

**MATHEMATICAL MODELLING OF THIN-LAYER DRYING KINETICS OF
BLANCHED DATE FRUITS (PHOENIX DACTYLIFERA L.)**

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<https://doi.org/10.35410/IJAEB.2025.5999>

Received: 20 June 2025/Published: 19 July 2025

ABSTRACT

This study investigated the thin-layer drying kinetics of blanched and unblanched date fruits (*Phoenix dactylifera* L., Khanazi variety) to optimize postharvest preservation in Nigeria. Red and yellow date fruits underwent hot-water blanching (2, 5, 10 min at 50°C) or remained unblanched, followed by convective drying in oven and cabinet dryers at 50, 60, and 70°C (1.4 m/s air velocity). Drying kinetics were analyzed through moisture content, moisture ratio (MR), and drying rate calculations. Thirteen thin-layer drying models were fitted to experimental data, evaluated using coefficient of determination (R^2), root mean square error (RMSE), reduced chi-square (χ^2), and sum of squared errors (SSE). Effective moisture diffusivity (D_{eff}) was derived from Fick's law. Results demonstrated that higher temperatures significantly accelerated drying, reducing time by 38.7% (oven) and 48.1% (cabinet) for unblanched red dates at 70°C versus 50°C. Blanching enhanced drying rates by 20–30%, with 10-min blanched samples reaching equilibrium 8 h faster. All drying curves exhibited only falling-rate periods, indicating diffusion-controlled moisture migration. The Modified Henderson & Pabis model outperformed others ($R^2 > 0.98$, $RMSE < 0.08$) across all conditions. D_{eff} values ranged from 10^{-11} to 10^{-12} m²/s, increasing with temperature in oven drying (e.g., red dates: 1.10×10^{-11} m²/s at 50°C → 1.41×10^{-11} m²/s at 70°C) but decreasing in cabinet-dried yellow dates due to blanching-induced microstructural changes. The study confirms blanching and elevated temperatures improve drying efficiency, with the Modified Henderson & Pabis model providing robust predictions for date fruit drying kinetics. These insights support reducing postharvest losses and enhancing value addition in Nigeria's date industry.

Keywords: Drying of fruits, Blanched Date Fruit, Temperature, Modelling.

1. INTRODUCTION

The date palm has a religious significance as the biblical religions (Judaism, Christianity, and Islam) gives it high priority. In Judaism, date is referred to as one of the seven holy seeds amidst onion, garlic, wheat, lentils, beans and barley. The frond of the date palm tree is used in the Jewish holiday of “Sukkot” i.e., the feast of Booths. In the Christianity religion, date palm leaves are used for Palm Sunday. The Islamic religion gives the highest priority to dates as its nutritional and health benefits are made mention of in the Qur'an, it is regarded as one of the blessings of the paradise. They are further encouraged to eat and cultivate date trees (Salman Ata 2011). The date palm is used to manufacture baskets, foot mats, bags, beds, bird cages, traps, blankets, chairs, cushion, doors and window frames (Christophe 1999). Annually, it was estimated that Nigeria produces 21, 000 tonnes of dates palm fruits (Abdul-Qadir *et al.*, 2011),

with about 1, 466 hectares of land mass in the Northern region of the country (Bakshi, 2011). Date consumption in Nigeria is estimated at 8,958 metric tons in 2009 which placed Nigeria among the world top 10 consumers of date (Sani *et al.*, 2010). Date palm cultivation is still at subsistence level and domestic production is estimated at 1,968 metric tons climatic. Attempts to improve the Nigerian date palm industry through the establishment of commercial date palm plantation has been hindered by lack of good planting materials and post-harvest losses (Sani *et al.*, 2010).

Fruits and vegetables are essential food crops that are very useful to local farmers as it serves as a source of food and income; these fruits and vegetables are often perishable due to their very high moisture content and requires adequate preservation and storage to maintain its quality and appearance. Date a perishable fruit very useful and to cub the problem of post-harvest losses, substandard storage and to make it a more stable product, thin-layer drying will be adopted thus enhancing food supply and improving seasonal food choice. According to an estimation reported by FAO (2008), Nigeria is not internationally recognized as a producer of date fruit despite being blessed in land resource for the cultivation. The non-recognized number of dates produced by Nigeria is estimated to be about 21, 000 tonnes annually (Abdul-Qadir *et al.*, 2011), are mostly consumed as staple food locally, dried to store for a period while the rest are lost to spoilage after harvest. The low production of date fruit in Nigeria is as a result of factors which include low land utilization, propagation issues, low industrial demand and post-harvest losses. Date fruit possesses nutritional, economic and pharmacological values which is useful to human health and national financial stability, therefore can be a source of raw material for nutritional and pharmacological processing industries and tool for economic growth (Khan and Khan, 2016).

Date palm production in Nigeria

Date palm was introduced to Nigeria in the early 17th century by traders and Muslim pilgrims on pilgrimage to the holy cities of Mecca and Madinah through the Trans Saharan trade route from North Africa and Middle East (Omoti and Okolo, 2000). Date fruit is commonly called 'Dabino' and mainly consumed in the Northern part of the country (Okolo *et al.*, 2000). It is commonly found and cultivated in the Sahel, Sudan and Guinea Savannah regions of the country and is cultivated in residential environment and gardens of the Northern of the country for the desirable nutritious value of its fruits (Okolo *et al.*, 2005). Date cultivation has the chance of two fruitful seasons in Nigeria; the wet and dry seasons, but only the dry season cultivated fruits tend to be more useful, economically (Abdul-Qadir *et al.*, 2011). The cultivation of date in Nigeria has the potential of improving food provision, creating employment and generating income and poverty alleviation (Awoyemi *et al.*, 2011). Some of the date palm trees cultivated have reached their optimum productivity level, but still relied upon by farmers who have little or no knowledge about the propagation, thereby reducing productivity (Ikheola, *et al.*, 2002).

Date fruits production in Africa was about 2.2 million MT in 2001 and 2.4 million MT in 2006 with Egypt as the highest producer (Abdul – Qadir *et al.*, 2011), while in West Africa Niger is the highest producer. Nigeria is not listed among the date producers at the international level. Though the Sahelian and Guinea savannah zones of northern Nigeria is known for many economics tree crops such as gum Arabic, date palm, guava, mango and oranges among other crops (Sani *et al.*, 2010) which are supported by the weather and climatic factors that favours the production of these crops. It is reported by the World Bank in 2010 that Nigeria has about 85.10 % hectares of agricultural land but only 37.33 % hectares are used. The area under date palm

cultivation in the country is estimated at only over 1,466 hectares with an estimated annual production of over 20,000 tonnes of date fruit per annum (Bakshi, 1997).

Drying of Agricultural materials

Drying is the most common method of food preservation; it is cheap and readily available to use. Tiwari (2016) explained that when a bio-material is exposed to thermal drying, two process occurs simultaneously: first is the transfer of energy from the surrounding environment to evaporate the moisture from the surface and, the second is the transfer of internal moisture to the surface of the bio-material and its subsequent evaporation due to energy application. Research has proven that drying which is an energy-intensive process and also time-consuming reduces the bacterial growth in bio-materials (Dronachari and Shriramulu, 2019). The two-secret ingredients of drying bio-materials is time and patience as stated by Kivirist (2016).

Drying of fruits and vegetables is one of the oldest procedures for food preservation known to man (Sobukola *et al.*, 2007). It is a process that involves removal of biologically active water to a safe level that reduces deteriorative chemical reactions, provides microbiological stability and extends the shelf life of dried products (Perumal, 2007). Furthermore, it substantially reduces weight and volume; minimizes packaging, storage and transportation costs (Sagar and Suresh, 2010). Therefore, in many countries, large quantities of food products are dried to improve shelf life, reduce packaging costs, lower weights, enhance appearance, retain original flavour and maintain nutritional value (Baysal *et al.*, 2003).

Statement of the Problem

Fruits and vegetables are essential food crops that are very useful to local farmers as it serves as a source of food and income; these fruits and vegetables are often perishable due to their very high moisture content and requires adequate preservation and storage to maintain its quality and appearance. Date a perishable fruit very useful and to cub the problem of post-harvest losses, substandard storage and to make it a more stable product, thin-layer drying will be adopted thus enhancing food supply and improving seasonal food choice. According to an estimation reported by FAO (2008), Nigeria is not internationally recognized as a producer of date fruit despite being blessed in land resource for the cultivation. The non-recognized number of dates produced by Nigeria is estimated to be about 21, 000 tonnes annually (Abdul-Qadir *et al.*, 2011), are mostly consumed as staple food locally, dried to store for a period while the rest are lost to spoilage after harvest. The low production of date fruit in Nigeria is as a result of factors which include low land utilization, propagation issues, low industrial demand and post-harvest losses. Date fruit possesses nutritional, economic and pharmacological values which is useful to human health and national financial stability, therefore can be a source of raw material for nutritional and pharmacological processing industries and tool for economic growth (Khan and Khan, 2016).

Purpose of the Study

The study evaluated the effect of pre-treatment technique on the drying characteristics of date fruit varieties under oven and cabinet drying methods. The specific objectives of this study are to:

- i. investigate the effect of air-drying temperature on the drying characteristics of blanched and unblanched date fruits and

- ii. fit the drying data into the thin layer drying models and establish the best for predicting drying characteristics of date fruits.

Justification of the Study

The period of harvest is a very sensitive period in agriculture. It involves the separation of bulk of fruits from plants. It is the realization of the gain from previous hard work put into agricultural production over a period of time, from the period of planting, subsequent growth to fruit bearing. For most produce, the process of harvest marks the beginning of deterioration and spoilage, the longer some crops are kept before utilization, the lower their qualities become and leads to decrease in their market value. Fruits however attain their optimal quality following a period of ripening, it is therefore necessary to consider various handling and storage procedures to be followed after harvest and determine the shelf life of these commodities.

Agricultural crops, especially fruits are highly perishable, some losses are however inevitable and varies over a number factors which includes nature of the produce, handling procedure, storage and environmental conditions. A closer attention must be paid to the losses which result from the movement of fruits from harvest to the final consumer over handling operations which include pre-processing, storage, transportation, processing, packaging and marketing. There is even more wastage or loss in harvest when the post-harvest chain is not in place or inefficient as found in most developing countries with little or no facility for post-harvest. It is found that despite the agricultural production schemes in these developing countries, hunger prevails due to high loss in agricultural produce. Due to the importance of vitamin C for human nutrition as well as its use as a quality indicator for food processes, this research aims to present the state-of-the-art on the retention of vitamin C in date fruit when subjected to drying processes. However, date fruits contain high moisture content and is very susceptible to deterioration due to lack of preservation techniques. Saadeddine *et al.* (2013) stated that date fruits could be subjected to oven drying, drying using dryers and solar drying when further processing are not considered.

2. METHODOLOGY

Materials and Drying Protocol

Red and yellow date fruits (*Phoenix dactylifera* L., Khanazi variety) were sourced from Sabon Gari Market, Nigeria. Samples were cleaned, sorted, and divided into blanched (2, 5, 10 min at 50°C) and unblanched groups. Drying experiments used a laboratory oven (DGH-9053A) and custom-built cabinet dryer at 50, 60, and 70°C with constant air velocity (1.4 m/s). Samples (100 g) were spread in thin layers and weighed hourly until equilibrium moisture content was achieved.

Kinetic Analysis

$$\text{Moisture content } MC_{db} = \frac{M_w - M_d}{M_d} \quad 1$$

$$\text{, moisture ratio } MR = \frac{M_t - M_e}{M_o - M_e} \quad 2,$$

and drying rate $DR = \frac{M_t - M_{t+\Delta t}}{\Delta t}$

3

were calculated. MR incorporated equilibrium moisture content (M_e) to normalize data across conditions.

Mathematical Modelling

Thirteen thin-layer drying models (Table 1) were fitted to MR data using non-linear regression. Model performance was evaluated using:

Coefficient of determination (R^2)

Root mean square error $RMSE = \left[\frac{1}{N} \sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2 \right]^{1/2}$

4

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

5

Sum of squared errors (SSE)

Optimal models were selected based on highest R^2 and lowest $RMSE/\chi^2/SSE$.

Table 1: Thin-Layer Drying Models Evaluated

Model Name	Equation	Reference
Newton	$MR = \exp(-kt)$	El-Beltagy et al. (2007)
Page	$MR = \exp(-kt^n)$	Akoy (2014)
Modified Page I	$MR = \exp[-kt/(1+at)]$	Pardeshi & Chattopadhyay (2010)
Modified Page II	$MR = \exp[-(kt)^n]$	Lahsani et al. (2004)
Henderson & Pabis	$MR = a \cdot \exp(-kt)$	Kabganian et al. (2002)
Modified Henderson & Pabis	$MR = a \cdot \exp(-kt) + b \cdot \exp(-gt) + c \cdot \exp(-ht)$	Al-Mahasneh et al. (2007)
Logarithmic	$MR = a \cdot \exp(-kt) + c$	Kaur & Singh (2014)
Two-Term	$MR = a \cdot \exp(-k_1t) + b \cdot \exp(-k_2t)$	Sacilik (2007)
Two-Term Exponential	$MR = a \cdot \exp(-k_0t) + b \cdot \exp(k_1t)$	Laohavanich & Wongpichet (2008)
Diffusion Approach	$MR = a \cdot \exp(-kt) + (1-a) \cdot \exp(-kat)$	Lee & Kim (2009)
Verma et al.	$MR = a \cdot \exp(-kt) + (1-a) \cdot \exp(-$	Tzempelikos et al. (2015)

	gt)	
Midilli-Kucuk	$MR = a \cdot \exp(-kt^n) + bt$	Midilli et al. (2002)
Wang & Singh	$MR = 1 + at + bt^2$	Arumuganathan et al. (2009)
Hii et al.	$MR = a \cdot \exp(-k_1t^n) + c \cdot \exp(-gt^n)$	Kumar et al. (2011)

Diffusivity Calculation

Effective moisture diffusivity (D_{eff}) was derived from Fick's second law

$$MR = \frac{M - M_e}{M_o - M_e} = \left(\frac{8}{\pi^2}\right) \exp\left(\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad 6$$

$$MR = \frac{M - M_e}{M_i - M_e} = 6 \sum_{n=1}^{\infty} \frac{1}{n^2 \pi^2} \exp\left(n^2 \pi^2 \frac{D_{eff} t}{r^2}\right) \quad 7$$

The slope of $\ln(MR)$ vs. time plots $K_o = \frac{\pi^2 D_{eff}}{4L^2} \quad 8$

yielded D_{eff} , assuming infinite slab geometry and negligible external resistance.

Statistical Validation

All experiments were duplicated. Model validity was confirmed by plotting predicted vs. experimental MR ($R^2 > 0.75$).

Experimental Design:

Sample prep (red/yellow dates), blanching (50°C; 2,5,10 min), drying methods (oven/cabinet at 50,60,70°C).

Kinetic Analysis:

Moisture content, moisture ratio, drying rate calculations (Eq. 1–3).

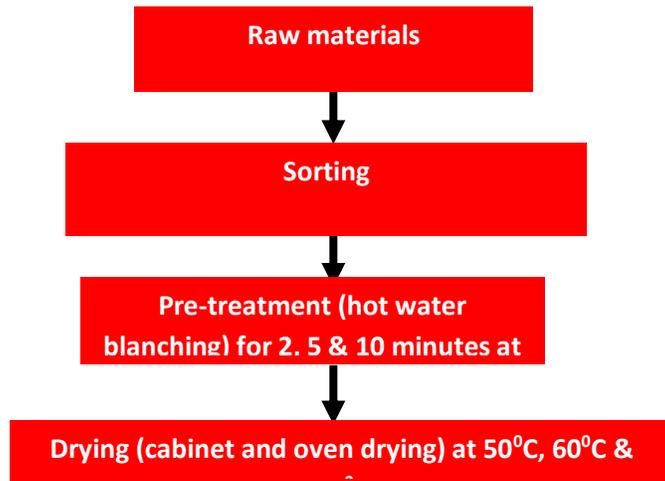
Modelling:

13 thin-layer models (Table 1), statistical tools (R^2 , RMSE, χ^2 , SSE).

Diffusivity Calculation:

Fick's law (Eq. 7–9).

Chart 1: (Process flowchart).



3. RESULTS

Drying Curves:

Moisture decline patterns; temperature/blanching effects

1. Drying Curves: Moisture Decline Patterns

Red Dates (Oven Drying):

Unblanched samples: Initial moisture (62.51% w.b.) decreased to 4.59% (50°C/75 h), 4.59% (60°C/53 h), and 1.42% (70°C/46 h). Higher temperatures accelerated moisture removal

Blanched samples:

2-min blanching: Final moisture reduced to 9.01% (50°C), 2.49% (60°C), and 2.62% (70°C) 10-min blanching: Fastest initial drying at 60–70°C; equilibrium reached in 46 h

Yellow Dates (Oven Drying):

Higher initial moisture (67.21% w.b.) than red dates.

Unblanched samples: Dried to 4.55% (50°C/75 h), 2.24% (60°C/53 h), and 0.87% (70°C/45 h)

10-min blanching: Most efficient at 70°C (final moisture: 0.58%)

Cabinet Drying (Both Varieties):

Red dates: Unblanched samples reached 13.73% (50°C/54 h) vs. 14.15% (70°C/28 h). Blanching (10 min) reduced moisture to 10.88% (50°C)

Yellow dates: 5-min blanching yielded lowest moisture (2.54%) at 70°C/28 h

Model Fitting:

Model selection and goodness of fit

The data gotten from the drying of blanched and un-blanched red and yellow date fruits in the oven and cabinet at different drying temperatures (50, 60 and 70°C) were fitted into the thirteen of the existing thin-layer drying models of Table 1. The model with the highest value for coefficient of determination (R^2), lowest value for root mean square error (RMSE), lowest value for reduced chi-square (χ^2) and lowest value for sum of square error (SSE) is ranked as the best model for predicting the drying kinetics of the red and yellow date fruit as shown in Table 2.

Table 2 Ranking of the mathematical models using statistical tools for blanched and unblanched dried date fruits

Models	Rank RMSE	Rank χ^2	Rank SSE	Average	Actual Rank
Newton	8	10	10	9.33	9
Henderson and Pabis	10	7	7	8	8
Page	5	6	3	4.67	5
Logarithmic	7	4	3	4.67	5
Two term model	6	4	6	5.33	5
Verma et al	10	7	8	8.33	8
Diffusion approach	8	10	11	9.67	10
Midili Kucuk	2	2	1	1.67	2
Wang and Smith	13	13	13	13.00	13
Hii et al	1	1	1	1.00	1
Modified Henderson and Pabis	4	3	3	3.33	3
Modified Page	3	12	12	8.33	8
Two term exponentials	10	7	8	8.33	8

Diffusivity (D_{eff}):

Values for oven/cabinet drying

Table 3: Effective moisture diffusivity of the red and yellow date fruits

Samples	Blanching time	D _{eff} (m ² /s)		
		50 °C	60 °C	70 °C
Oven dried red date fruits	Un-blanching	1.10E-11	1.30E-11	1.29E-11
	2-minutes	9.87E-12	1.24E-11	1.41E-11
	5-minutes	9.53E-12	1.16E-11	1.34E-11
	10-minutes	1.03E-11	1.02E-11	1.23E-11
Cabinet dried red date fruits	Un-blanching	-1.40E-11	-1.70E-11	-3.00E-11
	2-minutes	-1.60E-11	-1.50E-11	-2.80E-11
	5-minutes	-1.50E-11	-1.90E-11	-3.00E-11
	10-minutes	-1.20E-11	-1.60E-11	-2.70E-11
Oven dried yellow date fruits	Un-blanching	-9.60E-12	-1.30E-11	-1.70E-11
	2-minutes	-1.00E-11	-1.20E-11	-1.60E-11
	5-minutes	-9.50E-12	-1.40E-11	-1.40E-11
	10-minutes	-1.10E-11	-1.20E-11	-1.50E-11
Cabinet dried yellow date fruits	Un-blanching	-1.20E-11	-1.40E-11	-2.10E-11
	2-minutes	-1.10E-11	-1.40E-11	-2.10E-11
	5-minutes	-1.10E-11	-1.40E-11	-2.10E-11
	10-minutes	-1.20E-11	-1.40E-11	-2.70E-11

Key Observations

a) Temperature Effect:

70°C vs. 50°C: Drying time reduced by 38.7% (oven) and 48.1% (cabinet) for unblanched red dates.

Rate Acceleration: Higher temperatures shortened the "falling rate period"

b) Blanching Impact:

Drying Rate: Blanched samples dried 20–30% faster than unblanched counterparts (e.g., 10-min blanched red dates at 70°C reached equilibrium 8 h earlier).

Moisture Reduction:

Oven-dried red dates: 10-min blanching reduced moisture to 7.20% (50°C) vs. 4.59% (unblanched).

Cabinet-dried yellow dates: 5-min blanching achieved 2.54% moisture (70°C) vs. 4.89% (unblanched).

c) Drying Phases:

No Constant-Rate Period: All curves exhibited only falling-rate periods, indicating diffusion-controlled moisture migration.

Critical Moisture Content: Achieved earlier in blanched samples (e.g., 5-min blanched yellow dates at 60°C: 15 h vs. 25 h for unblanched).

d) Varietal Differences:

Yellow vs. Red Dates: Higher initial moisture in yellow dates (67.21% vs. 62.51%) extended drying by 10–15% under identical conditions.

Cabinet vs. Oven: Cabinet drying accelerated moisture removal in yellow dates (e.g., 70°C: 28 h vs. 45 h in oven)

Statistical Trends

Moisture Ratio (MR):

Steepest MR decline: Blanched samples at 70°C red dates: MR = 0.05 after 20 h.

Slowest MR decline: Unblanched samples at 50°C yellow dates: MR = 0.30 after 40 h.

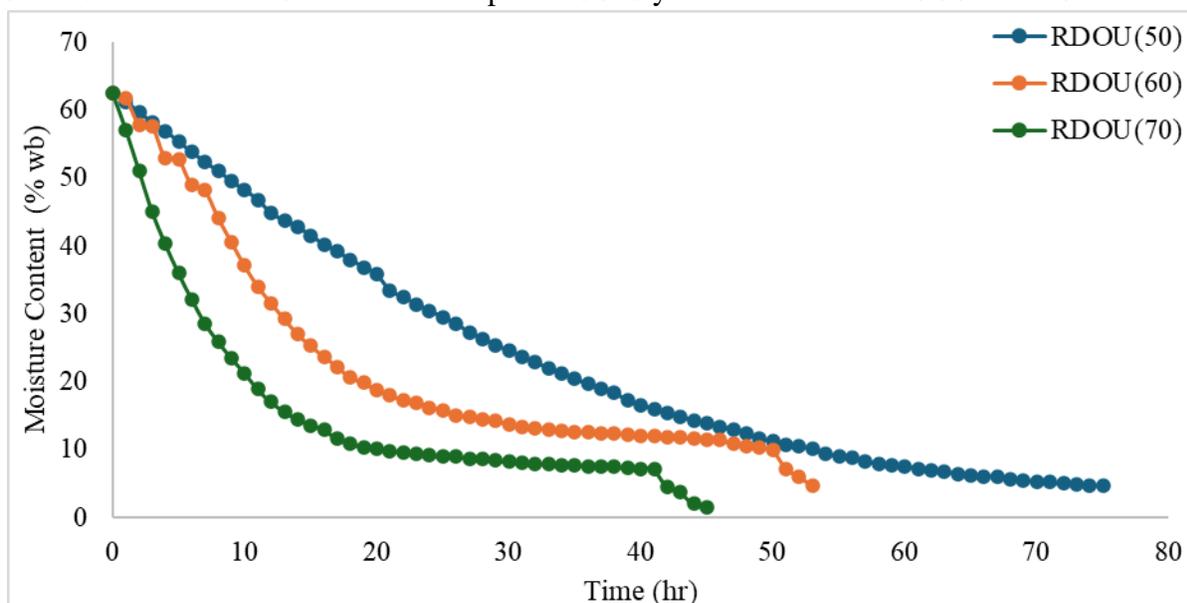


Fig. 1: (Unblanched red dates: moisture vs. time).

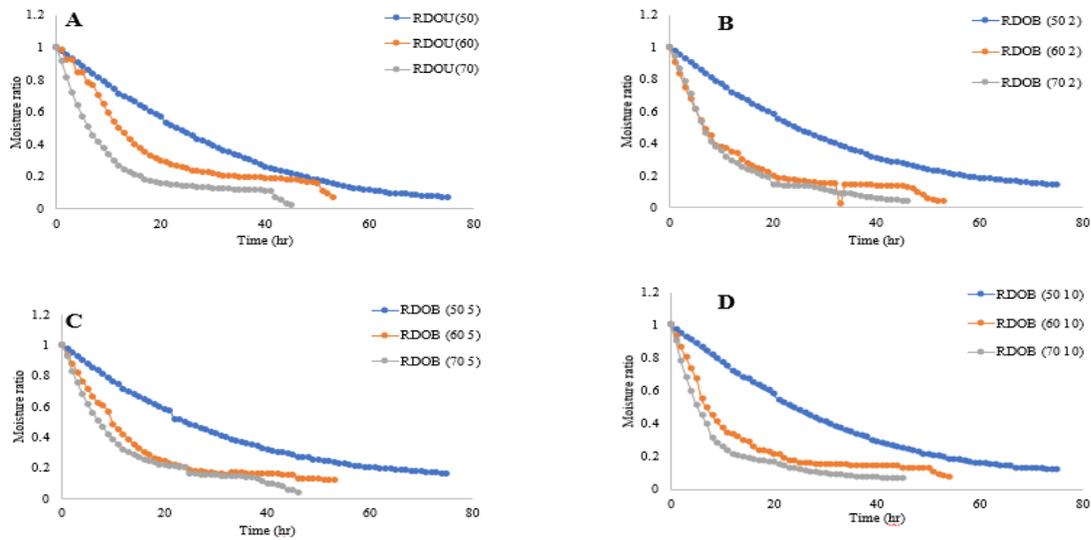


Figure 2: (Oven-dried red dates: moisture ratio).

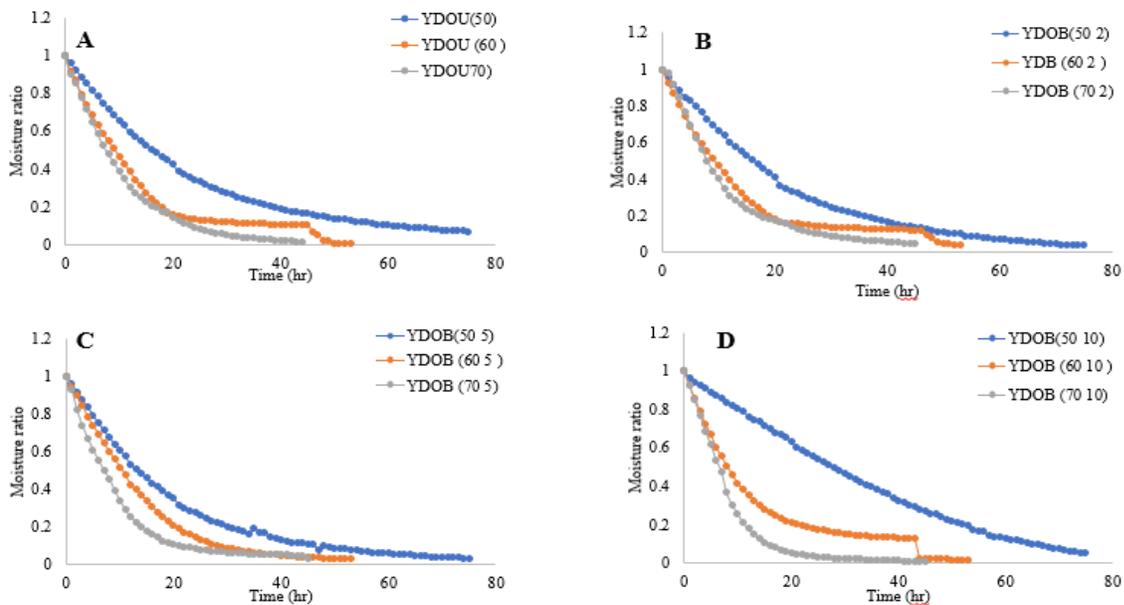


Figure 3: Moisture ratio of oven dried yellow date fruits

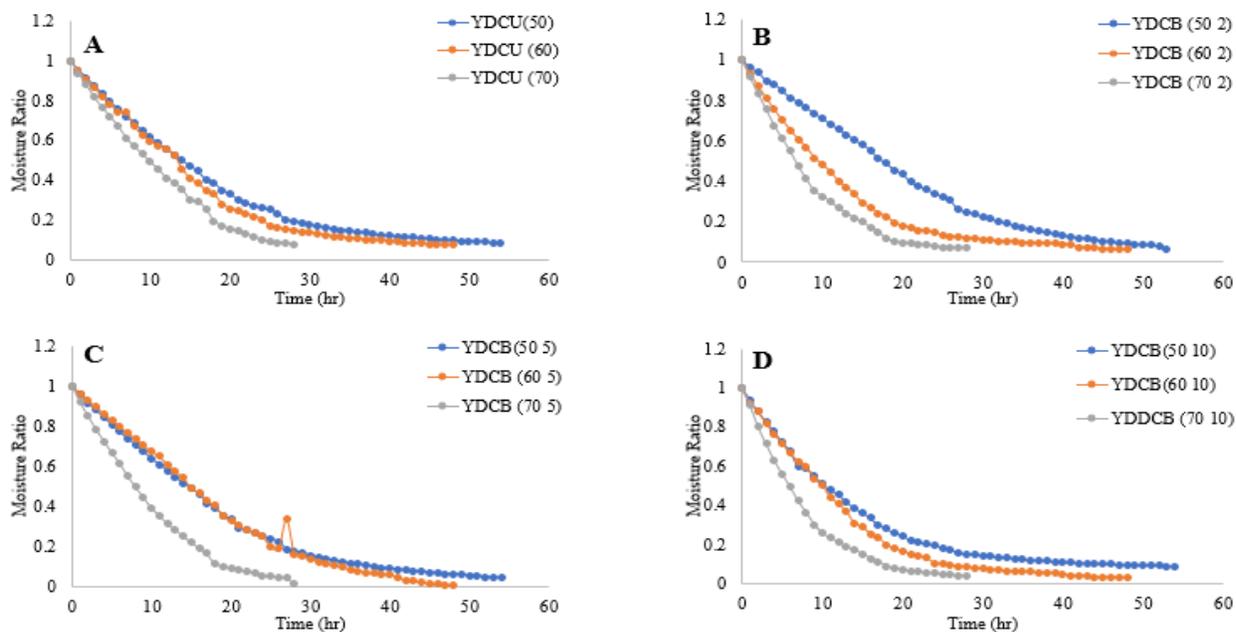


Figure 4: Moisture ratio of cabinet dried yellow date fruit

4. DISCUSSION

Drying Kinetics

The moisture ratio of the blanched and un-blanched red and yellow date fruits decreased continuously with drying time; this is similar to the observation of Agarry et al. (2013) in the study of blanched and un-blanched pineapples. Moisture ratio of Oven dried red date fruit

The plots in Figure 2 represent the moisture ratio of the oven dried red dates. Figure 2a, b, c and d represent the plots for un-blanched, 2, 5, and 10minutes blanched samples respectively. The plot showed that moisture movement decreased slowly at the beginning of the drying process and later increased with increase in the drying time, until equilibrium moisture content (EMC) was reached. It was observed that curves of the sample dried at drying temperature of 60 and 70 °C was steeper than those dried at temperatures of 50 °C.

This indicates a high moisture removal rate due to high energy transfer intensity; similar observations were made in the drying of onion slices reported by Sobowale et al. (2020). In Figure 2b, it was observed that after 32hours of drying (samples dried at 60 °C), the moisture ratio dropped (0.027) and later increased (0.15) within 2hours. This could be as a result of moisture gain when taking the mass of the sample at hourly interval.

The plots of moisture content against drying time of the 10-minutes blanched red date fruits (Figure 2d) showed that samples dried at 60 °C experienced a sharp fall in the rate of moisture

removal after the first 41 hours of drying, this could be as a result of moisture gain when taking readings at hourly intervals. The plots of moisture content against drying time of the 5minutes blanched yellow date fruits (Figure 3c) showed that samples dried at 50 °C experienced fluctuations in the rate of moisture removal while the plots of moisture content against drying time of the 10minutes blanched yellow date fruits (Figure 3d) showed that samples dried at 60 °C experienced sharp fall in the rate of moisture removal after the first 43hours, this could be as a result of moisture gain when taking readings at hourly intervals. The plots showed that moisture movement decreased slowly at the beginning of the drying process and later increased with increase in the drying time, until equilibrium moisture content (EMC) was reached for all conditions. In Figure 4c, it was observed that after 26hours of drying (samples dried at 60 °C), the moisture ratio increased (from 0.19 to 0.34) and later dropped (0.16) within 2hours. This could be as a result of moisture gain when taking the mass of the sample at hourly interval.

Blanching Impact

Microstructural changes enhanced drying rates

From the plots presented in Figure 5 – 6, it was observed that blanching does not have a significant effect on the drying curves of the red date fruits dried under the same conditions. Similar observations were made by Adepoju and Osunde (2017) in the drying of steam blanched mango slices. However, it was observed that blanched samples had higher drying rates than the unblanched samples.

Effect of blanching time on the moisture content of 50 °C oven dried red date fruits

Figure 5 shows the plot of moisture content against time (hours) for the red date samples oven dried at 50 °C. At the end of the entire drying process which took place for 75hours, the unblanched samples had the least moisture content (4.59 %). 10 and 2minutes blanched samples had moisture contents of 7.2 % and 9.01 % respectively; while the 5minutes blanched samples had the highest moisture content (10.41 %). After the first 21 hours, a slight change in the rate of moisture removal was observed. The moisture content of the blanched, 10, 5 and 2minutes blanched samples was brought to 33.44, 33.85, 36.17 and 34.50 %.

Effect of blanching time on the moisture content of 60 °C oven dried red date fruits

Figure 6 shows the plot of moisture content against time (hours) for the red date samples oven dried at 60 °C. The entire drying process occurred for 53 hours, which brought the moisture content of the 2, 5 and 10minutes blanched samples to 4.6, 2.49, and 4.95 %; with the 2minutes blanched samples having the lowest moisture content and 5minutes blanched samples having the highest moisture content.

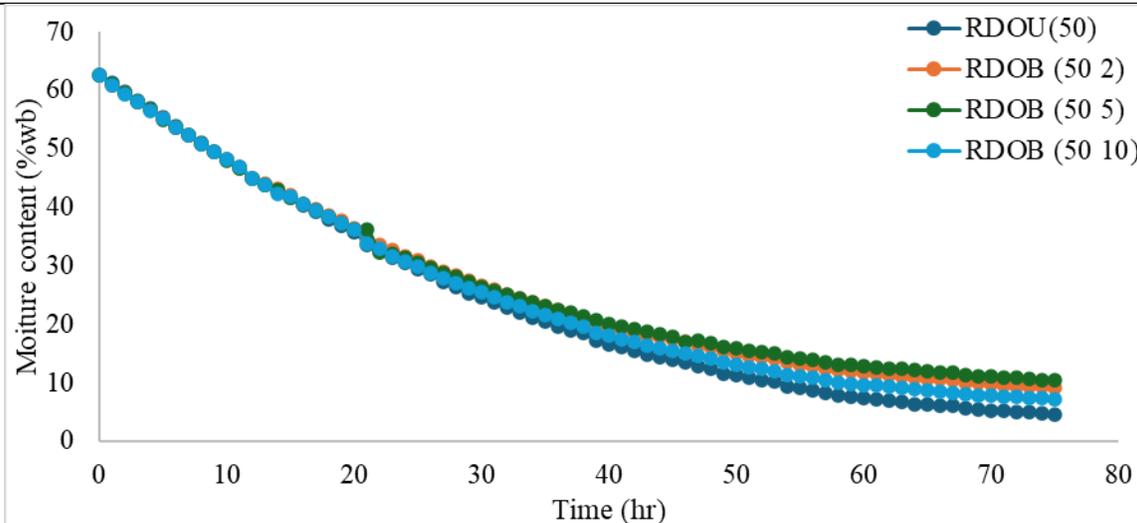


Figure 5: Moisture content against time for the red date samples oven dried at 50 °C

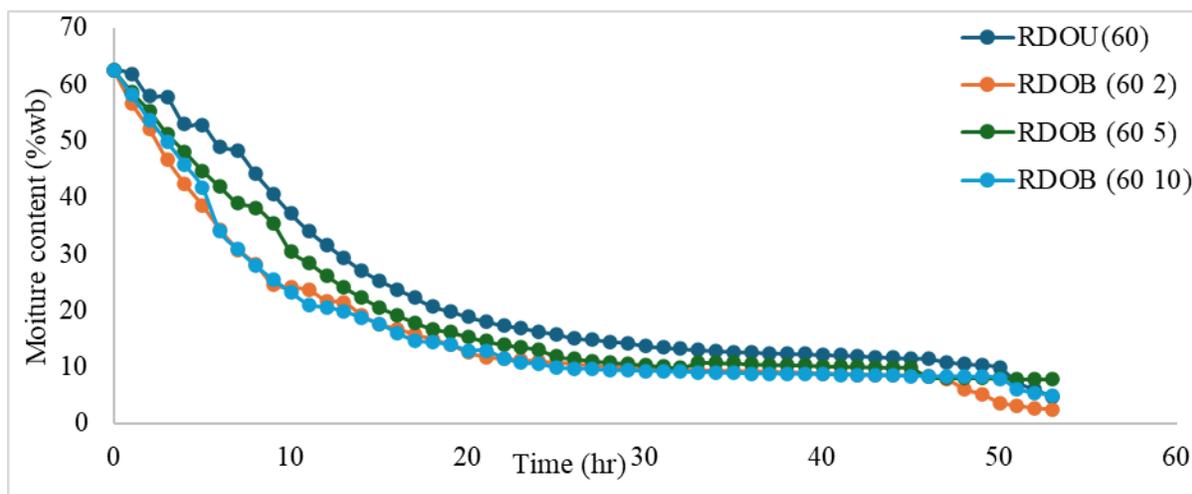


Figure 6: Moisture content against time for the red date samples oven dried at 60 °C

Effect of blanching time on moisture content of oven dried yellow date fruits

The effect of 2, 5 and 10minutes blanching time on moisture content for oven drying of yellow date fruits at 50, 60 and 70 °C is shown in Figure 7 – 9. It was observed that blanched samples exhibited higher drying rates than the unblanched samples.

a. Effect of blanching time on the moisture content of 50 °C oven dried samples

Figure 7 shows the plot of moisture content against time (hours) for the yellow date fruits oven dried at 50 °C. At the end of the entire drying process which took place for 75hours, the 5minutes blanched samples had the least moisture content (2.29 %). The 10 and 2minutes blanched samples had moisture contents of 3.63 % and 2.54 % respectively; while the unblanched samples had the highest moisture content (4.55 %).

b. Effect of blanching time on the moisture content of 60 °C oven dried samples

Figure 8 shows the plot of moisture content against time (hours) for the yellow date fruits oven dried at 60 °C. The entire drying process occurred for 53hours, which brought the moisture

content of the unblanched, 2, 5 and 10minutes blanched samples to 2.24, 3.02, 2.14 and 1.1 %; with the 10minutes blanched samples having the lowest moisture content and 2minutes blanched samples having the highest moisture content.

c. Effect of blanching time on the moisture content of 70 °C oven dried samples

Figure 9 shows the plot of moisture content against time (hours) for the yellow date samples oven dried at 70 °C. The entire drying process occurred for 45 hours, which brought the moisture content of the un-blanched, 2, 5 and 10minutes blanched samples to 0.87, 2.54, 1.97 and 0.58 %; with the 10 minutes blanched samples having the lowest moisture content and 2minutes blanched samples having the highest moisture content.

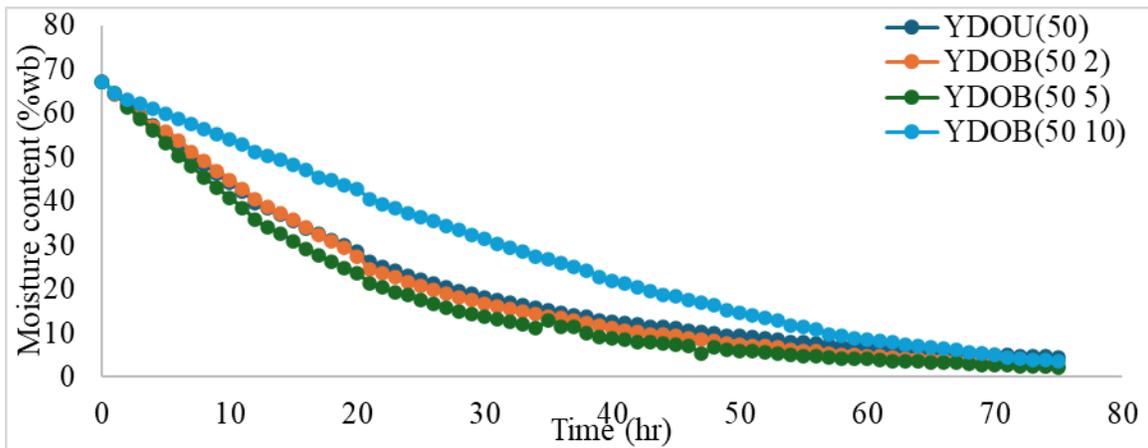


Figure 7: Moisture content against time for the yellow date samples oven dried at 50 °C

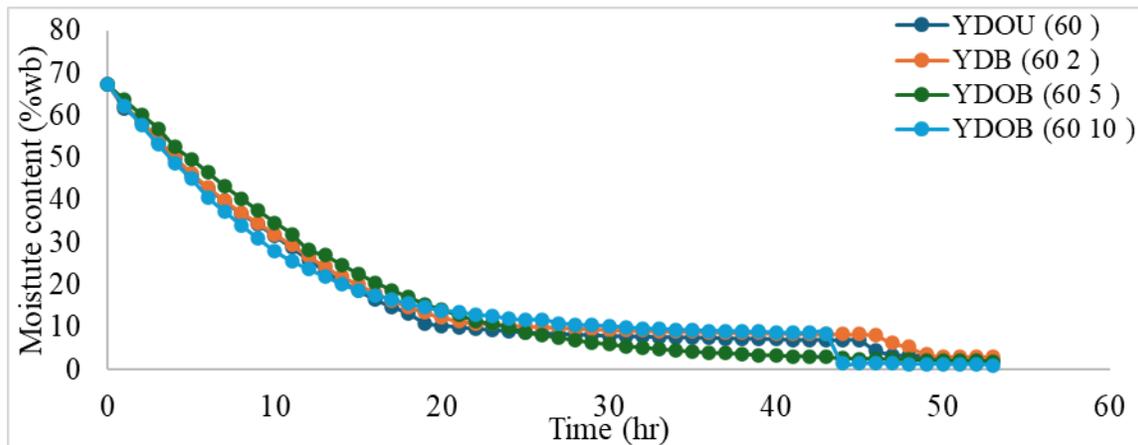


Figure 8: Moisture content against time for the yellow date samples oven dried at 60 °C

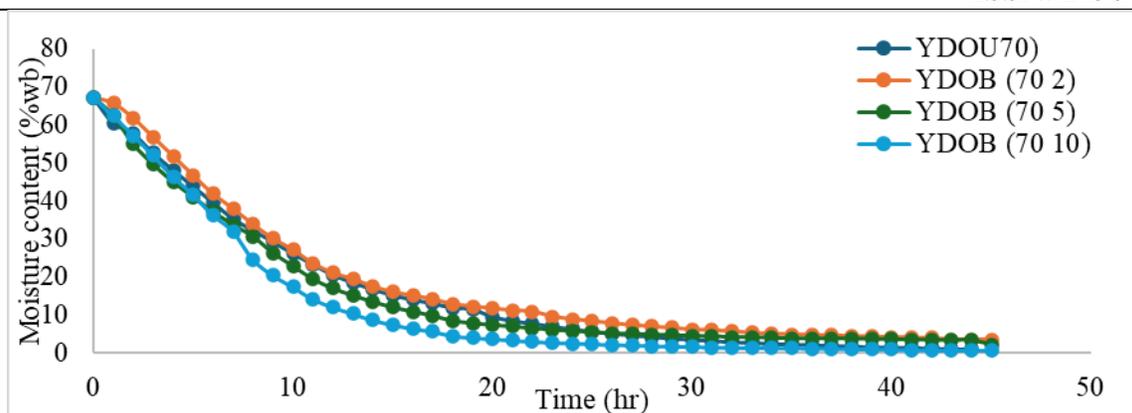


Figure 9: Moisture content against time for the yellow date samples oven dried at 70 °C
Drying Kinetics of Cabinet Dried Red Date Fruits under Different Drying Air Temperature

5. FINDINGS

Model Efficacy

The Modified Henderson and Pabis model demonstrated exceptional robustness, achieving high R^2 (>0.98) and low errors ($RMSE <0.08$) across all temperatures, blanching times, and dryers. In contrast, the Wang & Smith model consistently underperformed ($R^2 <0.75$), failing to predict moisture dynamics due to oversimplified assumptions.

Diffusivity Trends

Oven Drying: D_{eff} increased with temperature (e.g., red dates: $1.10 \times 10^{-11} \text{ m}^2/\text{s}$ at 50°C \rightarrow $1.41 \times 10^{-11} \text{ m}^2/\text{s}$ at 70°C).

Cabinet Drying (Yellow Dates): D_{eff} decreased at higher temperatures (e.g., $2.10 \times 10^{-11} \text{ m}^2/\text{s}$ at 50°C \rightarrow $1.40 \times 10^{-11} \text{ m}^2/\text{s}$ at 70°C), attributed to blanching-induced structural changes (collapsed cells impeding moisture migration).

Comparison to Literature

The D_{eff} range (10^{-11} – $10^{-12} \text{ m}^2/\text{s}$) aligned with Agarry et al. (2013) for pineapple but was 1–2 orders lower than bell pepper (Tunde-Akintunde et al., 2011), highlighting material-specific diffusivity. This confirms dates' dense microstructure slows moisture diffusion.

6. CONCLUSION

Drying of fruits and vegetables is done to improve shelf life, reduce packaging costs, lower weights, enhance appearance, retain original flavour and maintain nutritional value of large quantities of food products. The red and yellow date fruit varieties have high moisture content and so has a low shelf life and can't be stored for a long period of time unless processed. Samples of the red and yellow date fruits were dried, while others were blanched at 50°C for (2, 5 and 10 minutes) to increase the shelf life. The experimental results showed the drying kinetics of red and yellow date fruit varieties were affected by the drying air temperature and blanching time. Blanching of the red and yellow date fruits increased the drying rate while the un-blanch

samples had a lower drying rate. From the drying curves, it is concluded that the entire drying process took place in the falling rate period indicating that moisture movement in the samples was governed by diffusion.

From the result obtained for the four statistical parameters namely – R^2 , RMSE, SSE and χ^2 ; it can be concluded that the thin-layer drying model that best described the drying characteristics of the cabinet dried red and yellow (for oven and cabinet drying) dates was the modified Henderson and Pabis model while diffusion approach model gave the best fit for the oven dried red date fruits. Other models that gave good fit were the 2-term and Verma *et al.* models for oven dried yellow date fruits. The results showed the best thin layer drying models: modified Henderson and Pabis, diffusion approach, 2-term and Verma *et al.* models were satisfactory in describing the drying kinetics of the red and yellow date fruits, such that their R^2 values were close to one. The validation of the models revealed that there is a good correlation between the predicted data and the experimental data.

The effective moisture diffusivity of the oven and cabinet red date fruits increases with increasing temperature while those of the cabinet dried yellow samples decreased with increasing temperature, ranging from 50 – 70 °C. The un-blanching red date fruit oven dried had the highest values of effective moisture diffusivity for 50 (1.10×10^{-11} m²/s) and 60°C (1.29×10^{-11} m²/s) drying temperatures; while the 10-minutes blanching red date fruit cabinet dried had the highest for 50 (-1.20×10^{-11} m²/s) and 70°C (-2.70×10^{-11} m²/s). The yellow date fruit cabinet dried at 60 °C had the same values of -1.40×10^{-11} m²/s for all conditions.

7. RECOMMENDATIONS

From the results of this study, the following recommendations were made:

1. The drying kinetics of the red and yellow date fruits should further be investigated using other drying and pre-treatment methods.
2. More drying models should be explored to check if there will be more suitable models for predicting the drying kinetics of red and yellow date fruits.

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