The Use of Performance Indicators for Evaluating Models of Drying Jackfruit (*Artocarpus heterophyllus* L.): Page, Midilli, and Lewis

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Abstract—Mathematical models of drying are used for the purpose of understanding the drying process in order to determine important parameters for design and operation of the dryer. The jackfruit is a fruit with high consumption in the Northeast and perishability. It is necessary to apply techniques to improve their conservation for longer in order to diffuse it by regions with low consumption. This study aimed to analyze several mathematical models (Page, Lewis, and Midilli) to indicate one that best fits the conditions of convective drying process using performance indicators associated with each model: accuracy (Af) and noise factors (Bf), mean square error (RMSE) and standard error of prediction (% SEP). Jackfruit drying was carried out in convective type tray dryer at a temperature of 50°C for 9 hours. It is observed that the model Midili was more accurate with Af: 1.39, Bf: 1.33, RMSE: 0.01%, and SEP: 5.34. However, the use of the Model Midilli is not appropriate for purposes of control process due to need four tuning parameters. With the performance indicators used in this paper, the Page model showed similar results with only two parameters. It is concluded that the best correlation between the experimental and estimated data is given by the Page's model.

Keywords—Drying, models, jackfruit.

I. INTRODUCTION

THE high perishability of tropical fruits induces studies of preservation methods, which aims to increase the shelf life, minimizing losses and preventing the growth of microorganisms.

Among the tropical fruits, jackfruit is highly appreciated because of the excellence of the fruits, good quality of the wood and the great rusticity that has revealed.

Jackfruit (*Artocarpus heterophyllus* L.) belongs to family *Moraceae*. Considered a major tropical fruit in the world, it reaches 80 pounds in weight, up to 36 inches in length, and 20 inches in diameter. It is believed to be originated in rainforests of India and has been spread to other parts of tropical countries, such as Brazil, due to its spontaneous proliferation in warmer regions [1], [2].

This oval fruit has a pale-green to dark-yellow rind when ripe and is covered with small and hard fleshy spines in hexagonal format. The interior consists of large and soft yellow bulbs with an appealing flavor, eaten fresh or processed in form of jams, frozen pulp fruits, juices and soft drinks. The jackfruits are oval with brown seed inside. Following the seeds withdrawal, are commonly served as a snack. The fruit is adapted to humid tropical and near-tropical climates, but the mature jackfruit still can withstand bouts of frost, unlike its cousin, the breadfruit. Only 35% of the whole fruit is edible. The maturation time is 3 to 8 months after flowering. This can be observed by the change in color of the fruit of intense green to yellow-brown. After ripening, the pre-cut bulbs are prone to flavor loss, tissue softening, turning brown the surface, and spoil very quickly [1]–[3].

It is evident that one way of preserving food against microbiological and chemical deterioration is by reducing the water content and activity. Drying, traditional method of conservation based on removing moisture, is the removal of water by mass transfer from a product [4]. Food products can have a variety of different processes of drying, ranging from solar drying, convection drying, air-drying until the more expensive, freeze drying [9].

The convection drying process is considered a simultaneous heat and mass transfer, in which the water is transferred by diffusion from the interior to surface of food. Heat is transferred by convection to the air-air interface and by conduction to the interior of the food.

Mathematical modeling of drying processes is one of the most relevant aspects of the drying technique. The information contained in the drying curves through the models is of fundamental importance for the development of processes and equipment sizing. Thus, it is possible to estimate the drying time of a given quantity of feedstock. With the time required for production, it is estimated energy consumption for inferring the processing cost. The principle of the model is based on a set of mathematical equations that can characterize the system phenomenologically. In particular, the solution of these equations must allow the prediction of process parameters depending on the process time at any spatial point of the dryer only based on the boundary conditions of the process [12].

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In order to improve the control of this unit operation is important to dispose of accurate models to simulate the drying curves under different conditions [10]. The attention is focused on the development of semi-theoretical models that reconcile the theory with the facility of use in practice. These semi-theoretical models are generally based on Newton's law of cooling. It is assumed that the conditions are isothermal and resistance to moisture transfer is limited only to the product surface [11]. Among the semi-theoretical models, the Lewis, the Page and the Midilli models have been widely used [6].

The ideal is not produce the most comprehensive and descriptive model but the simplest possible model that incorporates the assumptions of the drying phenomenon. To validate the model it is necessary a set of parameters, obtained from experimental data, that will evaluate the relationship of the predicted values with observed, called performance indicators. According to the analysis of each index can be defined which model is more suitable for the process conditions. The objective of this study was to evaluate different mathematical models of convective drying at 50°C with performance indicators of each model.

II. MATERIALS AND METHODS

The work was conducted at the Laboratory of Processing Products from Vegetable Origin (LPPOV), located in the Department of Food Technology (DTA), at Universidade Federal de Sergipe (UFS), São Cristóvão, Sergipe, Brazil.

A. Raw Material

The Jackfruit variety "hard" were acquired at Central Market in Aracaju city, Sergipe and transported to the laboratory. The fruits were selected in accordance to maturation degree, evaluating by the visual appearance alterations in the green peel and in the consistency and the characteristic fruity odor. After this, the fruits were washed in running water to remove dirt and cropped for separation of jackfruit.

B. Drying

The drying was conducted in a dryer with forced air circulation (Pardal dehydrator, 100 PE) and heating system set to a temperature of 50°C for a period of 9h. The samples were initially weighed in an interval of 30min for six hours, and then at each 1h. The data were used to construct the drying experimental curve.

C. Mathematical Modeling

For purposes of mathematical modeling, it was determined the ratio of moisture from experimental data using (1):

$$RM = \frac{(M(t) - M_{eq})}{(M_i - M_{eq})} \qquad (1)$$

The experimental data of the ratio of moisture were used to fit the models described in Table I. STATISTICA ® version 11.0 software was used to perform the parameter estimation of the models of Lewis, Page and Midilli. An analysis by non-linear regression Levenberg-Marquardt method with the convergence criterion being the least squares was performed.

The choice of the best model was made by the performance indices in Table II. The results were calculated using the software Excel ® version 2007 for Windows.

TABLE I
DRYING MATHEMATICAL MODELS

Type	Models
Page	$U = \exp(-k \cdot t^n)$
Lewis	$U = \exp(-k \cdot t)$
Midilli	$U = a \cdot \exp(-k \cdot t^n) + b \cdot t$

TABLE II
PERFORMANCE INDICATORS OF THE MATHEMATICAL MODELS

Performance indices	Equations
Root mean square error ($RMSE$)	$RMSE = \sqrt{\dfrac{\Sigma(obs - pred)^2}{n}}$
Standard error of prediction ($\%SEP$)	$\%SEP = \dfrac{100}{mean\ obs}\sqrt{\dfrac{\Sigma(obs - pred)^2}{n}}$
Bias factor (B_f)	$B_f = 10^{\frac{\Sigma \log\left(\frac{pred}{obs}\right)}{n}}$
Accuracy factor (A_f)	$A_f = 10^{\frac{\Sigma \left|\log\left(\frac{pred}{obs}\right)\right|}{n}}$

III. RESULTS AND DISCUSSION

Several mathematical models of drying are used to predict the behavior of the drying process, with estimation of parameters process for the operation and design of a singular dryer. In view of this, Fig. 1 graphically presents experimental drying curves and the curves show the values predicted by the model application. It can be seen that all models applied fits a good relation with the experimental data However, it is necessary the use of performance indicators to assess quantitatively which semi-theoretical model best adjusted to the experimental data.

The estimated values of model parameters are explicit in Table III. It is noted that the value of k constant drying to model Page Midilli and was approximately 0.53min^{-1}. This similarity between the models mentioned was due to the influence of the constant n, with values of 0.89 and 0.81 for models Page and Midilli respectively. The small difference between the models of Midilli and Page is due to the four parameters that exist in Midilli's model. On the Page's model, only two parameters were necessary for the proper fit of the data with performance indicators similar to the Midilli.

TABLE III
PARAMETERS OF THE MODELS FITTED TO DRYING DATA OF JACKFRUIT

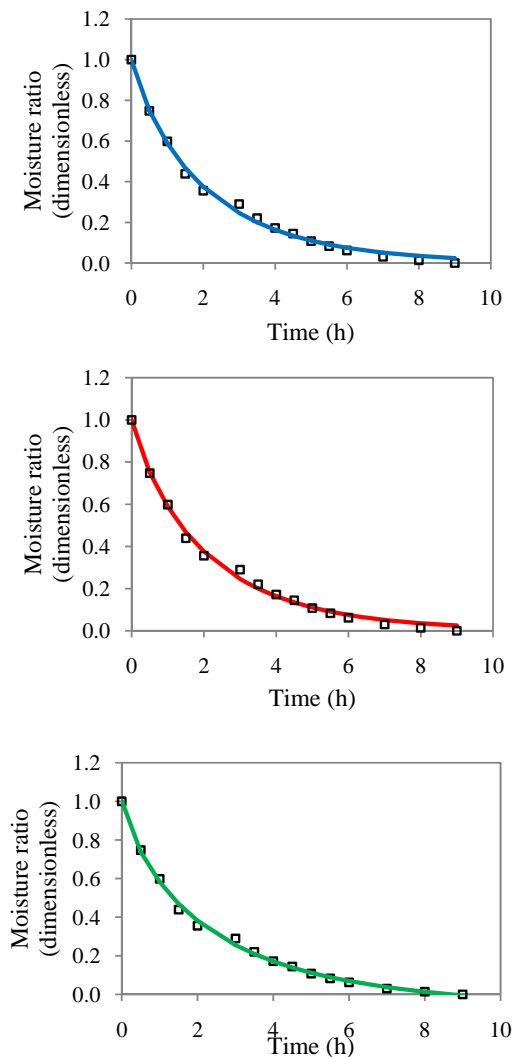| Mathematical models	Parameters			
	k (min^{-1})	n	a	b
Page	0,53	0,89	-	-
Lewis	0,47	-	-	-
Midilli	0,53	0,81	1	-0,01

Fig. 1 Comparison between the models used for drying jackfruit

Table IV shows the results of indices for performance. The *RMSE* establishes a comparison between the experimental and predicted values. The best model is the one that submit a reduced value of this parameter, observed in Midilli model. The %*SEP*, standard error of prediction, is the residual of the models, which should be reduced. The Midilli's model shows the best result. The bias factor is the best indicator of the model performance. The perfect concordance between predicted and observed values, represented by a B_f equal to 1 [8], was suitable to Midilli model. Finally, the precision factor indicates the average difference between the experimental data and predict and its increase suggests the low capacity of the accuracy between the estimated and observed data. With this, the appropriate model is one of the factor is smaller, which was the model of Lewis followed by Page model.

According to the indices of performance, the Midilli model has the best fit to drying jackfruit at 50°C, with more accurate results for A_f (1.39), B_f (1.33), *RMSE* (0.01) and %*SEP* (5.34).

This fact was also observed in the drying of Cumari Pará pepper at three different temperatures, 45, 55 and 65°C for a period of approximately 3 hours [7], as well as the modeling of the coffee drying at 45°C [13]. In the drying of cut apple thin layer at temperatures of 60 to 80°C was observed that Midilli model was best adapted to the experimental data [5].

TABLE IV
RESULTS OF THE PERFORMANCE INDICATORS

Parameters	Mathematical models		
	Page	Lewis	Midili
Root mean square error (RMSE)	0.019	0.027	0.015
Standard error of prediction (%SEP)	6.800	9.566	5.344
Bias factor (B$_f$)	1.59	1.380	1.335
Accuracy factor (A$_f$)	1.680	1.014	1.389

On the other hand, Page's model presented similar results to the Midilli model, with A_f (1.68), B_f (1.59), *RMSE* (0.02) and %*SEP* (6.80). The advantage of the Page model is the fact that it is necessary to estimate only two parameters, which are the drying coefficient and a constant, as can be seen in Table III, while in the Midilli model are needed four parameters for better estimates.

IV. CONCLUSIONS

It was found that the model Midilli was more accurate in predicting the experimental data for drying of jackfruit with the use of performance indicators and using four parameters of the model fit. Page model showed similar results with only two parameters. For drying jackfruit operating conditions studied, the Page model is most appropriate for the study, demonstrating excellent correlation with the experimental data. It was shown that a detailed study of the semi-theoretical models with performance indicators is key to choosing the most appropriate to the process model.

APPENDIX

RM corresponds to the moisture ratio;
M(t) consists in moisture at time t, on dry basis;
M_{eq} moisture balance, on dry basis;
M_i the initial moisture content, on dry basis.

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