Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.1173443

Turk J Agr Eng Res
(TURKAGER)

ISSN: 2717-8420
2022, 3(2), 338-356

Research Article

Effects of Drying Temperature on the Drying Characteristics of Parboiled Palm Nuts

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ABSTRACT

The effect of drying temperature on drying characteristics of cooked and fermented palm nuts were determined. The samples were processed using two methods (cooking and fermentation). The rate of drying the samples was observed to increase with corresponding increase in temperature and drying time. It was duly observed that at 70°C, Tenera sample (TS), Pisifera sample (PS) and Dura sample (DS) attained their constant drying rates at 720 mins, 600 mins, and 780 mins. At 80°C TS, PS and DS drying rates falls to zero at 660mins, 600 mins and 720 mins, for 90°C drying temperature, TS and PS had same constant drying rate at 540 mins, DS constant drying rate was found at 600mins. For 100°C TS constant drying rates was observed at 480mins while PS and DS had same constant drying rate at 420mins respectively. The effective drying of the samples was observed to occur at falling rate across the varieties and processing methods. The lower temperature (70°C) decreased the drying rates while the higher temperature increased the drying rates. The average drying time for cooked samples irrespective of sample varieties were 740 mins, 620 mins, 460 mins and 500 mins for temperature range of 70-100°C respectively while for the fermented samples, the average drying time were 680 mins, 660 mins, 560 mins and 440 mins at temperature range of 70-100°C respectively. The regression equations were found to give the best fit with highest coefficient of variation (R^2) values. Mostly all the samples irrespective of processing methods exhibited quadratic regression equations. The cooked samples displayed better dry characteristics than fermented samples.

RESEARCH ARTICLE

Received: 15.09.2022
Accepted: 22.11.2022

Keywords:

- Palm nuts,
- Drying,
- Fermentation,
- Cooked,
- Temperature

To cite: Godson EE, Oluka I and Ide PE (2022). Effects of Drying Temperature on the Drying Characteristics of Parboiled Palm Nuts. *Turkish Journal of Agricultural Engineering Research (TURKAGER), 3(2), 338-356.* https://doi.org/10.46592/turkager.1173443

INTRODUCTION

Oil palm (*Elaeis guineensis*) is one of the most important economic tree crops in Nigeria. The global growing demand for palm oil and its products is making oil palm cultivation a necessary means of livelihood for many rural families, and indeed the farming culture of millions of people in Nigeria. The oil palm tree is a useful crop that is relevant in all aspects of life with socioeconomic and socio-cultural values. According to Ibitoye *et al.* (2011), oil palm is a versatile tree crop with almost all parts having economic value and useful for everyday livelihood. The different parts of oil palm include: the fronds, leaves, trunk and roots. These parts give a wide range of products which are of benefit to mankind. The importance of oil palm to the national economy of Nigeria cannot be over emphasized. It ranges from production of food for human consumption, employment, income to farmers and nation and raw materials for industries. Oil palm has been a major source of foreign exchange to Nigeria as well as source of revenue to major segment of the rural population of Southeast Nigeria (Onoh and Peter-Onoh, 2012). The most important product of oil palm is the palm fruit, which is processed to obtain three commercial products namely: palm oil, palm kernel oil and palm kernel cake. Palm oil and palm kernel oil are two distinct oils which are important in World Trade (Barcelos *et al.*, 2015). Hence, oil palm is often referred to as a crop of multiple values, which underscores its economic importance (Akangbe *et al.*, 2011). It has been established in literature that the domestic consumption of palm oil in Nigeria, in 2017/2018, amounted to about 1.29 million metric tons (Conway, 2018). Palm oil is used in the manufacturing of margarine, soap candle, base for lipstick, waxes and polish bases in a condense form, confectionary (Embrandiri *et al.*, 2011). Oil palm is a monocotyledonous plant belonging to the palm family Arecaceae. It is a monoecious species known to produce unisexual male and female inflorescences in an alternating cycle (Barcelos *et al.*, 2015). Oil palm is, no doubt, the richest tree on earth in terms of natural endowments. It is one of the best trees given by God to man in the tropics for his survival and for all his vegetable oil and related needs. It has been described as the 'tree of life' not only because every part of the tree is useful to man but also because it lives and flourishes for many years. At present, oil palm produces the highest yield (output per land area) of vegetable oil of all known oil crops (Corley and Tinker, 2007). The three main varieties of the oil palm distinguished by their fruit's characteristics are Dura, Pisifera and tenera (Stephen and Emmanuel, 2009). Dura: this has a very thin pericarp, 40-70% of fruit weight with very little and a very big shell of about 2-5 mm thickness. The kernel size is generally bigger than other varieties. Tenera: this has a thick pericarp of about 60% fruit weight very high oil and thick shell (1-2.5 mm) which promotes easy cracking. Pisifera: this has a thicker pericarp with higher oil yield with little or no kernel.

Drying characteristics is the commonest agricultural products processing employed in improving agro-products stability and security, as far as it noticeably declines the negative effect of water in the material, deterioration, microbiological activity, physical and chemical changes during its processing and storage (Mujumdar and Law, 2010). It also, causes colour change, weight reduction, and enhances aesthetic and sensory effects of biomaterials (Brennan, 2006). Therefore, the basic goal is to limit moisture content to levels that halt or slow down the growth of spoilage microorganisms and incident of chemical reactions in order to extend the shelf-life of food (Oduro *et al.*, 2007). According to Maskan (2001) the high quality fast-dried foods have become necessary in the recent times which aggravated a renewed interest in drying operations. Furthermore, there is a high demand for convenient foods more especially ready to eat and instant products, which are desired to contain the less contents of additives and preservatives (Mujumdar and Law, 2010). In spite of the different physical processes used in various drying methods, the underlying principles are very similar, with few exceptions. Several drying systems have been reported by several researchers but were mostly solar dryers depending on climatic conditions (Alonge and Hammed, 2007; Folaranmi, 2009; Alonge, 2008; Amer *et.al.*, 2009; Gatea, 2010). Some electric dryers have also been constructed but were mostly for grains and tuber crops. Therefore, the interest of the research was to determine the effects of drying temperature on the drying characteristics of parboiled and fermented palm nuts.

MATERIALS and METHODS

Source of sample

The samples Dura, Tenera and Pisifera used for this experimental work were all sourced from Enugu East Local Government Area of Nigeria, at harvest moisture content. The latitude of Enugu East, Enugu, Nigeria is 6.489472, and the longitude is 7.517159. Abakpa, Enugu, Nigeria is located at Nigeria country in the Towns place category with the GPS coordinates of 6° 29' 22.0992'' N and 7° 31' 1.7724'' E.

Preparation of the sample

The palm, fruits of Dura, Tenera and Pisifera varieties were harvested from palm-oil processing mill farm located at Enugu East Local Government Area, Enugu State Nigeria. The harvested palm fruits varieties were debouched, and the fruits are detached from their parent stalk and parked in a local basket. The detached fruits were further wiped with a wet clean cloth to removed dirty, dust, broken nuts and nonviable nuts. Each variety were divided into two equal batches, first batch and second batch were subjected to 72 hours fermentation and parboiling which are two pre-treatment methods used. The fermented and parboiled sample were further divided into four equals. The first, second, third and fourth batches were dried to constant weight/moisture using 70, 80, 90 and 100°C drying temperature at interval of 1 hour. The drying characteristics of the processed samples were determined.

Experimental methods

Drying kinetic of palm nut

Drying kinetics reveal the detailed information about the drying process of trifoliate yam slices (John *et al.*, 2020). Their parameters are determined using the following formula.

Moisture content at any time of drying

The moisture content of the sample at any given time and condition were determined using the equation reported by (Chineze *et al.*, 2020):

$$M_{ct} = \frac{W_t - W_d}{W_t} \quad (1)$$

Where:
M_{ct} = Moisture content (%wt)at time t;
W_t = Initial weight of the sample at any time
W_d = Weight of the dried sample

Drying rate at any time of drying
The drying rate of the sample were determined using the equation reported by Dai *et al.* (2017) with little modification.

$$D_R = \frac{M_{t1} - M_{t2}}{t_2 - t_1} \quad (2)$$

D_R = Drying rate (% h)
M_{t1} = Moisture content of drying basis at t_1, (g g^{-1})
M_{t2} = Moisture content of drying basis at t_2 (g g^{-1})
t_2 = Time of drying at M_{t2}
t_1 = Time of drying at M_{t1}

Moisture ratio
Moisture ration of the samples were determined using the equation reported by Dai *et al.* (2017) with little modification.

$$M_R = \frac{M_{t1}}{M_0} \quad (3)$$

M_R = Moisture ratio
M_{t1} = Moisture content of dry basis at any time
M_0 = Initial dry moisture content of the sample.

Statistical analysis
The experiment was carried out in a completely random design. The results obtained were submitted to analysis of variance (ANOVA), with the means compared by Duncan's test at 5% of significance. All results were expressed as the mean value standard error (SE). Statistical analyses were performed using SPSS for Windows 8.0.

RESULTS AND DISCUSSION

Data presentation/analysis
The data collected from this study was analysed using tables, graphs and statistical method.

Drying characteristics is generally determined experimentally by measuring the weight of a drying sample as a function of drying time, drying temperature and moisture content reduction (Saeed *et al.*, 2008). The drying curves which indicate the rate of change in moisture content during drying process of cooked and fermented palm kernel varieties are presented in table 1&2 and from Figure 1 to Figure 8. The curve is important as it indicates the time the drying of the samples should stop at required moisture content to ensure a good quality product. It is obvious that as the drying time increases, the moisture content of the sample decreased.

Table1. Drying characteristics of cooked palm kernel varieties dried at varied temperature 70°C, 80°C, 90°C and 100°C using oven drying method.

	70°C			80°C			90°C			100°C		
TIME	TS	PS	DS	TS	PS	DS	TS	PS	DS	TS	PS	DS
0	23.64	34.72	26.36	23.64	34.72	26.36	23.64	34.72	26.36	23.64	34.72	26.36
60	19.61	26.04	22.16	20.01	24.72	24.42	18.46	26.62	21.01	19.81	19.64	11.84
120	13.14	18.24	19.18	15.18	20.16	19.94	14.28	18.15	14.26	13.13	9.83	7.43
180	9.74	13.44	15.42	10.64	12.83	16.47	10.82	12.64	10.01	8.48	5.84	3.46
240	6.12	10.52	12.16	5.94	9.45	10.89	5.47	9.47	5.64	3.86	3.27	1.61
300	4.78	8.61	9.28	3.93	6.12	7.14	3.88	5.44	3.26	1.61	1.24	1.05
360	3.48	5.82	6.41	2.15	4.01	5.94	1.16	2.99	2.12	1.14	1.01	1.04
420	2.04	3.04	4.24	1.82	2.81	4.11	1.17	1.84	1.34	1.09	1.01	1.04
480	1.71	2.24	2.18	1.42	2.10	2.72	1.07	1.10	1.04	1.09	0.00	0.00
540	1.52	1.16	1.14	1.26	1.18	1.95	1.07	1.10	1.02	0.00	0.00	0.00
600	1.31	1.16	1.10	1.04	1.18	1.31	0.00	0.00	1.02	0.00	0.00	0.00
660	1.17	0.00	1.02	1.04	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.00
720	1.17	0.00	1.01	0.00	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.00
780	0.00	0.00	1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
840	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TS=Tenera sample, PS=Pisifera sample, DS=Dura sample

Table 2. Drying characteristics of fermented palm kernel varieties dried at varied temperature 70°C, 80°C, 90°C and 100°C using oven drying method.

	70°C			80°C			90°C			100°C		
TIME	TS	PS	DS	TS	PS	DS	TS	PS	DS	TS	PS	DS
0	11.95	20.07	14.63	11.95	20.07	14.63	11.95	20.07	14.63	11.95	20.07	14.63
60	10.20	15.82	12.3	10.40	12.32	11.63	7.00	9.64	11.3	9.41	8.18	9.61
120	9.60	12.28	10.96	7.70	10.30	9.41	4.28	4.54	7.31	5.20	5.61	4.74
180	8.30	9.92	9.86	7.10	7.20	7.15	2.01	2.48	3.71	3.01	2.13	2.48
240	7.60	5.65	8.41	6.50	5.40	4.18	1.06	1.27	3.02	1.68	1.14	1.96
300	6.40	4.81	9.64	5.80	3.74	2.88	1.02	1.04	2.61	1.41	1.12	1.36
360	6.20	3.74	5.02	4.70	1.87	1.96	1.01	1.03	1.71	1.17	1.06	1.19
420	4.17	2.24	3.84	2.01	1.31	1.48	1.01	1.03	1.16	1.16	1.03	1.07
480	3.60	1.76	2.21	1.71	1.07	1.28	0.00	0.00	1.06	1.16	1.03	1.03
540	2.02	1.08	1.66	1.61	1.06	1.14	0.00	0.00	1.06	0.00	0.00	1.02
600	1.18	1.04	1.64	1.16	0.00	1.09	0.00	0.00	0.00	0.00	0.00	0.00
660	1.15	1.04	1.15	0.00	0.00	1.05	0.00	0.00	0.00	0.00	0.00	0.00
720	1.15	0.00	1.07	0.00	0.00	1.05	0.00	0.00	0.00	0.00	0.00	0.00
780	0.00	0.00	1.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
840	0.00	0.00	1.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TS=Tenera sample, PS=Pisifera sample, DS=Dura sample

From Table 1, the drying curve of cooked palm kernel samples were presented at temperature range of 70°C to 100°C. It was observed also across the drying temperatures tested DS recorded highest drying time apart samples dried under 100°C. Drying curves which measures the pattern at which moisture migrate from the drying samples to the surroundings, showed that all the samples had a good drying curve trend. From Table 2, the TS, PS and DS rate of moisture removal with respect to time was found to constant at 720 mins, 660 mins and 840 mins for 70°C, 600 mins, 540 mins and 720 mins for 80°C, 420 mins, 420 mins and 540 mins for 90°C and 480 mins, 480 mins and 540 mins for 100°C respectively. This Table 2, showed that DS samples consumed more time to attain constant drying rate than other samples irrespective of processing method adopted.

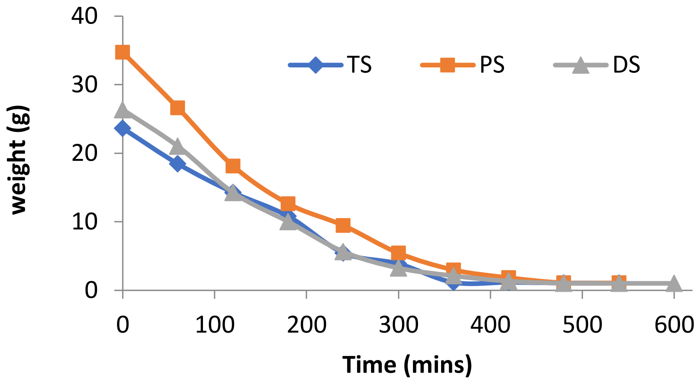

Figure 1. Drying curves for Dura, Tenera and Pisifera cooked samples at 70°C.

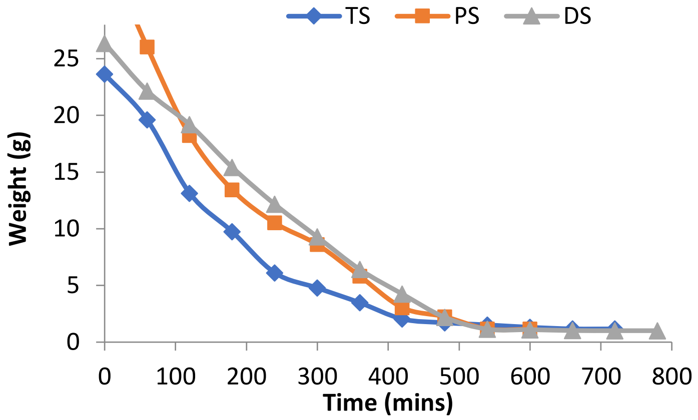

Figure 2. Drying curves for Dura, Tenera and Pisifera cooked samples at 80°C.

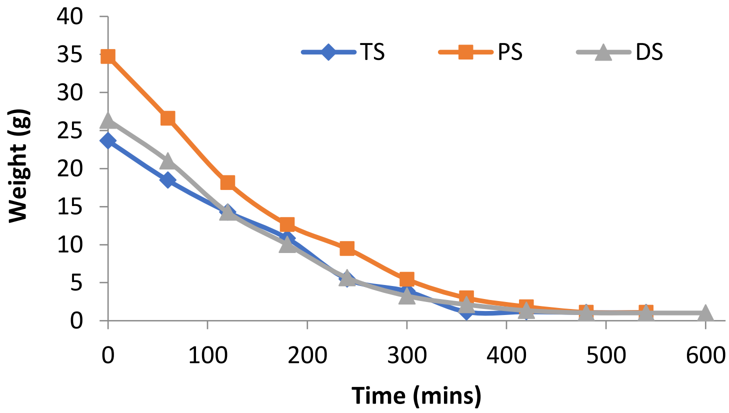

Figure 3. Drying curves for Dura, Tenera and Pisifera cooked samples at 90°C.

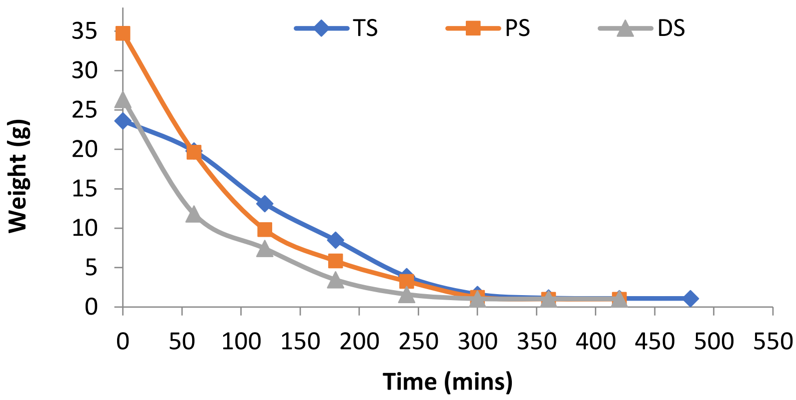

Figure 4. Drying curves for Dura, Tenera and Pisifera parboiled samples at 100°C.

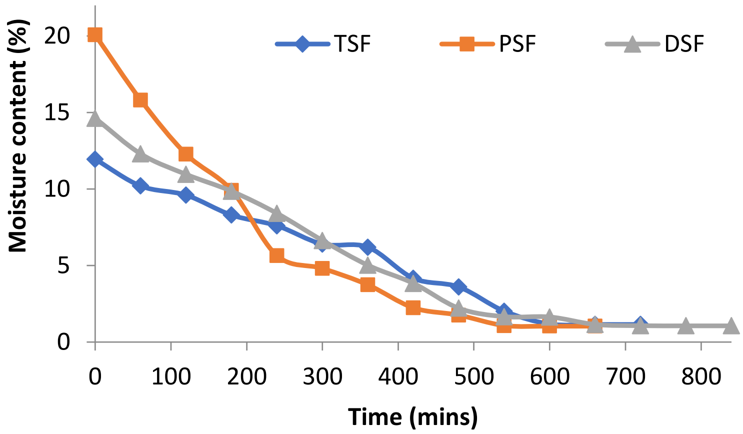

Figure 5. Drying curves for Dura, Tenera and Pisifera fermented samples at 70°C.

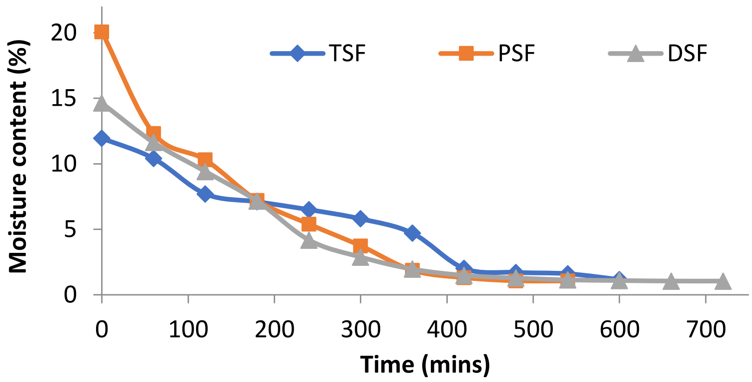

Figure 6. Drying curves for Dura, Tenera and Pisifera fermented samples at 80°C.

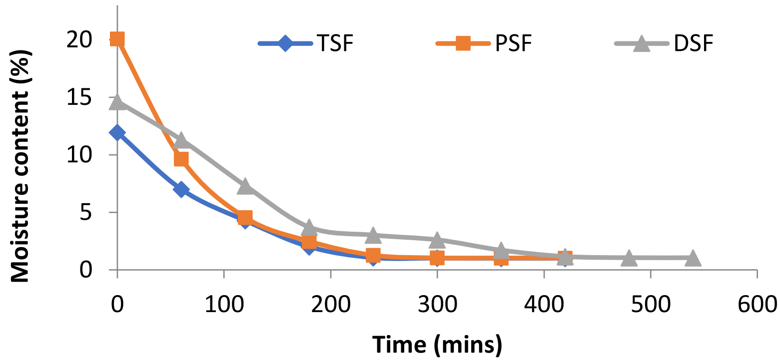

Figure 7. Drying curves for Dura, Tenera and Pisifera fermented samples at 90°C.

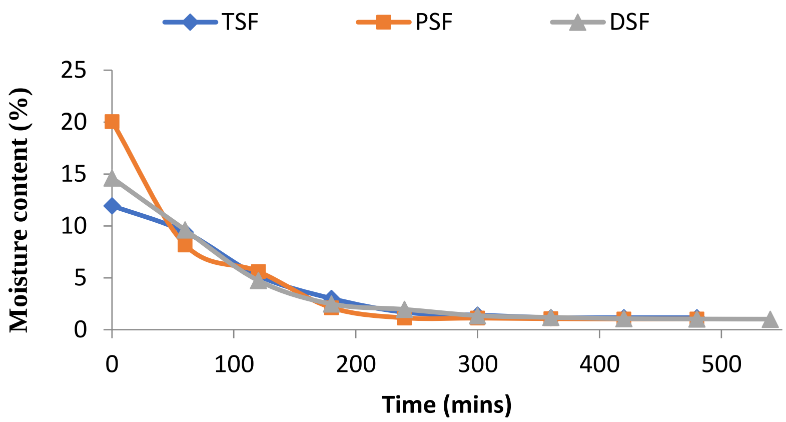

Figure 8. Drying curves for Dura, Tenera and Pisifera fermented samples at 100°C.

Table 3. Relationships between drying curves of tested samples at different moisture contents.

Moisture contents		Regression Equations			
		Cooked		Fermented	
Dura	70	$W_{DS} = 6E\text{-}05T^2 - 0.076T + 26.92$	$R^2 = 0.997$	$W_{DSF} = 2E\text{-}05T^2 - 0.033T + 14.92$	$R^2 = 0.960$
	80	$W_{DS} = 6E\text{-}05T^2 - 0.083T + 28.01$	$R^2 = 0.989$	$W_{DSF} = 5E\text{-}05T^2 - 0.050T + 14.46$	$R^2 = 0.989$
	90	$W_{DS} = 0.000T^2 - 0.109T + 26.30$	$R^2 = 0.994$	$W_{DSF} = 8E\text{-}05T^2 - 0.064T + 14.31$	$R^2 = 0.977$
	100	$W_{DS} = 0.000T^2 - 0.156T + 23.65$	$R^2 = 0.952$	$W_{DSF} = 9E\text{-}05T^2 - 0.069T + 13.37$	$R^2 = 0.948$
Tenera	70	$W_{TS} = 7E\text{-}05T^2 - 0.081T + 22.95$	$R^2 = 0.983$	$W_{TSF} = = 6E\text{-}06T^2 - 0.020T + 11.86$	$R^2 = 0.984$
	80	$W_{TS} = = 9E\text{-}05T^2 - 0.092T + 24.24$	$R^2 = 0.987$	$W_{TSF} = = 1E\text{-}05T^2 - 0.026T + 11.72$	$R^2 = 0.970$
	90	$W_{TS} = 0.000T^2 - 0.098T + 24.06$	$R^2 = 0.994$	$W_{TSF} = 0.000T^2 - 0.070T + 11.36$	$R^2 = 0.983$
	100	$W_{TS} = 0.000T^2 - 0.117T + 24.82$	$R^2 = 0.990$	$W_{TSF} = 8E\text{-}05T^2 - 0.062T + 12.03$	$R^2 = 0.982$
Pisifera	70	$W_{PS} = 0.000T^2 - 0.119T + 32.95$	$R^2 = 0.988$	$W_{PSF} = 6E\text{-}05T^2 - 0.067T + 19.69$	$R^2 = 0.993$
	80	$W_{PS} = 0.000T^2 - 0.128T + 33.28$	$R^2 = 0.992$	$W_{PSF} = = 1E\text{-}05T^2 - 0.026T + 11.72$	$R^2 = 0.970$
	90	$W_{PS} = = 0.000T^2 - 0.141T + 34.19$	$R^2 = 0.996$	$W_{PSF} = 0.000T^2 - 0.122T + 18.09$	$R^2 = 0.95$
	100	$W_{PS} = 0.000T^2 - 0.204T + 32.46$	$R^2 = 0.976$	$W_{PSF} = 0.000T^2 - 0.105T + 17.07$	$R^2 = 0.909$

From Figure 1-Figure 8, drying characteristics curves were represented graphically as averaged moisture content versus time (Coumans, 2000; Saeed *et al.*, 2008). It was observed from the Figure 1 to Figure 8, that the fermented samples displayed a better drying curve properties with longer drying time while cooked samples had short drying time and this could be as a result of hardened surface of the fermented samples which prevented free migration of water from the sample during drying (Saeed *et al.*, 2008). The drying rate also indicates the quantity of moisture evaporated per unit time. It was found that at the beginning of drying, there was a higher rate of moisture loss in all the samples and this rate decreased as the drying time increased and this might be as a result of the nature of water present in the sample (Akpinar *et al.*, 2003) or due to internal pressure generated that forces the moisture in vapour from outside the palm kernel samples (Nguyen and Price, 2007).

From Figure 1 - 8 and Table 3 the relationship between change in moisture content and with time are presented. The average values of correlation coefficient (R^2) of the samples which measures the relationship and variation between variables were 0.983, 0.989, and 0.988 for DS, TS, and PS at temperature range of 70-100°C for cooked samples respectively. While DS, TS and PS had average values of correlation coefficient of 0.969, 0.979 and 0.956 for fermented samples at temperature range of 70-100°C respectively. The Table, 3 presented best fit regression equations and it was observed that all the samples displayed quadratic regression equations for both cooked and fermented samples in Table 3. These values of mathematical equation and correlation coefficient are good prediction of the drying basis of moisture value at any time in the drying process and indicated that the mathematical equation best fits the drying processes since their values are very close to 1.

From Table 4 and 5, the moisture ratio was presented, the moisture ration which measures the ratio of water diffusion or migration from a drying sample with respect to time of drying. The ration of water diffusion and migration from the samples during drying were found to be ±0.01 across all the tested samples irrespective of the drying temperatures. For the cooked samples, the moisture ratio at which the water both bounded and unbounded water migrates from the drying samples falls to zero (constant moisture ratio) with respect to drying time were found to be 720 mins (0.096), 660 mins (0.051) and 840 mins (0.072) for TS, PS and DS at 70°C. For 80°C the constant moisture ratio were 600 mins (0.097), 540 mins (0.052) and 720 mins (0.071) for TS, PS and DS respectively. For 90°C and 100°C, the moisture ratio attained their constant values with respect to time were observed at 420 mins (0.084), 420 mins (0.054), 540 mins (0.072) and 480 mins (0.097), 480 (0.051), 540 (0.069) for TS, PS and DS respectively. For the fermented samples dried at 70°C and 80°C drying temperature attained constant moisture ratio at 720 mins (0.049), 600 mins (0.033), 720 mins (0.039) and 660 mins (0.044), 600 mins (0.034), 720 mins (0.039) for TS, PS and DS respectively. The average drying time for cooked samples irrespective of sample varieties were 740 mins, 620 mins, 460 mins and 500 mins for temperature range of 70-100°C respectively while for the fermented samples, the average drying time were 680 mins, 660 mins, 560 mins and 440mins at temperature range of 70-100°C respectively. It could be observed that, at the beginning of drying the ratio of drying with time was controlled by free water on the surface of samples. As the drying time increased, the moisture ratio decreased indicating that water was no longer free, this indicated that the water present in the samples was held by molecular adsorption and capillary condensation

(Dairo and Olayanju, 2012). At this point diffusion-controlled process in the moisture ration occurred, in which the ratio of moisture migration with time limited by the diffusion of water from internal to external part of the samples (Dairo and Olayanju, 2012; Kajuna *et al.*, 2001; Sobukola *et al.*, 2007).

Table 4. Moisture ratio of cooked palm nut samples at temperature range of 70-100°C.

	70°C			80°C			90°C			100°C		
TIME	TS	PS	DS	TS	PS	DS	TS	PS	DS	TS	PS	DS
0	-	-	-	-	-	-	-	-	-	-	-	-
60	0.853	0.788	0.840	0.870	0.613	0.794	0.585	0.480	0.772	0.787	0.407	0.656
120	0.803	0.611	0.749	0.644	0.513	0.643	0.358	0.226	0.499	0.435	0.279	0.323
180	0.694	0.494	0.673	0.594	0.358	0.488	0.168	0.123	0.253	0.251	0.106	0.169
240	0.635	0.281	0.574	0.543	0.269	0.285	0.088	0.063	0.206	0.140	0.056	0.133
300	0.535	0.239	0.658	0.485	0.186	0.196	0.085	0.051	0.178	0.117	0.055	0.092
360	0.518	0.186	0.343	0.393	0.093	0.133	0.084	0.051	0.116	0.097	0.052	0.081
420	0.348	0.111	0.262	0.168	0.065	0.101	0.084	0.051	0.079	0.097	0.051	0.073
480	0.301	0.087	0.151	0.143	0.053	0.087	0.00	0.00	0.072	0.097	0.051	0.070
540	0.169	0.053	0.113	0.134	0.052	0.077	0.00	0.00	0.072	0.00	0.00	0.069
600	0.098	0.051	0.112	0.097	0.00	0.074	0.00	0.00	0.00	0.00	0.00	0.00
660	0.096	0.051	0.078	0.00	0.00	0.071	0.00	0.00	0.00	0.00	0.00	0.00
720	0.096	0.00	0.073	0.00	0.00	0.071	0.00	0.00	0.00	0.00	0.00	0.00
780	0.00	0.00	0.072	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
840	0.00	0.00	0.072	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TS=Tenera sample, PS=Pisifera sample, DS=Dura sample

Table 5. Moisture ratio of fermented palm nut samples at selected temperatures.

	70°C			80°C			90°C			100°C		
TIME	TS	PS	DS	TS	PS	DS	TS	PS	DS	TS	PS	DS
0	-	-	-	-	-	-	-	-	-	-	-	-
60	0.830	0.75	0.841	0.846	0.712	0.926	0.780	0.766	0.797	0.837	0.565	0.449
120	0.556	0.525	0.728	0.642	0.581	0.756	0.604	0.522	0.540	0.555	0.283	0.281
180	0.412	0.387	0.585	0.450	0.369	0.624	0.458	0.364	0.379	0.358	0.168	0.131
240	0.259	0.302	0.461	0.251	0.272	0.413	0.231	0.272	0.213	0.163	0.094	0.061
300	0.202	0.248	0.352	0.127	0.176	0.271	0.164	0.156	0.123	0.068	0.035	0.039
360	0.147	0.168	0.243	0.091	0.115	0.225	0.049	0.086	0.080	0.048	0.029	0.039
420	0.086	0.088	0.161	0.077	0.081	0.156	0.049	0.052	0.050	0.046	0.029	0.039
480	0.072	0.065	0.083	0.060	0.060	0.103	0.045	0.031	0.039	0.046	0.000	0.000
540	0.064	0.033	0.043	0.053	0.034	0.074	0.045	0.031	0.038	0.000	0.000	0.000
600	0.055	0.033	0.042	0.044	0.034	0.049	0.000	0.000	0.038	0.000	0.000	0.000
660	0.049	0.000	0.039	0.044	0.000	0.039	0.000	0.000	0.000	0.000	0.000	0.000
720	0.049	0.000	0.039	0.000	0.000	0.039	0.000	0.000	0.000	0.000	0.000	0.000

TS=Tenera sample, PS=Pisifera sample, DS=Dura sample

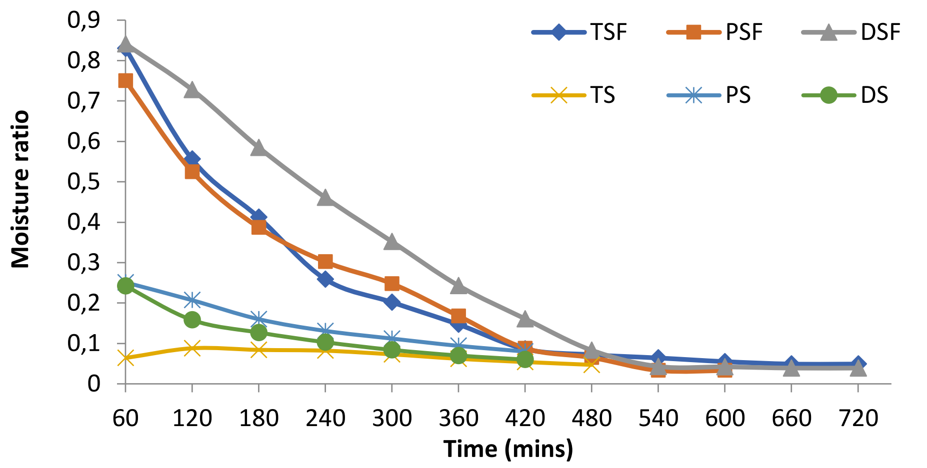

Figure 9. Effect of drying time on moisture ratio of parboiled and fermented samples at 70°C.

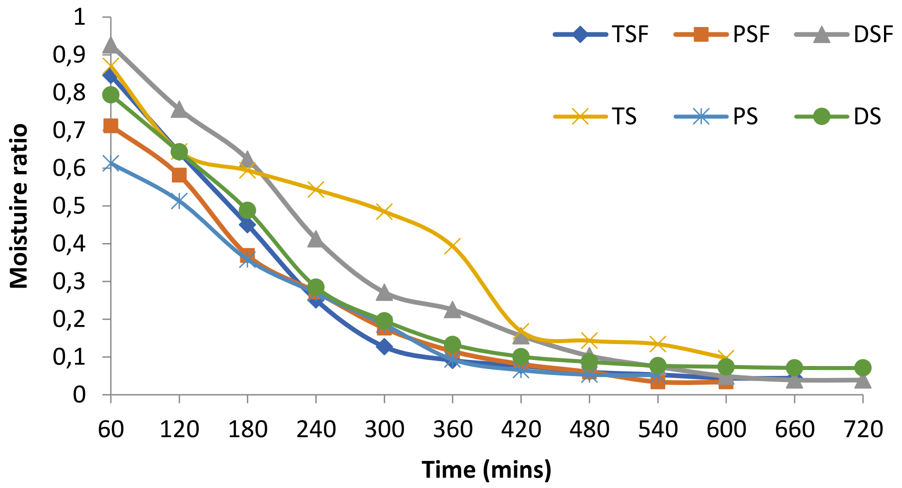

Figure 10. Effect of drying time on moisture ratio of cooked and fermented samples at 80°C.

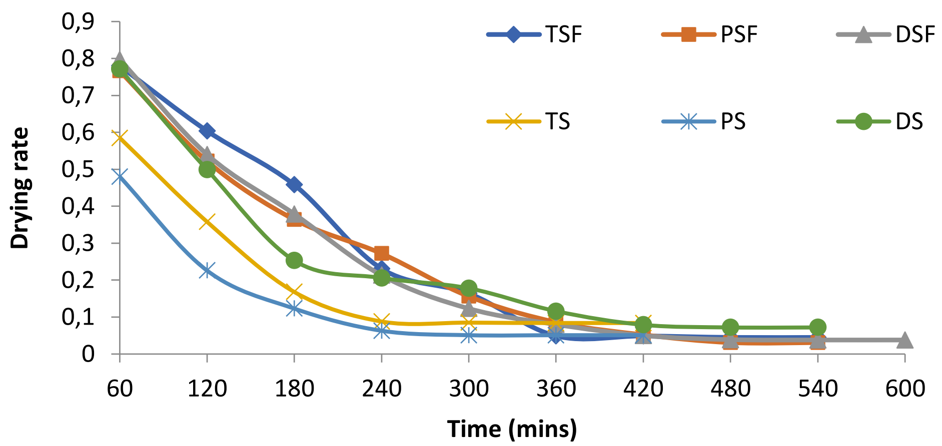

Figure 11. Effect of drying time on moisture ratio of parboiled and fermented samples at 90°C.

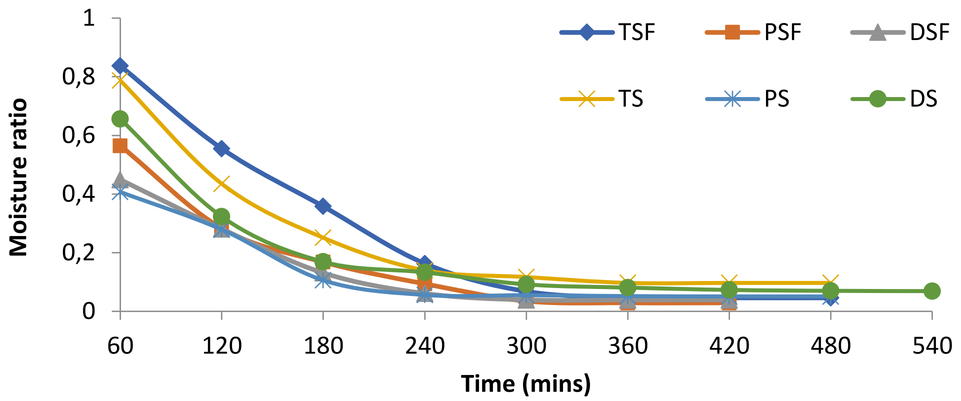

Figure 12. Effect of drying time on moisture ratio of parboiled and fermented samples at 100°C.

From Figure 9 to Figure 12, the moisture ratio at which moisture content leaves the samples were presented graphically. The curves showed that the ratio at which water leaves the samples decreased as the drying time increases, the process continues until equilibrium moisture is attained. It was observed that, at first phase region in the curves there was rapid moisture decrease, accompanied by a falling rate period where the proper drying of agricultural products begins with decrease in moisture removal (Saeed *et al.*, 2008). These findings revealed that diffusion is a physical mechanism governing the moisture movement in the samples (Dairo and Olayanju, 2012).

From Table 6, the drying characteristics equation which describes the relationship between moisture ratio and drying time at 70-100°C. It was observed that, the moisture ratios of fermented and cooked samples at the different drying temperatures were described by best fits regression characteristics equations as shown in Table 6. Most of the samples were seen to exhibit quadratic relationships with time with higher values of coefficient of variation (R^2) which describe the best fit in the regression analysis. As drying progressed, there was decrease in moisture ratio across all samples. There was also decrease in moisture ratio values as temperature increased which corroborates reports of researchers that moisture ratio is greatly influenced by drying temperature and drying time.

Table 6. Drying characteristic equations and relationships between Moisture ratio and drying time of cooked and fermented samples at 70-100°C.

Moisture contents		Regression Equations			
		Cooked		Fermented	
Dura	70	$M_R = 0.09\ln(t) + 0.609$	$R^2 = 0.988$	$M_R = 2E\text{-}06t^2 - 0.003t + 1.04$	$R^2 = 0.996$
	80	$M_R = 3E\text{-}06t2 - 0.003t + 0.976$	$R^2 = 0.982$	$M_R = 3E\text{-}06t^2 - 0.003t + 1.129$	$R^2 = 0.993$
	90	$M_R = 5E\text{-}06t^2 - 0.004t + 0.942$	$R^2 = 0.955$	$M_R = 4E\text{-}06t^2 - 0.004t + 0.994$	$R^2 = 0.988$
	100	$M_R = 5E\text{-}06t^2 - 0.003t + 0.774$	$R^2 = 0.910$	$M_R = = 6E\text{-}06t^2 - 0.003t + 0.647$	$R^2 = 0.990$
Tenera	70	$M_R = 3E\text{-}09t^3 - 3E\text{-}06t^2 + 0.000t + 0.033$	$R^2 = 0.970$	$M_R = 3E\text{-}06t^2 - 0.003t + 0.940$	$R^2 = 0.973$
	80	$M_R = 1E\text{-}06t^2 - 0.002t + 0.955$	$R^2 = 0.950$	$M_R = 4E\text{-}06t^2 - 0.004t + 1.056$	$R^2 = 0.980$
	90	$M_R = 7E\text{-}06t^2 - 0.004t + 0.831$	$R^2 = 0.980$	$M_R = 5E\text{-}06t^2 - 0.004t + 1.046$	$R^2 = 0.990$
	100	$M_R = = 7E\text{-}06t^2 - 0.005t + 1.019$	$R^2 = 0.962$	$M_R = 7E\text{-}06t^2 - 0.005t + 1.146$	$R^2 = 0.995$
Pisifera	70	$M_R = 1E\text{-}06t^2 - 0.001t + 0.305$	$R^2 = 0.997$	$M_R = -0.32\ln(t) + 2.071$	$R^2 = 0.995$
	80	$M_R = 3E\text{-}06t^2 - 0.002t + 0.795$	$R^2 = 0.995$	$M_R = 3E\text{-}06t^2 - 0.003t + 0.901$	$R^2 = 0 .992$
	90	$M_R = 6E\text{-}06t^2 - 0.004t + 0.66$	$R^2 = 0.961$	$M_R = 4E\text{-}06t^2 - 0.003t + 0.959$	$R^2 = 0.995$
	100	$M_R = 4E\text{-}06t^2 - 0.003t + 0.559$	$R^2 = 0.953$	$M_R = 4E\text{-}06t^2 - 0.003t + 0.559$	$R^2 = 0.953$

The drying rate indicates the quantity of moisture evaporated per unit time. Akpinar *et al.*, 2003 reported that the nature of water present in the sample determines the rate of moisture loss as drying progresses. Table 7 and table 8 presented the drying rate of palm 350 kernel samples drying at temperature range of 70-100^{0}C. This rate of moisture loss can also be due to internal pressure generated that forces the moisture in vapour form outside the samples. The drying rate decreased continually with drying time for all samples considered. It was observed that the amount of water removed at the initial stage of drying was higher for all temperatures and decreases with time. This was as a result of low internal resistance of moisture at the beginning of drying, in which when energy was impacted, moisture easily moved to the surface where it was evaporated. As the drying progressed, more energy was required to break the molecular bond of the moisture and since constant energy (heat) was supplied, it took longer time to break the bond, therefore drying rate decreased. This agrees with the findings of Ndukwu (2009), who observed that the drying rate was highest at the first hour of continuous drying of cocoa bean. This also was in line with what was reported by other researchers such as Saeed *et al.* (2008), Doymaz, (2011) and Zhao e*t al.* (2016). It was observed that fermented samples had lower drying rates than the cooked samples. This can be attributed to the fermentation process which may have altered the internal structures of the samples and loosened the sample pores thus hastening the free movement of water both on the surface and internal portion in the sample. From the results it was observed that polynomial relationships existed between drying rate and time for fermented samples while mostly quadratic and exponential were obtained for cooked samples. These equations are presented in Table 4-10 and can also be used to model the drying kinetics of the investigated samples.

Table 7. Drying rate of fermented palm nut samples at selected temperatures.

	70^{0}C			80^{0}C			90^{0}C			100^{0}C		
TIME (mins)	**TSF**	**PSF**	**DSF**	**TSF**	**PSF**	**DSF**	**TSF**	**PSF**	**DSF**	**TSF**	**PSF**	**DSF**
0	-	-	-	-	-	-	-	-	-	-	-	-
60	0.029	0.071	0.039	0.026	0.129	0.05	0.083	0.173	0.056	0.042	0.198	0.084
120	0.020	0.065	0.031	0.035	0.081	0.044	0.064	0.129	0.061	0.056	0.121	0.082
180	0.020	0.056	0.027	0.027	0.072	0.042	0.055	0.098	0.061	0.050	0.020	0.068
240	0.018	0.060	0.026	0.023	0.061	0.044	0.045	0.078	0.048	0.043	0.079	0.053
300	0.019	0.051	0.017	0.021	0.054	0.039	0.036	0.063	0.040	0.035	0.063	0.044
360	0.016	0.045	0.027	0.020	0.051	0.035	0.031	0.053	0.035	0.030	0.053	0.037
420	0.018	0.042	0.026	0.024	0.045	0.031	0.026	0.045	0.032	0.026	0.045	0.032
480	0.017	0.038	0.026	0.021	0.040	0.028	0.024	0.042	0.028	0.022	0.040	0.028
540	0.018	0.035	0.024	0.019	0.035	0.025	0.000	0.000	0.025	0.022	0.037	0.025
600	0.018	0.032	0.022	0.018	0.033	0.023	0.000	0.000	0.024	0.000	0.000	0.024
660	0.016	0.029	0.020	0.018	0.030	0.021	0.000	0.000	0.000	0.000	0.000	0.000
720	0.015	0.028	0.019	0.017	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000
780	0.015	0.000	0.000	0.015	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000
840	0.000	0.000	0.000	0.014	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.000

TS=Tenera sample, PS=Pisifera sample, Dura sample

Table 8. Drying rate of parboiled palm nut samples at selected temperatures.

	70⁰C			80⁰C			90⁰C			100⁰C		
TIME	TS	PS	DS	TS	PS	DS	TS	PS	DS	TS	PS	DS
0	-	-	-	-	-	-	-	-	-	-	-	-
60	0.067	0.145	0.070	0.060	0.167	0.032	0.086	0.135	0.089	0.064	0.251	0.242
120	0.088	0.137	0.069	0.071	0.121	0.054	0.078	0.138	0.101	0.088	0.207	0.158
180	0.077	0.118	0.061	0.072	0.121	0.055	0.071	0.123	0.091	0.084	0.160	0.127
240	0.073	0.101	0.059	0.074	0.105	0.065	0.076	0.105	0.086	0.082	0.131	0.103
300	0.063	0.087	0.057	0.069	0.095	0.064	0.066	0.098	0.077	0.073	0.112	0.084
360	0.056	0.080	0.055	0.060	0.085	0.057	0.062	0.088	0.067	0.062	0.094	0.070
420	0.051	0.075	0.053	0.052	0.076	0.053	0.054	0.078	0.060	0.054	0.080	0.060
480	0.046	0.068	0.050	0.046	0.068	0.049	0.047	0.070	0.053	0.047	0.000	0.000
540	0.041	0.062	0.047	0.041	0.062	0.045	0.042	0.062	0.047	0.000	0.000	0.000
600	0.037	0.056	0.042	0.038	0.056	0.042	0.000	0.000	0.042	0.000	0.000	0.000
660	0.034	0.000	0.038	0.034	0.053	0.038	0.000	0.000	0.000	0.000	0.000	0.000
720	0.031	0.000	0.035	0.000	0.000	0.035	0.000	0.000	0.000	0.000	0.000	0.000
780	0.000	0.000	0.032	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
840	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TS=Tenera sample, PS=Pisifera sample, Dura sample

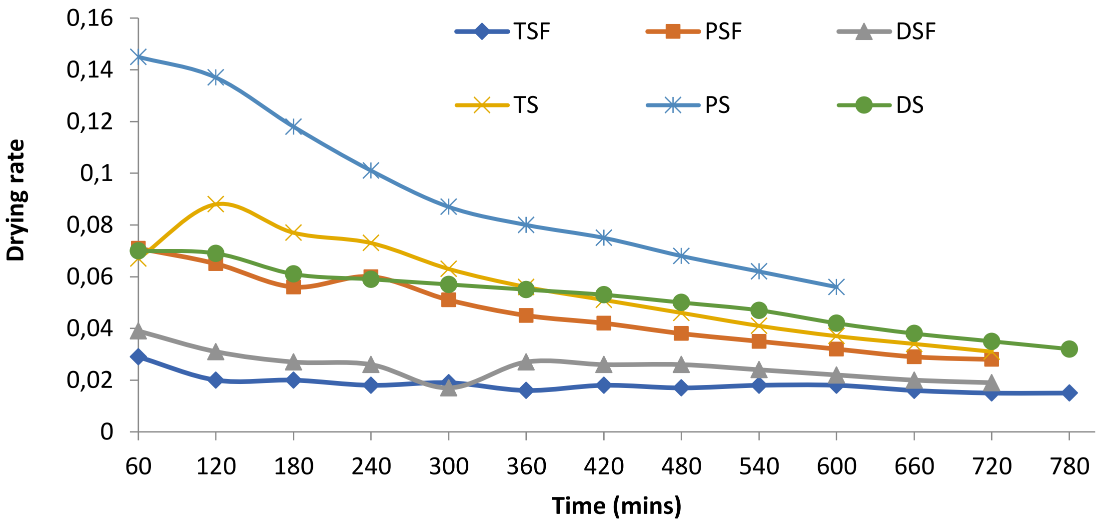

Figure 13. Drying rate of parboiled and fermented samples at 70°C.

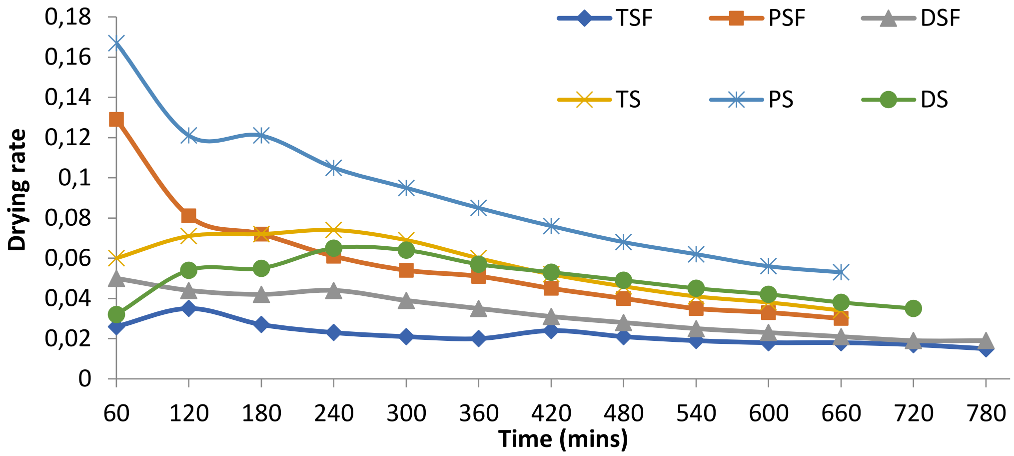

Figure 14. Drying rate of parboiled and fermented samples at 80°C.

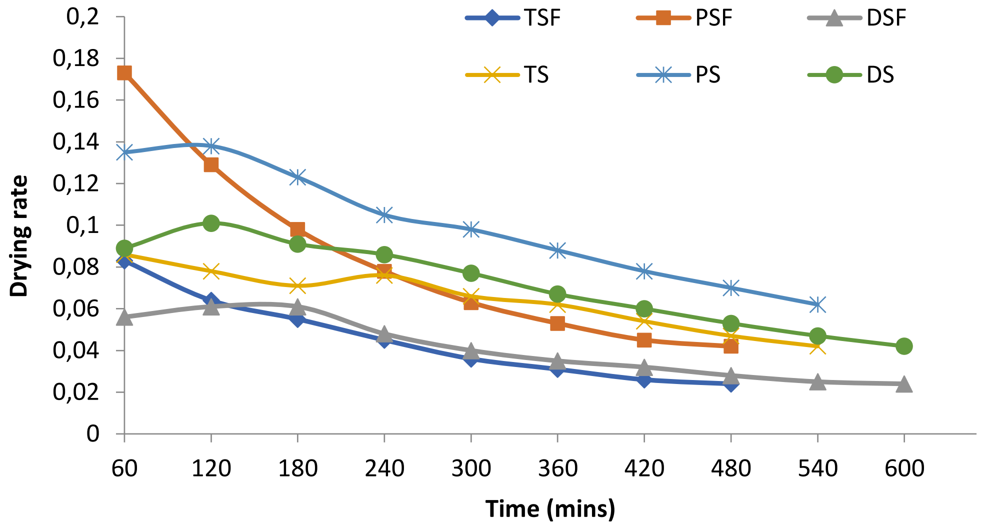

Figure 15. Drying rate of parboiled and fermented samples at 90°C.

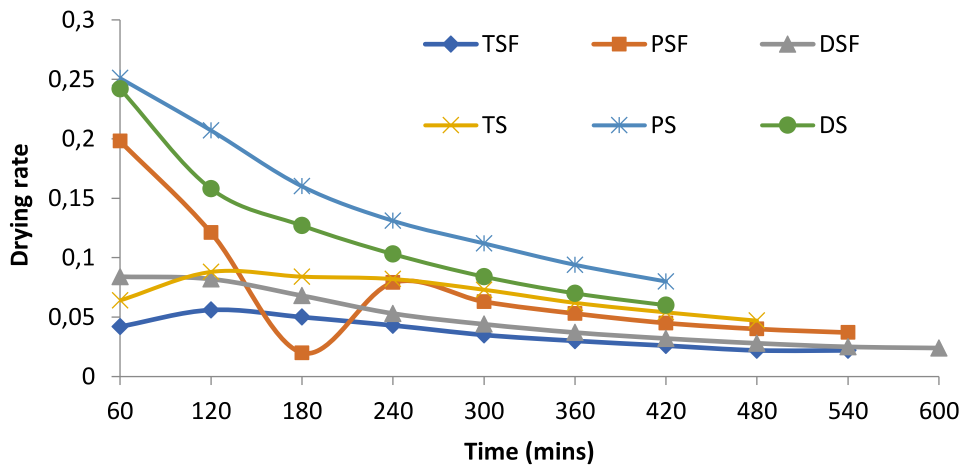

Figure 16. Drying rate of parboiled and fermented samples at 100°C.

The typical effect of initial moisture content on the drying rate across the drying temperature investigated were presented from Figures 13-16. From the curves it was observed that drying rate increased with increased in initial moisture content. This may be as a result of availability of surplus water at the surface of samples for evaporation at higher level which led to higher drying rates. As the drying time increases, movement of water is controlled by diffusion process, the quantity of water to be evaporated at interval reduced drastically. This finding is in agreement with the reports of Dairo and Olayanju, (2012); Sobukola and Dairo, (2007); Hii *et al.* (2008). Also, the drying rate increased with a corresponding increase in temperature from 70 to 100°C. The drying rate at 70°C was observed to be lower than other drying temperatures irrespective of palm kernel varieties and processing methods. This can be attributed to the fact that the samples required more heat to diffuse the core water to pressure the diffusion process. From the Figure 13 to 16, it was noticed that drying rate curves at first phase had enough water to evaporate but as the drying time increased, the quantity of water to be removed decreased at falling rate period.

Table 9. Drying kinetic equations and relationships between drying rate and drying time of parboiled and fermented samples.

Moisture contents		Regression Equations			
		Parboiled		Fermented	
Dura	70	$D_R = -5E\text{-}05t + 0.073$	**$R^2 = 0.985$**	$D_R = 4E\text{-}10t^3 + 5E\text{-}07t^2 – 0.000t + 0.048$	**$R^2 = 0.808$**
	80	$D_R = 7E\text{-}10t^3 – 1E\text{-}06t^2 + 0.000t + 0.01$	**$R^2 = 0.942$**	$D_R = 1E\text{-}10t^3 – 1E\text{-}07t^2 – 1E\text{-}05t + 0.049$	**$R^2 = 0.983$**
	90	$D_R = 9E\text{-}10t^3 – 1E\text{-}06t^2 + 0.000t + 0.083$	**$R^2 = 0.982$**	$D_R = 8E\text{-}10t^3 – 8E\text{-}07t^2 + 0.000t + 0.053$	**$R^2 = 0.962$**
	100	$D_R = -7E\text{-}09t^3 + 6E\text{-}06t^2 – 0.002t + 0.347$	**$R^2 = 0.993$**	$D_R = 4E\text{-}10t^3 – 2E\text{-}07t^2 – 0.000t + 0.096$	**$R^2 = 0.987$**
Tenera	70	$D_R = 0.095\ e^{-0.00t}$	**$R^2 = 0.924$**	$D_R = -2E\text{-}10t^3 + 2E\text{-}07t^2 – 0.000t + 0.032$	**$R^2 = 0.865$**
	80	$D_R = 0.085\ e^{-0.00t}$	**$R^2 = 0.796$**	$D_R = -2E\text{-}11t^3 + 4E\text{-}08t^2 – 4E\text{-}05t + 0.032$	**$R^2 = 0.735$**
	90	$D_R = 0.096\ e^{-0.00t}$	**$R^2 = 0.939$**	$D_R = -3E\text{-}10t^3 + 6E\text{-}07t^2 – 0.000t + 0.101$	**$R^2 = 0.996$**
	100	$D_R = 3E\text{-}09t^3 – 3E\text{-}06t^2 + 0.000t + 0.033$	**$R^2 = 0.970$**	$D_R = 2E\text{-}09t^3 – 1E\text{-}06t^2 + 0.000t + 0.030$	**$R^2 = 0.952$**
Pisifera	70	$D_R = 2E\text{-}07t^2 – 0.000t + 0.166$	**$R^2 = 0.991$**	$D_R = 0.077\ e^{-0.00}$	**$R^2 = 0.986$**
	80	$D_R = 2E\text{-}07t^2 – 0.000t + 0.174$	**$R^2 = 0.965$**	$D_R = -1E\text{-}09t^3 + 2E\text{-}06t^2 – 0.000t + 0.159$	**$R^2 = 0.966$**
	90	$D_R = 4E\text{-}08t^2 – 0.000t + 0.152$	**$R^2 = 0.978$**	$D_R = -2E\text{-}09t^3 + 2E\text{-}06t^2 – 0.001t + 0.228$	**$R^2 = 0.999$**
	100	$D_R = 1E\text{-}06t^2 – 0.001t + 0.305$	**$R^2 = 0.997$**	$D_R = -7E\text{-}09t^3 + 7E\text{-}06t^2 – 0.002t + 0.316$	**$R^2 = 0.838$**

Table 9 presented the drying characteristics regression equation and relationship between drying rate and drying time of cooked and fermented samples. The cooked and fermented samples irrespective of sample varieties at temperature range of 70 to 100°C were found to have quadratic relationships apart from cooked Tenera variety which displayed exponential regression equation with respect to drying rate and time. The mathematical equations from these relationships are presented in Table 9 with the coefficient of determination *(R^2)* values. It was also observed that lower temperatures (70 and 80°C) appeared to have fluctuations in the drying curve. Higher temperatures on the other hand appeared to be displayed almost uniform drying rate. Effective drying can therefore be said to take places for all three samples at higher temperatures (falling rates).

CONCLUSION

The effect of temperature and processing methods on drying characteristics of palm kernel were determined. The rate of drying the samples was observed to increase with corresponding increase in temperature and drying time. The effective drying of the samples was observed to occur at falling rate across the varieties and processing methods. The lower temperature (70°C) decreased the drying rates while the higher temperature increased the drying rates. The average drying time for cooked samples irrespective of sample varieties were 740 mins, 620 mins, 460 mins and 500 mins for temperature range of 70-100°C respectively while for the fermented samples, the average drying time were 680 mins, 660 mins, 560 mins and 440 mins at temperature range of 70-100°C respectively. The regression equations were found to give the best fit with highest coefficient of variation *(R^2)* values. Mostly all the samples irrespective of processing methods exhibited quadratic regression equations. The cooked samples displayed better dry characteristics than fermented samples. The results have provided an insight to agricultural and food processors the best method for thermal processing of palm nuts that is time and energy efficient.

DECLARATION OF COMPETING INTEREST

The authors declared that there is no conflict of interest during and afater this research

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Patrıck Ejike Ide: Investigation, formal analysis, writing - original draft, methodology, writing - original draft
Ike Oluka: Methodology, validation and review, and editing.
Eze Godson Ekene: Investigation, writing - original draft, data curation.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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