Modelling the Drying Characteristics of Osmosised Coconut Strips at Constant Air Temperature

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Abstract
Drying was performed on osmotically dehydrated coconut meat. The coconut was osmotically pre-treated using three different concentrations of sucrose solutions and immersed in a temperature water bath for 3 h at temperatures of 30, 40 and 50°C, respectively. The osmosised and non-osmosised (control) coconut strip samples were dried in an oven at a drying temperature of 60°C. The results showed that drying regime was characteristically in the falling rate period. A regression analysis was used to fit three thin layer drying models to the experimental drying data. The most appropriate model(s) was selected using correlation coefficient (R²) and root mean square error (RMSE). The page model showed a better fit of the experimental drying data (as compared to other models) on the basis that R² > 0.99 and RMSE < 0.0130. The effects of the osmotic pre-treatment on the drying data of coconut samples were also explained. The effective moisture diffusivity ranged from 5.74 to 7.88 x 10⁻¹⁰m²/s for osmosised coconut sample and 5.44 x 10⁻¹⁰m²/s for non-osmosised coconut sample.

Keywords: Coconut; Osmotic dehydration; Drying; Effective diffusivity; Water content; Drying models

Introduction
Drying is one of the oldest processes used in the preservation of cultural food products. It is gaining attention as one of the emerging technology which requires innovations for research studies. Drying is dependent on two fundamental principles (i.e. heat and mass transfer). Firstly, heat has to be transferred to the product and secondly moisture has to be removed from the product [1]. Since drying is an energy driven unit operation, its efficiency can be improved if the drying rate that determines the drying period is increased. Long drying periods may lead to poor quality of final products [1,2]. Conditions which result in higher drying rates are sought for giving rise to acceptable final products that are economically and nutritionally viable [1].

It is on this basis that physical pretreatments such as osmotic pretreatment have been investigated in order to improve drying kinetics or product quality [3-6]. The beneficial effect of osmotic pretreatment includes higher quality of the final product and lower energy requirements [7,8]. Several factors affecting this treatment process include the type and concentration of the osmotic solutions, processing temperature and time, rate of agitation and raw material characteristics [9]. However, extensive studies have not been done on the effect of osmotic process variables on the drying behavior of food materials.

Notable workers who have studied the effect of osmotic solution concentrations on the drying characteristics of food materials include Karathanos and Kostaropoulos [5], Nieto et al. [10], Madamba [6] and Garcia et al. [11]. However, no relevant information has been provided on this subject (osmotic air-drying) except that the concentrations of osmotic solution have been observed to affect the drying properties of agricultural produce [6]. Specifically, that of coconut has not been studied. Also, many studies have emphasized drying kinetics and thin-layer drying models for fruits and vegetables such as organic apple slices [12], carrots [13], rose hips [14], raw mango slices [10,15], young coconut and chopped coconut [6,16,17]. Nonetheless, the preceding thin-layer drying models provided no data for drying of osmotically pretreated coconut chips or strips.

Coconut (Cocos nucifera L.) being one of the most important crops in the tropical countries and grown in more than 80 countries of the world with a total production of 61 millions tonnes per year [18]. Nigeria produced 1088500 million tonnes of coconut palm between 2004 and 2008 [19]. Coconut can be consumed in various types of coconut derived products - coconut milk, coconut juice, coconut flour, coconut oil, and desiccated coconut [17]. The desiccated coconut with very low moisture content of about 3% dry weight basis can be use for the decoration of ice cream, cake, donuts and as flavoring agent in chocolate bars, sweets and biscuits [17,18].

Therefore, the objective of this work is to study the effect of osmotic solution concentration and its operating temperature (pretreatment variables) on the air drying properties of coconut and to fit some thin-layer drying models in which the drying rate constants and model coefficients rely on the osmotic pretreatment conditions or variables.

Materials and Methods
Materials
The coconut used for this study was obtained from a local city market of Ogbomoso in Oyo state, Nigeria. The coconut was broken up and the meat was removed, washed and cleaned after which it was cut (using vegetable shredder) into thick strips of regular rectangular shape (6.0 x 3.0 x 0.5 cm) with nearly 1.0 cm thickness. Sugar (sucrose) with trade mark ST LOUIS Sucre, France, bought from local supermarket in Ogbomoso was used as the osmotic agent (solute) for the osmotic

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pretreatment. The other materials that were used in this study include electric oven, temperature controlled water bath, electronic weighing balance and beakers.

Methods

Osmotic dehydration: 30 g of coconut meat chips were placed in three different 250 ml beakers containing sucrose solution of concentration 40, 50 and 60% w/w, respectively. The beakers were then placed in a temperature controlled water bath (DK-420 Glufex Medical and Scientific, England) maintained at 30°C for 3 hours. Thereafter, the osmotic dehydrated samples (coconut samples) were removed and the excess solution on the surface of samples was removed with absorbent paper and then re-weighed. These procedures were repeated with a constant sucrose solution concentration of 40% w/w at 40 and 50°C. The weight reduction (WR), sugar gain (SG) and the water content loss (WL) of coconut meat samples was respectively calculated using Equations (1) to (3) [7]:

\[
WR = \frac{M_f - M_p}{M_o} \quad (1)
\]

\[
SG = \frac{m_f - m_p}{M_o} \quad (2)
\]

\[
WL = \frac{(M_o - m_f) - (M_f - m_p)}{M_o} \quad (3)
\]

Where: \(M_o\) is initial weight of fresh coconut before osmotic treatment (g); \(M_f\) final weight of coconut after time \(t\) of osmotic treatment (g); \(M_p\) dry weight of fresh coconut (g); \(M_f\) final dry weight of coconut after time \(t\) of osmotic treatment (g).

Oven drying: Drying experiments were carried out in an oven dryer (Uniscope SM 9053A, England). The dimensions of the dryer are 0.693 x 0.470 x 0.486 m. The dryer consisted of a tray, electrical heater, fan and a temperature controller (50-200°C, dry bulb temperature). The osmotically pretreated coconut meat samples were charged into the dryer and drying was performed at a dry bulb temperature of 60°C. At regular time intervals of 60 minutes, the samples were withdrawn for weight measurement. The total drying time was obtained as the time required for the sample to attain a constant weight (or bone dry weight). Drying rates for each pretreatment condition were estimated between the moisture ratio and the effective moisture diffusivity, the correlation coefficient (R²) and root mean square error (RMSE) were criteria used for selecting the best model equation that describes the drying curve. In order to evaluate the goodness of fit of the simulation given by the selected models, the mean relative error, %E [33,34] and the reduced chi-square, \(\chi^2\) were estimated [32-36].

\[
%E = \frac{100}{N} \sum_{i=1}^{N} \left[ \frac{MR_{exp} - MR_{pre}}{MR_{exp}} \right] \quad (9)
\]

\[
\chi^2 = \sum_{i=1}^{N} \frac{(MR_{exp} - MR_{pre})^2}{N - Z} \quad (10)
\]

Where, \(N\) total number of observations, \(Z\) number of model parameters, \(MR_{exp}\), experimental moisture ratio values and \(MR_{pre}\), predicted moisture ratio values. It is generally considered that %E ≤ 10% gives a good fit [34,37].

Effective moisture diffusivity: For the determination of the effective moisture diffusivity \(D_{eff}\), a mathematical model was used based on Fick’s second law of diffusion which expresses a relationship between the moisture ratio and the effective moisture diffusivity, the solution for which was given by Crank [38] can be applicable for slab geometry by assuming uniform initial moisture distribution, constant diffusivity and negligible shrinkage is presented in Equation (11):

\[
MR = \frac{8}{\pi^2} \exp \left[ \frac{D_{eff}}{4t} \pi^2 t \right] \quad (11)
\]

Where, \(D_{eff}\) is effective moisture diffusivity (m²/s), \(t\), drying time and \(l\), thickness (m).

Linear regression analysis was used to adjust the experimental data to Equation (11) which is the slope method [39].

Results and Discussion

Osmotic dehydration

Table 2 showed the results of the osmotic dehydration parameters. The water loss (WL) and weight reduction (WR) for the coconut chips increased as the sucrose concentration and osmotic processing temperature increased, respectively (i.e. the more concentrated osmotic dehydration solution and the higher temperature produce the higher water loss and weight reduction). Similar observations have been reported [40,41]. The water loss after the osmotic dehydration

| No | Model Names | Model Equation |
|----|-------------|----------------|
| a. | Newton      | MR = exp(-kt)  | (6) |
| b. | Page        | MR = exp(-k't) | (7) |
| c. | Two-term exponential | MR = a exp(-kt) + (1 - a) exp(-k't) | (8) |

Table 1: Typical models for thin layer drying [35].
was in the order of 9-20%, indicating that the proposal made for the possibility of pre-processing is viable.

**Oven drying**

The moisture ratio variations with drying times for each osmotic pretreatment condition of coconut chips (Figure 1) showed that moisture ratio decreases continuously with drying time for both the osmosised and control (non-osmosised) coconut samples. The continuous decrease in moisture ratio with time indicates that the internal mass transfer for coconut chips was governed by diffusion. This corroborates Piga et al. [42] and Kingsly et al. [24] observations.

The influence of the osmotic pretreatment conditions drying rates of coconut chips (Figure 2,3) showed that the initial drying rates of the pretreated samples took less time for drying than the untreated sample. Moreover, it was observed that as the osmotic agent (sucrose) concentration and pretreatment temperature increased, the initial drying rate probably occurred because of the complex nature of the internal moisture movement and pretreatment temperature increased, the hot air-drying time consequently decreased.

| Osmotic Pretreatment Conditions | Sample Weight (g) | Moisture Content (w/w) % | Weight Reduction (WR) % | Water Loss (WL) % | Sugar Gain (SG) % |
|--------------------------------|-------------------|--------------------------|--------------------------|------------------|------------------|
| 30°C - 40% (w/w)               | 30                | 0.343                    | 6.33                     | 9.15             | 4.9              |
| 30°C - 50% (w/w)               | 30                | 0.280                    | 12.67                    | 16.55            | 6.0              |
| 30°C - 60% (w/w)               | 30                | 0.250                    | 15.67                    | 19.92            | 6.3              |
| 40°C - 40% (w/w)               | 30                | 0.300                    | 10.67                    | 14.20            | 5.4              |
| 50°C - 40% (w/w)               | 30                | 0.270                    | 13.67                    | 17.69            | 6.2              |
| Control (Non-osmosised)        | 30                | 0.401                    | -                        | -                | -                |

**Table 2:** Osmotic dehydration parameters for coconut chips.

Figure 3 showed the influence of osmotic pretreatment on the drying rates of coconut chips. It was observed that the initial drying rates decreased as the pretreatment temperature increased. The initial drying rate for the samples pretreated at 30°C was higher than that pretreated at 40°C and 50°C, respectively. From Figure 2 and 3, it can be seen that the drying regime of coconut is characteristics of the falling rate period. The constant rate period was in the order of 9-20%, indicating that the proposal made for the possibility of pre-processing is viable.

**Drying models prediction**

Drying data for the different pre-osmosised and control (non-osmosised) coconut samples (Figure 1) were fitted to 3 different thin layer mathematical drying models (Equations (6)-(8)) listed in Table 1.

Using regression analysis, the parameters of the different models were determined, while values of $R^2$ and RMSE were obtained as...
It was also observed that the drying constant \( k' \) value for the osmosised samples were higher than of the non-osmosised sample. Thus, osmotic pretreatment increases the drying constant \( k' \) values during thermal air drying phase. The higher the \( k' \) value, lower is the drying time.

In order to mathematically evaluate the simulation, the mean relative error (%E), correlation coefficient (R²), root mean square error (RMSE) and reduced chi-square (\( \chi^2 \)) were calculated from comparing the experimental moisture ratio and those given by the proposed model for the non-osmosised and pre-osmosised coconut samples dried at 60°C. These results are shown in Table 4. By using Equations (12) and (13) (page model), the moisture ratio variation during drying has been estimated. From Table 4, the %E values were equal or below 10%, the R² value very high, RMSE and the reduced chi-square value (\( \chi^2 \)) were low for all osmosised and non-osmosised samples. Thus, the page model allowed an accurate simulation of the thermal drying curves of coconut for the whole range of osmotic process variables studied, exhibiting a high agreement between experimental and estimated (predicted) moisture ratio (Table 4).

Effective moisture diffusivity

The transport of water (or moisture transfer mechanism) during drying can be described by the Fick's diffusion model. The experimental drying curves obtained at drying temperature of 60°C for non-osmosised and pre-osmosised samples were adjusted to the Fick's diffusion equation (Equation (11)). The excellent linear adjustment to this equation with correlation coefficient of 99% show that drying of

| Osmotic Pretreatment Conditions for Coconut Samples | Model Name | Constants | R² | RMSE  |
|---------------------------------------------------|------------|----------|----|-------|
| 30°C/40%w/w | Newton     | a         | k  | n    |        |
| Control(Non-osmosised) | Newton     | a         | k  | n    |        |
| 30°C/50%w/w | Newton     | a         | k  | n    |        |
| Control(Non-osmosised) | Newton     | a         | k  | n    |        |
| 30°C/60%w/w | Newton     | a         | k  | n    |        |
| Control(Non-osmosised) | Newton     | a         | k  | n    |        |
| 40°C/40%w/w | Newton     | a         | k  | n    |        |
| Control(Non-osmosised) | Newton     | a         | k  | n    |        |
| 50°C/40%w/w | Newton     | a         | k  | n    |        |
| Control(Non-osmosised) | Newton     | a         | k  | n    |        |

Table 3: Drying model constants and goodness of fit parameters for coconut samples.

| Osmotic Pretreatment | \( k \) | \( n \) | %E | RMSE  | \( \chi^2 \) | R² |
|---------------------|-------|-------|----|-------|--------------|----|
| 30°C/40%w/w         | 0.4663 | 0.6476 | 11.4 | 0.0415 | 0.00259 | 0.95 |
| 30°C/50%w/w         | 0.4795 | 0.6395 | 1.82 | 0.0138 | 0.00032 | 0.98 |
| 30°C/60%w/w         | 0.5326 | 0.6273 | 1.02 | 0.0038 | 0.00003 | 0.99 |
| 40°C/40%w/w         | 0.4730 | 0.6998 | 0.70 | 0.0041 | 0.000027 | 0.99 |
| 50°C/40%w/w         | 0.5071 | 0.7073 | 0.36 | 0.0032 | 0.000021 | 0.99 |
| Control(Non-osmosised) | 0.3568 | 0.7594 | 2.99 | 0.0163 | 0.000355 | 0.97 |

Table 4: Summary of the values of page model parameters together with the mean relative error (%E) reduced chi-square (\( \chi^2 \)), root mean square error (RMSE) and correlation coefficient (R²) for the drying of coconut.

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coconut slices is well represented by the diffusion model proposed by Fick, and this enable the calculation of the effective moisture diffusivity \(D_{eff}\) for both the non-osmosised and pre-osmosised samples. The results showed that the effective moisture diffusivity of pre-osmosised coconut slices ranged from 5.74 to 7.88x10^{-10} m^2/s, while that for non-osmosised coconut sample is 5.44x10^{-10} m^2/s. These values were found to be within the general range 10^{-11}-10^{-9} m^2/s for drying of food materials [6,12,20,36,45-47].

Also, it could be observed from Table 5, that the effective moisture diffusivity increased with increase in the osmotic predrying process variables (sucrose concentration and pretreatment temperature) used in pre-processing of osmotic dehydration prior to drying. The values for the pre-osmosised samples are higher than that of non-osmosised sample. Thus, osmotic pretreatment increased the effective moisture diffusivity. This is in contrast to the observation of Nieto et al. [10]. These workers reported that osmotic pretreatment strongly decreased diffusivity. This is in contrast to the observation of Nieto et al. [10].

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