Food Research (2020) : pp - pp
Journal homepage: http://www.myfoodresearch.com

FULL PAPER

Drying kinetics and thin layer modeling of ogi produced from six maize varieties at varying soaking period and drying temperature

[1]Bolaji, O.T, [1]Adepoju, P.A. [2]Adelana, E.O. and [3]Adesina, B.S.

[1]*Department of Food Technology, Lagos State Polytechnic Ikorodu, Lagos*
[2]*Department of Food Technology, Yaba College of Technology, Lagos*
[3]*Department of Agricultural and Environmental Engineering, Lagos State Polytechnic, Ikorodu, Lagos*

Article history:
Received: 22 March 2020
Received in revised form: 3 June 2020
Accepted: 8 June 2020
Available Online: 13 August 2020

Keywords:
Ogi,
Drying kinetics,
Drying temperature,
Activation energy,
Effective moisture diffusivity

DOI:

Abstract

The drying kinetics of ogi produced from six varieties of maize at varying soaking period (12, 24 and 36 hrs) and drying temperature of 40, 50 and 60°C, respectively were studied. Seven common thin layer models were evaluated, and the best models were selected. The moisture content of ogi decreased with increased drying temperature and drying time while the drying rate increased with an increase in drying temperature and decreased with an increase in drying time. Logarithmic and two term models best fitted about 40.77% (22 samples each). However, where two term models were selected best, the R^2 values ranged from 0.9858-0.99999999, χ^2 = 0.03715-0.000412, RMSE = 0.02206-0.0000677, unlike Logarithmic model that ranged from 0.8876-0.9964, χ^2 = 0.07045-0.001447, RMSE = 0.1084-0.01098. There was no definite pattern for effective moisture diffusivity (D_{eff}) and Activation energy (E_a). This research work strongly suggests that the drying process was predominantly in the falling rate period (FRP) and was significantly affected by the change in temperature and moisture gradient. The activation energy obtained for ogi at varying soaking period and drying temperature ranged from 2.58-12.00 kJ/mol (A4Y), 7.72-44.95 kJ/mol (A4W), 14.53-35.88 kJ/mol (S7Y), 6.02-20.10 kJ/mol (D2Y), 14.024-45.31 kJ/mol (DIY) and 19.34-64.22 kJ/mol (T3W). It was obviously indicated in this research that the soaking period had less or no impact on the drying behavior of ogi compared with the influence of drying temperature, drying time and initial moisture content.

1. Introduction

Application of dehydration is relevant in many food processes, particularly in food preservation. This is often achieved by removing or reducing moisture capable of aiding some undesirable reactions, deterioration and spoilage (Maskan *et al.,* 2002; Simal *et al.*, 2005; Sahin and Dincer, 2005). Drying process of food may be a complex dynamic of simultaneous heat and mass transfer (Bart-Plange *et al.,* 2012). Apart from the strong potential for drying operation to prolong shelf-life of the product, it encourages volume reduction, product diversity, ease of transportation and distribution (Bart-Plange *et al.,* 2012). Drying may aid the production of high-density product which can conveniently and adequately be packaged to prolong the shelf-life. These products can easily and rapidly be reconstituted without significant loss in some quality characteristics (Maskan, 2001; Maskan *et al*., 2002; Shi *et al.*, 2008). However, physical changes, chemical reactions and alteration in sensory characteristics of some food products during and after drying operation have been reported (Ansari *et al.,* 2004; Shi *et al.*, 2008).

Two major possible stages (Constant-rate drying period and falling rate drying period) were widely reported in the literature (Maskan *et al.,* 2002; Sahin and Dincer, 2005; Shi *et al.*, 2008). The common relevant properties reported useful in the study and behavior of drying operations are moisture diffusivity, thermal conductivity, density, specific heat capacity, interphase heat and mass transfer coefficients (Maskan *et al.,* 2002; Shi *et al.*, 2008). Description and prediction of drying process of food are often possible with the aid of drying models (Midelli *et al.,* 2002; Babalis and Belessiotis, 2004; Karim and Hawlader, 2005; Akpinar *et al*., 2006; Shi *et al.*, 2008). Thin-layer drying models have found wide application because few parameters are needed in their computation (Maskan, 2001; Maskan *et al.,* 2002; Kingsly *et al.,* 2007; Erenturk and Erenturk, 2007; Shi *et*

---

*Corresponding author.
Email: *olusholat@yahoo.com*

eISSN: 2550-2166 /

al., 2008).

Some of the thin layer models reported in the literature were for drying of Chilli pepper, millets samples, Sesame seeds, Amaranth grain, hazelnut, green pepper, green bean, squash, apricot, green chilli, pistachio, apple, pumpkin, red pepper, eggplant, bay leaves, rosehip, strawberries, green beans, okra, carrots, bananas and many other food materials (Yaldiz and Ertekin, 2001; Hossain and Bala, 2002; Midilli and Kucuk, 2003; Togrul and Pehlivan, 2003; Ertekin and Yaldiz, 2004; Erenturk *et al.,* 2004; Sacilik and Unal, 2005; Gunhan *et al*., 2005; Doymaz, 2005; Karim and Hawlader, 2005; Toyosi and Adeladun, 2010; Ojendiran and Raji, 2010; Ronoh *et al*., 2010).

Ogi slurry is the product obtained from the fermentation of cereal and important in the Nigerian and West African diet (Bolaji *et al.,* 2017). The process consists of soaking the maize for as long as 96 hrs (Bolaji *et al.,* 2014; Bolaji *et al.,* 2015; Bolaji *et al.,* 2017). Large scale production may be indispensable either in the dried or wet form basically for the growing population, the increased female (mothers) working force, the need for an alternative source of weaning food and increased shelf life. The Ogi material could be dried and packaged in polythene bags (Bolaji *et al.,* 2014; Bolaji *et al.,* 2015). The drying process and behavior of Ogi cannot be independent of its thermal properties, some of which were investigated by Bolaji *et al.* (2015).

The drying pattern of Ogi produced from yellow and white maize with the aid of oven and cabinet dryers were earlier attempted at 50°C (Bolaji *et al.,* 2014), however effect of varietal influences, soaking period and varying drying temperature were not evaluated. In most cases of application of thin-layer drying, fine particles are rarely attempted as done in this research work. Past works were limited to cereal and legumes grains, fruits and vegetables with larger area compared to individual fine particles sizes of the milled slurry of ogi which are between 0.212-0.6 microns. The thin layer drying models application for these fine grains were rarely computed however attempted by Bolaji *et al.* (2014) for ogi produced from white and yellow maize grains and dried at a temperature of 50°C. Varying soaking period and drying temperature and about six different maize breeds were employed in this research and this should give reliable representative for industrial application.

2. Material and method

Six maize varieties were obtained from the Institute of Agricultural Research and Training (IAR & T) Ibadan. As shown below

Codes	**Bred Name**
D1Y-	DMR-LSR
D2Y-	DMR-ESR-Y
T3W-	TZPB-SR-W
A4Y-	ART/98/SW1-SR-Y
A5W-	ART/98/SW5-OB-W
S7Y-	SUWAN-SR-Y

About 1 kg of each maize variety was weighed, cleaned and soaked in water for 12, 24 and 36 hrs, respectively. It was wet-milled using 230 watts attrition mill, sieved and wet ogi obtained. The ogi was squeezed using a muslin cloth to reduce the moisture content. The initial moisture content of wet ogi obtained from each maize variety at the varying soaking period was determined using moisture analyzer Model 0HAUS MB45 (10 mins at 100°C). These were dried in Genlab drying cabinet, model DC 125 at 40, 50 and 60°C. The dried ogi was further milled using laboratory mill IKA model M20 and sieved through 212 µm mesh.

2.1 Drying kinetics computation

Drying kinetics of the process was studied, and curve fitted with selected models as shown in Table 1. The drying constant and coefficients of the models were determined by non-linear regression analysis with the aid MATLAB 2017. Drying experiments were expressed of dimensionless form as moisture ratios MR as shown in equation (1) (Shivhare *et al*., 2000; Özbek and Dadali, 2007):

$$MR = \frac{M - M_e}{M_i - M_e} = \exp\left(-kt\right) \qquad (1)$$

Where M is the moisture content at any time, M_i is the initial moisture content and M_e is the equilibrium moisture content (Thakor *et al*., 1999; Togrul and Pehlivan, 2002; Akgun and Doymaz, 2005). The non-linear regression analysis in the present study was performed using MATLAB 2017. The goodness of fit of the tested mathematical models from the experimental data was evaluated with correlation coefficient (R^2), the reduced chi-square (χ^2) and the root mean square error (RMSE). The higher the values of the R^2, and lower values of the χ^2 and *RMSE*, the better the goodness of fit (Yaldiz and Ertekin, 2001; Gunhan *et al*., 2005; Sacilik and Unal, 2005). The reduced χ^2 and RMSE were computed as shown in equations (2) and (3)

$$RMSE = \left[\frac{1}{N}\sum_{I=1}^{N}(MR_{pred,i} - MR_{exp,})^2\right]^{1/2} \qquad (2)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})}{N - n} \qquad (3)$$

2.2 Estimation of effective moisture diffusivities

The effective diffusivities of the drying process of ogi were estimated by the method reported for drying

Table 1. Selected mathematical models for drying curves fitting

S/n	Model	Mathematical expressions
1	Lewis	$MR = \exp(-kt)$
2	Page	$MR = \exp(-kt)^n$
3	Herderson and Pabis	$MR = a.\exp(-kt)$
4	Two term model	$MR = a.\exp(-k_0 t) + b.\exp(-k_1 t)$
5	Wang and Singh	$MR = 1 + at + bt^2$
6	Logarithmic	$MR = a * \exp(-bt) + c$
7	Midelli *et al.*	$MR = a * \exp(-bt) + b * c$

characteristics of biological products in falling rate period using Fick's diffusion equation (4) (Flores *et al.,* 2012)

$$MR = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}exp\left[-n^2\frac{\pi^2 D_{efft}}{r^2}\right] \qquad (4)$$

Where MR is the moisture ratio, D_{eff} is the effective moisture diffusivity (m^2/s), r is the equivalent radius (m) and t is the time (s). This could be written in a logarithmic form as shown in Equation (5). The effective moisture diffusivity was calculated from the slope of a straight line when experimental data in terms of ln (MR) were plotted against drying time (Flores *et al.,* 2012):

$$\ln MR = \ln\frac{8}{\pi^2} - \left(\frac{\pi}{r}\right)^2 D_{eff}\, t \qquad (5)$$

The effective moisture diffusivity was estimated by using the method of slopes. From Equation (5), a plot of lnMR versus drying time is expected to give a straight line with a slope as written in equation (6)

$$Slope = \frac{\pi^2 D_{eff}}{r^2} \qquad (6)$$

3. Result and discussion

3.1 Moisture content

The moisture content of ogi decreased with an increase in drying temperature and drying time. The moisture decreased significantly ($p<0.05$) for all drying temperatures. A similar observation was noted for computed moisture ratio. There were higher drying rates at high moisture contents. These decreased rapidly with decreased moisture content. This may be unconnected with the free moisture near the surface of the product. The changes in moisture content are as shown in Table 2.

The moisture content of drained ogi slurry ranged from 44.59 to 47.27%. This work revealed that drying temperature had an impact on the drying time of ogi, irrespective of the soaking period. The drying time of ogi slurry produced from all the maize varieties at 12, 24 and 36th hour of soaking ranged from 17-19, 13-15 and 9-11 hrs at 40, 50 and 60°C, respectively. There was no significant difference in the initial moisture content of drained ogi.

The moisture decrease followed a similar trend reported by Bolaji *et al.* (2014). The changes in the moisture content appeared to be the function of drying temperature and time as shown in Figure 1. Initially, there was a rapid decrease in moisture content with increased drying time. This then slowly decreased with an increase in the drying time. Falling rate periods was noticeably dominant in the drying of ogi in this experiment.
However, the drying time to attain respective final moisture content decreased with increased drying temperature. This is consistent with the findings of some researchers (Doymaz, 2005; Karim and Hawlader, 2005; Akpinar *et al.,* 2006; Kingsly *et al.*, 2007; Erenturk and Erenturk, 2007; Shi *et al.*, 2008; Bolaji *et al,* 2014).

According to Demirel and Turhan (2003), the prevalent fallen rate periods observed in this experiment indicated that the drying rate was effectively governed by internal resistance within the ogi slurry. It can be deduced that there was a decrease in moisture migration with an increase in drying time. (Demirel and Turhan, 2003; Doymaz, 2005; Karim and Hawlader, 2005; Akpinar *et al.,* 2006).

The increased drying rate observed most especially at the beginning of the drying may be due to the increased heat transfer potential within the drying environment because of increased temperature (Maskan, 2001; Akpinar *et al.,* 2006; Waewsak *et al.*, 2006). The drying rate presented in Figure 2 also followed a similar trend reported for drying of ogi by Bolaji *et al.* (2014). Also, food composition was reported among factors that may affect the rate of water removal in the food materials. Some researchers reported that surface-to-volume ratio of the food can minimize the resistance to heat and mass transfer (Maskan, 2001; Maskan *et al.,* 2002; Akpinar *et al.,* 2006; Erenturk and Erenturk, 2007) while Chirife (1983) reported that drying behavior may be a function of the equipment employed in the dehydration operation.

Table 2. Initial and moisture content of ogi

Maize Variety	Drying Temperature	Initial Moisture Content (%)			Final Moisture Content (%)		
		12 hrs	24 hrs	36 hrs	12 hrs	24 hrs	36 hrs
D2Y	40	46.54	46.22	44.47	8.44^{bcde}	8.51^{bcde}	7.87^{de}
D2Y	50	44.97	44.59	45.15	7.89^{ef}	7.82^{ef}	7.80^{de}
D2Y	60	44.21	44.85	41.96	8.12^{def}	8.36^{def}	8.49^{bcde}
A5W	40	45.9	45.45	45.71	7.86^{ef}	8.29^{def}	8.11^{dce}
A5W	50	45.62	44.44	44.82	8.16^{def}	8.05^{ef}	7.82^{de}
A5W	60	44.94	43.35	41.16	7.27^{f}	8.25^{def}	7.85^{de}
A4W	40	42.74	44.36	44.45	9.06^{abc}	7.92^{ef}	7.79^{de}
A4W	50	43.32	42.72	44.14	8.96^{abcd}	7.92^{ef}	8.79^{ab}
A4W	60	45.41	44.99	44.47	9.69^{a}	8.36^{bcde}	9.65^{a}
DIY	40	44.16	47.25	44.21	$8.18d^{ef}$	7.83^{ef}	7.51^{e}
DIY	50	45.63	43.95	44.39	8.05^{cdef}	7.93^{ef}	7.81^{de}
DIY	60	45.01	43.489	43.61	7.73^{ef}	7.97^{ef}	7.61^{e}
S7Y	40	44.51	45.74	44.86	7.92^{ef}	8.94^{abcd}	9.18^{abc}
S7Y	50	44.77	46.31	44.51	9.45^{a}	7.66	9.07
S7Y	60	47.27	44.67	43.47	9.58^{a}	7.56	9.35^{ab}
T3W	40	44.98	44.05	44.38	7.74^{ef}	7.47	8.14^{dce}
T3W	50	45	44.623	45.59	9.23^{ab}	8.64	7.88^{de}
T3W	60	44.34	44.06	44.59	8.35^{bcde}	9.15	8.65^{abcd}

Mean with same superscripts along the column are not significantly different at ($p>0.05$)

3.2 Thin layer models

The drying curves fitted to the experimental data using seven selected models as shown in Table 1 resulted in summarized best models selected based on recommended criteria are as shown in Tables 3, 4 and 5. The constant parameters are a, b and c while drying constants is k, respectively. The $R^{2,}$ RSME and chi-square (χ^2) were used to determine the best model. The best model for ogi produced from A5W and dried at 40°C (12 and 24 hrs), 50°C (12, 24 and 36 hrs) and 60°C (12 hrs) were best fitted with Logarithmic model with higher R^2, lowest χ^2 and RMSE. While ogi dried at 60°C (24 and 36 hrs) of soaking were best fitted with two term and Wang and Singh models, respectively. Apart from ogi dried at 60°C (12 hrs), 50°C (36 hrs) and 40°C (12 and 24 hrs) which were best fitted with Logarithmic model, others were best fitted with two term models.

Ogi produced from A5W (60°C) at 36th hour of soaking and dried at 60°C, DIY (60°C) at 12th hour of Soaking, DIY (50°C) at 24 hrs of soaking, S7Y (50°C) at 24th hour of soaking, T3W(40°C) at 12 hrs of soaking and T3W (40°C) were best fitted with Wang and Singh model. Dried ogi (DIY) produced at 12th hour of soaking and dried at 60°C, S7Y at produced 12 and 36th hour of Soaking and dried at 60 and 40°C, respectively were best fitted with Page models. Logarithmic and Two term models best fitted about 40.77% (22) samples each of ogi produced from six varieties, soaked and dried at varying period and temperature, respectively. However, where two term models were noted and selected best based on the recommended criteria, were relatively and significantly highest for R^2, lowest for χ^2 and RMSE, respectively when compared with Logarithmic models. The values for two term model ranged from 0.9858-0.99999999, $\chi^2 = 0.03715-0.000412$, RMSE 0.02206-0.0000677, unlike Logarithmic model which ranged from 0.8876-0.9964, $\chi^2 = 0.07045-0.001447$, RMSE, 0.1084-0.01098. The values of R^2 obtained for two term model were within the range reported for drying of apple (Akpinar *et al.,* 2006); green table olives Demir *et al.* (2007), and black grapes (Doymaz 2006).

3.3 Effective moisture diffusivity and activation energy

The effective moisture diffusivity and Activation energy is as shown in Table 6. Moisture diffusivity obtained for ogi slurry and dried at varying temperature ranged from 1.97-2.01 x 10^{-10} m^2/s, 1.16-2.77 x 10^{-10} m^2/s and 1.3-2.00 x 10^{-10} m^2/s (A4Y), 2.96-5.05 x 10^{-10} m^2/s 2.66-4.91 x 10^{-10} m^2/s, and 1.1-4.46 x 10^{-10} m^2/s (A5W), 2.81-3.19 x 10^{-10} m^2/s, 1.3- 7.61 x 10^{-10} m^2/s and 2.23-3.35 x 10^{-10} m^2/s(S7Y), 2.57-2.95 x 10^{-10} m^2/s,1.82-2.92 x 10^{-10} m^2/s and 2.23-2.44 x 10^{-10} m^2/s (D2Y), 4.65-10 x 10^{-10} m^2/s, 1.86-6.24 x 10^{-10} m^2/s and 2.05-3.61 x 10^{-10} m^2/s and 2.35-3.82 x 10^{-10} m^2/s, 1.05-2.95 x 10^{-10} m^2/s and 2.04-3.45 x 10^{-10} m^2/s(T3W). These values were within values reported by some researchers (Yashoda *et al.,* 2006; Gastón *et al.,* 2004; Doymaz, 2005; Gely and Santalla, 2007; Rahman *et al.,* 2009; Gaware *et al.,* 2010). Past work established that variation in effective

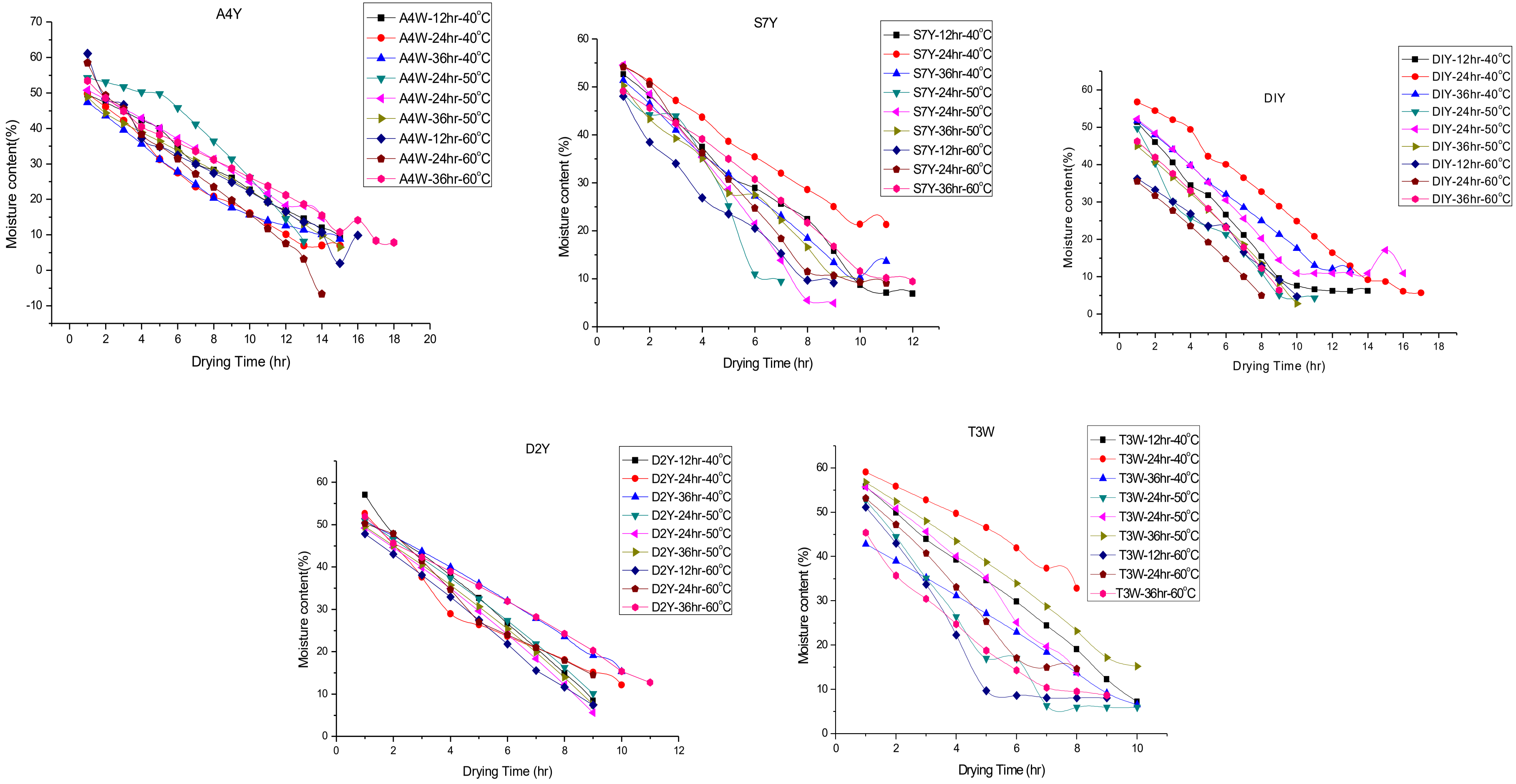
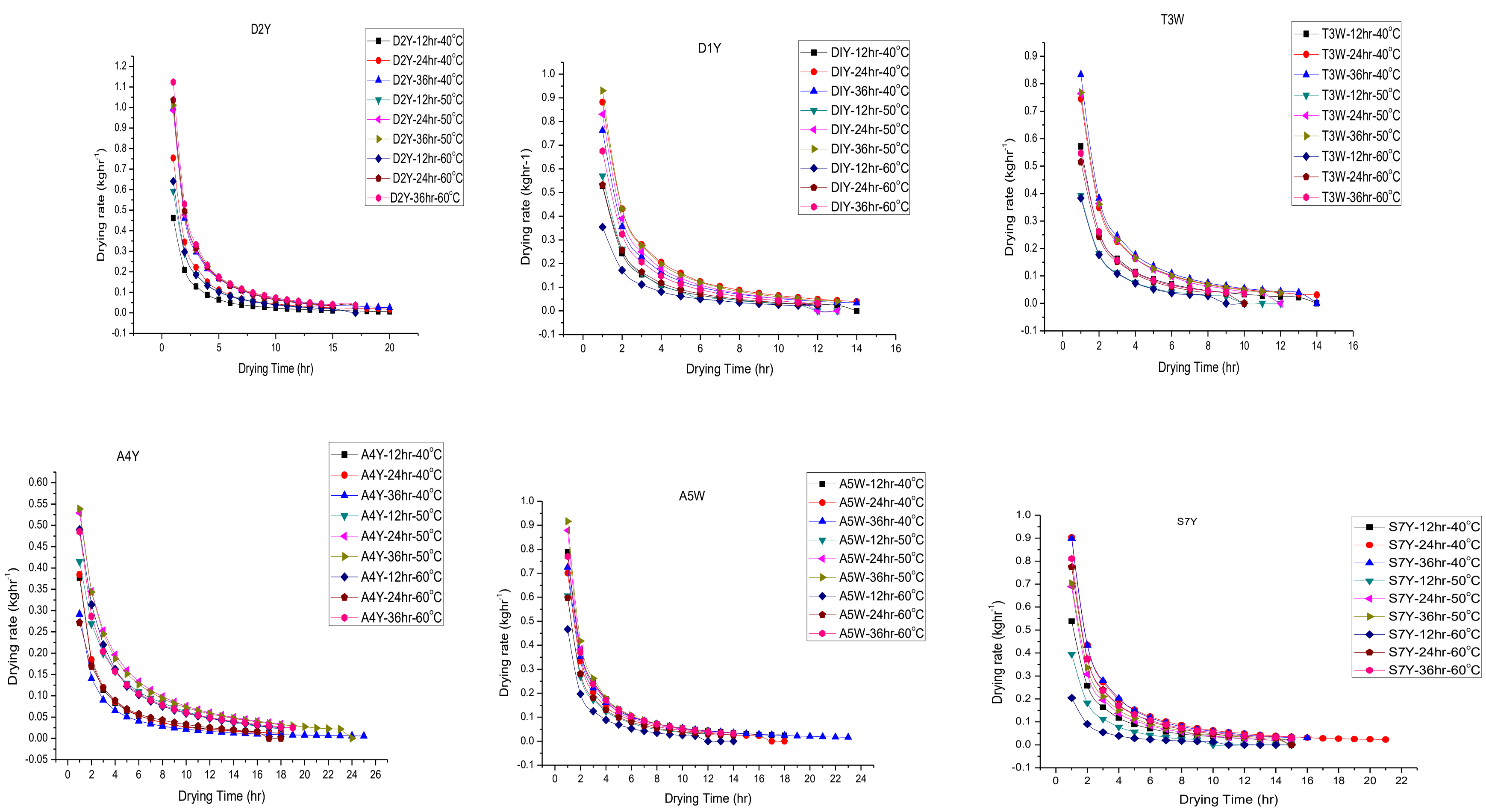


Figure 1. Moisture content and drying time relationship



Code	Variety	Code	Variety	Code	Variety	Code	Variety	Code	Variety	Code	Variety	Soaking period	Drying temperature
D1Y-12hr-40°C	DMR-LSR-Y	D2Y-12hr-40°C	DMR-ESR-Y	A5W-12hr-40°C	ART/98/SW5– OB –W	A4W-12hr-40°C	ART/98/SW1SR-Y	S7Y-12hr-40°C	SUWAN-SR-Y	T3W-12hr-40°C	TZPB-SR-W	12	40
D1Y-24hr-40°C	DMR-LSR-Y	D2Y-24hr-40°C	DMR-ESR-Y	A5W-24hr-40°C	ART/98/SW5– OB –W	A4W-24hr-40°C	ART/98/SW1SR-Y	S7Y-24hr-40°C	SUWAN-SR-Y	T3W-24hr-40°C	TZPB-SR-W	24	40
D1Y-36hr-40°C	DMR-LSR-Y	D2Y-36hr-40°C	DMR-ESR-Y	A5W-36hr-40°C	ART/98/SW5– OB –W	A4W-36hr-40°C	ART/98/SW1SR-Y	S7Y-36hr-40°C	SUWAN-SR-Y	T3W-36hr-40°C	TZPB-SR-W	36	40
D1Y-12hr-50 °C	DMR-LSR-Y	D2Y-12hr-50°C	DMR-ESR-Y	A5W-12hr-50°C	ART/98/SW5– OB –W	A4W-12hr-50°C	ART/98/SW1SR-Y	S7Y-12hr-50°C	SUWAN-SR-Y	T3W-12hr-50°C	TZPB-SR-W	12	50
D1Y-24hr-50°C	(DMR-LSR-Y)	D2Y-24hr-50°C	DMR-ESR-Y	A5W-24hr-50°C	ART/98/SW5– OB –W	A4W-24hr-50°C	ART/98/SW1SR-Y	S7Y-24hr-50°C	SUWAN-SR-Y	T3W-24hr-50°C	TZPB-SR-W	24	50
D1Y-36hr-50°C	(DMR-LSR-Y)	D2Y-36hr-50°C	DMR-ESR-Y	A5W-36hr-50°C	ART/98/SW5– OB –W	A4W-36hr-50°C	ART/98/SW1SR-Y	S7Y-36hr-50°C	SUWAN-SR-Y	T3W-36hr-50°C	TZPB-SR-W	36	50
D1Y-12hr-60 °C	(DMR-LSR-Y)	D2Y-12hr-60°C	DMR-ESR-Y	A5W-12hr-60°C	ART/98/SW5– OB –W	A4W-12hr-60°C	ART/98/SW1SR-Y	S7Y-12hr-60°C	SUWAN-SR-Y	T3W-12hr-60°C	TZPB-SR-W	12	60
D1Y-24hr-60°C	(DMR-LSR-Y)	D2Y-24hr-60°C	DMR-ESR-Y	A5W-24hr-60°C	ART/98/SW5– OB –W	A4W-24hr-60°C	ART/98/SW1SR-Y	S7Y-24hr-60°C	SUWAN-SR-Y	T3W-24hr-60°C	TZPB-SR-W	24	60
D1Y-36hr-60°C	(DMR-LSR-Y)	D2Y-36hr-60°C	DMR-ESR-Y	A5W-36hr-60°C	ART/98/SW5– OB –W	A4W-36hr-60°C	ART/98/SW1SR-Y	S7Y-36hr-60°C	SUWAN-SR-Y	T3W-36hr-60°C	TZPB-SR-W	36	60

Figure 2. Relationship with drying rate and drying time at varying drying temperature

Table 3. Summarised statistical results of the best fitted drying models for dried ogi from A5W and A4Y

Drying	Soaking	Best model	a	b	c	n	K_1	K_2	R^2	χ^2	RMSE
A5W (40)	12	Logarithmic	1.231	0.08612	-0.1492				0.984	0.02208	0.03715
	24	Logarithmic	2.806	2.701	-1.904				0.992	0.00853	0.02666
	36	Two term	0.8955	-0.02714			-0.05651	0.1294	0.9991	0.001063	0.008416
A5W (50)	12	Logarithmic	3.588	0.02855	-2.664				0.9915	0.008531	0.02978
	24	Logarithmic	0.9407	0.1525	-0.1787				0.9867	0.005848	0.02704
	36	Logarithmic	1.852	0.07057	-0.8726				0.9961	0.003295	0.0203
A5W (60)	12	Logarithmic	3.969	1.13E-03	-3.884				0.9979	0.002322	0.01205
	24	Two term	-0.1334	0.8476			0.1227	-0.04202	0.9999	3.75E-05	0.002314
	36	Wang and Singh	-0.06524	-0.00199					0.9988	0.001064	0.01087
A4Y (40)	12	Logarithmic	5.335	0.01259	-4.37				0.9957	0.004435	0.01922
	24	Logarithmic	3.008	0.02822	-1.963				0.9935	0.008487	0.02659
	36	Two term	-0.3529	1.251			0.05352	-0.01962	0.9996	0.000315	0.005349
A4Y (50)	12	Two term	-0.7833	1.402			0.08056	0.04169	0.9959	0.002261	0.01434
	24	Two term	0.8298	-0.1145			-0.0304	0.08033	0.99999	0.000011	0.0009841
	36	Logarithmic	3.856	0.01064	-3.251				0.9964	0.001446	0.01098
A4Y (60)	12	Logarithmic	1.141	0.08218	-0.3267				0.9719	0.02113	0.04197
	24	Two term	-0.3529	1.251			0.05352	-0.01962	0.9996	0.000315	0.005349
	36	Two term	-0.00014	0.761			0.4591	-0.09423	0.9987	0.000642	0.007639

Table 4. Summarised Statistical results of the best fitted drying models for dried ogi produced from DIY AND S7Y

Drying temperature	Soaking period	Best model	a	b	c	n	K_1	K_2	R^2	χ^2	RMSE
D1Y (40)	12	Wang and Singh	-0.1354	0.004421					0.9851	0.0166	0.03719
	24	Logarithmic	2.888	0.02342	-1.984				0.99210	0.00986	0.02654
	36	Logarithmic	2.125	0.04625	-1.082				0.9957	0.004112	0.02028
D1Y (50)	12	Logarithmic	1.147	0.2898	-0.00601				0.8876	0.07045	0.1084
	24	Wang and Singh	-0.125	0.004362					0.9681	0.03497	0.04828
	36	Two Term	-0.1779	0.9164			0.1174	-0.05209	0.99999	0.0000015	0.000549
D1Y (60)	12	page		0.02849		1.916			0.9703	0.04539	0.0615
	24	Two Term	0.8888	-0.2613			-0.04469	0.1076	0.999999	0.00000068	0.000412
	36	Two Term	-0.193	0.9542			0.1248	-0.04698	0.999999	0.0000088	0.001326
S7Y (40)	12	Logarithmic	3.353	0.02804	-2.326				0.9935	0.008702	0.02813
	24	Logarithmic	3.671	0.0115	-254.5				0.9955	0.001809	0.01228
	36	page		0.03145		1.673			0.9918	0.01007	0.02897
S7Y (50)	12	page		0.06197		1.707			0.9763	0.02958	0.04965
	24	Wang and Singh	-1.471	2.303					0.9964	0.003348	0.0183
	36	Logarithmic	3.747	0.01097	-286.3				0.9964	0.001447	0.01098
	24	Two term	-0.3529	1.251			0.05352	-0.01962	0.9996	0.000315	0.005349
	36	Two term	-0.00014	0.761			0.4591	-0.09423	0.9987	0.000642	0.007639

Table 5. Summarised statistical results of the best fitted drying models for dried ogi from T3W and D2Y

Drying temperature	Soaking period	Best model	a	b	c	n	K_1	K_2	R^2	χ^2	RMSE
T3W (40)	12	Wang and Singh	-0.13	0.00423					0.9842	0.01734	0.03801
	24	Two Term	-0.111	1.344			0.1808	-0.0278	0.9992	0.000209	0.00723
	36	Logarithmic	1.842	0.06162	-0.9419				0.9842	0.01958	0.04219
T3W (50)	12	Wang and Singh	-0.187	0.00858					0.9788	0.02328	0.04404
	24	two term	-2.212	3.155			0.05776	0.0182	0.9945	0.002604	0.02551
	36	Logarithmic	5.961	0.01775	-4.836				0.9773	0.04561	0.06439
T3W (60)	12	page		0.1049		1.75			0.9639	0.03582	0.05463
	24	Logarithmic	1.869	0.1204	-0.5552				0.9805	0.01519	0.05513
	36	Two Term	2.323	2.323			-0.1415	-0.1931	0.9924	0.005589	0.03052
D2Y (40)	12	Two Term	-0.013	2.402	0.3019	-0.14	0.3019	-0.1404	0.9985	0.005817	0.02883
	24	Logarithmic	0.9317	0.1855	-0.0294				0.994	0.003886	0.0188
	36	Two Term	-1.443	2.412			0.03307	-0.0054	0.9996	0.000441	0.007
D2Y (50)	12	Two Term	1.16	-0.1463			-0.0633	0.1023	0.9955	0.02585	0.02585
	24	Two Term	0.9456	-0.19			-0.0315	0.1002	1	0.0.0000073	0.0009
	36	Two Term	1.116	-0.244			-0.0313	0.0967	1	0.0000049	0.00074
D2Y (60)	12	Two Term	-2.068	3.024			0.01912	-0.01	0.9989	0.001085	0.01098
	24	Logarithmic	2.553	0.03033	-1.619				0.9931	0.004978	0.02231
	36	Two Term	-0.002	0.9279			0.3373	-0.1165	0.9978	0.001501	0.01291

Table 6. Effective moisture diffusivity (D_{eff}) and activation energy (E_a) of ogi produced from varieties at varying soaking period

Soaking period (hr)	Drying Temperature	A4Y (x 10^{-10}) m^2/s	A5W (x10^{-10}) m^2/s	S7Y (x 10^{-10}) m^2/s	D2Y (x 10^{-10}) m^2/s	D1Y (x 10^{-10}) m^2/s	T3W (x 10^{-10}) m^2/s
12	40	1.97	2.96	3.19	2.57	4.65	3.27
	50	2.01	4.41	2.81	2.83	4.44	3.82
	60	2.09	5.05	6.8	2.95	10	2.35
24	40	2.5	2.66	1.3	2.91	2.2	1.05
	50	1.16	4.91	7.61	2.92	1.86	2.7
	60	2.77	3.15	2.89	1.82	6.24	2.95
36	40	1.3	1.1	2.49	2.44	2.05	3.45
	50	2	4.46	2.23	2.23	2.99	2.04
	60	1.71	3.05	3.5	2.14	3.61	3.31
Activation Energy (E_a)							
Soaking period (hr)		A4Y (J/mol)	A5W (J/mol)	S7Y (J/mol)	D2Y (J/mol)	D1Y (J/mol)	T3W (J/mol)
12		2589.25	23265.4	32394.4	6019.59	14024.25	193439.3
24		3759.12	7724.45	35881.6	20106.46	45310.1	64224.65
36		12005.1	44955.8	14531.5	5717.969	2269.775	373783.3

moisture diffusivity may be affected by types and conditions of experimental procedures employed for the determination of effective moisture diffusivity, data treatment methods, temperature, product properties, compositions, physiological state and heterogeneity of structure (Celma *et al.,* 2007). Contrary to the report of Celma *et al.* (2007), values obtained in this research work did not suggest that temperature increase caused increase in effective moisture diffusivity. The structure of ogi from different varieties may be responsible for this.

The values of activation energy obtained using Arrhenius type equation is as shown in Table 6. The values obtained were within reported values for Agricultural products (Bablis *et al.,* 2004; Aghbashlo *et al.,* 2008). The activation energy obtained for ogi at varying soaking period and drying temperature are in the range of 2.58-12.00 kJ/mol (A4Y), 7.72-44.95 kJ/mol (A4W), 14.53-35.88 kJ/mol (S7Y),6.02-20.10 kJ/mol (D2Y),14.024-45.31 kJ/mol (DIY) and 19.34-64.22 kj/ kJ/mol (T3W). Higher values of activation energy were obtained for ogi produced at 24th hour of soaking for all maize varieties with the exception of ogi produced from A4Y and A5W at 12th hour of soaking.

4. Conclusion

Drying operation of ogi was significantly affected by the change in temperature and moisture gradient. There was reduced drying time with the increase in drying temperature. There was a higher removal of water at the initial stage of the drying operation and drying process was predominantly in the falling rate period (FRP). The soaking period had no significant impact on drying behavior. Drying behavior was more connected with the amount of moisture in the drained ogi and the drying temperature. The structure of ogi slurry may have played an active role in the drying kinetics and effective moisture diffusivity, this may need to be investigated. Logarithmic and two term models best fitted about 40.77 % (22 samples each). There was no definite pattern for effective moisture diffusivity (D_{eff}) and Activation energy (E_a).

References

Aghbashlo, M. Kianmehr, M.H. and Samimi-Akhijahani, H. (2009). Evaluation of thin-layer drying models for describing drying kinetics of barberries (*Barberries vulgaris*). *Journal of Food Process Engineering*, 32 (2), 278 – 293. https://doi.org/10.1111/j.1745-4530.2007.00216.x

Akgun, N.A. and Doymaz, I. (2005). Modeling of olive cake thin-layer drying process. *Journal of Food Engineering*, 68(4), 455–461. https://doi.org/10.1016/j.jfoodeng.2004.06.023

Akpinar, E.K. and Bicer, Y. (2006). Mathematical modelling and experimental study on thin layer drying of strawberry. *International Journal of Food Engineering*, 2(5), 1-11. https://doi.org/10.2202/1556-3758.1045

Ansari, F.A., Abbas, K.A. and Ahmad, M.M.H. (2004). Correlation between thermal diffusivity variation and quality of cold preserved fish. *ASEAN Journal on Science and Technology for Development*, 21(1), 1-10. https://doi.org/10.29037/ajstd.82

Babalis, S.J. and Belessiotis, V.G. (2004). Influence of drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs. *Journal of Food Engineering*, 65(3), 449–458. https://doi.org/10.1016/j.jfoodeng.2004.02.005

Bart-Plange, A.I., Addo, A., Ofori, H. and Asare, V. (2012). Thermal Properties of Gros Michel Banana Grown in Ghana. *ARPN Journal of Engineering and Applied Sciences*, 7(4), 478-484.

Bolaji, O.T., Olalusi, A.P. and Adesina, B.S. (2015). Mathematical Modeling of Drying Pattern of *Ogi* Produced from Two Types of Maize Grain. *Journal of Food Research*, 4(1),174-185. https://doi.org/10.5539/jfr.v4n1p174

Bolaji, O.T., Awonorin, S.O., Shittu, T.A. and Sann, L.O. (2017). Changes induced by soaking period on the physical properties of maize in the production of Ogi.
Cogent Food and Agriculture, 3(1), 4-14. https://doi.org/10.1080/23311932.2017.1323571

Bolaji, O.T. Oyewo, A.O. and Adepoju P.A. (2014). Soaking and Drying Effect on the Functional Properties of Ogi Produce from Some Selected Maize Varieties. *American Journal of Food Science and Technology*, 2(5), 150-157. https://doi.org/10.12691/ajfst-2-5-3

Celma, A.R., Rojas, S., López, F., Montero, I. and Miranda, T. (2007). Thin-layer drying behaviour of sludge of olive oil extraction. *Journal of Food Engineering*, 80(4), 1261–1271. https://doi.org/10.1016/j.jfoodeng.2006.09.020

Demirel, D. and Turhan, M. (2003) Air-drying behavior of Dwarf Cavendish and Gros Michel banana slices. *Journal of Food Engineering*, 2003, 59(1), 1–11. https://doi.org/10.1016/S0260-8774(02)00423-5

Doymaz, I. (2005). Drying behaviour of green beans. *Journal of Food Engineering*, 69(2),161-165. https://doi.org/10.1016/j.jfoodeng.2004.08.009

Erenturk, S. and Erenturk, K. (2007). Comparison of genetic algorithm and neural network approaches for the drying process of carrot. *Journal of Food Engineering*, 78(3), 905-912. https://doi.org/10.1016/j.jfoodeng.2005.11.031

Erenturk, S., Gulaboglu, M.S. and Gultekin, S. (2004). The thin-layer drying characteristics of rosehip. *Biosystems Engineering*, 89(2), 159-166. https://doi.org/10.1016/j.biosystemseng.2004.06.002

Ertekin, C. and Yaldiz, O. (2004). Drying of eggplant and selection of a suitable thin layer drying model. *Journal of Food Engineering*, 63, 349–359. https://doi.org/10.1016/j.jfoodeng.2003.08.007

Flores, M.J.P., Febles V.G., Pérez, J.J.C., Dominguez, G., Mendez, J.V.M., Gonzalez E.P. and Lopez G.F.G. (2012). Mathematical modelling of castor oil seeds (*Ricinus communis*) drying kinetics in fluidized bed at high temperatures. *Indian Crop Production*, 38, 64-71. https://doi.org/10.1016/j.indcrop.2012.01.008

Gastón, A.L., Abalone, R.M., Giner, S.A. and Bruce, D.M. (2004). Effect of modelling assumptions on the effective water diffusivity in wheat. *Biosystems Engineering*, 8(2), 175–185. https://doi.org/10.1016/j.biosystemseng.2004.02.009

Gaware, T.J., Sutar, N. and Thorat, B.N. (2010). Drying of tomato using different methods: comparison of dehydration and rehydration kinetics. *Drying*

Technology, 289(5), 651-658. https://doi.org/10.1080/07373931003788759

Gely, M.C. and Santalla, E.M. (2007) Moisture diffusivity in quinoa (*Chenpodiun quinoa* Willd.) seeds: Effect of air temperature and initial moisture content of seeds. *Journal of Food Engineering*, 78 (3), 1029–1033. https://doi.org/10.1016/j.jfoodeng.2005.12.015

Gunhan, T., Demir, V., Hancioglu, E. and Hepbasli, A. (2005). Mathematical modelling of drying of bay leaves. *Energy Conversion and Management*, 46 (11), 1667-1679. https://doi.org/10.1016/j.enconman.2004.10.001

Hossain, M.A. and Bala, B.K. (2002). Thin-layer drying characteristics for green chilli. *Drying Technology*, 20(2), 489-505. https://doi.org/10.1081/DRT-120002553

Karim, M.A. and Hawlader, M.N.A. (2005). Drying characteristics of banana: Theoretical and experimental validation. *Journal of Food Engineering*, 70(1), 35 - 45. https://doi.org/10.1016/j.jfoodeng.2004.09.010

Kingsly, R.P., Goyal, R.K., Manikantan, M.R. and Ilyas, S.M. (2007). Effects of pretreatments and drying air temperature on drying behavior of peach slice. *International Journal of Food Science and Technology*, 42(1), 65–69. https://doi.org/10.1111/j.1365-2621.2006.01210.x

Maskan, A. Kaya, S. and Maskan, M. (2002). Hot air and sun drying of grape leather. *Journal of Food Engineering*, 54(1), 81–88. https://doi.org/10.1016/S0260-8774(01)00188-1

Maskan, M. (2001). Drying, shrinkage, and rehydration characteristics of Kiwi fruits during hot air and microwave drying. *Journal of Food Engineering*, 48 (2), 177-182. https://doi.org/10.1016/S0260-8774(00)00155-2

Midilli, A. and Kucuk, H. (2003). Mathematical modelling of thin layer drying of pistachio by using solar energy. *Energy Conversion and Management*, 44(7), 1111-1122. https://doi.org/10.1016/S0196-8904(02)00099-7

Özbek, B. and Dadali, G. (2007). Thin-layer drying characteristics and modeling of mint leaves undergoing microwave treatment. *Journal of Food Engineering*, 83(4), 541-549. https://doi.org/10.1016/j.jfoodeng.2007.04.004

Ojendiran, J.O. and Raji, A.O. (2010). Thin layer drying of millet and effect of temperature on drying characteristics. *International Food Research Journal*, 17, 1095-1106.

Rahman, M.S., Al-Shamsi, Q.H., Bengtsson, G.B., Sablani, S.S. and Al-Alawi, A. (2009). Drying kinetics and allicin potential in garlic slices during different methods of drying. *Drying Technology*, 27 (3), 467-477. https://doi.org/10.1080/07373930802683781

Ronoh, E.K., Kanali, C.L., Mailutha, J.T. and Shitanda, D. (2010). Thin layer drying kinetics of Amaranth grains in a natural convection solar tent dryer. *Journal of Food Agriculture Nutrition and Development*, 10(3), 2218-2233. https://doi.org/10.4314/ajfand.v10i3.54080

Sacilik, K. and Unal, G. (2005). Dehydration Characteristics of Kastamonu Garlic Slices. *Biosystems Engineering*, 92(2), 207–215. https://doi.org/10.1016/j.biosystemseng.2005.06.006

Sahin, A.Z. and Dincer, I. (2005). Prediction of drying times for irregular shaped multi-dimensional moist solids. *Journal of Food Engineering*, 71(1), 119 - 126. https://doi.org/10.1016/j.jfoodeng.2004.10.024

Shi, Q.-L., Chang-Hu, X., Ya, Z., Zhao-Jie, L. and Wang, X. (2008). Drying Characteristics of horse mackerel (*Trachurus japonicus)* dried in a heat pump dehumidifier. *Journal of Food Engineering*, 84(1), 12–20. https://doi.org/10.1016/j.jfoodeng.2007.04.012

Togrul, I.T. and Pehlivan, D. (2003). Modeling of drying kinetics of single apricot. *Journal of Food Engineering*, 58(1), 23-32. https://doi.org/10.1016/S0260-8774(02)00329-1

Toyosi, Y.T. and Adeladun, A. (2010). Air drying characteristics of chili pepper. *International Journal Food Engineering*, 6(1), 1-15. https://doi.org/10.2202/1556-3758.1649

Yaldiz, O. and Ertekin, C. (2001). Thin layer solar drying of some vegetables. *Drying Technology*, 19 (2), 583-596. https://doi.org/10.1081/DRT-100103936

Yashoda, H.M., Prabha, T.N. and Tharanathan, R.N. (2006). Mango ripening: changes in cell wall constituents in relation to textural softening. *Journal of the Science of Food and Agriculture*, 86(5), 713–721. https://doi.org/10.1002/jsfa.2404