Journal of Bioresources and Environmental Sciences, 2024, 3(1), 53-60
DOI: 10.61435/jbes.2024.19811

Research Article

Drying kinetics and thermal energy evaluation of *Moringa oleifera* leaves drying using dehumidification with zeolite

Zulhaq Dahri Siqhny[1*], Anisa Rachma Sari[1], Febiani Dwi Utari[2], Mohamad Djaeni[2]

[1] Faculty of Agriculture Technology, Semarang University, Semarang, Indonesia
[2] Department of Chemical Engineering, Faculty of Engineering, Diponegoro University, Semarang, 50275 Indonesia

* Correspondence: zulhaqdahrisiqhny@usm.ac.id

Received: 26th Sept 2023
Accepted: 15th November 2023
Published: 1st April 2024

Abstract. *Moringa Oleifera* leaves contain many phytochemical compounds, as the potential source of antioxidants. The leaves must be converted into dried form to extend the shelf life and prevent the nutritional qualities. The lack of a common sun-drying process for *Moringa Oleifera leaves* is dependent on the weather. But using convective dryers also requires high investment costs and results in very low energy efficiency. One potential option to enhance energy efficiency is lowering the humidity by dehumidification with zeolite. This research aims to evaluate the effect of drying temperature and the weight of adsorbent (zeolite) on drying kinetic and thermal efficiency of *Moringa Oleifera leaves* drying. *Moringa Oleifera* leaves were dried under different drying temperatures (30-70℃) and weight of zeolite (0-0.3 kg). The moisture content of *Moringa Oleifera* leaves and the input-output temperature was recorded to evaluate the moisture reduction and thermal efficiency. Results showed that the Page model can be used to predict the drying time. At the higher drying temperature and higher zeolite weight, moisture reduction and thermal efficiency increased. But the effect of zeolite is only significant in drying at temperatures below 50℃.

Keywords: *Moringa Oleifera* leaves, dehumidification, drying, zeolite

1. Introduction

Moringa Oleifera is a plant that originates from northwest India and is now cultivated in many tropical and subtropical countries (Mbikay, 2012). The leaves of this plant contain bioactive compounds such as proteins, carbohydrates, fiber, fats, minerals, and amino acids as well as various phytochemical components such as ascorbic acid, flavonoids, phenols, carotenoids, etc. (Vongsak et al., 2013). These phytochemical compounds make *Moringa Oleifera* leaves a potential source of antioxidants. Moringa plants are also rich in vitamin A, vitamin C, calcium, potassium, and iron (Vats & Gupta, 2017). *Moringa Oleifera* leaves contain more than 90 nutrients and all essential amino acids, making them suitable for daily supplementation and fortification (Fuglie et al., 1999). Regular consumption of flavonoid-rich foods can reduce the risk of chronic disease and maintain health (Hernandez-Jaimes et al., 2013).

Moringa Oleifera leaves are generally used as a cooked vegetable or soup (Vongsak et al., 2013). To increase its availability and consumption, *Moringa Oleifera* leaves are processed into dry powder which can produce functional food and drinks. Powdered *Moringa Oleifera* leaves can be used in the formulation of certain food products and can also be used directly as a food supplement. Processing of *Moringa Oleifera* leaves should be done immediately after harvest. The high-water content in post-harvest *Moringa Oleifera* leaves and high respiration rates can quickly reduce their physical and nutritional qualities (Mbikay, 2012).

Drying is a process that involves simultaneous heat and mass transfer to reduce the water content in a material. The drying process aims to extend the shelf life of a material (Mujumdar, 2006). In addition, drying aims to facilitate distribution because the mass of the material will be reduced, reduce packaging, reduce transportation costs and be easy to store (Kamalakar et al., 2014). The drying process is a process of reducing or removing the water content of a material until it reaches a certain value (Djaeni et al., 2014). Drying is the most crucial process that will determine the final quality of the pasta product. The drying rate and moisture content of the final product are very important in the drying process (Mujumdar, 2006). In addition, other factors influence the success of drying, including RH, surface area, temperature differences and the surrounding air, airflow velocity, and air pressure (Pakowski & Mujumdar, 2006).

Several drying methods have been conducted to improve the drying rate and quality of dried *Moringa Oleifera* leaves such as greenhouse (Sukmawaty et al., 2021), fluidized bed drying (Hasizah et al., 2022), cabinet drying (Setiaboma et al., 2019), and freeze-drying (Ademiluyi et al., 2018). The sun drying method can be an option to minimize the drying cost. However, the sun drying method takes a longer drying time (up to 6 hours) and it is depending on the weather. Convective drying such as fluidized bed drying, and cabinet drying can overcome the weather dependence of the sun drying process. But, the energy efficiency of the dryer is still low, less than 50% (Kemp, 2014). Additionally, using the high temperature can lead to the degradation of bioactive substances, for example, the phenolics content (Sasongko et al., 2020). The low-temperature drying and freeze-drying can be promising methods to preserve the bioactive substance in *Moringa Oleifera* leaves (Ademiluyi et al., 2018). On the contrary, the investment cost of freeze dryers is still high. It is important to discover the drying methods that allow the fast-drying time, medium temperature to maintain the bioactive compound in *Moringa Oleifera* leaves, and low operating cost.

The application of dehumidified air as a drying medium can be an option to overcome the problem of *Moringa Oleifera* leaves drying. Dehumidification drying with zeolite has become a potential choice for food products (Atuonwu et al., 2011). In this system, the zeolite can reduce the air's relative humidity. By reducing humidity, the driving force of the drying is higher. The research results show that energy efficiency can reach 70%. With a multistage system, energy efficiency can be increased by up to 90% (Djaeni et al., 2007). Dehumidification can shorten drying time and maintain the bioactive compounds (Djaeni, Kumoro, Sasongko, & Dwi, 2018). In the literature study, the application of dehumidified air for the *Moringa Oleifera* leaves drying is not easy to find. This research aims to evaluate the effect of drying temperature and the weight of adsorbent (zeolite) on drying kinetic and thermal efficiency of *Moringa Oleifera* leaves dring.

2. Method

2.1. Materials

Fresh *Moringa Oleifera* leaves were collected from Semarang, Indonesia. Gravimetry was used to calculate the fresh Moringa Oleifera leaves' moisture content, which was found to be 75.65% (wet basis) or 3.18 kg water/kg dry solid (dry basis) (Vera Zambrano et al., 2019). Zeochem (Switzerland) provided the zeolite 3A, which was utilised for dehumidification.

2.2. Moringa Oleifera Leaves Drying

The drying procedure was carried out in a convection drier that used zeolite for air dehumidification (see Figure 1). The ambient air was heated using an electric heater until a temperature of 70 °C (see Table 1). The hot air entered the dyer containing about 0.1 kgs of *Moringa Oleifera* leaves and 0.30 kgs of zeolite. The moisture content of *Moringa Oleifera* leaves and the input-output temperature was recorded every 10 min for 1 h. After 1 h of drying the observation continued every 30 min for 2h. The drying temperature and the weight of the zeolite were both variable processes, as shown in Table 1.

Table 1. Process variables of *Moringa Oleifera* leave drying

Run	Temperature (°C)	Weight of zeolite (kg)
1	30	0
2	30	0.15
3	30	0.30
4	50	0
5	50	0.15
6	50	0.30
7	70	0
8	70	0.15
9	70	0.30

2.3. Modelling of *Moringa Oleifera* Leaves Drying

The experimental moisture content data was then converted into moisture ratio (MR). The moisture ratio and drying time in *Moringa Oleifera* leaves drying can be correlated using Equation 1 (Utari et al., 2022).

$$MR = \frac{(X_t)}{(X_0)} \tag{1}$$

Where $\mathrm{M_t}$ was the moisture content at time t, $\mathrm{M_0}$ was the initial moisture content, all of them in dry basis (g/g).

This moisture ratio data was then fitted to several thin-layer drying models and were listed in Table 2 (Ertekin & Firat, 2017). The thin layer model uses several assumptions such as the distribution of the drying air and temperature over the material being uniform and the thickness of the layer being uniform (Onwude et al., 2016). The POLYMATH Educational 6.0 programme was used to calculate the thin layer model's constant. The coefficient of determination (R^2) and Root Mean Square Deviation (RSMD) were used to evaluate the best drying model to describe the phenomenon of *Moringa Oleifera* leaves drying.

Table 2. Thin layer models for *Moringa Oleifera* leaves drying

Model	Equation	
Newton	$\boldsymbol{MR = \exp(-kt)}$	(2)
Page	$\boldsymbol{MR = \exp(-kt^n)}$	(3)
Henderson- Pabis	$\boldsymbol{MR = a\exp(-kt)}$	(4)

2.4. Thermal Efficiency

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

$$\eta = \left(1 - \frac{T_o - T_{amb}}{T_i - T_{amb}}\right) \times 100 \tag{5}$$

Where η was the thermal efficiency at t time (%), T_o and T_i were outlet and inlet air temperature at the dryer (°C), and T_{amb} was the ambient temperature (°C).

3. Result and Discussion

3.1. Moisture ratio reduction

The experiment's moisture content data was transformed into a dimensionless moisture ratio (see Equation 2). Figure 1 presents the moisture ratio of *Moringa Oleifera* leaves drying at various air temperatures and various relative humidity. In all the variables, at 60 minutes of drying, the moisture ratio decreased significantly. The free mosisture in *Moringa Oleifera* leaves surface is easily evaporated. After 60 minutes of drying, the fee moisture on the surface are decreased. The bound moisture is difficult to evaporate. So the rate of moisture ratio reduction becomes slower. This phenomenon also happened in onion drying and roselle drying (Asiah et al., 2017; Djaeni, Kumoro, Sasongko, & Utari, 2018)

Figure 1A-C shows that the final moisture ratio was lower at higher drying temperatures. For example, at higher drying temperatures it should be 70°C, the final moisture content was 1.06-3.03 times lower than at temperatures 30°C. At higher drying temperatures, the driving force for the drying was higher and the moisture evaporation became faster (Djaeni et al., 2021). Additionally, that higher weight of zeolite in the drying process resulted in a lower moisture content. At low air relative humidity, the equilibrium moisture content was lower and enhanced the driving force for the moisture removal (Asiah et al., 2017).

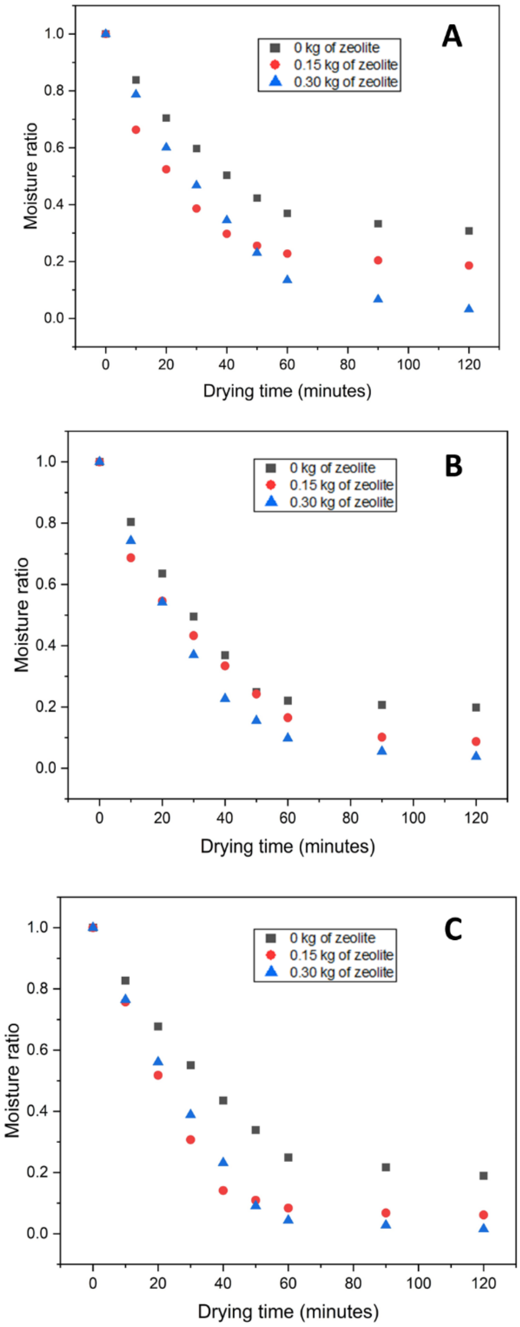

Figure 1. Moisture ratio *Moringa Oleifera* leaves drying at (a) 30 °C, (b) 50 °C, and (c) 70°C

3.2. *Kinetics model of Moringa Oleifera Leaves Drying*

The kinetics of drying *Moringa Oleifera* leaves at various temperatures and zeolite weights were modeled in three thin-layer models. Model constants and statistical parameters for drying *Moringa Oleifera* leaves are presented in Table 3. Parameter statistics, coefficient of determination (R^2), and Root Mean Square Deviation (RSMD) were used to obtain a more precise model to describe the kinetics of *Moringa Oleifera* leaves. Based on statistical analysis, the model with the highest R^2 value and the lowest RSMD value is the Page model. The Page model was also chosen to describe the drying phenomenon in several food products: thyme leaves (Turan & Firatligil, 2019), green bell paper (Doymaz & Ismail, 2010), plums (Goyal et al., 2007), and pineapple (Kingsly et al. .., 2009).

Table 3. Parameter estimation of thin layer models for *Moringa Oleifera* leaves drying

Model	Temperature (°C)	Weight of zeolite (kg)	Model constant			R^2	RMSD
			k	n	a		
Newton	30	0	0.01			0.80	0.06
	30	0.15	0.02			0.73	0.10
	30	0.30	0.02			0.87	0.07
	50	0	0.02			0.58	0.12
	50	0.15	0.02			0.92	0.08
	50	0.30	0.03			0.75	0.17
	70	0	0.03			0.99	0.04
	70	0.15	0.03			0.95	0.08
	70	0.30	0.04			0.94	0.12
Page	30	0	0.09	0.61		0.95	0.03
	30	0.15	0.11	0.59		0.90	0.06
	30	0.30	0.06	0.70		0.95	0.04
	50	0	0.24	0.47		0.95	0.04
	50	0.15	0.08	0.74		0.98	0.04
	50	0.30	0.17	0.61		0.90	0.11
	70	0	0.03	1.01		0.99	0.04
	70	0.15	0.07	0.80		0.97	0.06
	70	0.30	0.06	0.89		0.94	0.12
Henderson-Pabis	30	0	0.01		0.84	0.87	0.05
	30	0.15	0.01		0.77	0.81	0.09
	30	0.30	0.01		0.85	0.91	0.06
	50	0	0.01		0.66	0.80	0.08
	50	0.15	0.02		0.81	0.95	0.06
	50	0.30	0.03		0.66	0.82	0.14
	70	0	0.03		1.04	0.99	0.04
	70	0.15	0.03		0.84	0.95	0.08
	70	0.30	0.04		0.95	0.94	0.12

The constants of the Model Page in Table 1 then used to calculate the drying time. The drying time to reach the final moisture content (10% wet basis) were variated from 85 to 379 minutes, as shown in Figure 3. The addition of zeolite sucessfully reduced the drying time. But the effect of zeolite only significant in drying at temperature below 50°C. For example, for drying using 0.3 kg of zeolite at drying temperature of 30°C, the drying time was 96 minutes shorter than without zeolite. While drying using 0.3 kg of zeolite at drying temperature of 70°C, the drying time was 28 minutes shorter than without zeolite. This phenomenon was inline with another agricultural drying such as paddy (Djaeni et al., 2013) and roselle (Djaeni, Kumoro, Sasongko, & Utari, 2018)

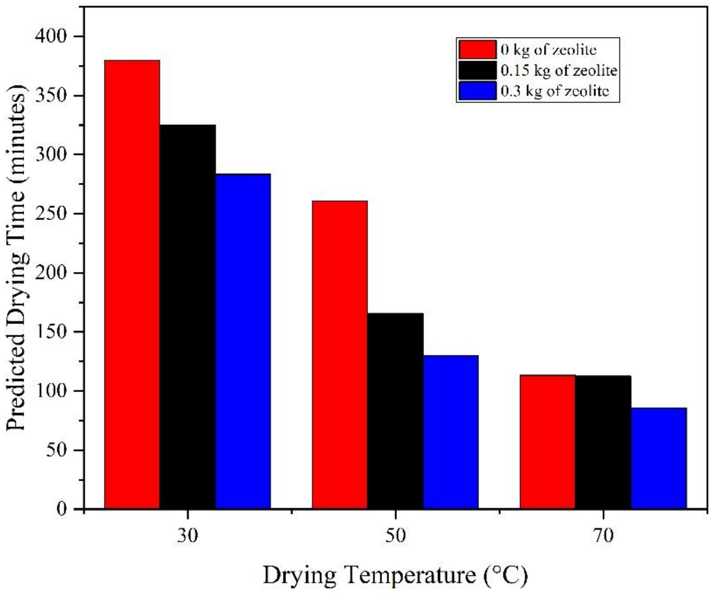

Figure 3. Predicted drying time of *Moringa Oleifera* leaves at different temperature and weight of zeolite

3.3. *Thermal Efficiency Evaluation*

The average thermal efficiency of *Moringa Oleifera* leaves drying at various drying temperatures and weight of zeolite were 7.78-51.43%, see Figure 4. At the higher drying temperature and higher zeolite weight, the relative humidity of the air becomes lower, so the mass transfer of moisture between the hot air and fresh *Moringa Oleifera* leaves is greater, and the thermal efficiency increases (Kemp, 2014). This study's findings were higher than other *Moringa Oleifera* leaves drying such as greenhouse effect dryers (Sukmawaty et al., 2021) and photovoltaic tray dryers (Aznury et al., 2021).

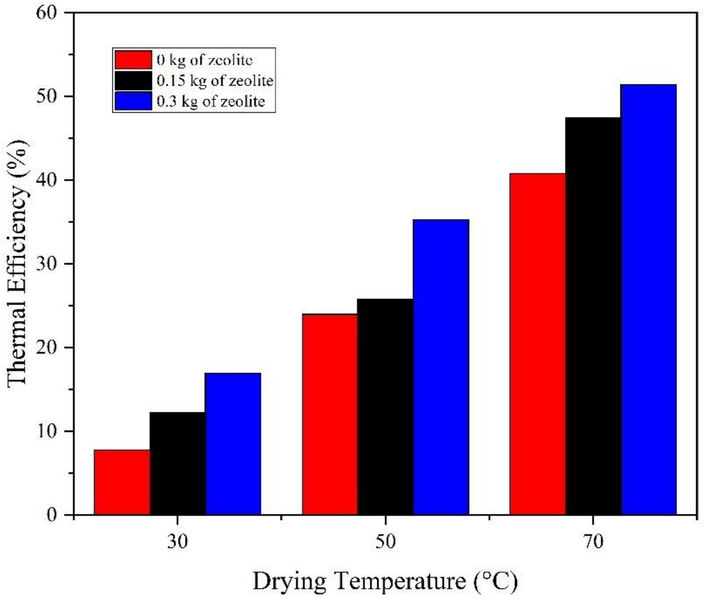

Figure 4. Thermal efficiency of *Moringa Oleifera* leaves drying at different temperature and weight of zeolite

4. Conclusion

The current study used varied zeolite weights and drying temperatures to dry the *Moringa oleifera* leaves. The outcome showed that the Page model had the greatest R2 value and the lowest RSME when used for simulating the drying of *Moringa oleifera* leaves. The Page Model can then be applied to predict drying times from the initial moisture content to the final moisture content (10% wet basis). The decrease of moisture was also improved by raising the drying temperature and zeolite weight. As a result, the relative humidity of the air decreases, mass transfer increases, drying time is reduced, and thermal efficiency rises. Zeolite's impact, however, is only felt while drying at temperatures below 50°C. It is important to observe the content of bioactive substances in *Moringa oleifera* leaves at varied zeolite weights and drying temperatures for the next study. Because of the short drying time and excellent thermal efficiency of the drying process, the drying condition recommended by this study can be used as a reference.

Acknowledgement

This research is fully funded by Semarang University.

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