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MODELLING THE DRYING KINETICS OF ACKEE APPLE (*BLIGHIA SAPIDA*) ARILS UNDER OVEN AND SUN DRYING METHODS

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Abstract
The ackee fruit (Blighia sapida), a tropical fruit belonging to the family of Sapindaceae, has its origin in West Africa but has traversed the Atlantic Ocean, making the Caribbean its home. Although Ackee fruit was first known for its poisonous properties, it is nowadays considered as one of the major fruits consumed in Jamaica due to its high nutritional and bioactive properties. The drying experiments were conducted using open sun and a laboratory oven drier at varying drying temperatures of 40, 50, 60, 65 and 70 ℃ with the air velocity of 1.4 m/s^2*. The obtained drying data were fitted into thirteen different thin layer drying mathematical models, using coefficient of determination (*R^2*), sum of square error (SSE), root-mean square error (RMSE) and reduced chi-square (*χ^2*) in determining the fitness. The best models fitted for air drying temperature at 40, 65,70 ℃ for oven drying and open sun drying was two-term exponential; Newton and Verma et al. models best described samples dried at 50 and 60 ℃ air dying temperature respectively. The predicted models were validated by plotting the predicted values against the experimental values with coefficient of determination of above 0.95 for all the predicted models, indicating the efficacy of the models. In addition, the effective moisture diffusivities increase with increase air-drying temperatures with the activation energy of 18.168 kJ/mol for oven drying. The result is useful in designing a reliable machine for processing ackee apple arils which will boost the production of ackee apple aril in Nigeria.*

Keywords: ackee fruit, moisture content, temperature, drying experiments, mathematical models

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1. INTRODUCTION

Ackee (*Blighia sapida*) is an indigenous tree crop of West Africa that is many times neglected; although it has great potentials for utmost agricultural development. Regardless, it is Jamaica's national fruit which makes the country refer to it as the 'Big Ackee' (Mitchell *et al*., 2008); it falls under the family of *Sapindaceae* and it is called *ishin* in the western part of Nigeria. The fruits of the ackee tree shaped like a pear and, capsule-like is green when young and then turns yellow or red at maturity (about 7cm to 10 cm long). The fruit weighs a maximum of 100g – 200g and splits open at maturity while still on the tree (Anupama and Sunilkumar, 2019; Mitchell *et al*., 2008). As the fruit ripens, it changes from green to yellow to yellow-red, it then splits longitudinally into three sections revealing the thick cream oily fleshy part called the *arillus/aril* (which has a nutty flavour is eaten fresh, dried, fried, roasted or made into a sauce) each tipped with a nearly round smooth, black shiny seed. All parts of the Ackee (*Blighia sapida*) are highly useful to man, for example, the tree trunk of the ackee is strong and immune to termite. The oil from the arils can be utilized for commercial soap and oil production; crushed new foliage applied on forehead heals severe headache; aqueous extracts from the seeds are applied as parasites expellant, oils from the seeds also have pesticidal properties (Atolani *et al*., 2009; Emanuel and Benkeblia, 2011; Mitchell *et al*., 2008). The juice from the leaf is applied as an eye drop in ophthalmia and conjunctivitis; volatiles extract from the flowers can be used as cologne and other perfumes; the bark and pungent spices are applied as an ointment to cure severe pains; the pods are also used in cosmetics for skin infection, ringworm; ackee leaf tea serves as a remedy for cold (Atolani *et al*., 2009; Emanuel and Benkeblia, 2011).

Food loss is a reduction in the quality or nutritional composition of food originally intended for human consumption; this occurs during the harvesting, post-harvest operations and processing stages. The arils of the Ackee (*Blighia sapida*) sometimes called the ackee aril apple is highly perishable this is why drying (a thermal post-harvest treatment) is adopted as a primary means of storage. Drying is the most common method of food preservation; it is also 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. The quality of bio-materials deteriorates from the point of harvest up until it eventually deteriorates. Ackee apple (*Blighia sapida*) is a perishable fruit with a lot of benefit; to curb the problem of post-harvest losses, substandard storage and to make it a more stable product, thin-layer drying was adopted using oven drying and open sun in order to enhancing supply and improving seasonal food choice of ackee arils.

2. MATERIALS AND METHODS

Fresh and mature ackee apple fruits (Figure 1) were plucked from its tree located at peace mass transit, opposite swan hotel, Akure, Ondo State, Nigeria. The ripe ackee apple fruits were sorted to take out the damaged ones, they were washed with clean water to remove sand. The ackee aril apples were removed from the pods, the seeds were separated from it (the aril) manually and, the raphe (red thin lining membrane) was also removed.

2.1 Drying

Drying was done using the open sun and an oven dryer (DHG-9053A, China) at a varying temperature of 40, 50, 60, 65 and 70°C, and a constant air velocity of 1.4ms^{-1}. 100g of the ackee aril apple was measured using a digital balance with ±0.01g accuracy and, placed in the oven at a temperature of 40°C; the weight of the samples was taken at an interval of 1hour until a constant weight was obtained. This procedure was repeated for samples kept under the sun and in the oven with temperatures of 50, 60, 65 and 70°C respectively. Temperature above 70 °C was not selected because it is a high temperature and it may reduce the quality of fruits and vegetables, temperature below 40°C was not selected because it may be promotion of fungi in the sample.

Fresh and Mature Ackee Apple Fruits

Ackee Aril Apple

Figure 1: Ackee apple fruits

2.1.1 Moisture content

The moisture of the ackee aril was determined using the standard method of AOAC 2010 and the moisture content was calculated using Equation1. Weight of a previously washed and dried empty evaporating dish was determined using a mettler balance as (W_1). 10g of the sample was weighed into the evaporating dish (W_2). The dish and sample were then placed in the oven and dried for 8hrs at 105°C. After drying, the dish and sample was then placed in the desiccator to cool to room temperatures after which it was then weighed. This process was continued until a constant weight was obtained, (W_3), (i.e, drying, cooling and weighing were done repeatedly at 30 mins interval until a constant weight was obtained). The weight of the moisture was calculated and expressed as a percentage of weight of the sample analysed.

$$\%\,\mathrm{MC} = \frac{W2 - W3}{W2 - W1} \times 100 \qquad (1)$$

Where W_1 is weight of empty evaporating dish;
W_2 is weight of sample + evaporating dish;
W_3 is weight of sample + evaporating dish after drying at 105°C.

2.2 Drying Kinetics

The experimental drying data was applied to evaluate the drying kinetics of the ackee aril apple. The variation in the moisture content of ackee aril apple with drying time, drying rate and effective moisture diffusivities were calculated. The drying rate of ackee aril apple were calculated using equation 2, the moisture content was then converted to moisture ratio, a dimensionless variable using equation 3 (Fernandez *et al*., 2018; Komolafe *et al*., 2018; Kumar *et al*., 2012; Sabat *et al*., 2018).

$$\mathrm{DR} = \frac{\mathrm{M_t} - \mathrm{M_{t+\Delta t}}}{\Delta \mathrm{t}} \qquad (2)$$

$$\mathrm{MR} = \frac{\mathrm{M_t} - \mathrm{M_e}}{\mathrm{M_i} - \mathrm{M_e}} \qquad (3)$$

Where: DR is drying rate,
$M_{t+\Delta t}$ is moisture content at t+Δt,
t it the time,
$M_t$is moisture content at any time,
MR is moisture ratio,
$M_i$is initial moisture content,
$M_e$is equilibrium moisture content.

2.3 Modelling the Drying Kinetics of Ackee Aril Apple

Thin-layer drying Equations have been used by many researchers to estimate the drying time for several bio-materials and also to generalize the drying curves (Akoy, 2014; Fernandez *et al*., 2018; Komolafe *et al*., 2018; Olabinjo and Adeniyan, 2020; Sabat *et al*., 2018; Sobowale *et al*., 2020). The moisture content data of ackee aril apple dried at different temperature was converted into moisture ratio using equation 3. These moisture ratio data were fitted to thirteen selected models of the existing thin-layer drying models as given in Table1. The constants (viz. a, b, c, d, g, k and n) were calculated using Microsoft Excel Solver.

2.4 Statistical Analysis

The experimental data was analyzed using one-way analysis of variance (ANOVA) and the non-linear regression tools of MS Excel. Statistical parameters were used as the primary criteria to select the best model to account for variation in the drying curves of the dried ackee aril apple. These parameters are – coefficient of determination (R^2), root mean square error (RMSE), the sum of square error (SSE) and reduced chi-square (χ^2) (Akoy, 2014; Meisami-asl and Rafiee, 2009; Sabat *et al*., 2018; Sobowale *et al*., 2020).

Table 1. Thin-layer drying mathematical models applied to the drying parameters of Ackee arils

S/N	Models	Equation	References
1	Newton	$MR = exp\ (-kt)$	El-Beltagy *et al.* (2007)
2	Page	$MR = exp(-kt^{n})$	Akoy (2014)
3	Modified page I	$MR = exp[-(kt^{n})]$	Vega *et al.* (2007)
4	Henderson and Pabis	$MR = a\ \exp\ (-kt^{n})$	Rosa *et al.* (2015)
5	Modified Henderson and Pabis	$MR = a\ \exp(-kt) + b\ \exp\ (-\mathrm{g}t) + c\ \exp\ (-ht)$	Zenoozian *et al.* (2008)
6	Midilli-Kucuk	$MR = a\ \exp(-kt) + bt$	Ayadi *et al.* (2014)
7	Logarithmic	$MR = a\ \exp(-kt) + c$	Kaur and Singh (2014)
8	Two-term	$MR = a\ \exp(-k_1t) + b\ \exp\ (-k_2t)$	Sacilik (2007)
9	Wang and Smith	$MR = 1 + at + bt^2$	Omolola *et al.* (2014)
10	Hii *et al.*	$MR = a\ \exp(-k_1t^{n}) + c\ \exp\ (-gt^{n})$	Kumar *et al.* (2012)
11	Diffusion Approach	$MR = a\ \exp(-kt) + (1-a)\exp\ (-kgt)$	Yald´yz and Ertek´yn (2007)
12	Two-term Exponential	$MR = a\ \exp(-kt) + (1-a)\exp\ (-kbt)$	Yaldiz *et al.* (2001)
13	Vermal *et al.*	$MR = a\ \exp(-kt) + (1-a)\exp(-gt)$	Tzempelikos *et al.* (2015)

Where a, b, and c are constants and coefficient in the drying models

These statistical parameters have been used by many researchers to select the goodness of fit and the best model for their samples and it is calculated using equations 4- 7 (Kumar *et al.*, 2012; Meisami-asl and Rafiee, 2009; Sabat *et al.*, 2018; Olabinjo and Adeniyan, 2020).

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(MR_{exp,ii} - MR_{pre,i})^2}{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})^2} \qquad (4)$$

$$RMSE = [\frac{1}{N}\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2]^{\frac{1}{2}} \qquad (5)$$

$$SSE = \frac{1}{N}\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2 \qquad (6)$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})^2}{N-n} \qquad (7)$$

Where $MR_{exp,i}$ is the ith experimental moisture ratio, $MR_{pre,i}$is the ith predicted moisture ratio, N is the number of observations and n is the number of constants.

2.5 Estimation of Effective Moisture Diffusivity and Activation Energy

The effective moisture diffusivity, D_{eff} can be estimated mathematically using Fick's second equation described in Equation 8 which when linearized becomes Equation 9 (Komolafe *et al.*, 2018; Sobowale *et al.*, 2020). The activation energy was calculated by plotting ($\ln D_{eff}$) against the reciprocal of the temperature$\left[-\frac{1}{R(T+273.15)}\right]$ (Akoy, 2014; Olabinjo and Adeniyan, 2020; Sabat *et al.*, 2018; Sobowale *et al.*, 2020).

$$D_{eff} = D_0\ exp\left[-\frac{E_a}{R(T+273.15)}\right] \qquad (8)$$

$$ln\ D_{eff} = \left[-\frac{1}{R(T+273.15)}\right]E_a + ln\ D_0 \qquad (9)$$

Where: R is the universal gas constant (KJ/mol K), D_0 is the pre-exponential factor of the Arrhenius Equation or maximum diffusion coefficient (at infinite temperature) (m^2s^{-1}), E_a is the activation energy (KJ/mol) and T is the temperature (°C).

3. RESULTS AND DISCUSSION

It was observed that the fresh ackee aril apple has an initial moisture content of 54.814%, an indication that poor storage will lead to spoilage. The moisture content of the samples dried at 70°C, 60°C, 50°C and 40°C was brought to 2.997, 4.530, 7.097 and 7.520% respectively, while the samples exposed to the open sun dropped the moisture content to 7.725%. It can be observed that the lowest moisture content for safe storage and to minimize the growth of microbial organism in the ackee aril apple was obtained at a drying temperature of 70°C. The ackee aril apple when compared to taro (10.48 - 13.08%), yam (11.16 - 16.39%) and cashew kernels (6.04 -7.58%) oven dried at 50 – 70°C was found to contain quite a lot of moisture (Akalu and Geleta, 2019; Olalekan-Adeniran and Ogunwolu, 2018). The result of the moisture content is in close agreement with that of Atolani *et al*. (2009), Emmanuel and Benkeblia (2011) and Mitchell *et al*. (2008). This is an indication that the ackee aril is highly perishable and, drying a thermal treatment has been adopted in order to make it (the ackee aril) a more stable product thus enhance food supply and improve seasonal food choice. At the end of the whole drying process, the experimental data were used to evaluate mathematical models of drying curve as well as calculate the effective moisture diffusivity and activation energy.

3.1 Drying Kinetics of Ackee Aril Apple

Drying kinetics is greatly affected by the air velocity, air temperature, material thickness, and others (Taheri-Garavand *et al*., 2011), nonetheless, the study investigate only the effect of temperature on the ackee aril apple, and this is because a constant air velocity and thickness was used throughout the experiment. The ackee aril apples were dried for 19, 19, 22, 27, 32 and 38 hours at oven drying temperatures of 70°C, 65°C, 60°C, 50°C, 40°C and the open sun respectively as shown in Figure 2. The initial moisture content of the ackee aril apple before drying was found to be around 54.814% wet basis; at the end of the drying experiment, the moisture content of the ackee aril apple was reduced to 2.997, 4.530, 7.097, 7.520 and 7.725%wet basis at 70, 60, 50, 40°C and open sun respectively. It was observed that at the beginning of the drying process the moisture movement decreased slowly, but at increased air-drying temperatures the moisture movement decreased rapidly until equilibrium moisture content (EMC) was reached. Previous studies show that the drying temperature and thickness of the bio-material are the utmost factors affecting the drying rate and moisture content of bio-materials as reported by Akoy (2014) and Sobowale *et al*. (2020). The drying curves presented shows that the moisture content in the sample decreases rapidly with increasing drying temperature and drying time. Similar results had been reported from the drying of other bio-materials by previous researchers; (Akoy, 2014; Alara *et al*., 2019; Komolafe *et al*., 2018; Olabinjo and Adeniyan, 2020; Rosa *et al*., 2015; Sobowale *et al*., 2020). From all the drying curves, it can be seen that the sample did not experience a constant rate period before entering the falling rate period. The drying curve of the samples dried under the open sun was found to be very unsteady, there were multiple falls at various part of the curve; this could be due to the fluctuations on the ambient temperature that occurred during drying period. Samples dried under the open sun, 40℃ and at 50℃ experienced no constant drying rate at all. Similar observations were made for ackee aril apples dried at 40℃, however, a very brief constant drying rate was observed at the tail end of the drying curve. All drying curves experienced sharp falls at different drying time. It can be observed that for every increase in the drying air temperature, the drying time was reduced and the slope of the curve becomes steeper. This could be because since moisture diffusion starts from the centre of the bio-material to its surface. An increased in air drying temperature also leads to an improved temperature gradient and surface evaporation rate, this was similar to observation by Nguyen *et al*. (2019).

3.2 Effect of temperature on the drying rate of the ackee aril apple

Figure 3 shows the plot of the drying rate against the drying time and, it can be observed that at higher air-drying temperatures, a higher drying rate occurred and moisture content decreased faster. The initial drying process occurred in a falling rate although a brief constant rate is observed towards the end of the drying curve for sample dried at 60℃, 65℃ and 70°C; this is because at this stage the ackee aril apple was approaching equilibrium moisture content. The highest and lowest drying rate curve was at 70°C and open sun drying respectively.

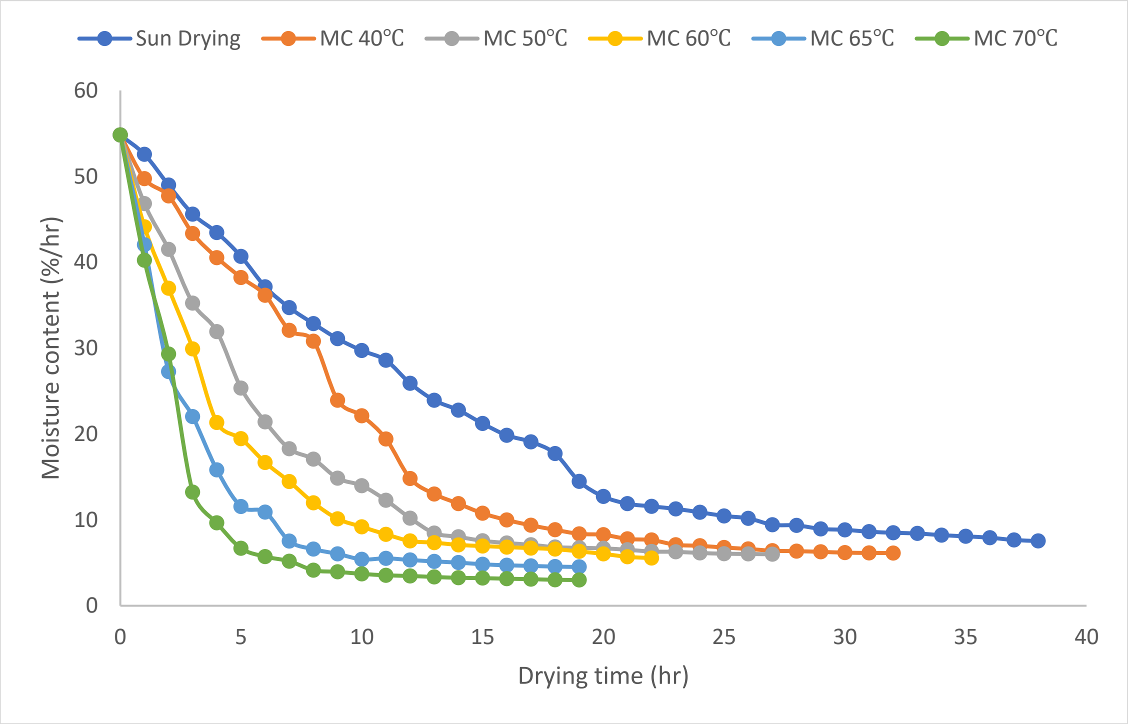

Figure 2: Moisture content against drying time (hour) at different drying temperature

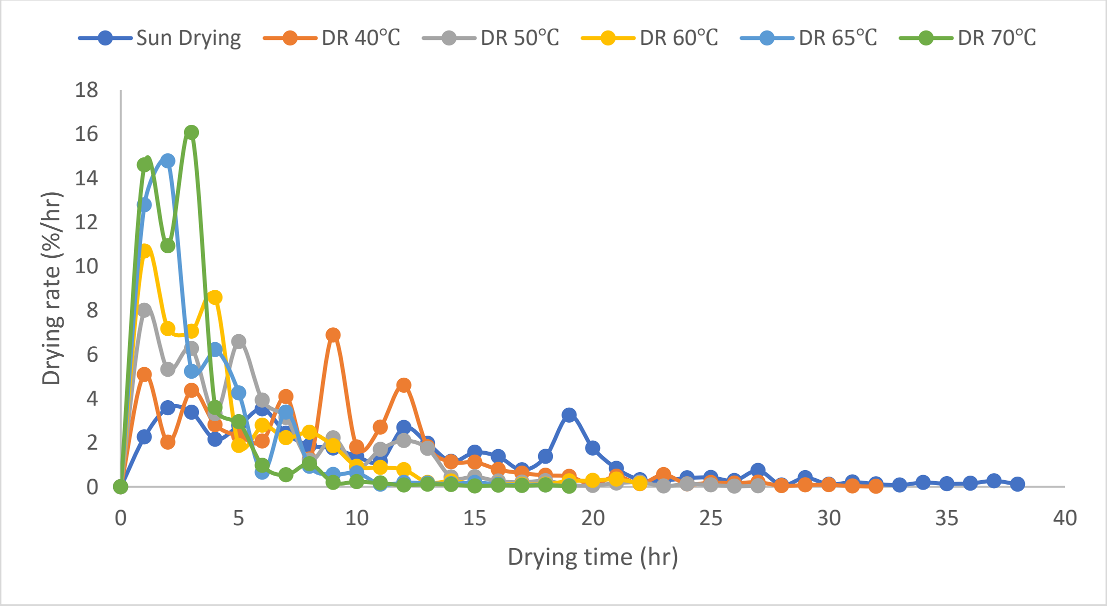

Figure 3: Drying rate against drying time (hour) at different drying temperature

For the two methods of drying, it can be observed that the initial moisture content of the ackee aril apple is the critical moisture content since the sample did not undergo a constant drying rate before exhibiting a falling drying rate, this proves that diffusion is the dominant physical mechanism governing moisture movement within the ackee aril apple. These observations are similar to previous studies on the drying kinetics of mango slices (Akoy, 2014), fish (Komolafe *et al*., 2018), potato slices (Silva *et al*., 2018) and onion slices (Sobowale *et al*., 2020). At the end of the drying process, it was observed that the dehydration rates in the ackee aril apple dependent on the drying temperature, similar to the result reported by Sobowale *et al*., (2020) for onion slices. It can also be observed that the sun-dried samples exhibited unsteady drying rate at unspecific intervals which may be due to the change in ambient temperature and relative humidity of the environment.

3.3 Mathematical Modelling of the Drying Kinetics of the Ackee Aril Apple

The moisture content data were converted to moisture ratio as shown in Figure 3. The moisture ratio data were fitted into the thirteen of the existing thin-layer drying models listed in Table 1 these models are often times utilized in the drying of agricultural produce and used by some researchers; Akoy, (2014); Meisami-asl and Rafiee, (2009) and Olabinjo and Adeniyan, (2020).

3.3.1 Moisture ratio curves

The moisture content data were converted to dimensionless moisture ratio so as to normalize the drying curves. The plot of moisture ratio against the drying time of the ackee aril apple (Figure 4) show that the moisture movement decreased slowly at the start of the drying process but at increased drying temperatures the moisture movement decreased rapidly until equilibrium moisture content (EMC) was reached. The plot also revealed that increased drying temperature led to a steeper curve, this shows higher rate of moisture removal.

3.3.2 Evaluation of mathematical models

The best drying model goodness of fit was selected based on the highest values of coefficient of determination (R^2), lowest values of reduced chi-square (χ^2), and the lowest values of root mean square error (RMSE). These statistical parameters have constantly been used in previous studies to evaluate models by (Meisami-asl and Rafiee, 2009; Olabinjo and Adeniyan, 2020; Sobowale *et al*., 2020). The model constants (drying constant, k and drying coefficients – a, b, c, g and n) of the thin-layer drying models and goodness of fit of the moisture ratios of ackee aril apple in varying temperatures, examined with the thirteen selected models are given in Table 2 with the best model highlighted.

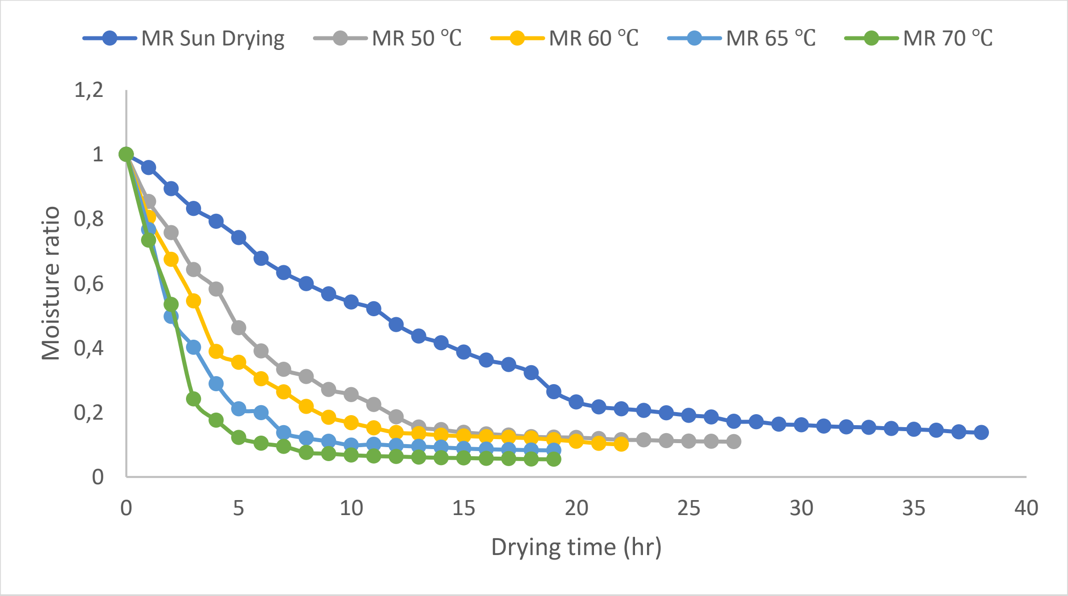

Figure 4: Moisture ratio against drying time (hour) at different drying temperature

3.3.3 Ranking of models

The model with the highest value for coefficient of determination (R^2), lowest value for root means 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 ackee aril apple. At drying temperature of 40°C, 65°Cand70°C the best drying model fitted is the two-term exponential model; it produced the highest coefficient of determination (R^2) of 0.9782, 0.9823 and 0.9597 respectively, lowest root-mean square error (RMSE) values of 0.0559, 0.0718 and 0.0625 respectively, lowest values of reduced chi-square (χ^2) of 0.0034, 0.0061 and 0.0046 respectively and sum of square error (SSE) of 0.1000, 0.0979 and 0.0742 respectively. The best drying model fitted at drying temperature of 50°C is the Newton model, this model has the highest coefficient of determination (R^2), and lowest root means square error (RMSE), lowest value of reduced chi-square (χ^2) and sum of square error (SSE) of 0.9752, 0.0482, 0.0024 and 0.0628 respectively. Verma *et al*. was the best fitted model at drying temperature of 60°C, with the highest coefficient of determination (R^2) of 0.9948, lowest root mean-square error (RMSE) of 0.0807, lowest value of reduced chi-square (χ^2) of 0.0075 and sum of square error (SSE) of 0.1434. The drying model that demonstrates a better concord between the experimental and predicted data fitted for the sun-drying data is the two-term exponential model; its coefficient of determination (R^2) is the highest with a value of 0.9940, lowest root mean-square error (RMSE) of 0.0462, lowest value of reduced chi-square (χ^2) of 0.0023 and sum of square error (SSE) of 0.0812, this indicates that the model is suitable in describing the drying of the ackee aril apple.

From the results presented in Table 2, Wang and Smith model gave the lowest coefficient of determination (R^2) for all the drying conditions. Hii *et al*. model gave the highest values of reduced chi-square (χ^2), root mean-square error (RMSE) and sum of square error (SSE); this explains that the Hii *et al*. model and the Wang and Smith model are not satisfactory for describing the drying kinetics of the ackee aril apple correctly. The Newton model and Verma *et al*. model is ranked as the best model for predicting the drying kinetics of the sample at drying temperatures of 50°C and 60°C respectively while the two-term exponential model is ranked as the best model for predicting the drying kinetics of the sample at drying temperatures of 40°C, 65°C, 70°C and for open sun drying.

3.2.4 Validation of best models

The selected models were validated by plotting graphs of the predicted moisture ratio against the experimental moisture ratio of the sample at the different drying temperatures. Validation is necessary to scrutinize the fitness of the models in predicting the drying kinetics of the ackee aril apple and to obtain a valid model, the coefficient of determination (R^2) generated from the graph should be ≥ 0.75 (Olabinjo and Adeniyan, 2020). The correlation between the predicted and experimented values for the best models open sun drying and oven drying methods at different temperature had the values of the coefficient of determination (R^2) are greater than 0.75, indicating a good fit (R^2 for open sun drying and oven drying at 40°C, 50°C, 60°C, 65°C and 70°C are 0.9941, 0.979, 0.9735, 0.9969, 0.991 and 0.9814 respectively. This reveals that all the models derived for drying of ackee aril apple under the selected drying methods are valid and can correctly predict its drying kinetics.

3.3 Effective moisture diffusivity

The effective moisture diffusivity of the sample was calculated using Equations 8 and 9, by plotting the logarithm of moisture ratio against the reciprocal of time (Figure 4); the results are presented in Table 3. The plot (Figure 5) produced a linear relationship with the coefficient of determination (R^2) ranging from 0.7508 to 0.9644; similar observations were made by Taheri-Garavand *et al*.(2011).

Table 2. Drying constant and statistical parameters

Drying temp. (°C)	Model names	Model constant	R^2	RMSE
Open	Newton	k = 0.15	0.9192	0.2177
	Page	k = 0.2; n = 0.516	0.9594	0.1217
	Henderson and Pabis	k = 0.156; a = 1.081	0.9166	0.1925
	Logarithmic	k = 0.012, a = 0.023, C = 0.026	0.9055	0.4040
	Two Term	k = 0.051, a = 1.927, c = 1.094, g = 0.011	0.9717	1.4389
	Two Term Exponential	**k = 10.842, a = 0, b = -3478.23**	**0.9940**	**0.0462**
	Verma *et al.*	k = 0.578, a = -0.044, g = 0.058	0.9843	0.0405
	Diffusion approach	k = 0.025, a = 0.991, g = -0.334	0.9418	0.2818
	Midili-Kucuk	k = 0.019, a = 0.989, n = 1.404, b = 0.004	0.9865	0.0911
	Wang and smith	a = -0.186, b = 0.912	0.8707	3.4681
	Hii *et al.*	k = 0.07, a = 2, g = 1.507, n = 0.792, c = 1.003	0.9000	0.7564
	Modified page	k = 0.046, a = 1.073, n = 1.097	0.9891	0.0577
	Modified Henderson and Pabis	k = 0.048, a = 1.09, g = 1.587, b = -0.054, c = 0.015	0.9894	0.1688
40	Newton	k = 0.04	0.9198	0.2488
	Page	k = 0.212; n = 0.543	0.9301	0.1577
	Henderson and Pabis	k = 0.156; a = 1.081	0.9585	0.1081
	Logarithmic	k = 0.039, a = 0.02, C = 0.002	0.9016	0.3948
	Two Term	k = -0.011, a = 0.012, c = 0.035, g = 0.025	0.9009	0.3763
	Two Term Exponential	**k = 3.611, a = 0, b = -3399.241**	**0.9782**	**0.0559**
	Verma *et al.*	k = 0.288, a = -0.044, g = 0.059	0.9310	0.1385
	Diffusion approach	k = 0.058, a = 0.916, g = 0.945	0.9467	0.1368
	Midili-Kucuk	k = 0.031, a = 0.983, n = 1.161, b = 0.004	0.9309	0.2500
	Wang and smith	a = -0.081, b = 0.92	0.8048	0.8336
	Hii *et al.*	k = 0.05, a = 2.987, g = 1.586, n = 0.876, c = 0.996	0.9016	1.5556
	Modified page	k = 0.053, a = 0.979, n = 1.344	0.9913	0.0914
	Modified Henderson and Pabis	k = 0.028, a = 0.862, g = 2.386, b = 0.059, c = 0.078	0.9026	0.2975
50	**Newton**	**k = 0.124**	**0.9752**	**0.0482**
	Page	k = 0.215; n = 0.751	0.9748	0.0662
	Henderson and Pabis	k = 0.156; a = 1.081	0.9904	0.0877
	Logarithmic	k = 0.085, a = 0.046, C = 0.006	0.9211	0.3121
	Two Term	k = -0.011, a = 0.008, c = 0.047, g = 0.07	0.9054	0.3069
	Two Term Exponential	k = 0.452, a = 0, b = -1424.393	0.9513	0.1141
	Verma *et al.*	k = 0.699, a = -0.019, g = 0.079	0.9053	0.1760
	Diffusion approach	k = 0.078, a = 0.944, g = -0.007	0.9148	0.1789
	Midili-Kucuk	k = 0.026, a = 0.977, n = 1.527, b = 0.006	0.9074	0.1657
	Wang and smith	a = -0.098, b = 0.92	0.7183	0.8503
	Hii *et al.*	k = 0.096, a = 2.981, g = 3.764, n = 0.788, c = 1.046	0.9146	1.3929
	Modified page	k = 0.071, a = 0.969, n = 1.338	0.9823	0.0758
	Modified Henderson and Pabis	k = 0.076, a = 0.814, g = 3.764, b = 0.064, c = 0.093	0.9197	0.1282
60	Newton	k = 0.132	0.9359	0.0942
	Page	k = 0.123; n = 0.349	0.9317	0.5447

	Henderson and Pabis	k = 0.156; a = 1.081	0.9542	0.1454
	Logarithmic	k = 0.129, a = 0.049, C = 0.045	0.9258	0.2562
	Two Term	k = -0.015, a = 0.002, c = 0.11, g = 0.117	0.9118	0.2600
	Two Term Exponential	k = 0.006, a = -0.036, b = -4.63	0.9625	0.0860
	Verma *et al*.	**k = 0.541, a = -0.035, g = 0.248**	**0.9948**	**0.0807**
	Diffusion approach	k = 0.142, a = 0.964, g = -0.212	0.9521	0.0957
	Midili-Kucuk	k = 0.046, a = 0.953, n = 1.612, b = 0.003	0.9257	0.0973
	Wang and smith	a = -0.075, b = 0.92	0.6769	0.3469
	Hii *et al*.	k = 0.082, a = 2.791, g = 1.995, n = 0.8, c = 0.999	0.9142	1.5250
	Modified page	k = 0.212, a = 1.041, n = 0.441	0.9398	0.3468
	Modified Henderson and Pabis	k = 0.018, a = 0.09, g = 2.784, b = 0.1, c = 0.094	0.9001	0.2556
65	Newton	k = 0.188	0.9191	0.1009
	Page	k = 0.377; n = 0.458	0.9537	0.2272
	Henderson and Pabis	k = 0.196; a = 1.081	0.9115	0.1881
	Logarithmic	k = 0.187, a = 0.08, C = 0.05	0.9019	0.1951
	Two Term	k = 0.028, a = 0, c = 0.378, g = 0.198	0.9126	0.1166
	Two Term Exponential	**k = 0.978, a = -0.069, b = -4.8**	**0.9823**	**0.0718**
	Verma *et al*.	k = 0.257, a = -0.035, g = 0.213	0.9253	0.1198
	Diffusion approach	k = 0.179, a = 0.925, g = -0.27	0.9372	0.1776
	Midili-Kucuk	k = 0.084, a = 960971369829206, n = 1.553, b = 0.001	0.9056	3.9269
	Wang and smith	a = -0.085, b = 0.92	0.5884	0.3453
	Hii *et al*.	k = 0.088, a = 2.483, g = 1.8, n = 0.794, c = 0.98	0.9007	1.4224
	Modified page	k = 0.171, a = 1.009, n = 1.024	0.9037	0.1136
	Modified Henderson and Pabis	k = 0.187, a = 0.903, g = 2.81, b = -0.028, c = 0.087	0.9244	0.1556
70	Newton	k = 0.3	0.9504	0.0625
	Page	k = 0.372; n = 0.88	0.9266	0.1175
	Henderson and Pabis	k = 0.298; a = 1.081	0.9096	0.1582
	Logarithmic	k = 0.366, a = 0.064, C = 0.078	0.9493	0.1701
	Two Term	k = -0.035, a = 0.02, c = 1.028, g = 0.298	0.9137	0.1524
	Two Term Exponential	**k = 0.347, a = -0.078, b = -4.976**	**0.9597**	**0.0625**
	Verma *et al*.	k = 0.075, a = -0.088, g = 0.288	0.9159	0.0824
	Diffusion approach	k = 0.259, a = 0.894, g = 0.729	0.9156	0.0892
	Midili-Kucuk	k = 0.109, a = 1.072, n = 1.572, b = 0.002	0.9056	0.1303
	Wang and smith	a = 0.146, b = 0.92	0.4994	2.4291
	Hii *et al*.	k = 0.203, a = 2.424, g = 1.16, n = 0.848, c = 1.02	0.9108	0.9206
	Modified page	k = 0.376, a = 1.01, n = 0.628	0.9028	0.1378
	Modified Henderson and Pabis	k = 0.257, a = 1.288, g = 2.27, b = 0.067, c = 0.022	0.9271	0.1812

The ackee aril apple exhibited a falling rate period; this proves that moisture diffusivity in the sample is predominantly by diffusion mechanism.

The effective moisture diffusivity of the ackee aril apple oven dried at temperatures of 40°C, 50°C, 60°C, 65°C, 70°C and under the open sun was estimated to be 4.13×10^{-9} m^2/s, 4.48×10^{-9} m^2/s, 5.28×10^{-9} m^2/s, 6.5×10^{-9} m^2/s, 7.71×10^{-9} m^2/s and 3.07×10^{-9} m^2/s respectively. From the results presented in Table 3, it was observed that the calculated values of effective moisture diffusivity fall within the general range of 10^{-9} to 10^{-12} m^2/s for food samples and agricultural crops and, an increase in the drying temperature led to increase in the effective moisture diffusivity similar observations were made by Alara *et al.* (2019), Sabat *et al.* (2018). The highest effective moisture diffusivity was found to be 7.71×10^{-9} m^2/s at oven drying temperatures of 70°C, while the lowest effective moisture diffusivity was estimated to be4.13×10^{-9} m^2/s at oven drying temperatures of 40°C; samples exposed to the open sun had effective moisture diffusivity of 3.07×10^{-9} m^2/s. The effective moisture diffusivity of the ackee aril apple was found to be higher than *vernonia amygdalina* leaves (5.48×10^{-12} m^2/s) oven dried at 60°C (Alara *et al.*, 2019); and, was found to be in the same range with those of red onion (4.1×10^{-9} m^2/s – 9.3×10^{-10} m^2/s) oven dried at 50°C (Sobowale *et al.*, 2020).

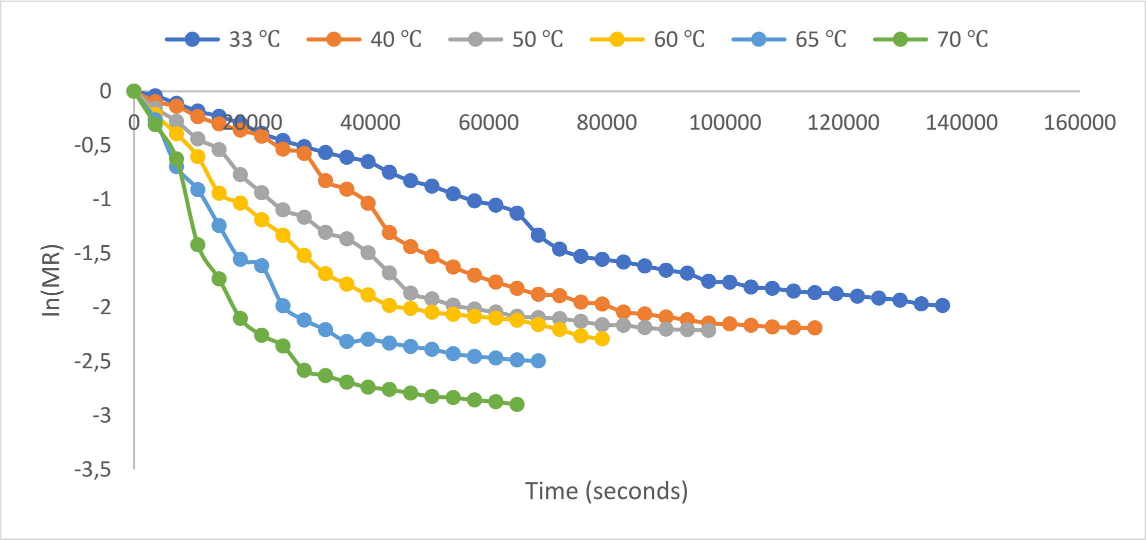

Figure 5: The change of logarithm of moisture ratio against time (seconds) at different drying temperature

Table 3. Estimation of effective moisture diffusivity

Temperatures		$\frac{1}{T}$ (K)	D_{eff} (m^2/s)	In (D_{eff})	R^2
℃	K				
33	306	3.268×10^{-3}	3.07×10^{-9}	-19.602	0.9644
40	313	3.195×10^{-3}	4.13×10^{-9}	-19.305	0.9213
50	323	3.095×10^{-3}	4.48×10^{-9}	-19.224	0.8842
60	333	3.003×10^{-3}	5.28×10^{-9}	-19.059	0.8707
65	338	2.959×10^{-3}	6.5×10^{-9}	-18.851	0.8035
70	343	2.915×10^{-3}	7.71×10^{-9}	-18.681	0.7508

The temperature of the open sun was assumed to be around 33°C

3.4 Activation energy

The activation energy of the ackee aril apple was determined using the Arrhenius Equation and by plotting a graph of the antilogarithm of effective moisture diffusivity ($\ln D_{\mathrm{eff}}$) against the reciprocal of the absolute temperature $\left[-\frac{1}{(T+273.15)}\right]$similar approach have been used by various researchers; Akoy, (2014) and Olabinjo and Adeniyan, (2020). The activation energy which is the energy required to eliminate moisture within the ackee aril apple was estimated to be 18.168 kJ/mol and a diffusivity constant of 4.1378×10^{-6} m^2/s was obtained. The activation energy obtained falls within the general range of 1.27 kJ/mol – 110 kJ/mol as reported by Alara *et al.* (2019) for food materials. The activation energy obtained for the ackee aril apple is in close range with those obtained in the oven drying of other agricultural produce: 19.85 kJ/mol – 19.87 kJ/mol for coriander leaves (Olabinjo *et al.*, 2020); 19.83 kJ/mol for aloe-vera (Sabat *et al.*, 2018). The activation energy of tomato (33.33 kJ/mol – 43.23 kJ/mol), 50℃ oven dried white onion (57.78 kJ/mol – 63.73 kJ/mol) was found to be higher than those of the ackee aril apple (Sobowale *et al.*, 2020; Taheri-Garavand *et al.*, 2011); the activation energy of *vernonia amygdalina* leaves (8.048 kJ/mol) was found to be lower (Alara *et al.*, 2019).

4. CONCLUSIONS

The ackee aril apple have high moisture content and so has low shelf life and can't be stored for a long period of time unless processed. In order to increase its shelf life, the moisture content should be reduced by drying or refrigerating or processing immediately after harvest. Drying kinetics of ackee apple arils were greatly affected by the drying air temperature. An increase in drying air temperature led to a decrease in the drying time. The entire drying process of ackee aril apple occurred in the falling rate period, indicating that moisture removal in the sample is predominantly by diffusion. The drying process of ackee aril apple affected the concentrations of the nutritional compositions since there was significant increase and decrease in some concentrations.

Based on the result obtained for the four statistical parameters namely – R^2, RMSE, SSE and χ^2; the two-term exponential model was the best in predicting drying kinetics of ackee aril apple under the varying temperatures of 40, 65, 70 ℃ and open sun method of drying. At drying temperatures of 50 ℃ and 60 ℃, Newton model and Verma *et al*. model proved to be the best respectively. The effective moisture diffusivity of the ackee aril apple increases with increasing air-drying temperature (that is itdecreases with increase in drying time), ranging from 40 – 70 ℃; which was estimated to be $4.13\times10^{-9} – 7.71\times10^{-9}$ m^2/s. The activation energy needed for the diffusion rate was successfully calculated to be 18.168 kJ/mol.

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