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Performance of a Moringa Leaf Dehumidification Drying System Using Peltier Effect Thermoelectric Cooling

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ABSTRACT

The study focuses on a drying system that integrates a rack-type convective dryer with a Peltier effect thermoelectric cooler to optimize the drying process of moringa leaves. This system is designed to achieve lower drying temperatures, which is essential for preserving the quality of the leaves. To evaluate the performance of this dryer, researchers use temperature and relative humidity data to construct a programmed psychrometric diagram. This diagram helps in calculating crucial parameters such as the absolute humidity and the specific volume of the drying air. These calculations are essential in determining the drying rate of moringa leaves. The results indicated that moringa leaves dried on drying rack-1 exhibited a higher drying rate compared to those on drying rack-2. Additionally, a drying air speed of 2.1 m/sec yielded a superior drying rate compared to a lower air speed of 1.5 m/sec. After 5.0 hours of drying, the Moringa leaves achieved a moisture content of 8.6% (wb) with a drying air speed of 2.1 m/sec, 9.3% (wb) with a speed of 2.6 m/sec, and 13.9% (wb) with a drying air speed of 1.5 m/sec. The drying process maintains a maximum temperature 59.3°C, placing it within the low-temperature drying category, which helps preserve the physicochemical quality of the dried Moringa leaves.

1. INTRODUCTION

Moringa plant (*Mongira oleifera*) contributes to increasing the intake of important nutrients and phytochemical compounds with antioxidant properties (Gopalakrishnan *et al*., 2016; Anjorin *et al*., 2010; Fahey, 2016). Moringa leaves are rich in macro and micronutrients, including protein, carbohydrates, fat, fiber, minerals, and various phytochemical compounds (Moyo *et al*., 2011). Bioactive compounds such as vitamin C (ascorbic acid), flavonoids, phenolics, and carotenoids are also present (Vongsak *et al*., 2014). Therefore, moringa leaves are a potential source of antioxidant compounds (Jothilakshmi *et al*., 2017).

One challenge in the post-harvest handling of moringa leaves is the rapid decline in the quality of fresh leaves, which have a relatively short shelf life of around two to three days (Jothilakshmi *et al*., 2017; Kumar *et al*., 2023). Drying fresh moringa leaves is an option to extend their storage time, simplify packaging and transportation, and increase the economic value of the product (Lindriati *et al*., 2022; Manuwa *et al*., 2020). The choice of method and operating conditions for drying moringa leaves affects the nutritional content and phytochemical properties of the dried leaves (Kumar *et al*., 2023). The ascorbic acid and β-carotene content of dried moringa leaves is influenced by the drying method (Anuja & Ramkumar, 2017; Martínez *et al*., 2017). Drying at high temperatures can reduce the quality of dried moringa leaves, leading to issues such as discoloration, decreased aroma and texture, loss of nutrients, and reduced antioxidant properties (Ali *et al*., 2014). Convective drying with an air flow speed of 0.5 m/sec and a drying air temperature of 60 °C can help maintain the quality and color of the dried moringa leaves (Premi *et al*., 2010).

Reducing the humidity (dehumidification) of drying air is an approach to avoid using high drying air temperatures. The role of drying air as a heat transfer medium and in mass transfer between the drying air and wet material is fundamental to convective drying. Decreasing the relative humidity of drying air through dehumidification and heating mechanisms aims to increase drying efficiency (Munters, 2019). The dehumidification mechanism in drying technology includes using zeolite as an adsorbent to absorb water vapor from the drying air (Djaeni *et al*., 2011; Djaeni *et al*., 2018). Additionally, dehumidification systems can be powered by solar energy (Yahya *et al*., 2008). The working principle of dehumidification using an Air Conditioner (AC) system involves channelling high-humidity air into a low-temperature evaporator grille. Condensation occurs when the environmental temperature reaches the dew point temperature. After the condensation process, the dry air can be used for drying operations (Susilo *et al*., 2020). Dehumidification of drying air by cooling it using a dehumidifier machine operating on the AC cooling mechanism has been employed for drying peanut seeds to lower the drying air temperature, thereby preserving the quality of the seeds (Sholikah *et al*., 2024).

The Peltier effect thermoelectric cooler functions to reduce the temperature of the drying air as it comes into contact with the cooling fins, achieving a water vapor saturation temperature. This allows the use of a drying air temperature that is not too high, thereby maintaining relatively low humidity. The advantages of Peltier effect thermoelectric coolers include their small dimensions, the use of clean and safe energy, and their practicality as cooling equipment that can provide a cooling effect below ambient temperature (Kurniawan & Setiawan, 2018).

The aim of the research was to determine the drying performance of moringa leaves using a dehumidification drying system that operates convectively with low-humidity drying air circulating in a closed system. This research contributes to the development of dehumidification drying technology by utilizing a Peltier effect thermoelectric cooling dehumidifier, which is more practical and environmentally friendly. Additionally, it provides valuable information on the performance of a dehumidification drying system incorporating a Peltier effect thermoelectric cooling dehumidifier for drying moringa leaves, a topic that has not been extensively explored. It is expected that results of this research can be to dry leafy vegetables in a better and more efficient way through dehumidification process.

2. MATERIALS AND METHODS

2.1. Design of Dehumidification Drying System

The concept of a low-humidity drying (dehumidification) system using a Peltier effect thermoelectric cooler was explained in Figure 1. The high-humidity drying air flow exited the drying chamber through an exit door (1) and flowed into the air duct (3) due to the operation of the suction fan (5). A Peltier effect thermoelectric cooling dehumidifier (2) was installed in the air duct, so the high-humidity drying air flow coming out of the drying chamber then makes surface contact with the heat sink on the cold side of the Peltier element. The cooling effect reduced the air temperature until it reached the condensation point of water vapor, causing the humidity of the drying air to drop further. The drying air flow is then recirculated into the drying chamber through the entrance (4). The drying air was then heated using an incandescent lamp (6) to produce hot air with low relative humidity (RH), which is ready to be reused as drying medium.

2.2. Drying Moringa leaves

Moringa leaves were spread evenly at 1 kg of wet leaves per square meter of the drying rack surface area, which is placed on a multi-tiered drying rack (7). The convective drying mechanism occurs in a closed drying room when there is direct contact between the drying air and the wet moringa leaves, with the drying room closed by the drying rack door (8). The drying air circulation and equipment layout was presented in Figure 2.

2.3. Drying Performance

2.3.1. Measurement of Drying Kinetic

Drying kinetic measurement in convective drying systems was carried out using a basic psychrometric concept approach, which considers the thermodynamic behavior of a mixture of air and water vapor (moist air) applied at atmospheric pressure. Therefore, the state of homogeneous moist air at atmospheric pressure can be clearly determined by the two variables: temperature and humidity (Meyer & Thevenard, 2019).

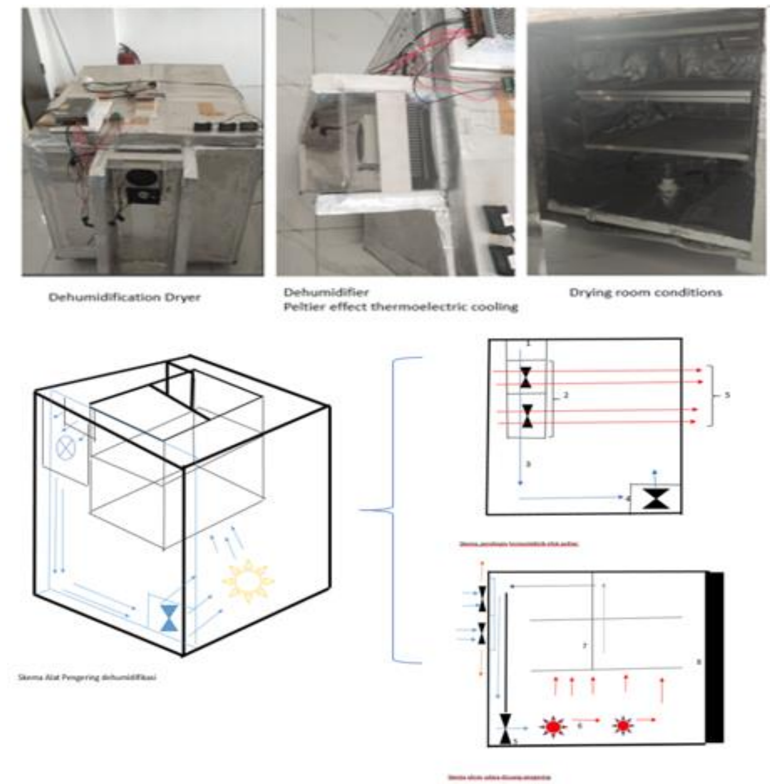

Figure 1. Dehumidification dryer (dehumidifier) system with a Peltier effect thermoelectric cooler

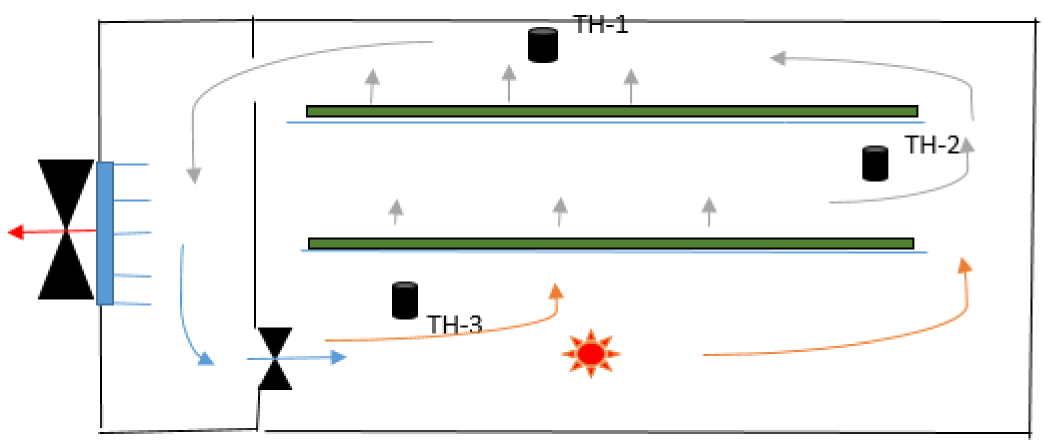

Figure 2. Position of Peltier kit, incandescent heating lamp, air fan, and digital thermometer-hygrometer

Measurement of temperature and RH of drying air is done to see the changes in psychrometric properties of wet air during drying. Measurements are made at three measurement points in the drying room by considering the direction of drying air circulation as in Figure 2. Measurements of temperature and RH of the drying air were carried out at three positions: before passing through drying rack-1 (TH-3), after passing through and coming into contact with moringa leaves on the first drying rack (TH-2), and after contacting and passing through the moringa leaves on the second drying rack (TH-1). The temperature and RH of the drying air are used as data input for programmed psychrometric graphic calculations to determine the absolute humidity and specific volume of the drying air under these conditions.

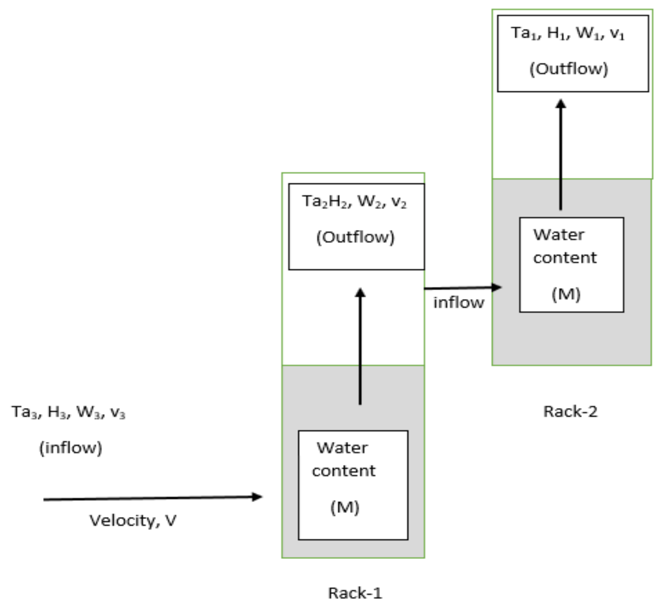

Figure 3. Airflow volume control scheme in contact with the drying rack

The drying kinetics of moringa leaves can be expressed as the mass rate of vapor that evaporates from wet leaves into the drying air. Assuming the drying chamber is water vapor-tight to the air outside the chamber, and applying the principle of mass balance of water vapor in the drying airflow control volume in Figure 3, it can be stated that the amount of water that evaporates from moringa leaves is equal to the increase in the absolute humidity of the drying air after contact with moringa leaves on a drying rack as Equation 1.

$$R_w M_d = \left(\frac{W_{out} - W_{in}}{v}\right) V \quad (1)$$

where R_W is drying rate of moringa leaves on a drying rack [g vapour / (g dry matter . min)], M_d is mass of dry matter of moringa leaves (g), W_{in} and W_{out} is respectively absolute humidity of the drying air before and after contact with moringa leaves on the drying rack (g vapour / g dry air), V is volume rate of drying air flow that comes into contact with moringa leaves (cm^3/min), and v is specific volume of drying air at a certain temperature and RH (cm^3/g dry air) The water content of dried moringa leaves, calculated using Equation 1, was tested for accuracy against the measured water content of moringa leaves using the following statistical criteria calculations.

2.3.2. Physicochemical Properties of Dried Moringa Leaves

The effect of dehumidification drying conditions on the physicochemical properties of dried moringa leaves measured in this study included changes in the color of dried moringa leaves, changes in the total flavonoid content and vitamin C levels in the solvent extract of dried moringa leaf powder.

2.3.2.1. Color measurement

The color of dried moringa leaves was measured using a quantitative color measurement tool, expressed in the three-dimensional Hunter *L**, *a**, *b** notation system. The *L** (lightness) ranges from 0 for black to 100 for white. The *a** (green-red) is positive (+*a*) for red and negative (-*a*) for green, while the *b** (blue-yellow) is positive (+*b*) for yellow and negative (-*b*) for blue. The numerical values of *a** and *b** represent the chromaticity of the color.

2.3.2.2. Chemical properties measurement

Determination of total flavonoid content was conducted using spectrophotometry method, involving several steps: preparation of a series of standard quercetin solutions, wavelength optimization, measurement of the absorbance of flavonoid isolates obtained from ethanol solvent extraction of dried moringa leaf powder with maceration, and calibration of the measurement results.

Determination of total vitamin C content was conducted using spectrophotometry, involving several steps: to prepare the Vitamin C stock solution, preparation of Calibration Curve Solution, determination of the Maximum Wavelength of Vitamin C Solution, subsequently, a calibration curve was plotted, and the linear regression equation was calculated based on the obtained data.

3. RESULTS AND DISCUSSION

3.1. Psychrometric Properties of Drying Air

A graph of the changes in temperature and RH of the drying air during the drying of moringa leaves is presented in Figure 4. It can be seen that the highest drying air temperature was obtained at the measurement point TH-3. The drying air temperature then decreased at the measurement point TH-2, and the lowest drying air temperature value was obtained at the measurement point TH-1. On the other hand, the highest RH of the drying air was obtained at the measurement point TH-1, which represents the drying air after passing through the moringa leaves on both drying racks. It can be seen that at different drying air speeds, the highest drying air temperature (T3) was obtained at the measurement point TH-3. The drying air temperature then decreased at the measurement point TH-2 (T2), and the lowest drying air temperature value was obtained at the measurement point TH-1 (T1).

The temperature range of the measurement results in Figure 4 shows that the highest drying air temperature (T3) does not exceed 60 °C. This shows that the performance of the designed dryer meets the operating conditions for the safe drying of moringa leaves. In accordance with the results of previous research, which state that to maintain the quality of dried moringa leaves, the maximum drying air temperature should be around 60 °C (Premi *et al*., 2010).

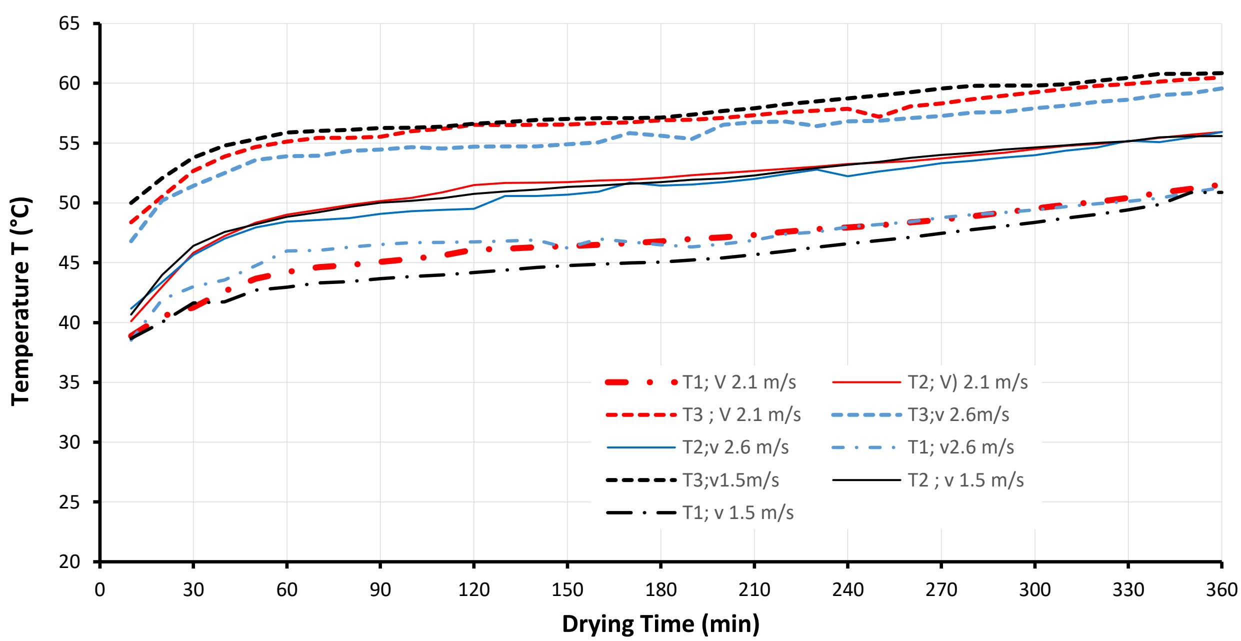

Figure 4. Changes in drying air temperature at three points during drying of moringa leaves with different air flow speeds.

On the other hand, the increase of RH in the drying air occurs after passing through wet leaves (Figure 5). The highest RH of the drying air was obtained at the point TH-1 (H1), which represents the drying air after passing through the moringa leaves on both drying racks. Curve of changes in temperature and RH of the drying air in the drying room, can indicate the heat and mass transfer of water vapor between the drying air, incandescent heating lamp, and wet leaves. This phenomenon is consistent with the heat and mass transfer mechanism of water vapor in the convection drying system that occurs in the drying chamber. The drying airflow entering the drying chamber is heated by an incandescent

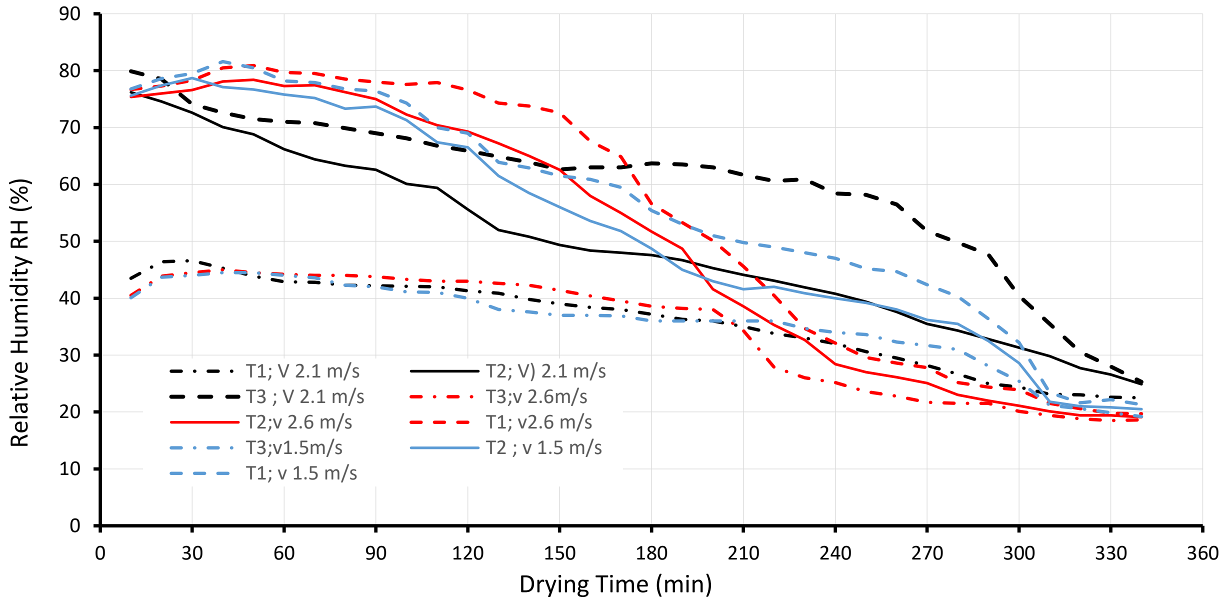

Figure 5. Changes in RH of drying air at three measurement points during drying of moringa leaves with different air flow speeds.

lamp installed parallel to the direction of the airflow. After passing through the incandescent lamp, the temperature and RH of drying air were measured at TH-3, where the highest drying air temperature (T3) and the lowest RH (H3) were obtained. Next, the airflow passes through and comes into contact with the moringa leaves on drying rack-1. The temperature difference between the drying air and the moringa leaves causes convection heat transfer from the air to the leaves. The amount of heat received by the moringa leaves is used to meet the heat requirements for the evaporation of water. Consequently, the temperature of drying air decrease, but its RH increase. After passing through the moringa leaves on drying rack-1, the temperature and RH were measured at TH-2, showing that the drying air temperature (T2) had decreased, while the RH (H2) had increased. The airflow then moves past and comes into contact with the moringa leaves on drying rack-2, where temperature and RH were measured at TH-1, indicating further decreases in temperature and increases in RH. This is in accordance with Darvishi *et al*. (2015) that convective drying process is a heat and mass transfer phenomenon taking place simultaneously between the drying air and the material being dried.

Different drying air speeds influence the pattern of temperature reduction and RH increase within the drying chamber. The drying air temperature range during the convective drying of moringa leaves in Figure 4 can also describe the performance of the designed dehumidification drying system. Besides determining the working capacity of the drying system, it is also necessary to monitor the increase in drying air temperature to ensure it does not exceed the highest limit, preventing damage to the material being dried. The highest drying air temperature obtained at the TH-3 measurement point was the result of maximum heating by an incandescent lamp when a drying load was applied. To achieve an average water content of dry moringa leaves is 8.60 (% wb), the drying process needs to last for 300 min at an air speed of 2.1 m/s, resulting in a maximum drying air temperature of 59.3 °C. With an air speed of 2.6 m/s, the drying process needs to last for 320 min, resulting in a maximum drying air temperature of 58.5 °C to achieve an average water content of dry moringa leaves is 9.20 (% wb), and the drying process needs to last for 340 min, resulting in a maximum drying air temperature of 60.8 °C to achieve an average water content of dry moringa leaves is 9.85 (% wb).

3.2. Dehumidification of Drying Air

The dehumidification effect of the drying air was assessed only at a flow rate of 2.6 m/s, based on the optimization of achieving a water content of dry moringa leaves below 10% (wet basis) within a drying time of 320 min. The temperature and RH of the drying air measured at TH-1 describe the psychrometric condition of the drying air after passing through and coming into contact with moringa leaves on both drying racks. Next, the drying airflow moves outside the drying room to be reconditioned. Recirculating the drying airflow aims to restore drying air conditions by reducing RH and increasing temperature. The humidity of the drying air is reduced by condensing water vapor after the drying air comes into contact with the cooling element of the dehumidifier component during the recirculation of the drying airflow. The effect of dehumidification of the drying air occurs in a fluctuating manner, as seen in Figure 6.

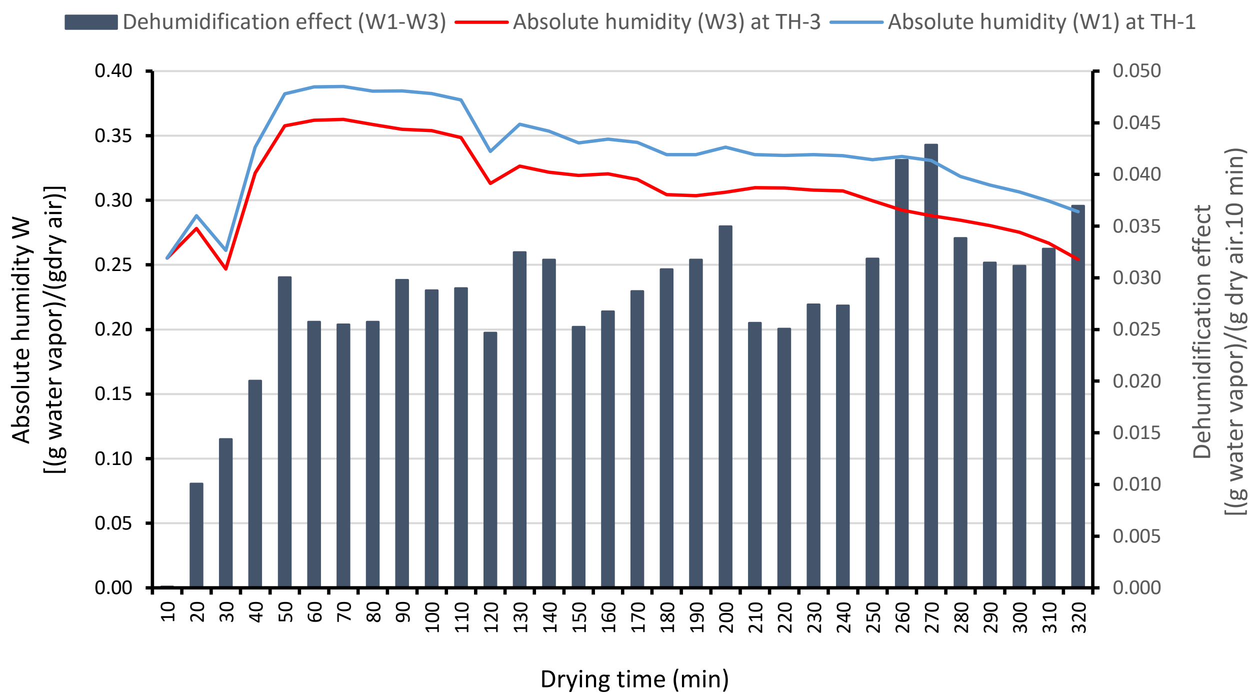

Figure 6. Dehumidification of drying air during drying of moringa leaves at speed drying air 2.6 m/s

The decreasing in the absolute humidity of the drying air measured by TH-1 and TH-3 indicates the performance of the dehumidifier component in this dehumidification dryer system. The effect of decreasing the absolute humidity of the drying air gradually increased from the beginning of the drying period to the end. The increasing in the dehumidification effect aligns with the increase in the rate of evaporation of water vapor from the moringa leaves and the decrease in the surface temperature of the cold side of the Peltier element as long as direct current continues to flow. Thus, it can be stated that the effective function of the dehumidifier component is influenced by the drying load in the drying room. Therefore, when designing a dehumidification drying system, accurately knowing the mass transfer rate is an important factor in controlling the drying system to save energy and improve product quality (Hasizah *et al*., 2022).

3.3. Drying Kinetics of Moringa Leaves

3.3.1. Drying Rate

The drying rate of moringa leaves was calculated using equation (1), which is derived from the volume control scheme for changes in the psychrometric properties of drying air in Figure 3. The drying curve, which depicts the decrease in the water content of moringa leaves during drying, can be seen in Figure 7 and Figure 8. A decrease in the water content of the moringa leaves is observed on drying rack-1. Water content of moringa leaves decreases rapidly during the first 90 min of drying, with the highest reduction observed at an air speed of 1.5 m/s. The decrease in water content then began to slow down toward the end of the drying process. During this period, the highest reduction in water content was achieved at an air speed of 2.6 m/s.

The curve of the decrease in water content of wet moringa leaves on drying rack-2 shows a different pattern compared to that on drying rack-1. The decrease in water content of wet moringa leaves on drying rack-2 (Figure 8) occurs at a slower rate from the beginning of drying up to 150 min. Subsequently, the rate of decrease in water content begins to increase until the drying process is complete. This increase in the rate of water content reduction is related to the speed of the drying air flow. The highest rate of water content decrease in wet moringa leaves on drying rack-2 occurred at an air flow speed of 2.1 m/s. The condition of the drying air after passing through drying rack-1 shows a decrease in temperature and an increase in RH. To ensure the convective drying mechanism operates effectively, increasing the speed of the drying air flow can enhance the convection heat transfer coefficient and reduce the water vapor pressure of the drying air by accelerating its circulation. This increase in heat and mass transfer accelerates the evaporation rate and reduces the water content of moringa leaves on both drying racks. The mass transfer of water vapor is generally influenced by drying conditions such as heat transfer mechanisms (convection, conduction, or radiation), layer thickness, RH of the surrounding air, product temperature, air flow speed, and product type (Darvishi *et al*., 2018; Ee *et al*., 2021).

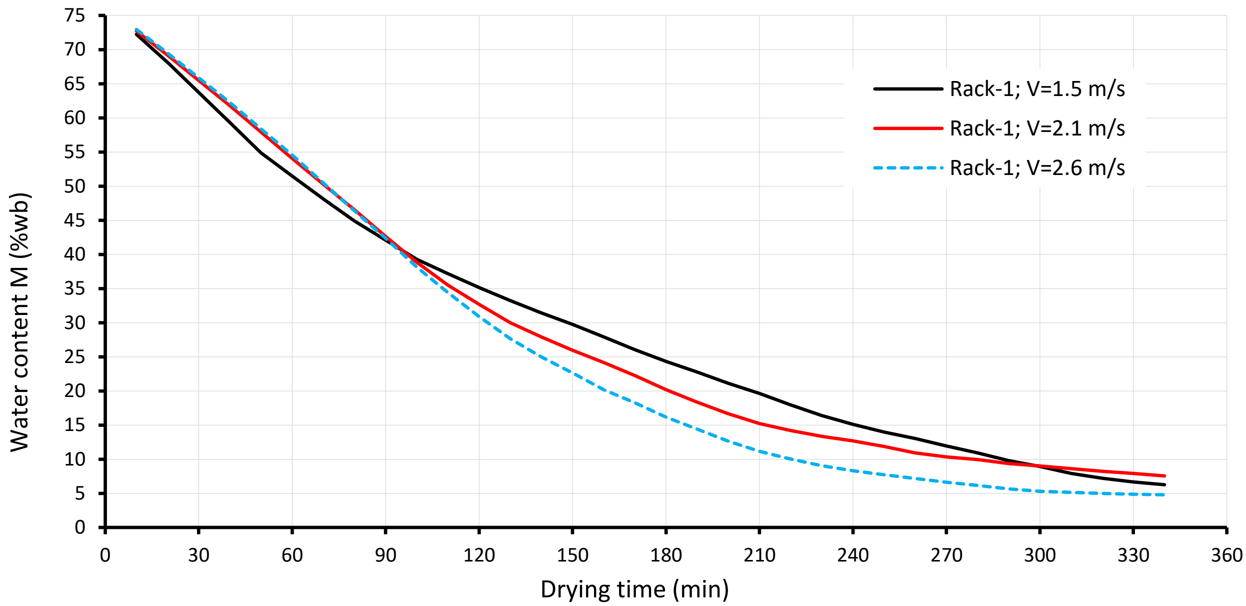

Figure 7. Curve of water content reduction of moringa leaves on drying rack-1 with different drying air speeds

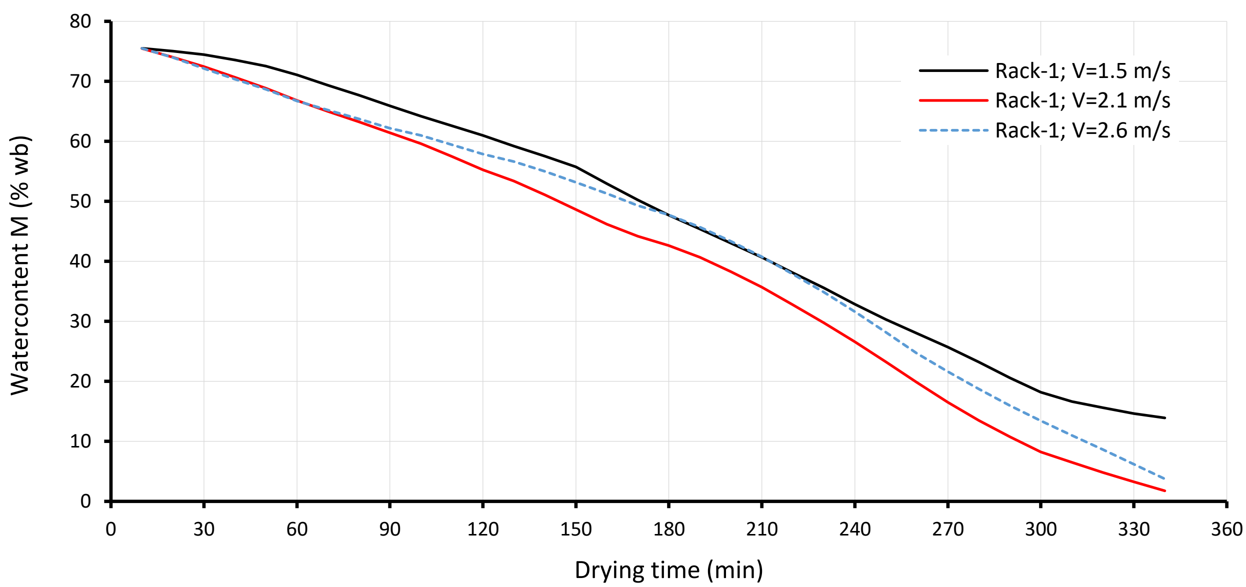

Figure 8. Curve of water content reduction of moringa leaves on drying rack-2 with different drying air speeds

3.3.2. Drying Rate Constant

The drying rate constant is an important parameter in analyzing the efficiency of the drying process. The drying rate constant (R) is calculated based on the rate of water evaporation from wet moringa leaves relative to the amount of dry material in the leaves, expressed as (g water per g dry material per min) as expressed in equation (1). The drying rate of moringa leaves describes the amount of water vapor that evaporates from wet moringa leaves over a certain drying period. The drying rate constant of moringa leaves on drying rack-1 in Figure 9. It is influenced by the speed of the drying air flow, and shows that at the beginning of the drying process, the drying rate constant increases, with the highest increase as 0.0183 g water/(g dried material.min) observed at an air flow speed of 1.5 m/s, after drying for 50 min. Increasing the speed of the drying air flow delays the maximum increase in the drying rate constant for moringa leaves on drying rack-1. The maximum drying rate constant of moringa leaves at a drying air velocity of 2.1 m/s was 0.0160/g water/g dry material/minute, achieved after 90 minutes of drying, and drying rate constant of moringa leaves at a drying air velocity of 2.6 m/s was 0.0174, achieved after 100 min of drying.

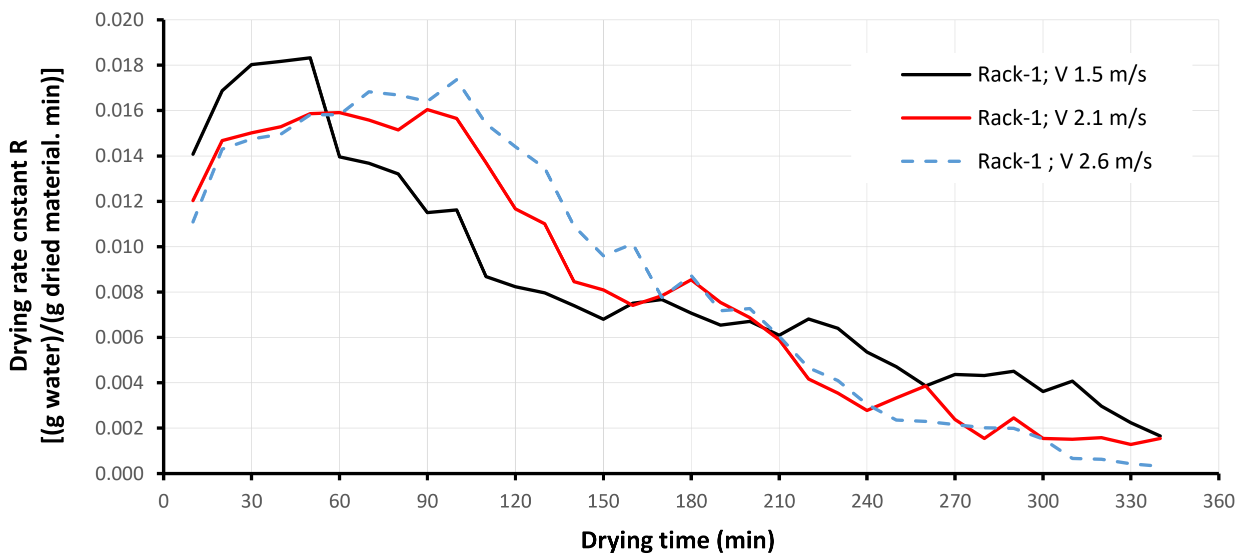

Figure 9. Curve of drying rate constant of moringa leaves on drying rack-1 with different drying air speeds.

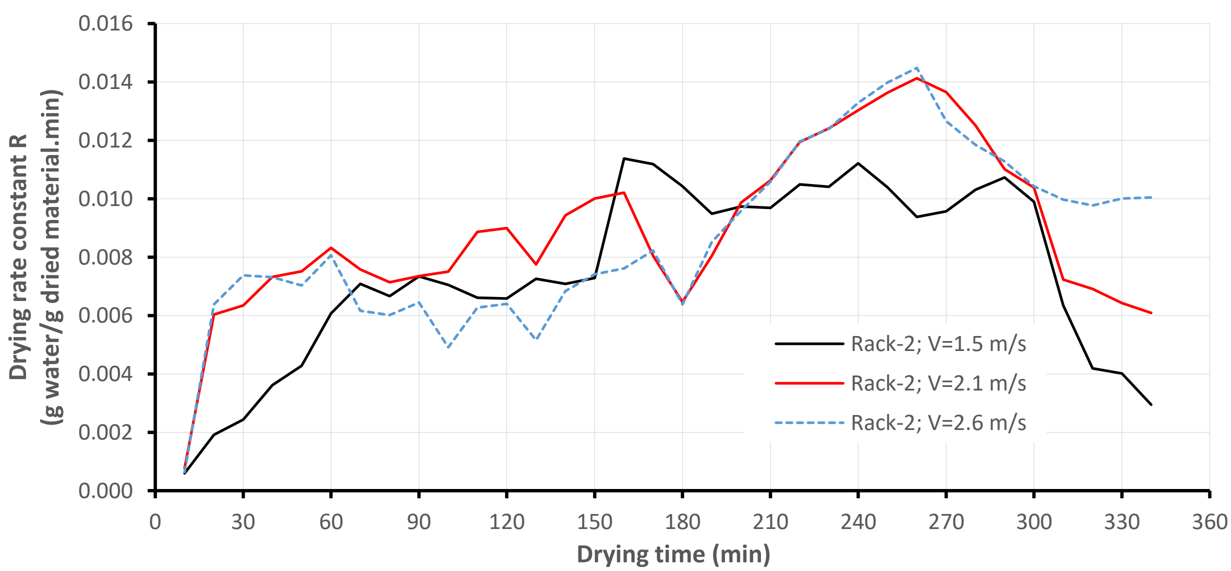

Figure 10. Curve of drying rate constant of moringa leaves on drying rack-2 with different drying air speeds.

The drying rate constant of moringa leaves on the drying rack-2 (Figure 10) increased during the drying process. The increasing in drying rate constant of moringa leaves on drying rack-2 was reached earlier as the drying air speed increased. The maximum increase in the drying rate constant of moringa leaves on drying rack-2, at a drying air speed of 2.6 m/s, was 0.0145 after 260 minutes of dryer operation, maximum increase in the drying rate constant of moringa leaves at at a drying air speed of 2.1 m/s, was 0.0137 after 270 minutes of dryer operation, and maximum increase in the drying rate constant of moringa leaves at at a drying air speed of 1.5 m/s, was 0.0114 after 160 minutes of dryer operation.

The time required to reduce the water content of wet moringa leaves 540 g (1 kg/m² drying rack area) in dehumidification drying at a drying air speed of 2.1 m/s is shortest was 300 minutes (5 hours), and the lowest average water content 8.2 % (wb). Followed by drying air speed of 2.6 m/s was 320 minutes with average water content 8.6% (wb), and drying air speed of 1.5 m/s was 340 minutes with average water content 11.8% (wb). In a convective drying mechanism, the rate of heat transfer from the drying medium to the wet material and the rate of mass transfer from the wet material to the drying air increase with higher drying air flow speeds. The drying process aims to reduce the material's water content through heat transfer and mass transfer mechanisms. The mass transfer of water vapor is affected generally by drying conditions such as heat transfer mechanisms (convection, conduction, or radiation), layer thickness, RH of the surrounding air, product temperature, air flow speed, and product type (Darvishi *et al*., 2018; Ee *et al*., 2021).

3.4. Physicochemical Properties of Dried Moringa Leaves

The speed of the drying airflow affects the maximum temperature reached, the final water content of the moringa leaves, and the drying time required to achieve this water content. Additionally, the operating conditions during the drying process influence the physicochemical properties of the dried moringa leaves. In Table 1, it can be observed the difference in dehumidification drying performance can also be observed from the changes in the physicochemical properties of dried moringa leaves. The highest maximum drying air temperature was achieved at an airspeed of 1.5 m/s was 60.8 °C, with a drying time of 340 min to reach a moisture content of 9.85% (wet basis). The relatively high temperature and extended drying time result in changes to the color values of moringa leaves. On the L^* scale, lower values indicate reduced brightness, while on the a^* scale, the lowest negative value (-9.63) signifies a less green appearance. The vitamin C and flavonoid content in the extract of dried moringa leaves obtained from dehumidification drying at an airspeed of 1.5 m/s are the lowest compared to those obtained at other airspeeds. Dehumidification drying at an airspeed of 2.1 m/s delivers the best drying performance, as it achieves the lowest moisture content in dried moringa leaves, maintains a relatively low maximum drying air temperature below 60 °C, and requires the shortest drying time. The optimal drying performance also influences changes in the physicochemical properties of dried leaves. On the L^* scale, the highest value indicates greater brightness; on the a^* scale, the highest negative value signifies a greener color; and on the b^* scale, the smallest positive value represents a less yellow hue. The optimal drying performance of dehumidification drying at an airspeed of 2.1 m/s yields the highest vitamin C and flavonoid content in the extract of dried moringa leaves.

Table 1. Effect of operating conditions on the physicochemical properties dried moringa leaves

Air flow speed V (m/s)	Time (min)	Temperature (°C)	Characteristic of Dried Leaves					
			WC (%wb)	Color L^*	Color a^*	Color b^*	Vit. C (%)	Flavanoid (%)
1.5	340	60.8	9.85	40.6	-9.63	23.11	2.61	0.138
2.1	300	59.3	8.60	44.0	-9.96	20.84	2.80	0.176
2.6	320	58.4	9.20	43.7	-9.83	22.29	2.74	0.163

The color of fresh and dried moringa leaves was measured using a chroma meter and expressed in the Hunter scale notation L^*, a^*, b^*. The results, shown in Table 1, indicate that the chromatic values range from green to yellow, with a medium brightness level. The decrease in green color saturation was not very noticeable between fresh and dried moringa leaves. The same was true for the decrease in yellow color saturation. Therefore, it can be stated that the drying conditions using the designed dehumidification dryer can maintain the color characteristics of dried moringa leaves, making them not significantly different from fresh moringa leaves. In this study, the results showed that the maximum drying air temperature measured was 59.26 °C. These results confirm previous convective drying research that using a drying air flow speed of 0.5 m/sec and a drying air temperature of 60 °C can maintain the quality and color of moringa leaves (Premi *et al*., 2010).

The determination of the total vitamin C content and total flavonoid content of dried moringa leaves was carried out using the spectrophotometric analysis method on samples of dried moringa leaf extract. The total vitamin C content of dried moringa leaves dried with a dehumidification dryer at different air speeds showed no significant differences. The average total vitamin C content of dried moringa leaves obtained in this study is similar to that of Moringa leaves dried using a lamp heater at a temperature range of 40 °C to 60 °C, which is 26–28% (Lindriati *et al*., 2022). The highest total flavonoid content of dried moringa leaves was obtained at a drying air flow rate of 2.1 m/sec, measuring 0.176% of the sample weight. This value was not significantly different from the average total flavonoid content at an air flow speed of 2.6 m/sec, which was 0.163% of the sample weight. However, significantly different results were obtained for the average total flavonoid content of dried moringa leaves in dehumidification drying at a drying air flow speed of 1.5 m/sec and in air drying. Increasing the drying air flow speed causes the drying rate to increase, resulting in dried moringa leaves with lower water content. The low water content of dried moringa leaves, when used as sample material for testing the total flavonoid content, causes the ratio of the weight of the extract fraction to the weight of the sample to be higher, resulting in high test results for the total flavonoi content (Jothilakshmi *et al*., 2017).

4. CONCLUSION

A rack-type convective drying system with a Peltier effect thermoelectric cooled dehumidifier component has been used for drying Moringa leaves. Changes in temperature and RH of the drying air were used as data input in programmed psychrometric diagram calculations to measure drying performance. To dry 540 grams of Moringa leave with an initial average water content of 78% wb (wet basis), evenly distributed across both drying racks, an airflow speed 2,1 m/s demonstrated the best performance. This setup achieved a final water content of 8.60 % (wb) within 300 min at maximum temperature of 59.26 °C. Followed by drying air speed of 2.6 m/s was 320 min with average water content 8.6% (wb), and drying air speed of 1.5 m/s was 340 min with average water content 11.8% (wb). The designed dehumidification drying operating conditions can maintain the physicochemical quality of dried moringa leaves.

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