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Drying characteristics and mathematical modelling of the drying kinetics of oyster mushroom (*Pleurotus ostreatus*)

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Abstract

This study was conducted to determine the drying characteristics of oyster mushroom (Pleurotus ostreatus) at 50, 60 and 70 °C. Pleurotus ostreatus were cleaned and dried in a laboratory cabinet dryer. The drying data were fitted to six model equations namely Newton, Pabis and Henderson, Logarithmic, Two-term diffusion, Wang and Singh, as well as Modified Henderson and Pabis equations. The goodness of fit of the models were evaluated by means of the coefficient of determination (R^2), root mean square error (RMSE) and reduced chi-square (χ^2). The Logarithmic model best describes the drying data and could be used to predict its drying behaviour.

Keywords: *oyster mushroom; thin-layer drying; characteristics; modelling*

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1. Introduction

Drying is the removal of moisture from food material, to make it stable and thus promote its shelf life. Mushrooms are highly perishable and lose their qualities during storage. Due to the high moisture content, there is the problem of seasonal availability and wastage. The shelf life of mushrooms is only due to 2 to 5 days after harvest depending on the variety, hence there is a need for adequate preservation to ensure proper shelf stability and all year round availability without quality compromise [1]. Drying is seen as the removal of undesired moisture from a product. Many agricultural products are dried for various purposes like safe storage, easy handling, value addition, further processing and quality improvement [2]. Therefore, the drying process offers an alternative way for food material consumption and especially, the seasonal and perishable ones. The renewed interest in high quality fast-dried foods [3] and the upward swing in the demand for convenient foods including ready to eat and instant products, which are desired to contain the minimum quantities of additives and preservatives [4] is increasing the interest in drying operations. The drying process can be carried out using the sun (solar drying), though it is cheap however this method of drying is time consuming, it is climate dependent, time consuming and produces products of low quality especially in terms of colour and microbial infestation. Hence the conventional means of drying is a better alternative because they were able to overcome this short comings even thou, they may be more expensive and out of all the different mechanical means of drying such as drum dryer, freeze dryer, fluidized bed dryer, the hot air oven drying (cabinet dryer) is the most commonly used because they are generally acceptable and they are cheaper. Drying kinetics is generally evaluated experimentally by measuring the weight of a drying sample as a function of time. Drying process can be described completely using an appropriate drying model, which is made up by differential equations of heat and mass transfer in the interior of the product and at its interphase with the drying agent. The drying behaviour of biological materials can be predicted using many thinlayer drying mathematical models which have been classified into three groups namely; theoretical (Fick's second law of diffusion), semi-theoretical (Lewis, Page, modified Page, Henderson-Pabis, logarithmic, Two-term, Two-term exponential, approximation of diffusion, Verma, etc.), and empirical (Wang-Singh). These models have been found to be drying time and constants, dependent while influence of all other factors is negligible [5]. The objectives of this study therefore were to: (i) to study the drying kinetics of oyster mushroom specie (*Pleurotus ostreatus)* in a cabinet dryer, (ii) to evaluate a suitable thin layer drying model, and (iii) the optimum temperature of drying at which best quality product is obtainable.

2. Materials and Methods

2.1. Material

Freshly harvested samples of oyster mushrooms (*Pleurotus ostreatus)* were cleaned and used for the drying study. Before the commenement of a drying test, the initial moisture content of the mushrooms was determined.

2.2. Experimental procedure

Drying experiments were performed in a laboratory cabinet dryer designed in the Department of Food Science and Technology, Federal University of Technology, Akure, Nigeria. The dryer consists of a centrifugal fan to supply the air flow, an electric heater, and an electronic proportional controller. The temperature and relative humidity in the drying chamber were measured by temperature sensor (accuracy ±1%) and relative humidity sensor (accuracy ±2%), respectively. The air velocity in the drying chamber was measured with a Tri-Sense hot wire probe anemometer (accuracy±2%). Air flow was perpendicular to the drying surfaces of the samples and the hot air used in the drying process was circulated in the cabinet. The dryer was started about one hour before each drying run to achieve steady-state conditions. After the dryer had reached this condition, 100 g samples of the mushroom were uniformly spread in a single layer on a sample tray and were dried. The drying experiments were performed at 50, 60 and 70 °C air temperatures. The air velocity was kept constant at 0.6 m/s in all drying experiments. Relative humidity of the ambient air changed between 21% and 23%. During drying, the samples were removed at intervals and weighed. Removing, weighing, and replacing the mushrooms took about 1 min. The weight loss of the samples was recorded using an electronic balance (Midfield, MF-1000, Göttingen, Germany) in a range of 0–1100 (±0.01g) at hourly intervals until no measurable weight loss was observed. At the end of each drying experiment, the final moisture content of the sample was determined. Moisture contents were reported on wet basis. The amount of dry matter was calculated by using the mean final moisture content and the weight of the dried mushrooms [6]. All the experiments were replicated three times at each air temperature and the average values were used. Calculations of the moisture ratio, correlation coefficient, mean bias error, random square error and fitting the values generated into six drying models were carried out [6].

2.2.1. Moisture ratio

The moisture ratio (MR) of oyster mushrooms during the single layer drying experiments was calculated using equation (1).

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad (1)$$

Some investigators [7]; [6]; [8] observed continuous fluctuations in the instantaneous moisture content during the drying processes, and therefore reduced equation (1) to:

$$MR = \frac{M_t}{M_0} \qquad (2)$$

where MR indicates the moisture ratio (dimensionless quantity), M_0 the initial moisture content (kg water/ kg dry matter, M_t the instantaneous moisture content at time $t > 0$ (kg water/kg dry matter), and M_e the equilibrium moisture content (kg water/ kg dry matter).

2.2.2. Drying rate

The drying rates of the samples were calculated using equation (3)

$$\frac{dM}{dt} = \frac{M_{(t+\Delta t)} - M_t}{\Delta t} \qquad (3)$$

where $\frac{dM}{dt}$ denotes the drying rate and Δt is elemetal time increment (hr).

2.3. Mathematical modelling of the drying curve

The drying curves obtained were evaluated to find the most suitable model for describing the drying process of the selected mushroom species. Drying curves data were fitted into six (6) thin-layer drying equations at three temperatures 50, 60 and 70 °C. The drying curves obtained were processed for drying rates to find the most convenient model among the six different expressions (Table 1). A nonlinear regression analysis was performed using the SigmaPlot and Microsoft Excel 2010 Statistical software to evaluate model parameters and determine the predicted moisture ratio for each model equation. The correlation coefficient (R^2) is generally considered one of the primary criteria for evaluating the goodness of fit of a drying model. It was therefore used for comparing the predictive ability of the models in this study. Other criteria used for model evaluation and comparison are reduced chi-square (χ^2) and root mean square error (RMSE). The model with the highest R^2 and lowest χ^2 and RMSE was condidered to best fit the drying data [9], [10]. Both χ^2 and RMSE were calculated, respectively, from the following equations.

$$\chi^2 = \frac{1}{(N-n)} \sum_{i=1}^{N} \left(MR_{o,i} - MR_{p,i}\right)^2 \qquad (4)$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(\frac{MR_{o,i} - MR_{p,i}}{MR_{o,i}}\right)^2} \qquad (5)$$

Where MR and $\overline{MR}$ are the instantaneous and average moisture ratio values, while the subscripts o,i and p,i denote the ith observed (i.e. experimental) and predicted moisture ratio, respectively. N is the number of observations, and *n* is the number of constants in the drying model.

3. Results and Discussion

The changes in the moisture content during drying of the three species of oyster mushrooms are presented in Fig. 1 at different temperatures of 50, 60 and 70 °C. The drying behaviour of the samples exhibited the characteristic moisture desorption behaviour. High rate of moisture removal was observed, followed by the slower moisture removal in the later stages. This characteristic behaviour can be attributed to the various forms in which water is present in the food products. In the progression of drying process, the moisture ratio was observed to decrease non-linearly with respective to drying time for all the samples. Various reporters such as Doymaz [11] and Kingsley *et al.* [12] also observed that it is a general trend adopted by other food products such as sweet potatoes and mulberry. The drying rate for the *Pleurotus ostreatus* decreased with time and decreasing moisture contents and drying occur in the falling rate period. There was no constant rate-drying period in the entire drying process from the curves shown in Figure 1, all the drying process occurred in falling drying period, rather there was an increasing drying rate as drying progressed, which shows that drying is govern by the intense internal water and vapour flow and the drying processes were mainly controlled by diffusion mechanisms. The time taken for drying of mushroom samples varied with drying temperature, the drying time decreases with increase in drying temperature, the drying time was higher at 50^{o}C and lowest at 70 °C for all the samples. This trend agrees with the observation of several authors on the drying of various food materials [13], [14], [15].

3.1 Mathematical Modelling of Drying Curves

Table 1 shows the result of the statistical analysis for the six models namely; Newton, Pabis and Henderson, Logarithmic, Two-term, Wang and Sighn and Modified Henderson and Pabis. Drying constants a, b, c, d, g and h for the thinlayer drying obtained from drying data (moisture ratio against drying time) for the *Pleurotus ostreatus* mushrooms at varied temperatures 50, 60 and 70 °C at fixed air velocity 1 m/s respectively. The regression results presented in Tables 2 shows that Logarithmic model gave the lowest RMSE and $\varkappa^2$ when compared with the other five models. It also gave the highest R^2. Hence it is the model that best fits the drying of *Pleurotus ostreatus* mushrooms. This agrees with Doymaz [16] who reported that the Logarithmic model equation as the best fit model. However, this is at variance with Tulek [17] who reported that the model of Midilli et. al. [8] is the best fit model to predict the drying characteristics of mushrooms.

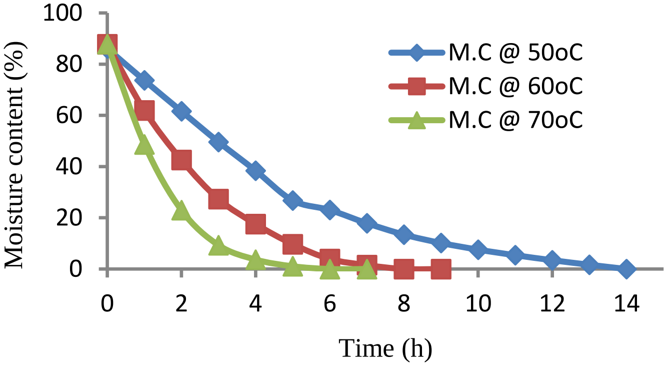

Fig. 1 Moisture content curves of *Pleurotus ostreatus* at different temperatures (°C)

Table 1. Result from linear progression analysis for dried Pleurotus ostreatus

Model name	T °C	R^2	χ2	RMSE
Newton	50	0.9871	0.0010	0.0299
	60	0.9909	0.0013	0.0328
	70	0.9953	0.0007	0.0223
Pabis and Henderson	50	0.9907	0.0013	0.0352
	60	0.9919	0.0007	0.0255
	70	0.9956	0.0006	0.0230
Logarithmic	50	0.9978	0.0003	0.0147
	60	0.9985	0.0028	0.0439
	70	0.9978	0.0004	0.0157
Two-term	50	0.9907	0.0012	0.0276
	60	0.9919	0.0026	0.0398
	70	0.9956	0.0010	0.0223
Wang and Singh	50	0.995	0.0005	0.0208
	60	0.9934	0.0018	0.0152
	70	0.9715	0.0043	0.0016
Modified Pabis and Henderson	50	0.9907	0.0085	0.0714
	60	0.9919	0.0153	0.0610
	70	0.9956	0.2069	0.2275

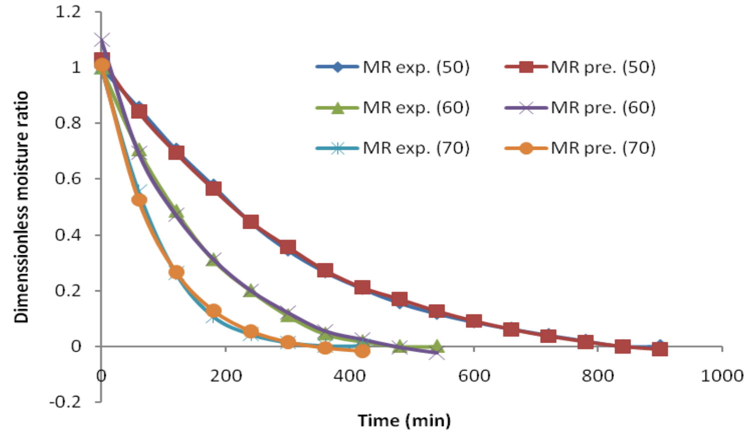

Fig. 2 Comparison between experimental and predicted moisture ratio for Pleurotus ostreatus using the logarithmic model

3. Conclusions

The drying behaviour of oyster mushroom (*Pleurotus ostreatus*) exhibited the characteristic moisture desorption behaviour. High rate of moisture removal was observed at the beginning, followed by a slower rate moisture removal at the later stages. The drying rate for the *Pleurotus ostreatus* decreased with decreasing moisture contents and drying occur in the falling rate period, with internal diffusion in the mushroom. An increase in the drying temperature reduced the drying time and increased the drying rate. Drying air temperature of 60 ˚C was found to be better as it gave dried product with lower shrinkage, better colour and better crispness. Logarithmic model gave the best fit to the drying data, and thus considered to best predict drying characteristics of *Pleurotus ostreatus*.

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