EMPIRICAL DRYING MODEL FOR THE MASS TRANSFER AND DRYING KINETICS OF TREATED AND UNTREATED SABA BANANA SLICES

ALAGBE E. E.*¹, DANIEL E. O.², AMLABU Y. S¹ & SOLE-ADEOYE O.³

¹Department of Chemical Engineering, Covenant University, Ota, Nigeria

²Department of Microbiology, Benson Idahosa University, Benin City, Nigeria.

³Department of Production, Analytical and laboratory Management, Federal Institute of Industrial Research, Oshodi, Nigeria

ABSTRACT

Banana fruit is a delight in most Nigerian homes, which is usually eaten fresh, but recently, dried bananas have found their way into the daily snacks. Unfortunately, this precious fruit suffers a huge post-harvest loss due to its high moisture content. This work includes the fitting of the drying process to empirical models to predict the drying process using a locally fabricated convective tray dryer. To prevent discolouring during drying, samples were treated with a 1:4 lemon juice. Drying was carried out (for both treated and untreated samples) at temperatures of 40 °C, 50 °C, 60 °C, and 70 °C. Four empirical models were examined (Newton, Peleg, Henderson-Pabis, and Logarithmic models), and the model with the highest R² and least RMSE values was adopted as the best fit for each drying temperature. Results showed that the Peleg model favoured air-drying and at temperatures of 50 °C and 60°C for untreated and treated samples, respectively, while other models considered, best described the drying at other temperatures, for both treated and untreated samples.

KEYWORDS: Post-Gather, Nourishment, Empirical Models, Drying of Fruits, Mass Transfer

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1 INTRODUCTION

Banana is an organic product yield of substantial monetary and wholesome importance that is cultivated in tropical and subtropical areas. In developing nations, the reported consumption of bananas is about 21kg for each individual every year [1]. Banana contains a reasonable amount of starches, minerals, protein, sugar, and vitamin A [2]. Be that as it may, the organic product is truly susceptible to biological degradation due to its high water content in the fresh fruit. This, in turn, attracts great misfortunes with a lack of strategies for collecting and post-gather [3, 4, 5, 6]. Drying is an old technique for safeguarding nourishment, and this includes the evacuation of the more significant part of the water typically present in the sustenance by dissipation [7, 8]. Drying is a standout amongst the most broadly utilized procedures for safeguarding nourishments, as it diminishes microbial development and deteriorative compound responses. In any case, an ill-advised drying procedure can prompt undesirable changes in concoction creation and structure of the organic product tissues, bringing about terrible utilization quality as far as shading, surface, and healthful qualities [9]. This behooves a banana drying process must be controlled painstakingly to attain the desired quality traits in the dried products [10]. This would allow for modification of drying parameters, within reasonable limits, to guarantee excellent quality dried products. Dried bananas and its peels have various uses in baby and adult food/snacks and the production of activated carbon [11], respectively.

The tray dryer is used mostly in industries because of its simple design and capability to dry products at high volume (12), which guarantees hygiene during the process (13). Generally, a tray dryer is fed with fan-distributed hot air to its stack of trays. Tray dryers can be operated batch-wise, as racks to hold products while air circulates over the material (14). The raw food samples are spread out on the trays at an acceptable thickness so that the product can be dried uniformly [12, 15].

Modeling of drying processes and kinetics helps in the analysis of the transfer process and equipment design [16]. These mathematical models give useful insight into the drying process and estimate the drying time of different agricultural products [17]. Therefore, the choice of the most appropriate method of drying for a particular product is essential and these models could be theoretical, semi-theoretical, or empirical models [18]. Semi-theoretical drying models are founded on the diffusion theory, which assumes a resistance to moisture in a product that occurs in the product layer [19]. Thus, from Newton's law of cooling, the drying rate can be expressed as;

$$\frac{\partial M}{\partial t} = -k(M - M_e)$$

where,

k- drying coefficient;

M_e - equilibrium moisture content

M- average moisture content product

Kinetics of drying describes the changes in the amount of moisture present in a material during the process [20]. It can be impacted by drying temperature/time, drying temperature, relative air humidity, flow rate (or velocity) of the drying air, material thickness/diameter, [21, 22]. The composition of the food products can also affect the drying kinetics of that particular product [20].

With different species of banana currently in the Nigerian market, it is imperative to know the drying models that best describe their drying. Therefore, this work serves to present the drying kinetics and also, the models that best describe the drying properties of the relatively common *Saba* banana specie.

2 METHODOLOGY

The ripe *saba* bananas used for this experiment were bought from Cafeteria 1 in Covenant University, Ota, Nigeria. The Eureka lemon (*citrus limon* 'Eureka') used to pre-treat the banana slices were purchased from Shoprite, Circle mall, Jakande, Lagos.

2.1 Preparation and Pre-Treatment of Banana Slices

The bananas were peeled and sliced equally using a banana slicer to a thickness of about 5mm. 100g of sliced samples were weighed with the measuring scale and dipped in a 1:4 lemon and water solution for 10 minutes. After 10 minutes, the banana slices were drained correctly and spread out on a foil paper. 100g of banana slices were weighed with a measuring scale and spread evenly on a foil paper.

2.2 Drying of Banana Slices

The tray drying process was carried out using a tray dryer consisting of two trays. The banana slices were dried at four

different temperatures (40°C, 50°C, 60°C and 70°C) with a steady air velocity of 1.2 m/s and relative humidity of 65. To ensure uniformity in drying, both the untreated and treated banana slices were dried simultaneously but loaded on separate trays. The weights of the banana samples were monitored and taken at an interval of thirty minutes until a constant weight was reached. Each weighing was repeated three times.

Control samples were treated and untreated sun-dried banana slices. The samples were weighed regularly at an interval of sixty (60) minutes until a constant weight was obtained.

2.3 Derivation of Thin-layer Drying Models

Existing derived models were used to predict and describe the drying process. Table 1 shows the mathematical models that were employed.

Table 1: Mathematical models for the description of drying kinetics of agricultural products [21]

SN	MODEL NAME	MODEL EQUATION
1	Newton/ Lewis	$MR = \exp(-kt)$
2	Peleg Model	$M - M_0 = \frac{1}{k_1 + tk_2}, \frac{dM}{dt} = MR = \frac{-k_1}{k_1 + tk_2}$
3	Henderson and Pabis	$MR = a \exp(-kt)$
4	Logarithmic	$MR = a \exp(-kt) + c$

Where,

MR- moisture ratio

t- time of drying

k- drying coefficient

a, b, n, c, g are model constants

3 RESULTS AND DISCUSSIONS

Table 2: Effect of drying temperature on moisture variation of untreated samples during drying

UNTREATED					
TEMPERATURE	40°C	50°C	60°C	70°C	AIR-DRIED
TIME	%MOISTURE	%MOISTURE	%MOISTURE	%MOISTURE	%MOISTURE
0	0.666	0.666	0.666	0.666	0.666
30	0.628	0.602	0.591	0.588	
60	0.598	0.565	0.519	0.524	0.644
90	0.576	0.508	0.460	0.449	
120	0.551	0.481	0.384	0.293	0.592
150	0.527	0.425	0.317	0.256	
180	0.496	0.387	0.271	0.215	0.554
210	0.478	0.332	0.190	0.200	
240	0.395	0.295	0.159	0.169	0.513

270	0.361	0.205	0.108	0.169	
300	0.332	0.187	0.108	0.169	0.483
330	0.302	0.150	0.108		
360	0.312	0.131	0.108		0.449
390	0.279	0.131			
420	0.279	0.131			0.403
450	0.256	0.131			
480	0.256	0.131			0.367
510	0.256				
540	0.231				0.338
570	0.231				
600	0.231				0.305
630	0.231				
660	0.231				0.269
690					
720					0.256
750					
780					0.215
810					
840					0.169
870					
900					0.169
930					
960					0.169

Figure 1: Plot of variation of moisture content versus time at different temperatures of treated banana slices

Figure 1 shows that for the untreated samples, drying took place mainly in the falling rate region, for all temperatures.

Table 2 shows the effect of time and temperature on the moisture content present in the untreated banana slices when dried. The initial moisture content of the untreated banana slices was 66.6%. The final moisture content of the untreated banana samples was 23.1%, 13.1%, 10.8%, 16.9% and 16.9% at 40 °C, 50°C, 60 °C, 70 °C and air-drying temperature. The moisture content present in the banana samples were decreasing with an increase in temperature except at 70°C. This is because, at a high temperature of 70 °C, a dried layer was formed on the surface of the banana slices, which made drying difficult. Hence, its higher final moisture content.

Table 3: Effect of drying temperature on moisture variation of treated samples during drying

Treated					
	40	50	60	70	AIR-DRIED
Time	% Moisture	% Moisture	% Moisture	% Moisture	% Moisture
0	0.699	0.699	0.699	0.699	0.699
30	0.663	0.640	0.608	0.609	
60	0.630	0.582	0.551	0.538	0.671
90	0.597	0.536	0.467	0.459	
120	0.572	0.487	0.420	0.335	0.631
150	0.534	0.434	0.344	0.285	
180	0.523	0.389	0.273	0.227	0.600
210	0.488	0.348	0.167	0.211	
240	0.390	0.287	0.131	0.194	0.549
270	0.362	0.215	0.111	0.194	
300	0.320	0.181	0.111	0.194	0.515
330	0.308	0.163	0.111		
360	0.272	0.163	0.111		0.476
390	0.272	0.145			
420	0.272	0.125			0.438
450	0.272	0.125			
480	0.259	0.125			0.374
510	0.246				
540	0.217				0.295
570	0.217				
600	0.217				0.282
630	0.217				
660	0.217				0.239
690					
720					0.192
750					
780					0.192
810					
840					0.157
870					

900					0.118
930					
960					0.118

Figure 2: Plot of variation of moisture content of treated banana slices versus time at different temperatures

Figure 2 shows that for the treated samples, drying occurred mainly in the falling rate region, also, for all temperatures under investigation.

Table 3 portrays the effect of time and temperature on the moisture content present in the treated banana slices. The initial moisture content of the untreated banana slices was 66.6%. The final moisture content of the untreated banana samples was 21.7%, 12.5%, 11.1%, 19.4% and 11.8% at 40°C, 50°C, 60°C, 70°C and air-drying temperature. The moisture content present in the banana samples was decreasing with an increase in temperature except for 70°C. This is because, at a high temperature of 70°C, a dried crust is formed in the surface of the banana slices, which makes drying difficult hence, a higher moisture content. This is similar to the results obtained in the treated samples.

3.1 Drying Models

Drying data obtained were fitted into four empirical drying models to describe the drying kinetics of banana. The drying models with the highest value of R^2 and the lowest value of RMSE were taken as the model(s) that best described the drying of banana samples. Below are a few of the selected models;

Table 4: Results of R^2 and Root Mean Square Error (RMSE) obtained at different temperatures with varying theoretical models for untreated banana samples

Models/Temperature, °C	Newton R^2 value (deviation)	Peleg R^2 value (deviation)	Henderson and Pabis R^2 value (deviation)	Logarithmic R^2 value (deviation)
40	0.9713 (0.06)	0.9503 (0.05)	0.9721 (0.05)	0.9713 (0.06)
50	0.9609 (0.09)	0.9932 (0.04)	0.9609 (0.09)	0.9609 (0.09)
60	0.9959 (0.00)	0.994 (0.03)	0.9959 (0.03)	0.9959 (0.00)
70	0.9739 (0.09)	0.9445 (0.06)	0.9739 (0.09)	0.9739 (0.09)
Air-dried	0.9743 (0.03)	0.9965 (0.02)	0.9743 (0.03)	0.9743 (0.03)

Table 4 shows that both air-dried samples and samples dried at 50 °C followed the Peleg model while at other temperatures, the Peleg model was not favoured. Drying at 60 °C and 70 °C followed all models except Peleg, while at 40 °C, the combined Henderson-Pabis model best described its drying kinetics. Considering same convective drying on banana slices and peels, the thin-layer drying in the works of Da Silva *et al.* (2013) [23] and Khawas *et al.* (2014) [24] respectively, followed the Page models while microwave drying of banana slices followed Wang and Singh model [20].

Table 5: Results of R^2 and Root mean square Error (RMSE) obtained at different temperatures with varying theoretical models for treated banana samples

Models/Temperature, °C	Newton R^2 value (deviation)	Peleg R^2 value (deviation)	Henderson and Pabis R^2 value (deviation)	Logarithmic R^2 value (deviation)
40	0.9627 (0.06)	0.9396 (0.05)	0.9627 (0.06)	0.9627 (0.06)
50	0.9804 (0.06)	0.9689 (0.04)	0.9804 (0.06)	0.9804 (0.06)
60	0.9547 (0.10)	0.9899 (0.05)	0.9547 (0.12)	0.9547 (0.10)
70	0.9812 (0.08)	0.9541 (0.06)	0.9812 (0.08)	0.9812 (0.08)
Air-dried	0.9628 (0.06)	0.9903 (0.02)	0.9628 (0.06)	0.9628 (0.06)

Table 5 shows that the Peleg model best describes the drying kinetics of the air-dried samples and samples dried at 60°C. at other temperatures, the Peleg model failed to qualify as best representing the drying kinetics while other models had equivalent statistical indicators.

The Henderson-Pabis model woefully represented the drying of banana specie (*Musa acuminata*) in Brazil while the Peleg model weakly represented the drying kinetics [23]. Works of Dandarongrak *et al.* (2002) [25], where treated banana slices were dried using a heat pump dehumidifier, followed the two-term exponential model.

4 CONCLUSIONS

The models that describe the drying kinetics of banana may be a function of the location of cultivation, that is, the prevailing climatic conditions, and the type of dryer used in the drying process. The Peleg model may be adopted for drying at 50 °C, 60°C, and air-dried samples. In contrast, other models with similar statistical indicators may be used to describe the drying kinetics at other temperatures under investigation.

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CONFLICT OF INTEREST

None declared by the members of the Team.

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