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Effect of Air Temperature on the Drying Kinetics of Pandan Leaves (*Pandanus amaryllifolius*) in a Fluidized Bed Dryer

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Pandan leaves are usually used when cooking to enhance aroma. Fresh pandan leaves are easy to rot because of the high water content. Drying is a very important method for preserving natural materials. The choice of drying parameters and the proper drying method is very important in order to produce quality dried leaves without removing the distinctive aroma and color. Drying of pandan leaves was usually conducted using conventional drying method. However there are some drawbacks especially on the loss of nutrients. Therefore, the purpose of this study was to examine the effect of drying temperature and drying method on the kinetics of pandan leaves drying. The drying parameters tested include hot air temperature (40-80 °C) and drying method (fluidized bed, oven). The results showed that the higher the temperature, the drying rate also increased. Drying pandan leaves in a fluidized bed dryer was faster than drying in oven due to the good contact between the hot air and the samples in a fluidized bed dryer. The drying kinetics of pandan leaves were represented in two types of curves, namely the moisture content curve with respect to drying time and the drying rate curve versus moisture content. Drying of pandan leaves in a fluidized bed dryer occured very fast and no initial and constant periods were observed. Page model was found to be the most suitable model to represent the kinetics of drying pandan leaves in a fluidized bed dryer.

1. Introduction

Apart from being a cake fragrance, pandan leaves are also used as a source of green color for food, as a component of food garnish, and also as part of flower arrangement at a wedding party to scent the room. The component that cause fragrance like jasmine on pandan leaves is 2-acetyl-1-pyrroline or 2AP Pandan leaves contain the most 2AP compared to other natural ingredients (Wei, et al., 2017). Pandan leaves contain the most 2AP compared to other natural ingredients (Wakte, et al., 2010). Pandan leaves contain chlorophyll thus it is often used as a natural coloring agent in various applications.

Conventional drying methods such as sun drying, hot air drying or oven drying were usually used to dry aromatic herbs. However, these drying methods have several disadvantages such as loss of nutrients, change of texture and structure of the dried products. Hot air drying also may cause browning of the product and make the dried product less attractive to consumers. Drying time using conventional drying methods also take a long time, resulted in higher consumption of energy. Although there have been several studies that have been reported on the extraction and preservation of pandan leaves, many of the research reported are using the conventional methods. Therefore, the purpose of this study was to investigate the kinetics of pandan leaves drying in a fluidized bed dryer.

The variables studied were air temperature (40-80 °C) and drying method (fluidized bed dryer and oven). The experimental data were also modeled using a number of drying models that were published in the literature. Several drying models were compared in terms of their suitability in describing the kinetics of thin layer drying of pandan leaves.

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2. Material and methods

2.1 Materials

Fresh pandan leaves were purchased from a traditional market In Sleman, Yogyakarta, Indonesia. The pandan leaves were prepared on the day of experiments. Prior to each experiment, 60 g of pandan leaves were cut manually into small pieces using a knife. Fresh leaves were cut with a width of about 0.5 cm each.

2.2 Drying experiments in a fluidized bed dryer

The drying experiments were carried out in a fluidized bed dryer at atmospheric pressure. The fluidized bed column dimension is 15 cm in diameter and the height is 30 cm. For each experiment, 60 g of pandan leaves in small pieces were prepared. The fluidized bed column was then filled with predetermined amount of pandan leaves, and the experiment was started with an air velocity of 4 m/s and a temperature of 40 °C. Throughout the experiment, about 1-2 g of sample were frequently weighed. The experiments were repeated for air temperature of 60 °C and 80 °C.

2.3 Drying experiments in an oven

60 g of cut pandan leaves were evenly spread on a tray and placed in an oven. The oven was then operated at a certain temperature. Every 15 minutes, all samples of pandan leaves were weighed. Drying was continued until the weight of the sample did not fluctuate over time.

2.4 Calculation methods

The moisture content of pandan leaves at time *t* were calculated using Eq(1):

$$X_t = \frac{W_t - W_{dry}}{W_{dry}} \tag{1}$$

where W_t is the sample's weight at time t, in g; W_{dry} is the dried sample's weight in g; X_t at time t, is the moisture content g water/g dry product.
Each sample may have varying initial moisture content, hence the results of each experiments were reported using Moisture Ratio (MR) or normalized moisture content. Eq.(2) was used to compute the normalized moisture content:

$$X_N = \frac{X_t - X_e}{X_0 - X_e} \tag{2}$$

where X_N is the normalized moisture content; X_0 is the initial moisture content, g water/g dry product; X_e is the equilibrium moisture content, g water/g dry product. In this study, the value of equilibrium moisture content was so small relative to X_0 and was almost similar to the dried value. Therefore, the normalized moisture content was simplified into Eq(3) as also used by Lin et al. (2023).

$$X_N = \frac{X_t}{X_0} \tag{3}$$

The drying rate at time *t* was calculated using the Eq(4):

$$\frac{dX_t}{dt} = \frac{|X_t - X_{t-1}|}{\mathrm{t} - (\mathrm{t} - 1)} \tag{4}$$

Six models (shown in Table 1) were fitted with the experimental data and utilized to model the drying curves. The SOLVER program in Microsoft Excel spreadsheets (Microsoft Office 2010, USA), was used to perform non-linear regression, by minimizing the sum of the squares. The reduced chi-square (χ^2), RMSE, and R^2 for each model were compared. The highest R^2 values and the lowest χ^2 and RMSE values were used to determine the best model. Eq(5) and Eq(6) were used to calculate the values of χ^2 and RMSE.

$$\chi^2 = \frac{\sum_{i=1}^{N}(X_{exp,i} - X_{pre,i})^2}{\mathrm{N} - \mathrm{z}} \tag{5}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(X_{exp,i} - X_{pre,i})^2\right]^{\frac{1}{2}} \tag{6}$$

where $X_{exp,i}$ dan $X_{pre,i}$ are represent the experimental and predicted moisture contents. N is the number of data and z is the number of constants in the model.

Table 1: Mathematical models used to describe the drying kinetics

Model	Equation	Reference
Lewis	$MR = \exp(-kt)$	Mbegbu et al. (2021)
Page	$MR = \exp(-kt^n)$	Rayaguru & Routray (2010)
Henderson and Pabis	$MR = a\exp(-kt)$	Rayaguru & Routray (2010)
Logarithmic	$MR = a\exp(-kt) + c$	Rayaguru & Routray (2010)
Midilli et al.	$MR = \exp(-kt) + bt$	Midilli et al. (2002)

3. Results and discussions

Figures 1 and 2 depict the plot of normalized moisture content against drying time using, respectively, fluidized bed drying and oven drying at various temperatures. The steepest curve gradient, which corresponds to the highest gradient value, can be shown in the figures to be at a temperature of 80 °C. This indicates that, when compared to drying at lower temperatures, the moisture content was reduced at the greatest speed at 80 °C. The gradient is the smallest, or in other words, the drying process was more slowly, for operating temperatures of 40 °C for fluidized bed drying and 50 °C for oven drying. Thus, an operating temperature of 80 °C results in the lowest drying time, which is then followed by working temperatures of 70 °C, 60 °C, 50 °C, and 40 °C. It is evident that as the temperature increased, the drying rate increased as well. The moisture content will be lower and the drying time will be shortened by high operating temperatures. For the operating temperature of 40 °C in fluidized bed drying and temperature of 50 °C in oven drying, the gradient is the smallest or in other words, the drying process occurs more slowly. Thus, the shortest drying time is at an operating temperature of 80 °C, followed by an operating temperature of 70 °C, 60 °C, 50 °C and 40 °C. It can be observed that the drying rate increased with increasing temperature (Kaur et al, 2018). High operating temperature will reduce the moisture content and shorten the drying time.

It is also obvious from the figures that drying of pandan leaves in fluidized bed dryer (Figure 1) resulted in much shorter drying time compared to drying in an oven (Figure 2). This is due to the high heat and mass transfer rates in fluidized bed dryer as a result of the uniform contact between the solid period and the hot air.

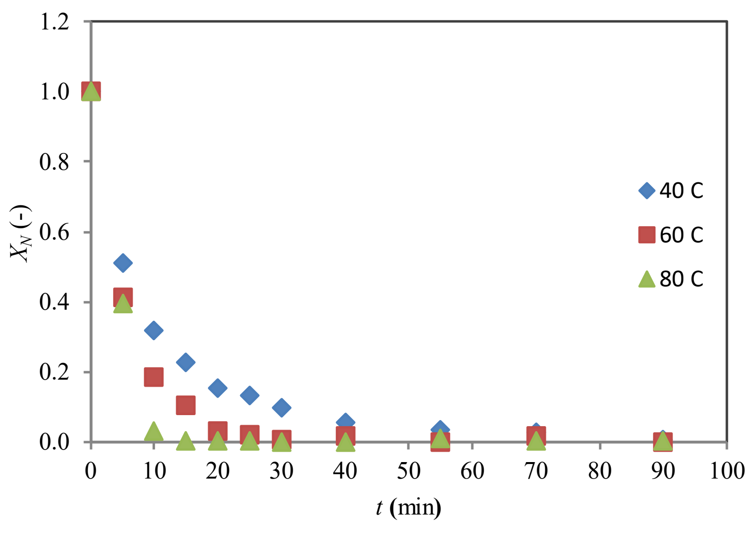


Figure 1: Normalized moisture content X_N of pandan leaves against drying time t in fluidized bed drying

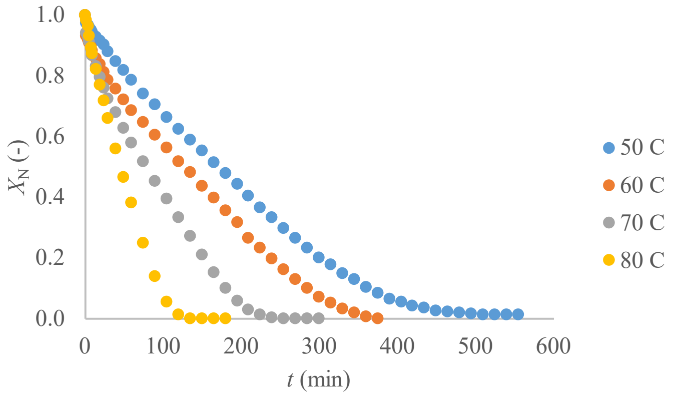


Figure 2: Normalized moisture content X_N of pandan leaves against drying time t in oven drying

Figure 3 shows the drying rate curves of pandan leaves at different temperatures. Different stages of drying can be observed from Figure 3, namely the initial period, constant drying period, and falling rate drying period. The initial period is the short drying time that the material needs to reach equilibrium temperature with the operating condition. At this point, the sample has absorbed most of the heat from the hot air, raising its temperature. However, there was no initial period observed for drying of pandan leaves in a fluidized bed dryer (Figure 4).

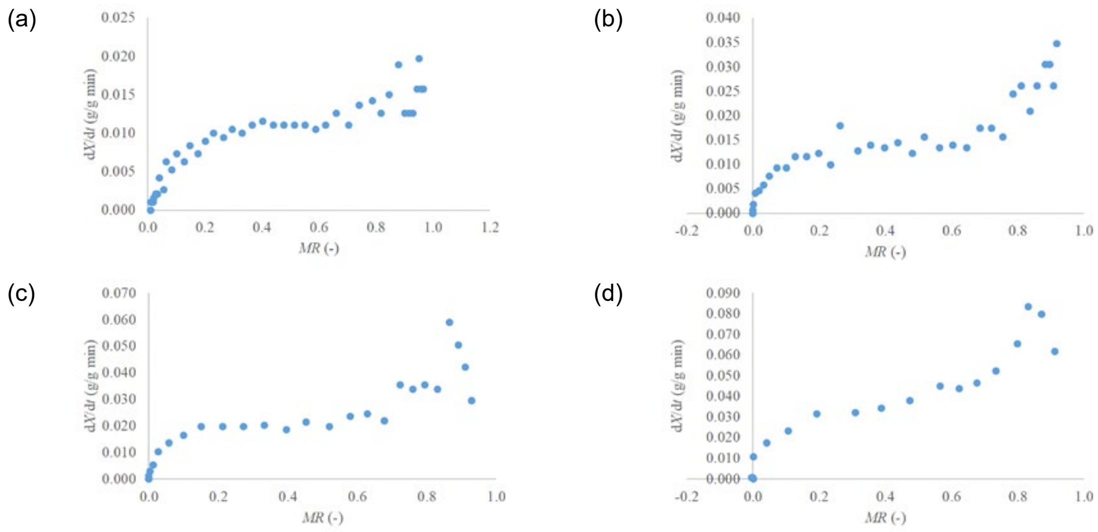


Figure 3: Drying rate curves of pandan leaves in oven drying at: (a) 50 °C, (b) 60 °C, (c) 70 °C, (d) 80 °C

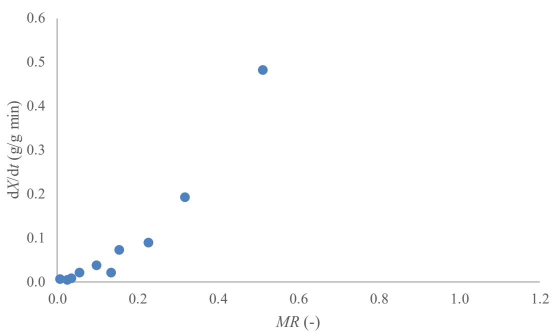


Figure 4: Drying rate curve for pandan leaves in fluidized bed drying at 40 °C

A constant drying period can be seen in Figure 3 for the drying of pandan leaves in oven. In this period, the drying rate is constant. On the contrary, as shown in Figure 4, due to the extremely fast drying time, this constant rate period was not observed when drying the pandan leaves in a fluidized bed dryer. When the rate of evaporation on the material's surface is greater than the rate at which moisture is absorbed from the inner substance to the surface, the drying period begins to deteriorate. The drying process now proceeds into the period of diminishing rate. The drying rate reduces while the moisture content in pandan leaves also reduces during the falling-rate period. There are two stages of falling-rate period, namely the first falling-rate period and the second falling-rate period, as shown in Figure 3 and 4. As shown in Figure 4, the drying of pandan leaves was took place in the falling rate period. This finding was similar to the finding from Rayaguru & Routray (2010). They studied the drying of pandan leaves in a heat pump dryer and observed that the drying of pandan leaves was mainly took place in the falling rate period.

Figures 3 and 4 showed that the rate of drying was increased with the increased in the moisture content of pandan leaves. The moisture gradient between pandan leaves and the surroundings is large at high moisture content. The moisture content will then evaporate quickly, as the drying process progresses, the moisture gradient becomes smaller, hence it is more difficult to remove the moisture. Not all natural materials proceeds with all the three stages of drying. Sometimes, during the drying process of some natural materials, the constant period is absent. Several research reported the absence of constant rate period such as for the drying of lemon (Torki Harchegan et al., 2016) and potato (Jabeen et al., 2015).

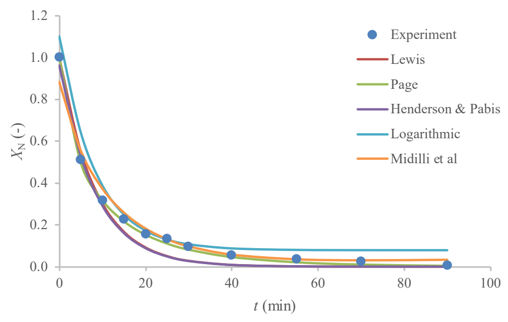
The results of fitting the curve to experimental data on pandan leaves drying in a fluidized bed drier in comparison to the five drying models are shown in Figure 5. Overall, all models can fit the experimental data well, as seen in the figure. The experimental data, however, were overestimated by the logarithmic model during the entire drying period. The Page model is the one that best represented the kinetics of pandan leaf drying over the drying process at various temperatures. Table 2 shows the R^2, reduced χ^2, and RMSE of pandan leaves dried in a fluidized bed drier at various drying temperatures. The Page model was selected as the best model for the current experiment to represent the drying kinetics of pandan leaves because it has the highest R^2 and the lowest χ^2 and RMSE values. The Page model is also simple because it employs fewer constants. The values of constants for Page model are shown in Table 3. Rayaguru & Routray (2010; 2011) also found that the Page model was the best model to describe the drying kinetics of pandan leaves in heat pump dryer and microwave dryer. Drying of parsley leaves in a forced convection dryer was also best modeled by the Page model (Akpinar et al., 2006).

Table 2: Statistical parameters for drying models

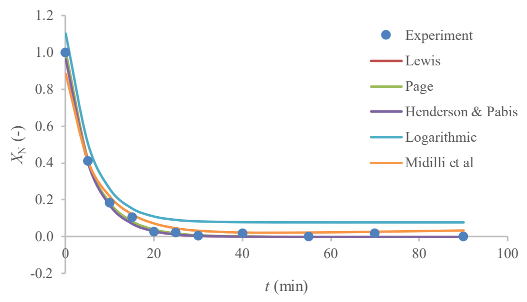
Model	Parameter	40 °C	60 °C	80 °C
Lewis	χ^2	0.0025	0.0002	0.0012
	RMSE	0.0480	0.0128	0.0324
	R^2	0.9904	0.9987	0.9885
Page	χ^2	0.0002	0.0001	0.0011
	RMSE	0.0123	0.0102	0.0304
	R^2	0.9994	0.9990	0.9898
Henderson and Pabis	χ^2	0.0031	0.0004	0.0016
	RMSE	0.0503	0.0183	0.0357
	R^2	0.9904	0.9987	0.9885
Logarithmic	χ^2	0.0055	0.0082	0.0117
	RMSE	0.0632	0.0770	0.0923
	R^2	0.9904	0.9987	0.9885
Midilli et al.	χ^2	0.0030	0.0027	0.0094
	RMSE	0.0439	0.0416	0.0773
	R^2	0.9822	0.9960	0.9630

Table 3: Values of constants and coefficients for Page Model

Model	Temperature	k	n
Page	40 °C	0.2218	0.7127
	60 °C	0.1990	0.9309
	80 °C	0.2076	1.0489



(a)



(b)

Figure 5: Modelling curves of pandan leaves in fluidized bed drying at: (a) 40 °C, (b) 60 °C

4. Conclusions

Pandan leaves have been dried in an oven and fluidized bed dryer in order to analyze the drying kinetics. This study investigated the effect of drying methods (fluidized bed drying and oven drying) and operating temperatures (40-80 °C) on the drying kinetics of pandan leaves. The results indicated that drying was faster with increasing operational temperature. Pandan leaves dried faster in a fluidized bed dryer than in an oven. While drying pandan leaves in a fluidized bed drier did not show the presence of the initial and constant periods, drying pandan leaves in an oven showed three drying periods, namely the initial period, the constant period, and the first falling-rate, and second falling-rate periods. The Page model was the most suitable drying model to describe the kinetics of drying pandan leaves in a fluidized bed dryer.

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