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Analyzing Effect of Temperature on Drying Moringa (*Moringa Oleifera*) Leaves Using Photovoltaic Tray Dryer

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Abstract: *Moringa oleifera* is a shrub with a height of 7-11 meters and thrives from the lowlands to 700 meters above sea level. Moringa leaves have various beneficial nutritional contents. Moringa leaves, dried into a powder, contain more nutrients than when the plant is fresh leaves. However, conventional drying of the material in the hot sun can reduce the quality of the dried material because the drying temperature cannot be controlled. Therefore, a photovoltaic tray dryer was designed with a drying device that utilizes sunlight through the photovoltaic solar energy system consisting of four trays. This research aims to analyze the effect of temperature on drying efficiency using a photovoltaic tray dryer. Before carrying out the drying process, the Moringa leaves are tested for the initial water content. Moringa leaves are weighed 100 grams for each tray. The drying process is carried out at temperature variations, 40°C, 50°C, 60°C, and 70°C within four hours to see the optimal temperature in the Moringa leaf drying process. Every 30 minutes, the Moringa leaves in tray 1, tray 2, tray 3, and tray 4 are weighed to determine the water content. The lowest water content in Moringa leaves was found in the drying process at 70ºC, 40.73%. The best drying process occurs in tray 3 with an average water content after drying, 49.49%. Meanwhile, the highest drying efficiency occurred in the drying process at 40ºC, 31.76%.
Keywords: Moringa leaves, drying, photovoltaic tray dryer, drying temperature, water content.

使用光伏托盤乾燥機分析溫度對辣木 (辣木) 葉子乾燥的影響

摘要：辣木是一種高7-11米的灌木，從低地生長到海拔700米。辣木葉具有各種有益的營養成分。辣木葉子，乾燥成粉末，比植物是新鮮葉子時含有更多的營養。但是，傳統的物料在烈日下乾燥會降低乾燥物料的質量，因為乾燥溫度無法控制。因此，光伏托盤乾燥機設計了一個乾燥裝置，通過由四個托盤組成的光伏太陽能係統利用陽光。本研究旨在使用光伏托盤乾燥機分析溫度對乾燥效率的影響。在進行乾燥過程之前，會測試辣木葉子的初始含水量。辣木葉每托盤稱重 100 克。乾燥過程在 40°C、50°C、60°C 和 70°C 的溫度變化下在四小時內進行，以查看辣木葉乾燥過程中的最佳溫度。每 30 分鐘，對托盤 1、托盤 2、托盤 3 和托盤 4 中的辣木葉進行稱重以確定其含水量。辣木葉在 70oC 乾燥過程中的含水量最低，為 40.73%。最佳乾燥過程發生在托盤 3，乾燥後的平均含水量為 49.49%。同時，乾燥效率最高出現在40℃的干燥過程中，為31.76%。
关键词：辣木葉，烘乾，光伏托盤烘乾機，烘乾溫度，含水量。

1. Introduction

The *Moringa oleifera* plant is one of the most unusual plants ever discovered, wherein it is scientifically a source of medicinal nutrients whose content are outside the usual plant content. Therefore, it is believed to potentially end malnutrition and hunger and prevent and cure various diseases [1]. Moringa leaf is one of the benefits of the Moringa tree [2]. To facilitate Moringa leaves as a functional food

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ingredient, they can be made into powder. Not only that, Moringa leaves that are dried into powder have more nutritional content than when this plant is in the form of raw leaves [3-5]. According to [6], there are many different drying treatments such as conventional, laboratory, and advanced methods. The drying method can be done conventionally or by using a drying machine. Drying using a dryer can improve the quality product of Moringa [7].

Several studies on drying using a rack-type dryer have been carried out, such as those conducted by [8], who designed a rack-type dryer using solar power, which is used to dry cassava from an initial moisture content of 38% to ± 14%. A rack-type dryer was able to reduce the moisture content of rice flour from 26% to 9.18% on the 1st shelf, while on the 2nd, 3rd, and 4th shelf were 13.8%, 15.07%, respectively. Design and testing of corn cabinet dryer or a capacity of 9 kg per cycle, which can reduce the moisture content of corn from 34% to 16.53% [9]. Another study [10] on the design and testing of a type cocoa cabinet dryer for a capacity of 7.5 kg per cycle was able to reduce the moisture content of cocoa from 61% to 6.45%. Based on the above, a photovoltaic tray dryer has been made. A rack-type drying device uses photovoltaic technology to harness energy from solar radiation and convert it into electrical energy as an energy source to operate the dryer. Therefore, it is necessary to test the photovoltaic tray dryer.

2. Materials and Methods

2.1. Materials

The material used in this study is Moringa leaves which are found in the Palembang area. The tools used include photovoltaic tray dryer, analytical balance, desiccator, schedule, oven, evaporating dish, thermometer, and anemometer GM816. The photovoltaic tray dryer can be seen in Fig. 1.

Fig. 1 The photovoltaic tray dryer

2.2. Methods

Experiments were carried out with various experimental variables, namely:

1. Variations in drying temperature were 40°C, 50°C, 60°C, and 70°C based on 4 h drying time and 100 g of Moringa leaf mass per tray.
2. Tray variations were tray 1, tray 2, tray 3, and tray 4 based on the same drying time and mass of Moringa leaves on each tray.

3. Results and Discussion

3.1. Effect of Drying Temperature on Decreasing Water Content

The drying temperature influences the rate of decreasing moisture content in Moringa leaves. The relationship between drying temperature and decreasing the moisture content of Moringa leaves is shown in Fig. 2.

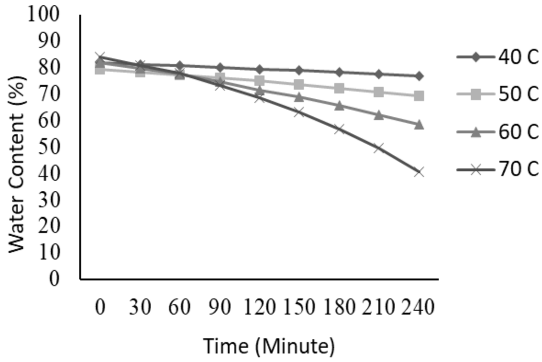

Fig. 2 Effect of drying temperature and decreasing Moringa leaves water content

Fig. 2 shows that the water content of Moringa leaves is influenced by the drying temperature, where the greater the temperature drying, the decrease in water content in the Moringa leaves will be even greater. The highest reduction in water content was at a temperature of 70°C from an initial 84% to 40.73%, it reduced from 82% to 58.50% at 60oC, from 79.50% to 69.31% at 50°C, and the lowest reduction was at 40°C – from 81.75% to 76.87%. Based on this, it can be seen that the greater the drying temperature, the greater the decrease in water content of Moringa leaves. The higher the drying room temperature, the faster the moisture content of the material decreases [11].

Based on the study results, the final water content in Moringa leaves after the drying process for four hours was not uniform on each tray. The final water content of Moringa leaves for each tray against the drying temperature is shown in Fig. 3.

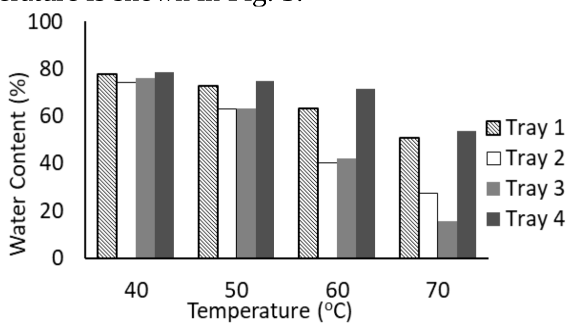

Fig. 3 Final water content of Moringa leaves for each tray to drying temperature

The result showed that in each tray after the drying process for four hours with temperature variations of 40°C, 50°C, 60°C, 70°C, the lowest water content was at a temperature of 70ºC on tray 3 – 15.79%, while the highest water content is was a temperature of 40ºC on tray 4 – 78.72%. Based on the average water content of Moringa leaves after drying, the lowest water content was obtained in tray 3 – 49.49%, followed by tray 2, tray 1, and tray 4 with water content values respectively 51.22%, 66.07 %, and 69.65%. The difference in water content of Moringa leaves after the drying process shows that the drying process is not evenly distributed due to the drying room's uneven drying temperature and air circulation. The duct location of the drying air intake was on the right and left between tray 2 and tray 3 of the drying chamber. Such location causes the drying air to contact the Moringa directly leaves on trays 2 and 3. When the drying air circulates to the Moringa leaves on the tray, there is another level of air saturation and drying air temperature to dry the Moringa leaves. The results differences are supported by research conducted by [12] that higher temperature, lower relative humidity, and higher fluid velocity indicated a high drying rate. In addition, steam pressure increases with increasing temperature [13]. At higher temperatures, the kinetic energy of the particles is higher, and with more energy available at higher temperatures, it is easier for the particles to change phases. If the two phases are not in equilibrium, the molecule will alter from one phase to another until it reaches equilibrium.

3.2. The Effect of Drying Temperature on The Drying Rate

The effect of temperature on the drying rate is shown in Fig. 4. The result showed that the drying rate from the highest occurs at a temperature of 70ºC, namely 0.185 kg/m^2 hours followed at a temperature of 60ºC, 50ºC, and 40ºC with subsequent drying rate is 0.1405 kg/m^{2}h, 0.0824 kg/m^2 h, and 0.0524 kg/m^{2}h. As seen in Fig. 4, the temperature of the drying air affects the drying rate. The higher the temperature used in the drying process, the greater the heat received by the Moringa leaves so that the rate of water evaporation increases. The higher the heating air temperature, the faster the material will experience drying, encouraging faster removal or evaporation of water so that the drying time will be shorter.

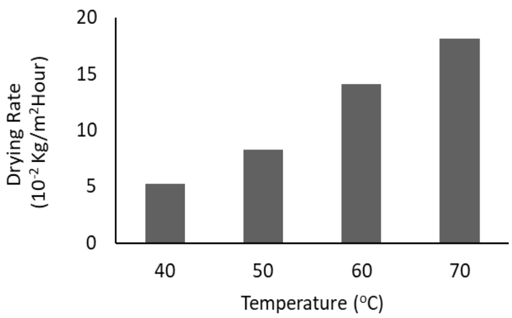

Fig. 4 Effect of temperature on drying rate

The heat given by the drying air will increase the temperature of the Moringa leaves, which causes the water vapor pressure in the Moringa leaves to be higher than the water vapor pressure in the air, resulting in a transfer of water vapor from the Moringa leaves to the air which is a mass transfer. Before the drying process takes place, the water vapor pressure in the material is in balance with the water vapor pressure in the surrounding air. When drying starts, a hot stream that flows over the material's surface will increase the water vapor pressure, especially in the surface area, in line with the increase in temperature. The temperature increase in all material parts results in the water diffusion from the material to its surface. So the evaporation process on the surface of the material is repeated. After the material water is reduced, the water vapor pressure of the material will decrease until there is a balance with the surrounding air. According to [14], increasing the temperature will increase the diffusivity value of water from inside the material and increase the material's transfer rate between the material and drying air. The relationship between temperature and diffusivity can be seen in the Arrhenius equation

$$D = Ae^{(-E / RT)},$$

where A is the diffusion rate constant, E is the activation energy of mass transfer, R is the ideal gas constant, and T is the absolute temperature.

Under the Arrhenius law, the reaction rate is proportional to the reaction temperature: the higher the reaction temperature, the greater the reaction rate constant, so greater the water diffusion rate [15].

The drying rate is calculated using the following formula:

$$R = \frac{\Delta W}{A \; x \; \Delta t}$$

where:

R - drying rate (Kg/m^{2}hours)

ΔW - mass of water the evaporated (kg)

A - surface area (m^2)

Δt - drying time (hours)

$$R = \frac{0.08443 \; Kg}{0.403 \; m^2 \; x \; 4 \; hours} = 0.0524 \text{ Kg/m}^2\text{hour}$$

3.3. Drying Efficiency

The drying efficiency is calculated by comparing the heat used to heat the material and evaporate the material's water against the incoming heat from the drying air. The effect of temperature variations on drying efficiency can be seen in Fig. 5.

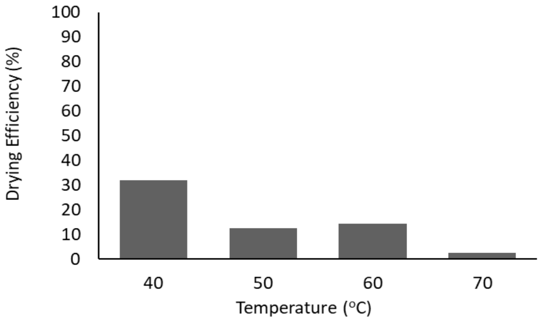

Fig. 5 Effect of drying temperature on drying efficiency

Based on Fig. 5, the highest drying efficiency occurs at a drying temperature of 40°C, namely 31.86%, followed by a temperature of 60°C, 50°C, and 70°C, respectively, namely 14.27%, 12.54%, and 2.64%. In the drying process of Moringa leaves with a temperature of 70°C, the heater and fan continue to work to maintain the drying temperature. In contrast, at the lower drying temperatures of 40°C, 50°C, and 60°C, the heater and fan work for a while and then turn off and live again. Based on observations, it was found that the greater the drying temperature, the higher the air rate in the tray dryer. At a temperature of 40°C, the average drying air rate is 1.96 m/s, then at a temperature of 50°C, 60°C, and 70°C, the average drying air rate is 4.59 m/s, 4.67 m/s, and 7.44 m/s, respectively. According to [16], the higher the temperature and the drying air rate, the higher the heat energy carried by the drying air. Drying efficiency is defined as the ratio of the energy used to heat the material with the total energy provided by the dryer [17]. Based on Fig. 5, drying efficiency tends to decrease with increasing drying temperature because the amount of heat to heat the Moringa leaves and evaporate water tends to be constant. In contrast, sensible heat is provided by the excess drying airflow. Drying efficiency at a temperature of 40°C is high because the energy that enters the drying air is 688.1018 kJ, while the heat used for the drying process is 219.2525 kJ. The drying efficiency at 70°C is low because the energy that enters the drying air is very high, namely, 26267.97 kJ, while the heat used for the drying process is 694.1068 kJ.

The drying efficiency of each temperature variable using the same method to determine the drying rate can be seen in Table 1.

Table 1 Drying rate R depending on drying temperature

Temperature (°C)	**R (Kg/m^{2}hour)**
40	0.0524
50	0.0824
60	0.1405
70	0.18115

3.3.1. The Equation of Drying Efficiency

Notations for calculating the heat balance: m = weigh, kg; T = temperature, °C; Cp = specific heat, kJ/kg°C; T_{ref} = reference temperature = 25°C.

3.3.1.1. Heat Input

a) *Sensible heat of dry Moringa leaves* (Q_{SI1})
m - Moringa leaves weigh
T - ambient air temperature
Q_{SI1} = m • Cp • (T – T_{ref}) = 0.073 • 1.7332 • (27.2 – 25) = 0.2783 kJ

b) *Sensible heat, water content in Moringa leaves* (Q_{SI2})
m - water weight
T - ambient air temperature
Q_{SI2} = m • Cp • (T – T_{ref}) = 0.3270 • 3,9447 • (27.2 – 25) = 2.8378 kJ

c) *Sensible heat of air* (Q_{SI3})
m - weight of air
Q_{SI3} = m • Cp • (T – T_{ref}) = 44.4165 • 0.2379 • (40 - 25) = 158.5136 kcal = 662.904 kJ

d) *Sensible heat of water vapor* (Q_{SI4})
m - vapor weight
Q_{SI4} = m • Cp • (T – T_{ref}) = 0.8972 • 1.8723 • (40 – 25) = 25.1978 kJ

3.3.1.2. Heat That Comes Out

a) *Sensible heat of Moringa leaves dry basis* (Q_{SO1})
m - weight of Moringa leaves
Q_{SO1} = m • Cp • (T – T_{ref}) = 0.073 • 1.7513 • (40°C – 25°C) = 1.9177 kJ

b) *Sensible heat of water in Moringa leaves* (Q_{SO2})
m - weight of water
Q_{SO2} = m • Cp • (T - Tref) = 0.2426 • 3.8853 • (40 – 25) = 14.1371 kJ

c) *Sensible heat of air* (Q_{SO3})
m - weight of air
Q_{SO1} = m • Cp • (T – T_{ref}) = 44.4165 • 0.2377 • (32.39 – 25) = 78.0252 kcal = 326.3013 kJ

d) *Sensible heat of water vapor* (Q_{SO4})
m = weight of moisture
Q_{SO4} = m • Cp • (T – T_{ref}) = 0.9816 • 1.8723 • (32.39 – 25) = 13.5803 kJ

e) *Latent heat of evaporation* (Q_{L1})
m - weight of evaporated water
H_{fg} - specific heat of vaporization, kJ/kg
Q_{L1} = m • h_{fg} = 0.08443 • 2406.7 = 203.1977 kJ

3.3.1.3. Drying Efficiency

The drying efficiency is calculated using the following formula:

$$\eta = \frac{Qg+Qev}{Q_{ET}} \, x \, 100\%$$

where:
Qg - Heat used to heat the material (kJ);
Qev - Heat used to evaporate water (kJ);

Q_{ET} - Heat from drying media (kJ).

$$\eta = \frac{(Q_{SO1}+Q_{SO2})+Q_{L1}}{Q_{SI3}+Q_{SI4}} \times 100\% = 31.86\%$$

The drying efficiency of each temperature variable using the same method to determine the drying efficiency can be seen in Table 2.

Table 2 Drying efficiency depending on drying temperature

Temperature (°C)	Efficiency (%)
40	31.86
60	12.54
70	14.27
80	2.64

3.4. Comparison of Research Results to Previous Research

A comparison of our research results on drying Moringa leaves with other research can be seen in Table 3.

Based on Table 3, Moringa leaves can be dried using various methods [18], namely oven blower, drying, drying at room temperature, and drying at cold temperatures, the most effective method was obtained, namely The oven method blower at a temperature of 55°C could reduce the water content in Moringa leaves from 77.98% to 5.53% in 2 hours while based on the results of research conducted using a tool was tray dryer could reduce it from only 84% to 40.73% at a temperature of 70°C for four hours. Research on drying Moringa leaves using method oven dryer with temperature variations of 60°C, 70°C, and 80°C for 24 hours obtained Moringa leaves with the lowest moisture content at 80°C, namely 8.62% [19]. [20] researched drying Moringa leaves using various methods: oven drying, sun drying, and shade drying. The best method was obtained, using oven drying at a temperature of 50°C for 12 hours, producing dry Moringa leaves with a water content of 1.65%. Based on the research results conducted by several researchers, the drying process of Moringa leaves using the method tray dryer or oven dryer has the advantage of being able to dry Moringa leaves in a longer time shorter than other methods independent of weather conditions.

This study aims to determine the drying process of Moringa leaves using temperature variables and different trays. Observations were started by weighing the mass of Moringa leaves before being put into the photovoltaic tray dryer. Then every 30 minutes, the mass of Moringa leaves is weighed again to determine the reduction in water content in the Moringa leaves on each tray and carried out for 4 hours. The goal is to find out the tray which is most effective in the drying process. In addition, measurements of the temperature of the wet and dry balls and the rate of the drying air are also carried out, where the temperature data is taken every 30 minutes for 4 hours to determine the value of air humidity, while the measurement of air velocity aims to determine the amount of air entering the room dryer. The method of testing the water content of Moringa leaves is based on [22].

Table 3 Comparison of research results conducted on other research

Materials	Drying Method	Mass (Kg)	Temperature (°C)	Time (Hour)	Water Content (%)		References
					Before	After	
Moringa Leaves	Oven blower	-	55	2	77.98	5.53	[21]
	Sun drying	-	43	120	77.98	6.58	
	Room Temperature	-	29	432	77.98	9.81	
	Cold Temperature (Refrigerator)	-	2	168	77.98	11.59	
Moringa Leaves	Oven dryer	-	80	24	-	8.62	[19]
		-	70	24	-	8.71	
		-	60	24	-	8.91	
Moringa Leaves	Oven drying	0.4	50	12	-	1.65	[20]
	Sun drying	0.4	-	120	-	4.25	
	Shade drying	0.4	-	168	-	5.89	
Moringa Leaves	Tray dryer	0.4	70	4	84	40.73	This study

4. Conclusion

This study successfully analyzed the effect of the temperature on drying Moringa leaves using a photovoltaic tray dryer, which used photovoltaic technology to earn energy for solar radiation. This energy is utilized as a source to operating oven tray. Four trays were used for drying the Moringa leaves. Tray 3 is the most effective tray, which reduced the water content by around 49.49 % for 4 h—the higher the drying temperature, the lower the drying efficiency of the photovoltaic tray dryer. In addition, using a tray dryer or oven dryer for drying Moringa leaves has the advantage of shortening time and not depending on weather conditions. For further research, the photovoltaic tray dryer will be observed by the drying air heating system used to increase the capacity or the quantity of heater and fan. It is intended that the drying process of the material occurs evenly and faster. It is also necessary to test the nutritional content of Moringa leaves after the drying process to determine whether there is a detriment to the nutrient content in the drying process at a certain temperature. Therefore, the Moringa leaves could be formed for the recommended dietary allowance which contains high amounts of vitamins, minerals, amino acids, and antioxidants.

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