Dehydration Kinetics of Cassava, Yam and Potato Slices Using a Refractance Window™ Dryer

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Abstract- This study aims to investigate the drying characteristics of cassava, yam, and potato slices using a laboratory scale batch Refractance Window™ (RW) dryer. The experimental dryer was constructed by modifying a laboratory water bath. The bath was covered with a transparent Polyethylene terephthalate (PET) plastic film held in place with angled edges. The cassava, yam, and potato slices were dried on the Refractance Window™ dryer, and the variation in the moisture content of the slices during the drying process was measured. The drying curves, the drying rate curves, and the Krischer curves, from the experimental drying data, were plotted. Observations indicate that the cassava, yams, and potatoes slices dried to below 0.11 g water/g-solid moisture content in about 150 min. This study was performed to facilitate the understanding of the design, modelling, and operations of a continuously operating RW dryer.

Keywords- Refractance Window Drying, Thin Layer Drying Models, Yams, Cassava, Potatoes

1 INTRODUCTION

Cassava, yams, and potatoes are important food crops; providing energy and food nutrients for several millions of people worldwide (Roy et al., 2006). In many parts of the world the tubers are dried, turned into powder and used for various cuisines. The typical method of drying of tubers in regions where they are grown is natural sun drying (Mlingi, 1995). However, this process is slow as it depends on the ambient temperature in these regions. Also, natural sun drying is seasonal, and the quality of the product may degrade when drying times are long. Prevention of this degradation is possible if drying process is fast enough (Marsh, 2002). There is, therefore, a need to find a method of significantly reducing the time to dry these tubers. In this study, the drying of cassava, yam, and potato slices was investigated using a Refractance Window™ drying technique.

The Refractance™ Window drying technique patented by Magoon (1986) is a unique, self-limiting dehydration method that uses infra-red light, rather than direct extremes of temperature, to remove water from food. The technique involves heating food samples places on the upper side of a transparent Polyethylene terephthalate (PET) plastic film. The plastics film is heated beneath by water. The technique relies on the conductivity of water together with the properties of infra-red and the reflectance of light; this is the preferred method for preserving the precious nutrients and phytonutrients found in whole foods. Studies by Abonyi et al., (2002), Nindo and Tang, (2007), Ochoa-Martinez et al., (2012), have shown that foods dried by Refractance Window™ dryer had higher retention of enzymes, minerals, antioxidants, and vitamins and compared to those dehydrated by more commonly practiced methods.

For example, Abonyi et al., (2002), demonstrated that the quality retention characteristics of strawberry and carrot purees dried using the Refractance Window™ (RW) drying method were similar to that when dehydrated by freeze-drying, a more expensive technology. Also, Nindo and Tang, (2007), work on purees and juices, prepared from fruits, vegetables, and herbs, had similar nutritional values when compared with those dried using the freeze-drying method. Nindo and Tang, (2007), indicated that the RW drying systems are simple, and are relatively inexpensive when compared with freeze drying, which usually needs large installations to be economical.

This study was performed to facilitate the understanding of a Refractance™ Window dryer for root tuber slices, with the objective of creating a basis for the design, modelling, and operations of a continuously operating RW dryer.

2 MATERIALS AND METHODS

2.1 DRYING APPARATUS

A schematic diagram of the equipment used in this study is presented in Fig. 1. The apparatus consists of a thermostatically heated water bath covered with a 0.15 mm thick transparent polyethylene terephthalate (PET) Mylar plastic film. The film remained secured in place with metal brackets, and it was always in contact with the heated water. An air draft of 1 m/s was maintained across the transparent plastic film using a fan. Also, an extractor in the hood above the dryer removed moist air from the equipment. The extractor and the air draft were to ensure that the evaporating vapour above the dryer did not inhibit the drying process.
2.2 Sample Preparation
For this study, the cassava, yam, and potato tubers were purchased from a local market. The tubers were peeled, washed and cut into 3 mm thick slices using a Mandolin type slicer.

2.3 Experimental Procedure
The temperature of the water in the drying apparatus was maintained at 60°C throughout the experiments. At separate times, the cassava, yam, and potato slices were placed on the plastic film to dry. The moisture content of the slices was determined after every 5 minutes, using a moisture analyser. The drying experiments were stopped when the moisture content of the sample was below 10% (dry basis). The drying experiments were performed in triplicates for each drying period and the average moisture content values for each period recorded.

2.4 Processing the Kinetic Data
The moisture ratio (MR) at different drying times was determined using equation 1.

\[ MR = \frac{MC_i}{MC_f} \]  

where

- MC is the moisture content of sample after drying for time t
- MC is the initial moisture content of the fresh sample.

The experimental data obtained in this study are fitted to the thin layer drying models presented in Table 1. The drying models were evaluated by performing a regression analysis using the drying data and the models listed in Table 1. The model chosen to be the best fit is that in which the value of the coefficient of determination (R²) is closest to unity and the root-mean-square-error (RMSE), and the mean-based-error (MBE) values are closest to zero. (Akpınar, 2010; John et al., 2014). The methods of calculating R², RMSE, and MBE have been discussed in detail by Ogunnaike, (2011). The drying curve, the drying rate curve and the Krischer curve was plotted from the kinetic data obtained from the experiments (Kemp et al. 2001).

3 Results and Discussion
Cassava, yam, and potato slices with an initial moisture content of 1.78, 1.63 and 1.56 g-water/g-solid respectively were dried using a Refractance™ window dryer until the moisture content was less than 0.11 g-water/g-solid. Drying was carried out with a 1 m/s draft of air across the drying surface. The humidity of air during drying varied between 48 and 59%, while the air temperature varied between 26 and 29°C. The dehydration moisture ratio data obtained, were fitted to the six (6) drying models presented in Table 1.

Table 1. Thin Layer Drying Models

| S/N | Model | Description |
|-----|-------|-------------|
| 1   | MR = a exp(−bt²) + dt² + et + f | Haghi and Ghanadzadeh Model (Haghi and Ghanadzadeh, 2005) |
| 2   | MR = exp(−ktᵈ) | Page Model (Page, 1949) |
| 3   | MR = a exp(−k₁t) + b exp(−k₂t) | Two term Model (Madamba, 1996) |
| 4   | MR = exp(−kt) | Newton Model (Ayensu, 1997) |
| 5   | MR = a − b exp(−k₄tⁿ) | Weibull Model (Onwude et al., 2016) |
| 6   | MR = a exp(−kt) + bt | Midilli et al. Model (Midilli et al., 2002) |

where a, b, c, d, e, f, k, k₀, k₁, k₂, and n are constants.

The regression analysis indicated that dehydration moisture ratio data fitted all the thin-layer models with an R² value greater than 98%, in all cases. However, the model that best fitted the moisture ratio data was the Haghi and Ghanadzadeh model all cases, because R² was closest to unity and the RMSE, and MBE values are closest to zero. The R², MBE, and RMSE values, for all the models for the cassava, yam, and potatoes slices are presented in Table 2, 3, and 4 respectively. The value of the constants obtained for the Haghi and Ghanadzadeh model are also given in Tables 5, 6, and 7.

Table 2. Coefficient Obtained by Fitting Data to the Various Thin Layer Models for Cassava

| No. | Model Name     | R²      | MBE     | RMSE   |
|-----|----------------|---------|---------|--------|
| 1   | Haghi and Ghanadzadeh | 0.9992  | 0.0007  | 0.0136 |
| 2   | Weibull        | 0.9990  | 0.0009  | 0.0121 |
| 3   | Midilli et al. | 0.9985  | 0.0013  | 0.0137 |
| 4   | Page           | 0.9973  | 0.0024  | 0.0174 |
| 5   | Newton         | 0.9972  | 0.0025  | 0.0167 |
| 6   | Two-term Model | 0.9958  | 0.0037  | 0.0249 |

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The drying curves, moisture content vs. time plots, for the cassava, yam, and potato slices are shown in Fig. 2. The figure displays the 3 sets of experimental data and line plots obtained from the Haghi and Ghanadzadeh model. Fig. 2 shows that the cassava and yam slices dried to a moisture content of less than 10% (dry basis) within 100 min., while the potato slices dry to a moisture content of less than 10% (dry basis) within 150 min. This drying time for yam slices is comparable to work done by Akinola et al. (2017), who dehydrated different sizes of yam slices.

The drying rate curves, i.e., drying rate vs. drying time plots for the cassava, yam, and potato slices are shown in Fig. 3. The plots of theoretical line forms of the drying rate which is based on the Haghi and Ghanadzadeh
model equation. The theoretical forms of the drying rates are used because of the limited number of data points. The plots for the 3 tubers are similar.

As indicated in Fig. 3, the drying rates increase with drying time to a maximum value, where it remains constant and then decreases. The increasing drying rate period for the tuber slices was shorter than the falling rate drying period indicating that most of the drying happens in the falling rate period. The maximum drying rate occurs at the constant rate period, and for the cassava, yam and potato slices, this period is short, probably a couple of minutes.

For the cassava, yam and potato slices used in this study, Fig. 3 shows that the falling rate drying period has the first and second falling rate periods. In the first falling rate period, the surface is drying out; this is the unsaturated drying. In second falling rate period, (saturated drying period), plane of evaporation moves into the drying material, and the drying rate falls further.

The Krischer curves, i.e., drying rate vs. moisture content plots for the cassava, yam, and potato slices are shown in Fig. 4. The curves are a combination of their respective drying curve and the drying rate curve. The curves in Fig 4 shows that the drying rate, moving from right to the left, increases from its initial value when the tuber slice is fresh (warming up), it reaches a peak value (constant rate period) and then falls (falling rate period).

4 CONCLUSIONS
Cassava, yam, and potato slices, with an initial moisture content of 1.78, 1.63, and 1.56 g-water/g-solid respectively were dried until the moisture content was less than 0.11 g water/g-solid, using a Refractance Window™ type dryer. The following conclusions can be made from this study
1. The Haghi and Ghanadzadeh thin layer model characterize the drying kinetics for the cassava, yam, and potato slices.
2. The experimental data from the drying study fitted the Hagh et & Ghanadzadeh thin layer model with the coefficient of determination (R²) values of 0.999, 0.998, and 0.998 for the cassava, yam, and potato slices respectively.
3. The cassava, yam and potato slices dried to a moisture content of less than 10% dry basis within 100, 100 and 150 min. respectively

While limited literature exists regarding dehydration of cassava, yam and potato slices using the Refractance Window™ Drying technology, the drying times for other products using this technology was comparable with that reported in this study. Ochoa-Martinez et al. (2012) dehydrated 1 and 2 mm thick mango slices using the Refractance Window™(RW) within 1 hour. Akinola et al. (2016), and Akinola et al. (2018), dehydrated carrots and okra respectively in about 120 min. These times are considerably less than the few days taken to dehydrate tubers by the natural sun drying method (Mlingi, 1995).

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