizomes, mechanical drying, particularly through hot air drying, addresses the limitations associated with sun drying. Achieving shorter drying times involves a combination of adjusting air flow rates and implementing a thin layer drying approach to reduce moisture migration resistance.

The main objective of this paper is to analyse the effect of different blanching times and drying temperatures on the drying characteristics for the turmeric rhizome and fit the suitable thin layer drying model for predicting the drying behaviour for the turmeric rhizome.

2. Materials and Methodology

The fresh turmeric rhizomes of *Salem* variety were procured from the local farm of the Junagadh, Gujarat. The turmeric rhizomes were blanched in an autoclave unit at 100 °C at atmospheric pressure for different times i.e., 15, 30, 45 and 60 min. The rhizomes were taken out from the autoclave and then allowed to cool at room temperature. An electric tray dryer (Khera Instruments Pvt. Ltd., India) was used for drying fresh turmeric rhizomes. The dryer consisted of a heating chamber with a thermostat-based control unit, an electrical centrifugal fan and measurement sensors. The product was spread in a thin layer on a steel perforated tray having an opening size of 0.001 × 0.001 m^2. The drying temperature was kept at 60, 70 and 80 °C. A digital balance with a measurement precision of ± 0.01 g was used for the measurement of weight loss of the sample.

2.1 Modelling of the thin-layer drying curves

In this study, the experimental drying data of turmeric rhizomes at different blanching times were fitted into different models used in thin layer drying models (Table 1). The experimental values of moisture ratio at every hour were plotted against drying time for different blanched turmeric rhizomes.

The goodness of fit of the selected mathematical models to the experimental data was evaluated with the correlation coefficient (R^2), the reduced chi-square (χ^2) and the root mean square error (RMSE). The goodness of fit will be better, if R^2 values are higher and χ^2 and RMSE values are lower (Kumar *et al*., 2012) [3]. The reduced chi-square (χ^2) and the RMSE were calculated using the following expressions:

$$\chi^2 = \frac{\sum_{i=0}^{N} (MR_{Exp,I} - MR_{Pre,i})^2}{(N-Z)} \quad (1)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=0}^{N} (MR_{Exp,i} - MR_{Pre,i})^2} \quad (2)$$

Table 1: List of drying models with references

Sr. No.	Model Name	Model	References
1	Lewis	Y = exp(-kt)	Bruce (1985) [4]
2	Page	Y = exp(-kt^n)	Page (1949) [5]
3	Henderson and Pabis	Y = a exp(-kt)	Henderson and Pabis (1961) [6]
4	Logarithmic	Y = a exp(-kt) +b	Togrul and Pehlivan (2002) [7]
5	Two Term	Y = a exp(-k_0t) +b exp(-k_1t)	Henderson (1974) [8]
6	Modified Henderson and Pabis	Y = a exp(-kt) +b exp(-gt) +c exp(-ht)	Karathanos (1999) [9]
7	Midilli	Y = a exp(-k(t^n)) +bt	Midilli *et al.* (2002) [10]
8	Two term exponential	Y = a exp(-kt) +(1-a) exp(-kat)	Verma (1985) [11]
9	Approximation of diffusion	Y = a exp(-kt) +(1-a) exp(-kbt)	Yaldiz and Ertekin (2001) [12]
10	Wang and Singh	Y=1+ at+bt^2	Wang and Singh (1978) [13]

2.2 Calculation of effective diffusivities and activation energy

For the characteristics of biological products, the falling rate period can be described by Fick's diffusion equation (Wang *et al*., 2007) [14]. This equation as solved for various geometric shaped bodies such as rectangular, spherical and cylindrical products. The following equation 3 can be applied for slab geometry by assuming equal distribution of moisture.

$$MR_i = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}t}{4L_0^2}\right) \quad (3)$$

Where, D_{eff} is the effective diffusivity (m^2/s); L_0 is the half thickness of turmeric rhizome which was taken as 0.0019 m. The equation can be written on logarithmic scale as:

$$\ln MR = \ln\frac{8}{\pi^2} - \frac{\pi^2 D_{eff}t}{4L_0^2} \quad (4)$$

Effective diffusivities for different blanching times were found by plotting the graph of moisture ration on logarithmic scale versus drying time t. The calculation of slope, k_0 and effective diffusivity was followed as:

$$\text{Slope, } k_0 = \frac{\pi^2 D_{eff}}{4L_0^2} \quad (5)$$

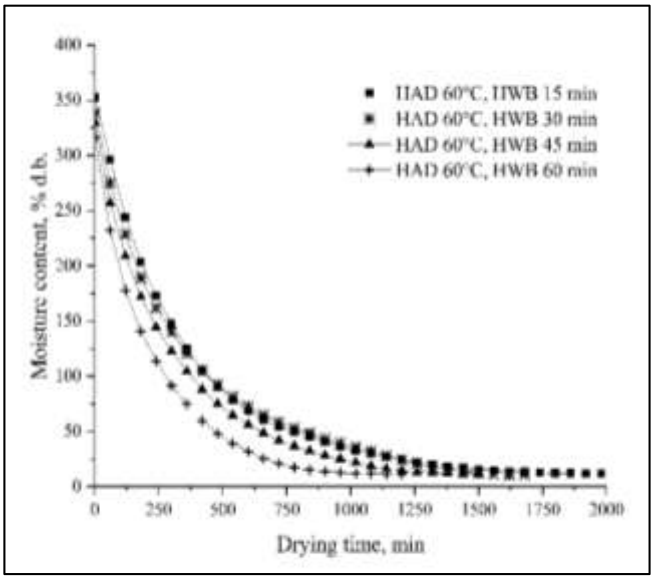
$$D_{eff} = \frac{4L_0^2 k_0}{\pi^2} \quad (6)$$

3. Results and Discussion

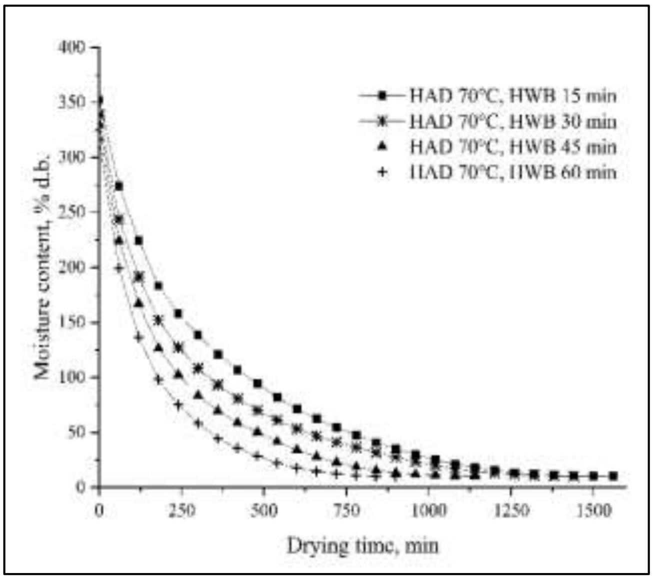
3.1 Drying characteristics of turmeric rhizomes

Moisture content of turmeric rhizomes blanched for different times and dried at different drying temperatures were recorded every hour up to constant moisture content. Comparison of moisture content with drying time (Figure 1), moisture ratio with drying time (Figure 2), drying rate with drying rate (Figure 3) and drying rate with moisture content (Figure 4) were carried out at different drying temperature and hot water blanching times.

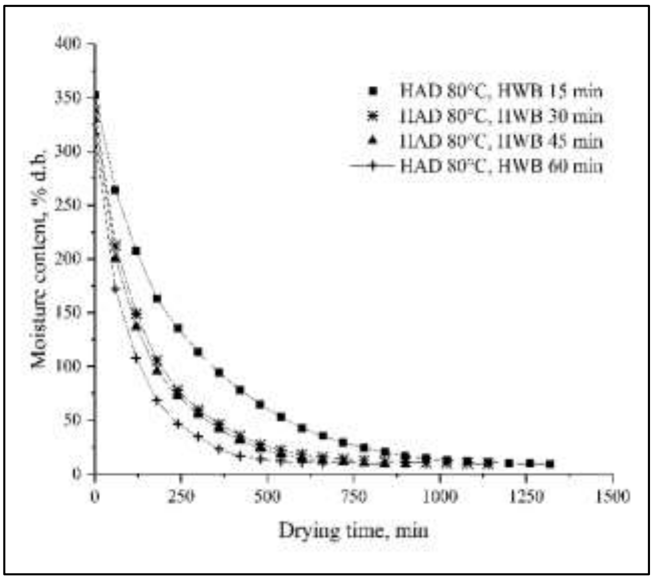
The figure 1 represents relation moistures content and drying time for all four blanching times. No constant rate drying phase was observed during the drying experiment. The turmeric rhizomes were dried to the final moisture content (d.b.) of 9.1 to 11.8%. The maximum drying time was observed 33 hours (1980 min) for turmeric rhizomes dried at 60 °C and blanched for 15 min. Increasing the blanching time from 15 to 60 min for turmeric rhizomes decreased the drying time from 1980 to 660 min, respectively. Increasing blanching time led to decrease 15.16, 24.25, 39.40% reduction in drying time at turmeric rhizomes dried at 60 °C. Subsequently, there was 21.22, 27.30, 42.43, 54.50% reduction in turmeric rhizomes dried at 70 °C. Increasing blanching time from 15 min to 60 min in dried turmeric rhizomes at 80 °C reduced 33.33%, 42.44, 54.55% and 66.65%, respectively in drying time compared to rhizomes dried at 60 °C and blanched at 15 min.



a)

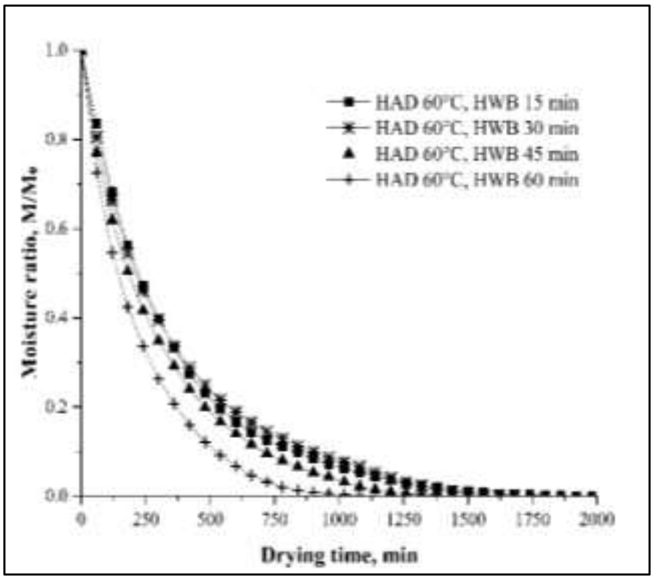


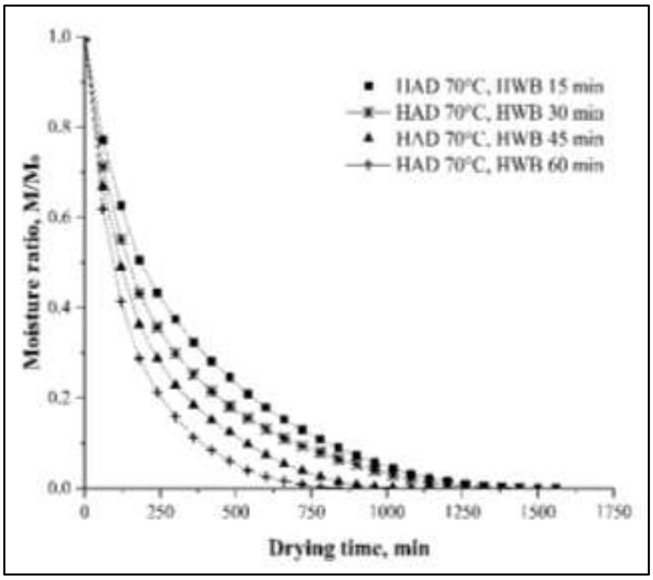
b)



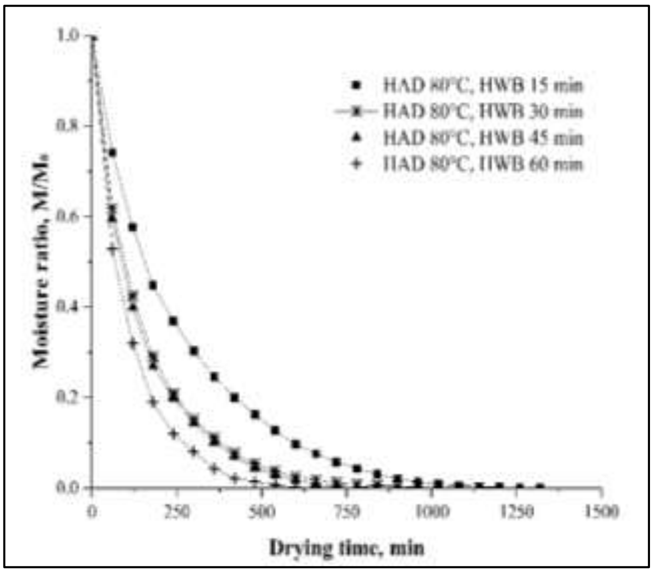
c)

Fig 1: Effect of hot water blanching times on thin layer drying curves of turmeric rhizomes at drying temperatures of a) 60 °C, b) 70 °C and c) 80 °C



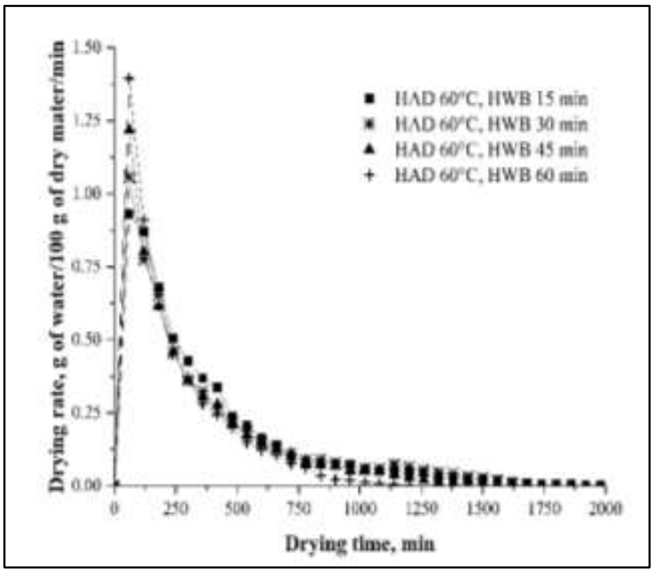


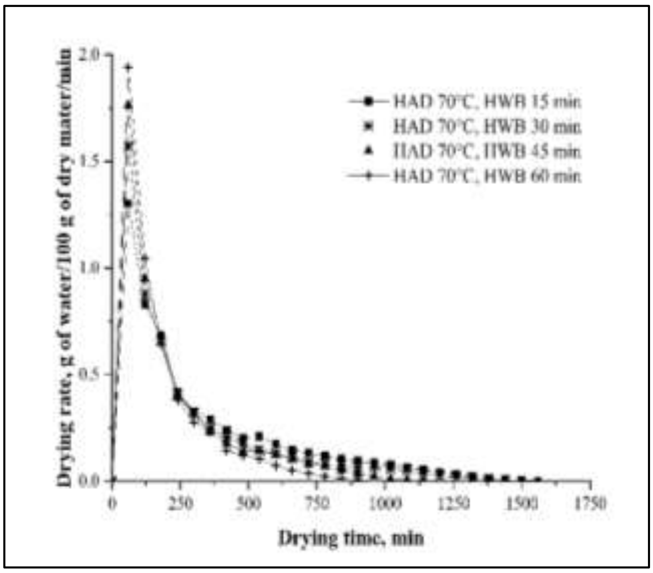
a) b)



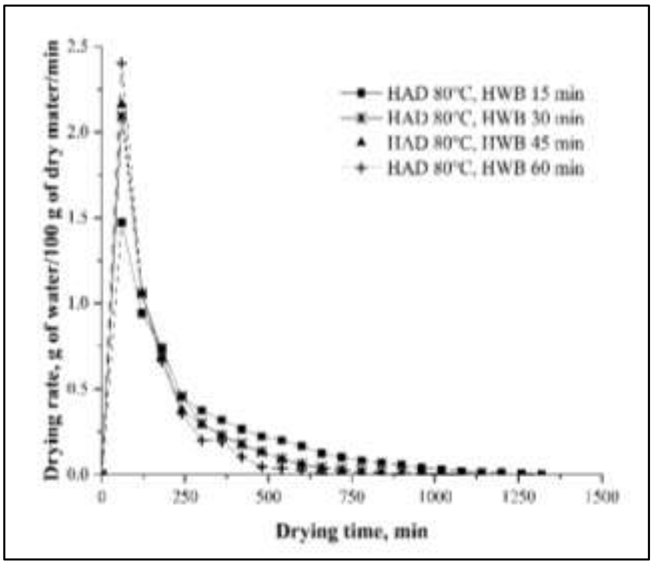
c)

Fig 2: Effect of hot water blanching times on moisture ratio of turmeric rhizomes at drying temperatures of a) 60 °C, b) 70 °C and c) 80 °C



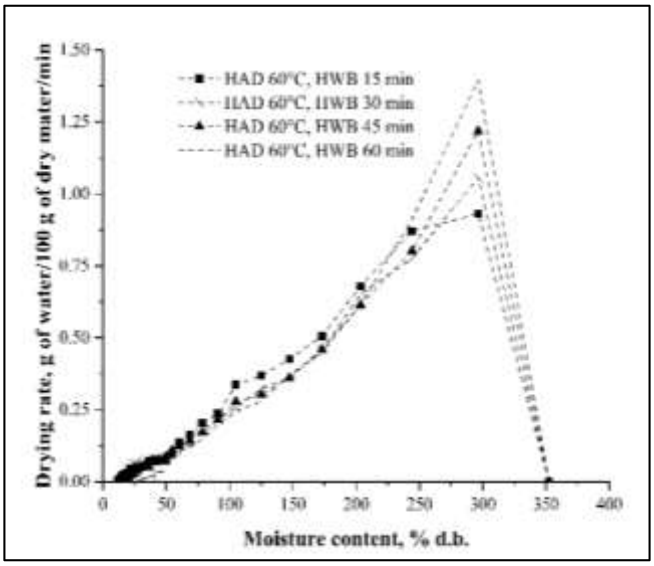


a) b)

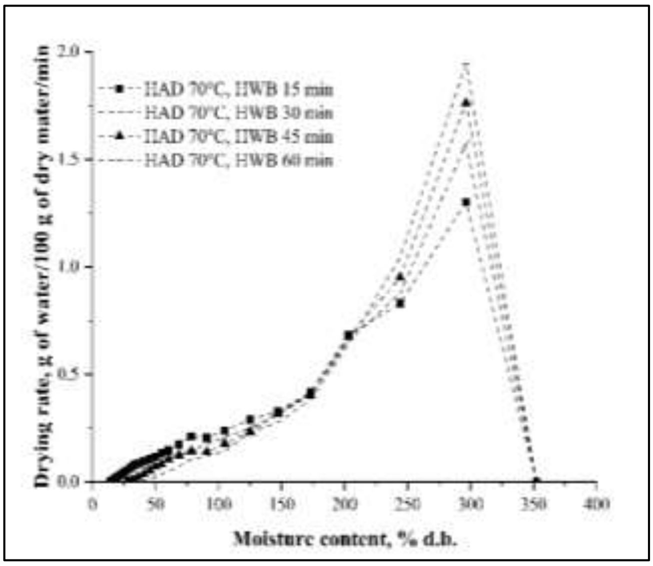


c)

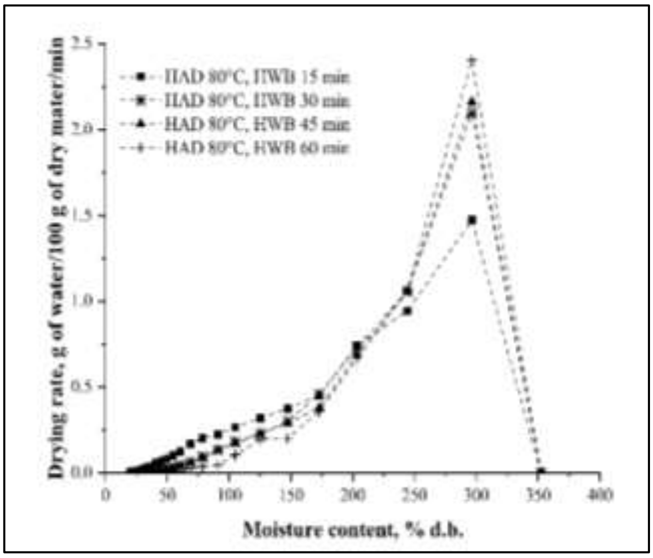
Fig 3: Effect of hot water blanching times on drying rate of turmeric rhizomes at drying temperatures of a) 60 °C, b) 70 °C and c) 80 °C



a)



b)



c)

Fig 4: Drying rate vs moisture content of turmeric rhizomes at drying temperatures of a) 60 °C, b) 70 °C and c) 80 °C

The moisture ratio of all treated samples was found to decrease at same drying time with the increase in the blanching time from 15 min to 60 min (Figure 2). Moisture ratio was decreased at same drying time with increase in drying temperature. The drying rate was also found to be increasing as the blanching time was increased. The drying rate was varied between 0.939 to 2.404 g of water/100 g of dry matter/min. The maximum drying rate was observed 2.404 g of water/100 g of dry matter/min for rhizome dried at 80 °C and blanching for 60 min. This increase in drying rate could be attributed to the samples blanched for longer duration got more thermal energy which resulted the change in internal structure due to starch gelatinization and more moisture migration.

The minimum drying time of 660 min was observed for drying the turmeric rhizomes at 80 °C with the maximum drying rate at 2.404 g of water/100 g of drying matter/drying rate among all twelve blanched dried samples.

3.2 Fitting of mathematical models

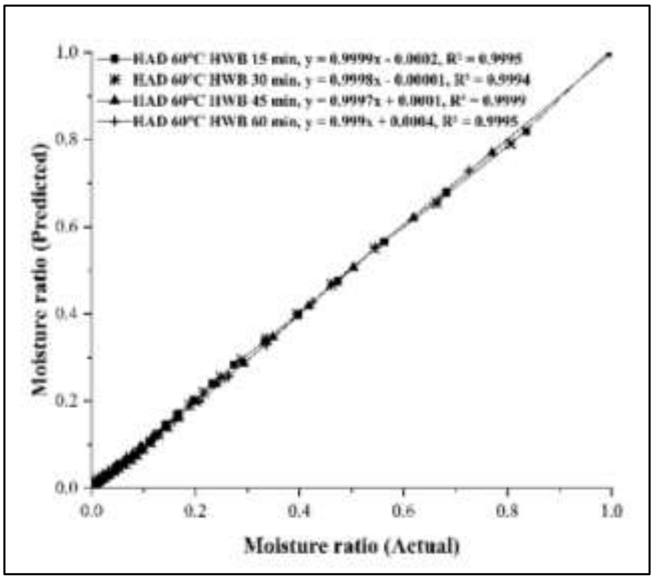
The experimental data of moisture content at one-hour interval was calculated in to moisture ratio for total drying time. These data were fitted to ten drying models given in Table 1. The different drying constants of all models presented in Table 2 for the effect of different drying temperatures and blanching times. The statistical comparison of various models for goodness of fit based on R^2, χ^2 and RSME values are also given in Table 3 for different drying temperatures and blanching times.

The Midilli, modified Henderson and Pabis and Two-term exponentials models were found to perform better than the other models with a coefficient of regression ranging from 0.9981 to 0.9999 which indicates a suitable fit. Among all the models, the Midilli model was found to be the best suitable model for fitting based on the highest R^2, the lowest χ^2 and RSME values. The residual sum of actual and predicted values of moisture ratio varied between 0.00012 to 0.00139 which was found least among all models. The predicted moisture ratio at different time intervals was fitted against the experimental data for different blanching times (Figure 5). The straight line at a 45º angle with a coefficient of regression ranging from 0.9925 to 0.9999 was found which indicates the suitability of the model in explaining the thin layer drying of turmeric rhizomes.

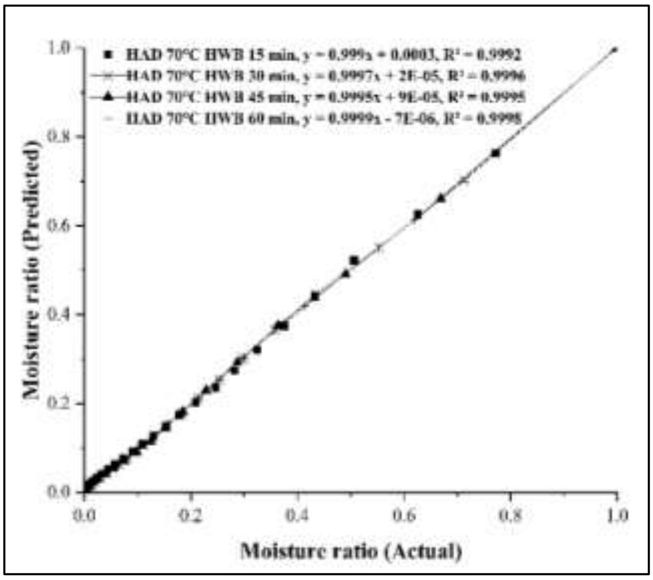
3.3 Effective diffusivity and activation energy

The effective diffusivity of turmeric rhizomes blanched at different times was calculated by plotting the relation between the moisture ratio on a logarithmic scale and drying time. The slope of the linear equation from the graph was used for the calculation of effective diffusivity. The effective diffusivity was varied between 4.82×10^{-9} to 14.77×10^{-9} m^2/s. The effective diffusivity was increased with the increase in the blanching time as well as drying temperature (Table 4). The maximum effective diffusivity was found to be 14.78×10^{-9} m^2/s for 80 °C dried turmeric rhizomes blanched for 60 min. The effective diffusivity was in the range of 10^{-11} to 10^{-9} which was similar to the various food materials (Wang *et al*., 2007) [14]. This increase in effective diffusivity could be attributed to higher thermal energy to the sample blanched for a longer period of time.

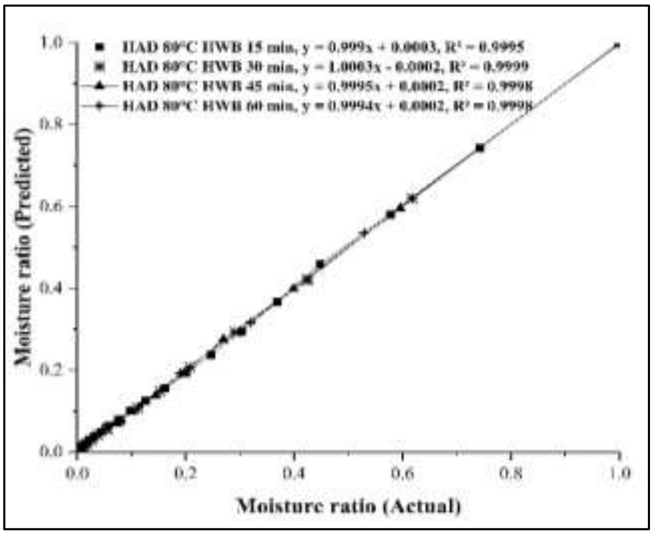
The activation energy of different blanching treatments was calculated from dividing the slope from the plot of calculated effective diffusivity on log scale and inverse of drying temperature in kelvin by the universal constant R. The activation energy was found to be 21.24, 33.06, 28.37 and 27.05 kJ/mol, respectively for sample blanched for 15, 30, 45 and 60 min. The activation energy was found to be the highest for the rhizomes treated with 30 min hot water blanching.



a)

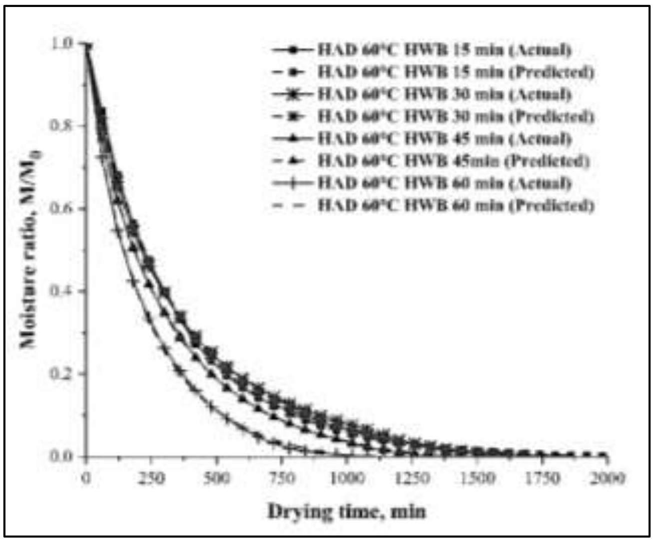


b)

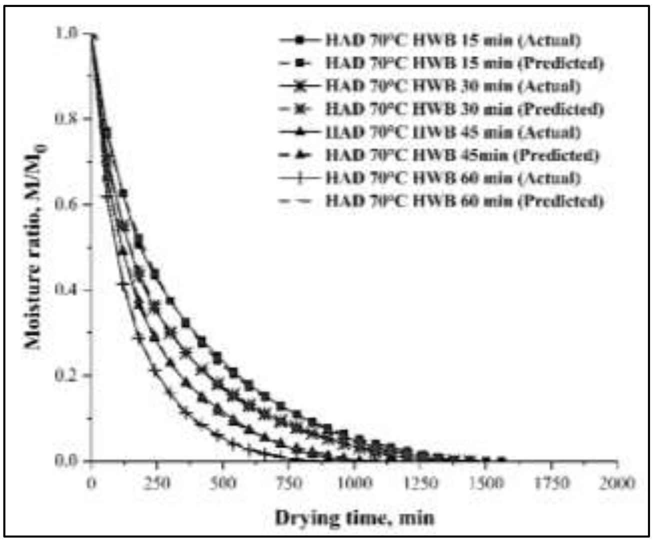


c)

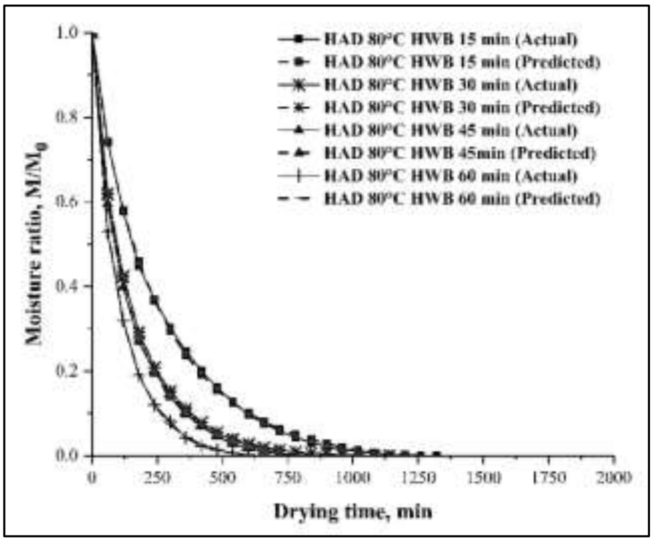
Fig 5: Experimental vs Predicted values for turmeric rhizomes at drying temperatures of a) 60 °C, b) 70 °C and c) 80 °C and different blanching times using the Midilli model



a)



b)



c)

Fig 6: Fitting of Midilli model on actual values of turmeric rhizomes at drying temperatures of a) 60 °C, b) 70 °C and c) 80 °C and different blanching times

Table 2: Drying constants of drying models for different drying temperatures and hot water blanching time

Sr. No.	Model	Blanching time, min	60 °C						70 °C						80 °C					
			Constants																	
			k	*a*	*n/g/k₁*	*b*	*h*	*c*	*k*	*a*	*n/g/k₁*	*b*	*h*	*c*	*k*	*a*	*n/g/k₁*	*b*	*h*	*c*
1	Lewis	15	0.180						0.190						0.246					
		30	0.176						0.169						0.406					
		45	0.210						0.309						0.432					
		60	0.277						0.405						0.570					
2	Page	15	0.201		0.944				0.246		0.867				0.284		0.914			
		30	0.224		0.878				0.337		0.797				0.473		0.869			
		45	0.249		0.908				0.398		0.825				0.508		0.856			
		60	0.304		0.939				0.480		0.856				0.626		0.888			
3	Henderson and Pabis	15	0.178	0.986					0.179	0.943					0.238	0.968				
		30	0.168	0.955					0.219	0.927					0.395	0.973				
		45	0.203	0.964					0.292	0.949					0.420	0.971				
		60	0.271	0.978					0.393	0.970					0.562	0.985				
4	Logarithmic	15	0.181	0.984		0.005			0.178	0.943		-0.001			0.237	0.969		-0.002		
		30	0.174	0.952		0.010			0.236	0.923		0.018			0.473	0.990		0.010		
		45	0.203	0.964		0.001			0.308	0.945		0.013			0.434	0.967		0.009		
		60	0.267	0.980		-0.005			0.411	0.965		0.012			0.500	0.871		0.129		
5	Two Term	15	0.152	0.735	0.330	0.271			0.179	0.944	0.179	-0.001			1.609	0.102	0.222	0.898		
		30	0.594	0.205	0.145	0.798			0.969	0.280	0.176	0.721			1.530	0.192	0.337	0.808		
		45	1.313	0.107	0.189	0.894			1.749	0.204	0.353	0.797			1.749	0.204	0.353	0.797		
		60	0.269	0.977	-0.161	0.000			1.177	0.254	0.237	0.746			3.508	0.138	0.497	0.862		
6	Modified Henderson and Pabis	15	0.152	0.527	0.354	0.231	0.162	0.248	1.175	0.158	0.405	0.000	0.162	0.844	1.616	0.102	0.222	0.816	0.223	0.082
		30	0.594	0.205	0.145	0.706	0.145	0.092	0.970	0.280	0.175	0.363	0.176	0.358	1.532	0.192	0.337	0.766	0.336	0.042
		45	1.313	0.107	0.189	0.806	0.189	0.088	1.240	0.246	0.240	0.474	0.237	0.281	1.770	0.203	0.353	0.770	0.365	0.028
		60	1.132	0.158	0.125	-0.347	0.196	1.189	1.353	0.231	0.325	0.535	0.325	0.234	3.763	0.138	0.489	0.898	0.351	-0.036
7	Midili	15	0.208	1.009	0.927	0.001			0.269	1.001	0.791	-0.002			0.295	0.999	0.872	-0.001		
		30	0.241	1.007	0.828	-0.001			0.356	1.003	0.743	-0.001			0.476	0.999	0.858	0.000		
		45	0.260	0.999	0.868	-0.001			0.413	1.002	0.777	-0.001			0.516	1.000	0.826	-0.001		
		60	0.313	0.997	0.905	-0.001			0.488	1.001	0.827	-0.001			0.620	0.997	0.881	-0.001		
8	Two Term Exponential	15	0.245	0.541					1.039	0.156					2.451	0.091				
		30	0.595	0.235					0.839	0.226					2.020	0.169				
		45	2.019	0.094					1.081	0.228					1.732	0.204				
		60	0.339	0.616					1.285	0.248					3.641	0.137				
9	Approximation of diffusion	15	0.288	0.345		0.511			1.179	0.156		0.137			1.474	0.105		0.150		
		30	0.587	0.203		0.247			0.967	0.280		0.182			1.529	0.192		0.220		
		45	1.309	0.106		0.144			1.175	0.254		0.202			1.749	0.203		0.202		
		60	0.276	1.000		-0.838			1.284	0.242		0.251			3.330	0.139		0.149		
10	Wang and Singh	15		-0.095		0.002				-0.111		0.003				-0.137		0.004		
		30		-0.103		0.003				-0.126		0.004				-0.176		0.007		
		45		0.164		-0.219				-0.161		0.006				-0.211		0.010		
		60		-0.153		0.006				-0.207		0.010				-0.285		0.019		

Table 3: Statastical comparision of different dryig model for different drying temperatures and hot water blanching

Sr. No.	Model	Hot water Blanching time, min	60 °C			70 °C			80 °C		
			R^2	χ^2	*RMSE*	R^2	χ^2	*RMSE*	R^2	χ^2	*RMSE*
1	Lewis	15	0.9989	0.0556	0.0096	0.9928	0.1119	0.0255	0.9970	0.0450	0.0160
		30	0.9957	0.1301	0.0210	0.9742	0.5072	0.0791	0.9973	0.0505	0.0156
		45	0.9975	0.0543	0.0156	0.9925	0.1210	0.0269	0.9960	0.0480	0.0196
		60	0.9981	0.0396	0.0127	0.9961	0.0619	0.0199	0.9980	0.0226	0.0142
2	Page	15	0.9994	0.0411	0.0063	0.9968	0.1449	0.0154	0.9987	0.0736	0.0104
		30	0.9986	0.0935	0.0098	0.9983	0.0932	0.0107	0.9999	0.0158	0.0035
		45	0.9992	0.0703	0.0081	0.9986	0.0758	0.0104	0.9994	0.0358	0.0069
		60	0.9989	0.0634	0.0096	0.9995	0.0316	0.0060	0.9997	0.0180	0.0052
3	Henderson and Pabis	15	0.9988	0.0484	0.0090	0.9935	0.0963	0.0206	0.9973	0.0442	0.0137
		30	0.9956	0.0947	0.0174	0.9892	0.1162	0.0264	0.9972	0.0337	0.0141
		45	0.9977	0.0470	0.0125	0.9921	0.0803	0.0234	0.9958	0.0355	0.0179
		60	0.9983	0.0418	0.0112	0.9958	0.0454	0.0171	0.9980	0.0193	0.0135
4	Logarithmic	15	0.9989	0.0720	0.0084	0.9935	0.0917	0.0206	0.9973	0.0349	0.0136
		30	0.9957	0.1220	0.0166	0.9900	0.1561	0.0246	0.9544	0.7883	0.0978
		45	0.9977	0.0518	0.0125	0.9925	0.1174	0.0222	0.9960	0.0601	0.0170
		60	0.9983	0.0186	0.0109	0.9962	0.0649	0.0167	0.9998	0.0105	0.0038
5	Two Term	15	0.9996	0.0451	0.0053	0.9935	0.0963	0.0206	0.9992	0.0562	0.0082
		30	0.9990	0.0815	0.0085	0.9991	0.0644	0.0078	0.9999	0.0059	0.0023
		45	0.9996	0.0524	0.0059	0.9991	0.0556	0.0082	0.9997	0.0222	0.0051
		60	0.9984	0.0081	0.0107	0.9997	0.0230	0.0049	0.9998	0.0108	0.0037
6	Modified Henderson and Pabis	15	0.9996	0.0431	0.0053	0.9982	0.1114	0.0119	0.9992	0.0561	0.0082
		30	0.9990	0.0815	0.0085	0.9991	0.0644	0.0078	0.9999	0.0059	0.0023
		45	0.9996	0.0524	0.0059	0.9991	0.0544	0.0083	0.9997	0.0221	0.0051

		60	0.9999	-0.0093	0.0029	0.9997	0.0221	0.0050	0.9999	0.0099	0.0037
7	Midili	15	0.9995	0.0209	0.0059	0.9992	-0.0151	0.0072	0.9995	-0.0135	0.0060
		30	0.9994	0.0186	0.0064	0.9996	-0.0017	0.0050	0.9999	-0.0096	0.0024
		45	0.9999	0.0200	0.0026	0.9995	-0.0014	0.0057	0.9998	-0.0044	0.0040
		60	0.9995	0.0256	0.0058	0.9998	-0.0003	0.0036	0.9998	-0.0005	0.0036
8	Two Term Exponential	15	0.9996	0.0570	0.0057	0.9981	0.1101	0.0121	0.9992	0.0542	0.0084
		30	0.9991	0.0920	0.0094	0.9978	0.0605	0.0124	0.9999	0.0052	0.0027
		45	0.9995	0.0506	0.0062	0.9987	0.0503	0.0095	0.9997	0.0222	0.0051
		60	0.9982	0.0657	0.0119	0.9997	0.0241	0.0050	0.9998	0.0108	0.0037
9	Approximation of diffusion	15	0.9996	0.0482	0.0054	0.9982	0.1112	0.0119	0.9992	0.0571	0.0082
		30	0.9990	0.0816	0.0085	0.9992	0.0644	0.0078	0.9999	0.0060	0.0023
		45	0.9996	0.0524	0.0059	0.9991	0.0556	0.0082	0.9997	0.0222	0.0051
		60	0.9983	0.0140	0.0124	0.9997	0.0230	0.0049	0.9999	0.0109	0.0037
10	Wang and Singh	15	0.9245	-1.3104	0.1008	0.9477	-7.6367	0.0882	0.9448	-0.6317	0.0899
		30	0.9411	0.1640	0.0895	0.9145	-1.9525	0.1097	0.8756	-0.1569	0.1311
		45	0.7306	1.0342	0.2588	0.9161	-2.5619	0.1082	0.9070	-0.0846	0.1136
		60	0.9451	-0.1777	0.0894	0.9139	-0.3689	0.1086	0.9152	-0.1212	0.1081

Table 4: Effective moisture diffusivity (deff) and its linear equation for turmeric rhizomes at different drying temperature and hot water blanching time

Dry-ing temp., °C	Blanch-ing time, min	Linear Equation	R^2	Slope, k_0	D_{eff}, m^2/s
60	15	y = -0.0033x +0.2177	0.9708	0.0033	4.82×10^{-9}
	30	y = -0.0032x +0.1844	0.9285	0.0032	4.68×10^{-9}
	45	y = -0.0042x +0.343	0.9506	0.0042	6.14×10^{-9}
	60	y = -0.0058x +0.3638	0.9666	0.0058	8.48×10^{-9}
70	15	y = -0.0039x +0.3827	0.9217	0.0039	5.70×10^{-9}
	30	y = -0.0042x +0.236	0.9301	0.0042	6.14×10^{-9}
	45	y = -0.0057x +0.3088	0.9473	0.0057	8.34×10^{-9}
	60	y = -0.0071x +0.2031	0.9558	0.0071	10.38×10^{-9}
80	15	y = -0.0051x +0.3727	0.9655	0.0051	7.46×10^{-9}
	30	y = -0.0063x +0.0100	0.9929	0.0063	9.21×10^{-9}
	45	y = -0.0075x +0.1924	0.9788	0.0075	10.97×10^{-9}
	60	y = -0.0101x +0.1919	0.9599	0.0101	14.78×10^{-9}

4. Conclusion

The turmeric rhizomes were blanched at 100 °C for 15, 30, 45 and 60 min and dried at 60, 70 and 80 °C. Drying characteristics of turmeric rhizome indicated that increasing the blanching time and drying temperature led to increase in the drying rate which resulted in shorter drying time. The effective diffusivity was also found to be increased with the increased blanching time. The effective diffusivity ranged from 4.82×10^{-9} to 14.78×10^{-9} m^2/s. The activation energy was decreased with increase in the blanching time. Midilli model was found to be the most suitable among all models with highest goodness of fit indices for the drying characteristics.

5. References

1. Rathaur P, Raja W, Ramteke PW, John SA. Turmeric: The golden spice of life. International Journal of Pharmaceutical Sciences and Research. 2012;3(7):1987-1994.
2. Chumroenphat T, Somboonwatthanakul I, Saensouk S. and Siriamornpun, S. Changes in curcuminoids and chemical components of turmeric (*Curcuma longa* L.) under freeze-drying and low-temperature drying methods. Food Chemistry. 2021;339:1-9.
3. Kumar N, Sarkar BC, Sharma HK. Mathematical modelling of thin layer hot air drying of carrot pomace. Journal of Food Science and Technology. 2012;49:33-41.
4. Bruce DM. Exposed-layer barley drying: Three models fitted to new data up to 150 °C. Journal of Agricultural Engineering Research. 1985;32(4):337-348.
5. Page GE. Factors influencing the maximum rates of air drying shelled corn in thin layers. Purdue University; 1949.
6. Hendreson SM, Pabis S. Grain drying theory. I. Temperature effect on drying coefficients. Journal of Agricultural Engineering Research. 1961;6:169-174.
7. Togrul IT, Pehlivan D. Mathematical modelling of solar drying of apricots in thin layers. Journal of Food Engineering, 2002;55:209-216.
8. Henderson SM. Progress in developing the thin layer drying equation. Transactions of the ASAE. 1974;17(6):1167-1168.
9. Karathanos VT. Determination of water content of dried fruits by drying kinetics. Journal of Food Engineering. 1999;39(4):337-344.
10. Midilli A, Kucuk H, Yapar Z. A new model for single-layer drying. Drying Technology. 2002;20(7):1503-1513.
11. Verma LR, Bucklin RA, Endan JB, Wratten FT. Effects of drying air parameters on rice drying models. Transactions of the ASAE. 1985;28(1):296-301.
12. Yaldiz O, Ertekin C, Uzun HI. Mathematical modeling of thin layer solar drying of sultana grapes. Energy, 2001;26(5):457-465.
13. Wang CY, Singh RP. A single layer drying equation for rough rice (No. 78-3001). ASAE paper; c1978. p. 33
14. Wang Z, Sun J, Liao X, Chen F, Zhao G, Wu J, Hu X. Mathematical modeling on hot air drying of thin layer apple pomace. Food Research International. 2007;40(1):39-46.