Kinetic drying experimental data and mathematical model for jackfruit (Artocarpus integrifolia) slices
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KINETIC DRYING EXPERIMENTAL DATA AND MATHEMATICAL MODEL FOR JACKFRUIT (Artocarpus integrifolia) SLICES

DATOS EXPERIMENTALES Y MODELO MATEMÁTICO DE LA CINÉTICA DE SECADO DE RODAJAS DE JACA (Artocarpus integrifolia)


Faculty of Food Engineering - Federal University of Tocantins (UFT)
Av. NS - 15, ALC NO -14, CEP: 77123-360. Campus Universitário, Palmas -TO, Brazil.

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*Correspondence author. E-mail: abraham@uft.edu.br

Abstract
Jackfruit drying curves were obtained using a convective vertical tray drier at dry bulb temperatures of 50, 60 and 70 °C requiring of 9.92, 6.1 and 4.75 h, respectively, to reach a dry basis moisture content of 21.3 %. The Fick diffusion and the PAGE models were fitted to the experimental data of drying velocity using non-linear regression analysis. The coefficient of determination obtained for the Fick model was high ($R^2 = 0.99$). Water activity was determined throughout the drying process for the three drying temperatures and used to generate moisture isotherms at the three drying temperatures.

Resumen
Se obtuvieron curvas de secado de jaca usando un secador de bandejas con convección vertical a temperaturas de bulbo seco de 50, 60 y 70 °C requiriendo 9.92, 6.1 y 4.75 h, respectivamente, para alcanzar un contenido de humedad de 21.3 % en base seca. Los modelos de difusión de Fick y de PAGE fueron ajustados a los datos experimentales de velocidad de secado usando análisis de regresión no lineal. El coeficiente de determinación obtenido para el modelo de Fick fue elevado ($R^2 = 0.99$). La actividad de agua fue determinada durante todo el proceso de secado para las 3 temperaturas y se utilizó para generar las isotermas de sorción a las 3 temperaturas de secado.

Keywords: Jackfruit, convective dryer, Fick model.
Palabras clave: Jaca, secador de convección, modelo de Fick

INTRODUCTION

Food drying is one of the oldest methods of preserving food for later use. Drying food is simple, safe and easy to implement commercially. Large and small food processors can use modern food dehydrators to produce fruit leathers, banana chips, pumpkin seeds and beef jerky (Holdsworth, 1971).

Dried foods are ideal for backpacking and camping. They are lightweight, take up little space and do not require refrigeration. However, they have been used in Brazil on a small scale to solve problems of excess of production. Drying is one of the unitary processes most used in the food industry, but is still a complex and little understood operation, especially regarding the selection and control of the process conditions to maintain the end product quality (Cano-Chauca et al., 2002).

Consumer demand is increasing for products that preserve their original characteristics as much as possible (El-Aouar and Murr, 2003). In industrial terms this means developing operations minimizing adverse processing effects (Saguy and Karel, 1980). Jackfruit is very rich in carbohydrates, process-sensitive vitamins and in mineral salts, such as calcium and especially, iron, what turns it very useful in the treatment of anemia.

In dehydration, the relationship between processing conditions and product quality is complex because of the large variation in temperature and air humidity. The degradation rates of the quality attributes are frequently functions of the air humidity and temperature (Cohen and Yang, 1995). In this study, a simple diffusion model based on Fick’s second law of diffusion was used to describe the transport mechanism in the falling drying rate regions and was expressed by the following equation:
\[ \frac{\partial w}{\partial t} = D \frac{\partial^2 w}{\partial x^2} \]  

(1)

where \( w \) = moisture content (g water/g dry mass); \( t \) = time (s); \( x \) = length (m); \( D \) = diffusion coefficient for moisture in solids (m²/s) under drying temperature conditions tested. Considering a slice of jackfruit as a flat plate of thickness \( L \) drying on both sides and under the following boundary conditions: \( t = 0, 0 = x = L, w = w_0 \), where \( w_e \) and \( w_0 \) represent the equilibrium and initial moisture content, respectively. Assuming constant sample temperature and thickness during and the absence of external resistances (Rao and Rizvi, 1986) yields:

\[ \frac{w_e - w}{w_0 - w} = C \exp\left(-Kt^\pi\right) \]  

(2)

Another model used in this work was the PAGE model, given by the following equation:

\[ \frac{w - w}{w_e - w} = C \exp\left(-Kt^\pi\right) \]  

(3)

where \( C \), \( K \) and \( \pi \) represent model parameters. The PAGE model is frequently used and excellent results in drying studies of agricultural product, particularly for grains and seeds (Gabas et al., 1999).

The objectives of this study were to determine the water activity for jackfruit during drying and obtain drying curves to produce rate data and evaluate the fit off the Fick diffusion and PAGE models to the drying curves.

**RESULTS AND DISCUSSION**

**Drying curve assessment**

A drying curve enables an estimation of the time required to reach desired moisture content (Figure 1). The dimensionless moisture content variation of the jackfruit as a function of the drying time at the three air dry bulb temperatures used showed a good fit to the drying curve using Fick’s law (\( R^2 = 0.9945 \)). Drying times of 9.9, 6.1 and 4.75 h were necessary at 50, 60 and 70 °C, respectively, to reach 0.1 dimensionless moisture content corresponding to a 21.3 % dry basis moisture content. The difference in the moisture content was not very high at the beginning increasing then with time because of the internal resistance to moisture transport. In this period, water interacts with polar groups of the molecules of the constituents and, therefore, the higher the temperature the more easily the water is removed. Since the use of low drying temperatures leads to longer processing times, high drying temperatures could be used because neither color nor texture were altered under the experimental conditions tested.

The Fick diffusion (Eq. 2) and PAGE models (Eq. 3) were fitted to the experimental data by non-linear regression analysis. The Fick diffusion model was adequate to the predict drying as shown by elevated values of the coefficient of determination (Table 1). The effective diffusion coefficient increased with temperature as expected and previously verified by Haylander et al., (1991) and Jaya and Das (2003).

Figure 2 shows experimental values and predicted drying curves using the PAGE model. Table 2 summarizes the values for the PAGE model parameters and determinations coefficients which were higher than values

**MATERIALS AND METHODS**

**Sample preparation**

Jackfruit (Artocarpus Integrifólia) was purchased from a local market using only fully ripe fruits of uniform size. They were washed in running water for 10 min, in water containing 50 ppm of total residual chlorine for 30 min, and then again in running water for 10 min. Shortly after washing firm and fully ripe fruits of uniform coloring were peeled and washed manually in running water for 5 min.

**Sample drying**

The jackfruit was dehydrated in a tray dryer (dryer construed in UFT- Brazil) operated at dry bulb temperatures of 50, 60 and 70 °C and relative humidity of 40 %. Three samples were removed at hourly intervals for each treatment totaling nine experimental test. Moisture losses were determined from weight loss determinations. The same samples were used for duplicate water activity determinations at 25 °C using an Aqualab (Decagon).
Table 1. Effective diffusion coefficients for Fick diffusion model (Eq. 2).

<table>
<thead>
<tr>
<th>Air temperature (°C)</th>
<th>Diffusivity x 10^-6 (m²/s)</th>
<th>R² value</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>2.74</td>
<td>0.9945</td>
</tr>
<tr>
<td>60</td>
<td>3.45</td>
<td>0.9925</td>
</tr>
<tr>
<td>70</td>
<td>4.67</td>
<td>0.9942</td>
</tr>
</tbody>
</table>

Figure 2. Experimental moisture loss during drying of Jackfruit and predicted using the PAGE moisture loss model.

Figure 3. Experimental and predicted dimensionless moisture.

for the Fick model. Values for the parameter K increased with air temperature in agreement with results obtained by Gabas et al., (1999). The excellent agreement between calculated and experimental values was determined plotting experimental and calculated values of dimensionless moisture values (Figure 3) resulting in R² higher or equal to 0.9995.

Table 2. Parameters of PAGE model and determination coefficient (R²).

<table>
<thead>
<tr>
<th>Air temperature (°C)</th>
<th>Parameters of PAGE model</th>
<th>R² value</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>C = 0.9996, K = 0.4315, N = 0.8613</td>
<td>0.9995</td>
</tr>
<tr>
<td>60</td>
<td>C = 1.0020, K = 0.4625, N = 0.9194</td>
<td>0.9992</td>
</tr>
<tr>
<td>70</td>
<td>C = 1.0020, K = 0.6418, N = 0.8530</td>
<td>0.9992</td>
</tr>
</tbody>
</table>

Figure 4. Jackfruit water activity curves with drying time at 50, 60 and 70 °C.

Water activity

Water activity is an important factor in food preservation because the physicochemical and microbiological alterations that can occur during processing and storing of a food product depend directly on this parameter (Mujumdar, 1995).

Figure 4 shows the variation in water activity during the drying period, for the three drying temperatures used (50, 60 and 70 °C). At the 50 °C drying temperature, water activity reached 0.73 after 12 hours drying. However, at 60 °C and 70 °C, values of 0.70 and 0.67 were attained after 9 and 7 hours drying, respectively.

Figure 4 also shows that for the same drying time, water activity in the product increases with decreasing drying temperature. However, at a fixed drying temperature, water activity decreased with drying time. Cano Chauca et al. (2002), obtained similar results when they studied the drying kinetics of banana. This is related to water loss during the drying process. At higher temperatures, the water evaporation rate is higher, influencing the moisture content and consequently water activity in the product.
CONCLUSIONS

The Jackfruit drying process was influenced by dry bulb temperature with lower temperatures leading to longer drying times. The Fick and PAGE models described successfully the jackfruit drying process. The effective diffusion coefficients for Fick diffusion model increased with temperature.

REFERENCES