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Optimization of Thermal Efficiency in Vermicelli Drying with Air Dehumidification

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Abstract

When making vermicelli, the drying process has a significant impact on the final product's quality. Vermicelli is typically dried in the sun. However, using a sun drier has a poor thermal efficiency and weather dependent. To solve the issue, palm starch-based vermicelli was dried using air dehumidification. In this study, the impact of dehumidification on the drying kinetics and thermal efficiency of vermicelli drying will be examined. The drying rate increased, according to the results, as the air temperature rose. On the other hand, thermal efficiency fell. The optimisation process was carried out to identify the ideal vermicelli drying conditions. The ideal condition with a thermal efficiency of 71.43% can be achieved at a drying temperature of 33.79°C and air relative humidity of 0.02.

Keywords: dehumidification; drying; thermal efficiency; vermicelli

Full-length article **Corresponding Author*, e-mail: moh.djaeni@live.undip.ac.id

1. Introduction

The potential area for palm sugar plantations in Indonesia is 60,482 ha [1]. The fact that all this plant's components may be used to make sugar, beverages (palm wine), and bioethanol 2 makes it a prospective commodity to be developed and has commercial significance [2]. Additionally, the stem of the plant can be used to extract starch, which is used to make white noodles and vermicelli [3]. The drying process is one of the primary steps in vermicelli production. Drying significantly reduces volume, improves the range of products, and extends storage life [4]. Inappropriate drying techniques can alter the texture characteristics of food despite these advantageous effects [5]. Conventional vermicelli drying usually uses sunlight. But sunlight dryers depend on the weather and the thermal efficiency is still low, about 11.15% [6]. A study combining the sunlight and convective dryer, namely a hybrid solar dryer has been done. But the dryer efficiency is still low, at about 17.02% [7]. The drying systems with trays are most widely used because of their simple and economical design [8]. Currently, the thermal efficiency of tray dryers in food drying is below 40% [9,10]. The innovation in the drying process is needed to reduce the drying time as well as enhance the thermal efficiency.

To speed up the drying process, air dehumidification can be used to reduce air humidity [11,12]. As a result, drying can be sped up at low or moderate temperatures [13]. However, it is not simple to use air dehumidification to the drying of vermicelli. In this study, the impact of air dehumidification on the drying kinetics and thermal efficiency of vermicelli drying will be investigated.

2. Materials and methods

2.1. Materials

The starch used to make the vermicelli was extracted from Indonesian Klaten palm sugar stems. The Ardin CM2020 manufactured the vermicelli extruder. The air's temperature and relative humidity were measured using the KW0600561 sensor, which was made by Krisbow® in Indonesia. An emometer, model KW0600562, was used to measure the air velocity in Indonesia.

2.2. Vermicelli Formulation

The palm starch was mixed with water at a ratio of 1:3 (6 grams of the starch and 18 ml of water). The mixture was then heated forming a gel which was used for a dough binder. The Binder and 24 grammes of palm starch were thoroughly combined. The dough is subsequently transformed into extruder tools or vermicelli strands. The vermicelli strands are boiled in boiling water until floating, then soaked in cold water at a temperature of 5 °C for 30 seconds and drained.

2.3. Drying Process

The drying process was conducted in the tray dryer as illustrated in Figure 1.

Table 1: Experimental design of vermicelli drying

Factor	Level				
	-α	-1	0	1	α
Drying temperature (°C)	33.79	40	55	70	76.21
RH	0.02	0.10	0.30	0.50	0.58

Table 2: Predicted drying time of vermicelli drying at different drying conditions

Drying temperature (°C)	RH	k×10-2(min^{-1})	R^2	RMSE	Predicted Drying Time (min)
40	0.1	1.247	0.989	0.008	100.957
40	0.2	1.267	0.989	0.008	101.011
40	0.3	1.296	0.990	0.008	101.103
40	0.4	1.342	0.991	0.008	101.291
40	0.5	1.420	0.992	0.008	101.749
50	0.1	1.578	0.989	0.009	78.967
50	0.2	1.564	0.989	0.009	78.947
50	0.3	1.570	0.989	0.009	78.912
50	0.4	1.580	0.989	0.009	78.852
50	0.5	1.598	0.989	0.010	78.749
60	0.1	1.635	0.980	0.014	63.836
60	0.2	1.719	0.980	0.014	63.832
60	0.3	1.930	0.980	0.014	63.822
60	0.4	1.932	0.980	0.014	63.800
60	0.5	1.935	0.979	0.014	63.749
70	0.1	1.942	0.973	0.017	59.072
70	0.2	1.959	0.973	0.017	59.071
70	0.3	2.007	0.972	0.017	59.069
70	0.4	2.085	0.972	0.017	59.064
70	0.5	2.086	0.972	0.017	59.045

Table 3: Experimental design and response of vermicelli drying

Run	Drying temperature (°C)	RH	Average Thermal Efficiency
1	40	0.1	62.93
2	70	0.1	25.94
3	40	0.5	56.90
4	70	0.5	25.83
5	33.79	0.3	66.32
6	76.21	0.3	16.15
7	55	0.02	42.28
8	55	0.58	49.35
9	55	0.3	41.24
10	55	0.3	42.14
11	55	0.3	43.11
12	55	0.3	41.46
13	55	0.3	41.31

Table 4: Results of ANOVA for of the orthogonal central composite design

Source	P-value	Note
$Model$	0.000	Significant
X_1	0.000	Significant
X_2	0.571	Not Significant
X_1^2	0.611	Not Significant
X_2^2	0.074	Significant
X_1X_2	0.238	Not Significant
R^2	98.52%	

Table 5: Results of optimization

Drying temperature (°C)	RH	Thermal Efficiency (%)
33.79	0.02	71.43

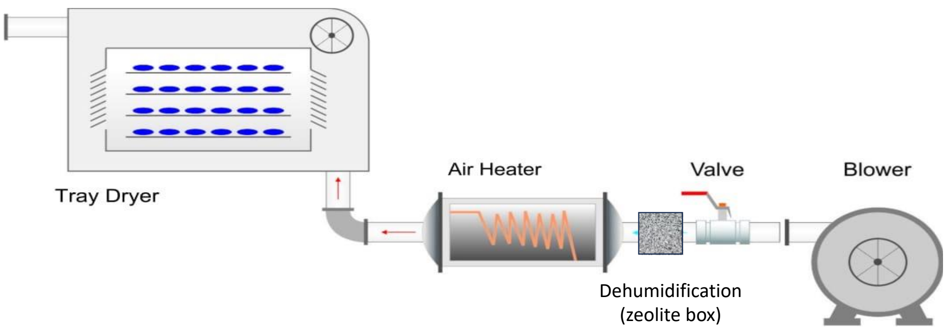

Figure 1: Schematic diagram of the tray dryer with dehumidification system

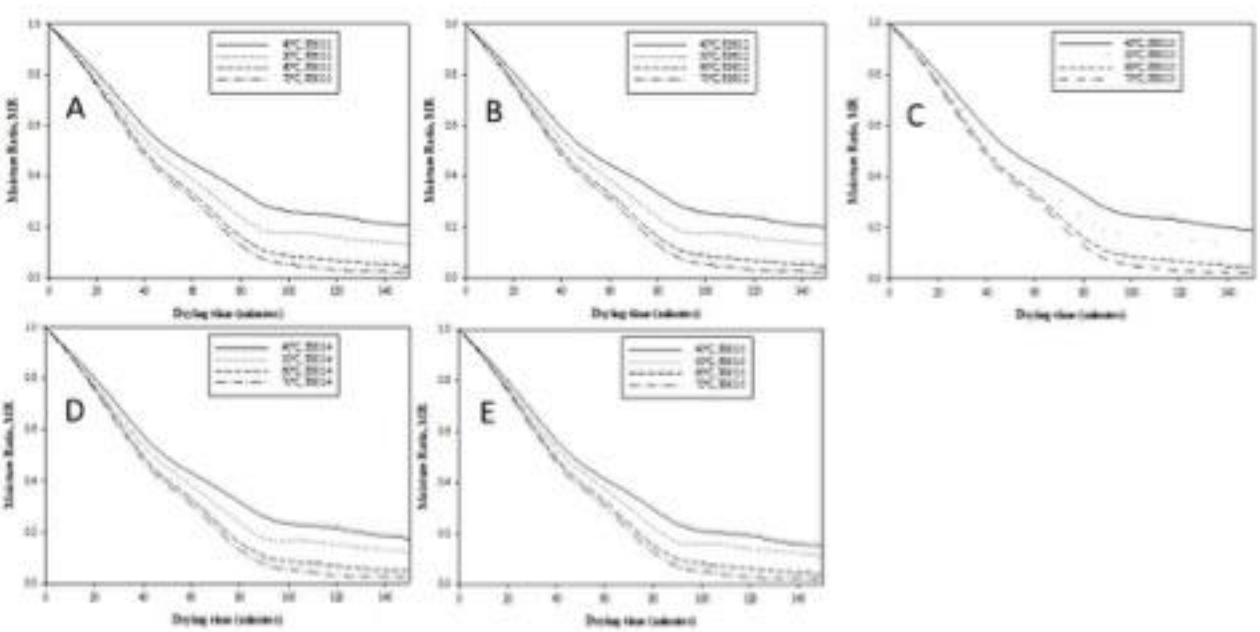

Figure 2: The moisture ratio of vermicelli drying at various air temperatures and relative humidity levels

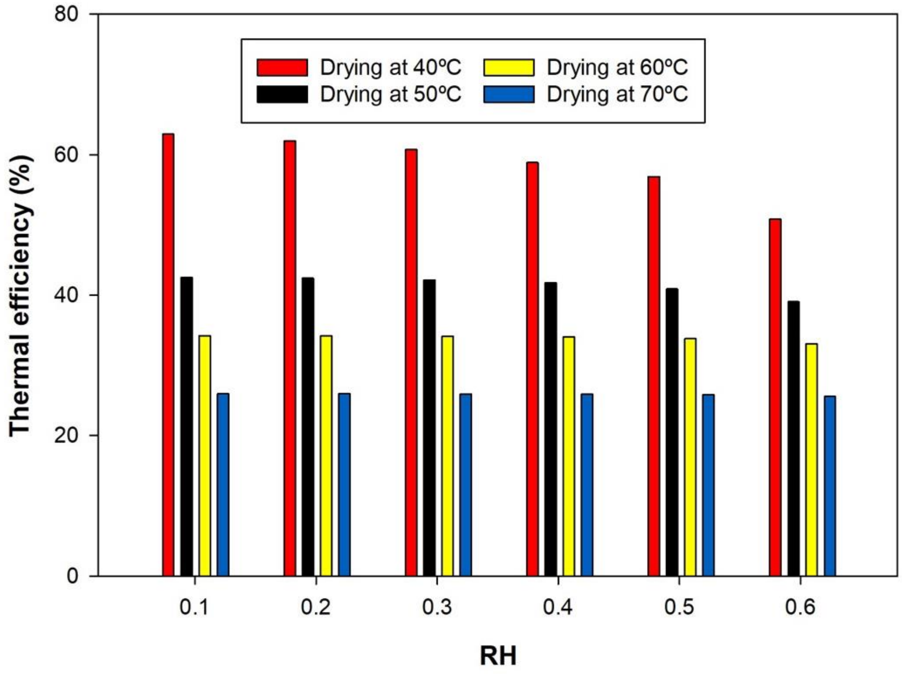

Figure 3: Thermal efficiency of vermicelli drying at different temperature and relative humidity

The wet vermicelli product with a diameter of 0.1 cm was put on the dryer (cross-sectional area 30 cm x 50 cm or 0.15 m2). The product was contacted with hot air at a certain operating temperature (suppose 40℃) for 150 minutes or 9000 s. The moisture content in vermicelli was observed every 15 minutes (600 s), using the gravimetric method. The procedure was repeated for drying temperatures 50°C, 60°C, 70°C. In this study, the relative humidity (RH) was also variated from 0.1-0.5. The relative humidity was adjusted by the addition of a dehumidification system that contained zeolite [12].

2.5. Thermal Efficiency

Thermal efficiency was based on the temperature of the air entering and exiting the dryer. Thermal efficiency was estimated, as follows:

$$\eta = \left(1 - \frac{T_o - T_{amb}}{T_i - T_{amb}}\right) \times 100\% \quad (4)$$

Where η was the thermal efficiency at the time of sampling (%), T_o *and* T_i were the dryer's output and intake air temperatures (°C), and T_{amb} was the ambient temperature (°C).

2.6. Optimization

The optimum drying condition was evaluated using Orthogonal Central Composite Design (CCD). The experimental desing consist of 2 process variable, namely drying temperature ($\boldsymbol{X_1}$) and relative humidity, RH ($\boldsymbol{X_2}$). The thermal efficiency (%) was the response and coded as **Y**. The lower and higher value of factors were listed in Table 1.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{12} X_1 X_2 \quad (5)$$

The correlation between the process variable and response as expressed in a second-order polynomial equation (see Equation 5).

3. Results and Discussions

3.1. Drying kinetics

Figure 1 depicts the moisture ratio of vermicelli at different air temperatures and relative humidity levels. The moisture ratio fell exponentially in all variables, which is a common observation in food items after drying. The decline in moisture ratio was greater in the first 60 minutes of drying than in later periods due to the high initial concentration of free moisture on the outer layer of the samples. As a result, moisture may be easily evaporated by the drying air [15]. From the Figure 1A-E, the final moisture ratio was lower at higher drying temperatures. For example, at higher drying temperatures supposed to be 70℃, the final moisture content was 8.47-10.20 times lower than at temperatures 40℃. At higher drying temperatures, the driving force for the drying was higher and the moisture evaporation became faster [11]. This result was like the drying rate data constant in Table 1. The constant drying rate at temperature 70℃ was 1.47-1.67 times higher than at temperatures 40℃.

Figure 1A-E showed that low air relative humidity resulted in lower moisture content. At low air relative humidity, the equilibrium moisture content was lower, enhancing the driving force for moisture removal [16]. At higher drying temperatures (70°C), the influence of air relative humidity was not significant in the present study.

The moisture ratio profiles were then matched to the Lewis model (Table 2). The statistical study revealed the low value of R^2 and the high value of RMSE. This proved that the Lewis model adequately represented the vermicelli drying behaviour. The model was used to estimate the drying time from an initial moisture content of 61.51% (wet basis) or 1.59 kg water/kg dry solid (dry basis) to a final moisture content of 10% (wet basis) or 0.11 kilogramme water/kg dry solid (dry basis), as shown in Table 1.

3.2. Thermal Efficiency

Figure 3 depicts the average thermal efficiency of drying vermicelli at various drying temperatures and relative humidity levels. Because the relative humidity of the air decreases at higher drying temperatures, the mass transfer of moisture between hot air and wet vermicelli is larger. However, as the drying process continues, the energy loss increases and the thermal efficiency declines. This has also occurred in paddy drying using a fluidized bed dryer [17].

3.3. Optimization of Response

Table 3 shows the experimental design and response of the Central Composite Design (CCD). The drying temperature was between 40 to 70°C. The relative humidity varied between 0.1 and 0.50. The experimental design comprises of 13 runs that were carried out to determine the best drying conditions. Optimization using orthogonal CCD associated with the process variable and response expressed in a second-order polynomial equation (see Equation 6). R^2 was used to assess the equation. R^2 was nearly equal to one. The greater the value of R^2, the more well the model was fitted to the data.

The process variable, drying temperatures, X_1, substantially affects the thermal efficiency of vermicelli drying with a P-Value of 0.05, according to Table 4. Figure 4 depicts two-dimensional and three-dimensional charts of the thermal efficiency of vermicelli drying derived by equation 6 and Table 3.

$$\boldsymbol{Y_1} = 110.9 - 1.08X_1 - 52.1\,X_2 + 0.002\,{X_1}^2 + 45.6{X_2}^2 + 0.493X_1X_2 \quad (6)$$

The optimization was used to find the optimum condition for vermicelli drying. The optimization goal was to find favorable conditions for maximum thermal efficiency. The result showed that the thermal efficiency of 71.43% with the optimum can be reached at a drying temperature of 33.79°C and air relative humidity of 0.02 (Table 5). The efficiency of this drying process was higher than that of another vermicelli drying study utilising a glasshouse dryer [6] and a hybrid solar dryer [7]. efficiency improved was the result of this study.

4. Conclusions

In this study, vermicelli prepared from palm starch was dried at various temperatures and relative humidity levels. The results showed that increasing the drying temperature increased the drying rate. As a result, the drying time was reduced. Furthermore, when temperature increased, thermal efficiency dropped. The optimisation was carried out in light of the negative feedback. The optimal condition with a thermal efficiency of 71.43% may be achieved at a drying temperature of 33.79°C and an air relative humidity of 0.02.

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