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Effect of the number of exhaust fans on a rotary dryer for turmeric drying

I.B. Alit*, I.G.B. Susana, I.G.A.K.C. Adhi, S. Hidayatullah, E. Gunawan

*Mechanical Engineering Department, Engineering Faculty, the University of Mataram, Jl. Majapahit no. 62, Mataram, NTB, 83125, Indonesia. HP. 081999183088

*E-mail: alit.ib@unram.ac.id

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ABSTRACT

One type of dryer frequently used in agricultural drying is the rotary dryer. When solids are dried in a rotary dryer, a transport phenomenon occurs that includes the simultaneous transfer of mass, heat, and momentum. This study aims to determine the effect of the number of exhaust fans on the drying performance of turmeric using a rotary dryer. The number of exhaust fans used varied from 1, 2, and 3 units. The main parameters observed included the final moisture content, drying rate, and energy efficiency. The results showed that the use of one exhaust fan resulted in the lowest final moisture content compared to other configurations. During the 8-hour drying process, the rotary dryer with one exhaust fan was able to reduce the turmeric moisture content from 89% to 57.8%, with an average drying rate of 0.55 kg/hour. The use of one exhaust fan resulted in an optimal temperature range of 50–60°C. In addition, this configuration also showed relatively high energy efficiency, ranging from 10.8% to 25.5%. Therefore, the use of a single exhaust fan in a rotary dryer is considered the most optimal configuration in balancing the quality of drying results and energy efficiency.

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1. INTRODUCTION

Turmeric (*Curcuma longa* L.), a perennial herbaceous plant of the Zingiberaceae family, is widely cultivated in tropical and subtropical regions, especially in South and Southeast Asia. It is extensively used not only as a culinary spice but also in traditional medicine and the pharmaceutical and cosmetic industries, largely due to its bioactive compound, curcumin. The global demand for turmeric has increased steadily due to its antimicrobial, anti-inflammatory, and antioxidant properties (Prasad et al., 2014). However, the quality of dried turmeric, particularly in terms of color, aroma, and curcumin content, is highly dependent on the post-harvest processing methods employed, especially during the drying process. Drying is a critical step in turmeric post-harvest processing as it reduces moisture content from approximately 70–90% (wet basis) to around 8–10%, ensuring shelf stability, preventing microbial spoilage, and reducing weight for transportation. Traditional sun drying is still commonly used in many rural areas; however, it is associated with several drawbacks, including long drying times, uneven drying, contamination, and dependency on weather conditions (Sharma et al., 2021). These limitations have led to an increased interest in mechanical drying methods, which offer faster and more controlled drying environments. Among mechanical drying systems, rotary dryers have gained attention for their ability to handle large volumes of material with relatively uniform drying. A rotary dryer consists of a rotating cylindrical drum, through which the turmeric moves while being exposed to heated air, enabling both convective

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and conductive heat transfer. Continuous rotation promotes uniform mixing and exposure of particles, thereby reducing the likelihood of localized overheating or under-drying (Bawa et al., 2023).

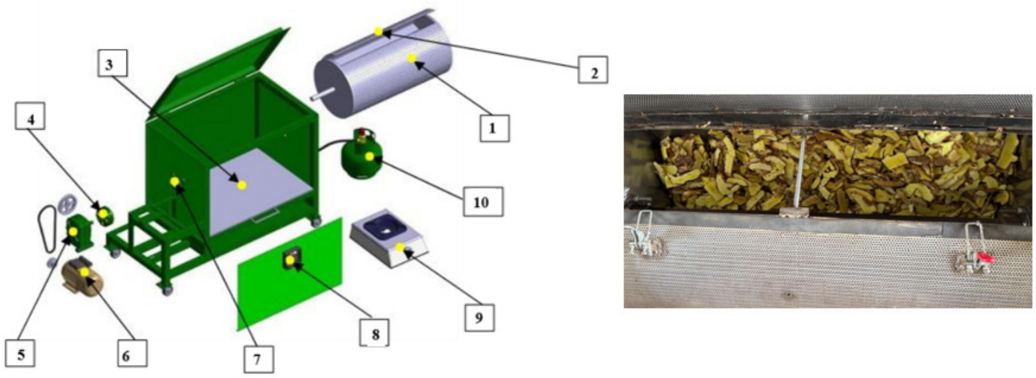
The rotary dryer, powered by LPG, provides a stable temperature during the drying process, resulting in shorter drying times and uniform moisture removal. This contributes to minimizing post-harvest losses in the agricultural sector, which are often caused by the high energy consumption of inefficient drying equipment (Nguimdo and Noumegnie, 2020;Li, et al,, 2020). For instance, tobacco drying accounts for up to 60% of total production energy consumption(Li, et al., 2022). Rotary dryers are advantageous due to their low maintenance costs and specific energy consumption that is 15–30% lower than conventional systems(Giudice et al., 2019). Rotary drums are widely used for mixing, cooling, heating, and drying granular materials (Ettahi *et al.*, 2022; Xie et al., 2018). In another example, a rice husk-fired rotary dryer reduced coffee bean drying time from 16 days (sun drying) to only 3–4 days with eight working hours per day (Susana et al., 2023). Farmer involvement in selecting and implementing drying technologies is essential to ensure the systems are practical, affordable, and sustainable. A participatory approach is effective for redesigning manual tasks, reducing physical workload, and providing more ergonomic and efficient tools (Burgess-Limerick, 2018; Sormunen et al., 2022).Numerous studies have been conducted on turmeric drying, such as drying using heat transfer methods powered by rice husk fuel (Alit et al., 2022). Pilot-scale turmeric drying using biomass has also been carried out. This study employs a rotary drum dryer with variations in drying chamber temperature (Balakrishnan et al., 2022).Analyzed the drying of turmeric rhizomes using a rotary dryer and observed that the drying time was significantly reduced compared to sun drying while maintaining better quality. In another study, found that mechanical drying improved the hygienic quality of turmeric and allowed for better control of the final moisture content(Jayashree et al., 2018). The application of rotary dryers has also been shown to enhance drying efficiency, especially when combined with hot air at controlled temperatures and airflow rates (Delele et al., 2015).

The thermal efficiency of the rotary drying process is influenced by several parameters, including air temperature, flow rate, drum speed, feed rate, and inclination angle of the drum. The optimization of these parameters is crucial to maximize drying efficiency while minimizing energy consumption and degradation of curcumin content (Sanni et al., 2015). Excessive temperatures may cause curcumin degradation or discoloration, while insufficient drying may lead to microbial spoilage during storage (Singh et al., 2010).In terms of energy consumption and sustainability, rotary dryers, though more energy-intensive than solar drying, offer improved productivity and consistent product quality. Integration of renewable energy sources such as solar-assisted rotary drying or use of biomass-fueled heaters has been proposed to improve the environmental footprint of the process (Delele et al., 2015).Further studies have highlighted the importance of drum rotation speed and internal flights or lifters in facilitating better heat and mass transfer during drying. Varying the rotational speed impacts the residence time of turmeric within the drum and the turbulence of the material, which directly affect the moisture removal rate (Balakrishnan et al., 2022). The inclusion of lifters enhances mixing, increasing the surface area exposure to hot air, thus improving drying efficiency.

Despite the advantages of rotary dryers, there are still challenges related to the uniformity of drying, energy efficiency, and initial capital cost. Continuous research is being carried out to improve the design of rotary dryers for turmeric and similar agricultural products. For instance, hybrid rotary dryers that combine conduction and convection modes or those integrated with heat recovery systems are being developed to reduce operational costs. In conclusion, the rotary drying of turmeric offers a promising alternative to traditional drying methods, with clear advantages in terms of process control, drying time, and product quality. However, continued efforts in optimizing process parameters, improving energy efficiency, and modeling drying kinetics are essential to fully harness its potential. This research aims to analyze and optimize the performance of a rotary dryer for turmeric drying under varying airflow and operational conditions to ensure efficient drying while preserving curcumin content and color.

2. RESEARCHMETHODS

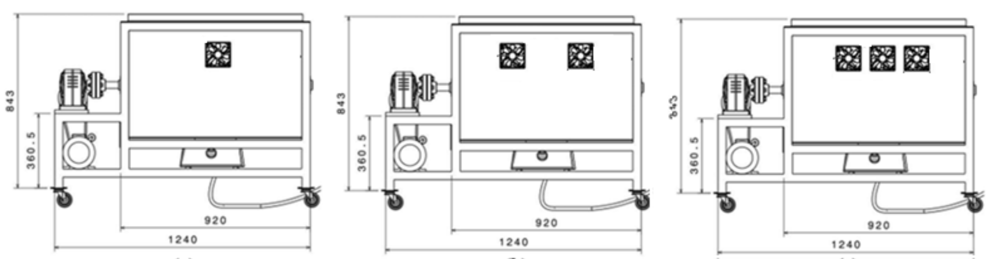
This research aims to test the performance of a rotary dryer in the turmeric drying process, with a design approach based on the needs of small-scale farmers. The rotary dryer is used to produce a uniform temperature distribution within the drying chamber, ensuring that the turmeric drying process occurs homogeneously. The dryer consists of heat exchanger plate, 1 HP dynamo, gearbox, rubber isolators, trolley wheels, a transmission system, a drying cylinder, and an exhaust fan. The research was conducted by varying the number of exhaust fans at a constant air velocity of 1 m/s and the cross-sectional area of each fan at 0.01 m^2. The heat transfer system is designed to be indirect, so the material is not contaminated by combustion gases. The drying chamber consists of two concentric cylinders. The outer cylinder is stationary and receives heat from the combustion of LPG gas. Via a gear system, an electric motor powers the dynamic inner cylinder. 6 kg of turmeric with a slice thickness of 2 mm is placed inside the rotating cylinder. The inner surface of the rotary cylinder is designed to be rough and equipped with small holes, which function to enhance the uniform distribution of heat. The rough surface texture on this cylindrical surface is also known to enhance the rate of heat transfer compared to a smooth surface (Boonloi and Jedsadaratanachai, 2021).



(a) (b)

Figure 1. (a) Schematic for rotary dryer run with LPG energy, and (b) Testing samples of turmeric slices. (1. Rotary cylinder, 2. Rotary cylinder cover, 3. Heating plate, 4. Gearbox connector, 5. Gearbox, 6. Electric motor, 7. Bearing, 8. Exhaust fan, 9. Gas stove, 10. LPG cylinder)

The testing was conducted using a rotary dryer design as shown in Figure1. The evaluation parameters include drying time, drying temperature, turmeric moisture content, and drying rate. The mass of the dried turmeric is 6 kg, with variations in the number of exhaust fans being 1, 2, and 3 units. The parameters measured in this study include ambient temperature, drying chamber temperature, drying time, initial and final mass of turmeric, electricity consumption, and the mass of fuel used. Based on these parameters, the amount of heat energy required for the drying process, the rate of heat transfer from the air to the material, the moisture content, the drying rate, and the drying efficiency were calculated.



(a) (b) (c)

Figure 2. number and position of exhaust fans (a) 1 exhaust fan, (b) 2 exhaust fan, (c) 3 exhaust fan

The moisture content of turmeric, k_a (%), is calculated based on the initial mass of turmeric, m_t (kg), and the dry mass of turmeric, m_k (kg) (Hemhirun and Bunyawanichakul, 2020). To obtain the dry mass of turmeric, m_k, it is heated in an oven at a temperature of 105-110°C until there is no weight loss.

$$k_a = \frac{m_t - m_k}{m_t} \quad (1)$$

The amount of heat used for drying Q_a (kJ) is shown in Equation 2.

$$Q_a = Q_1 + Q_2 \quad (2)$$

Q_1 is the sensible heat of turmeric (kJ). $Q_2$is the heat to evaporate the water in the material (kJ) (Cengel and Boles, 2015). Q_1 is obtained based on mass, specific heat, and temperature, as shown in Equation 3.

$$Q_1 = m_t C_{pb} (T_r - T_a) \quad (3)$$

C_{pb} is the specific heat of the material, which is turmeric (kJ/kg K), calculated based on Equation 4 that was taken from Jeevarathinam and Pandiarajan (2016). T_r is the temperature of the drying chamber (°C), and T_a is the ambient temperature (°C).

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$$C_{pb} = \frac{2241.4k_a + 1753.6}{1000} \quad (4)$$

The latent heat of evaporation, Q_2 (kJ), is calculated based on the mass of the evaporated water and the latent heat of evaporation of water, as shown in Equation 5.

$$Q_2 = m_{ah} h_{fg} \quad (5)$$

m_{ah} is the mass of evaporated water (kg), and h_{fg} is the latent heat of vaporization of water (kJ/kg). The drying rate, $\dot{m}_P$ (kg/hour), is determined by the ratio of the mass of evaporated water, m_{ah} (kg), to the drying time, t_h in hour.

$$\dot{m}_P = \frac{m_{ah}}{t_h} \quad (6)$$

The energy efficiency of drying, η, is the ratio of the amount of heat utilized for the drying process, Q_a (kJ), to the total energy used during the entire drying process, Q_b (kJ) (Cengel and Boles, 2015).

$$\eta = \frac{Q_a}{Q_b} \quad (7)$$

The amount of energy used during the drying process, Q_b (kJ), is the heat energy from LPG combustion and the electrical energy to drive the dynamo and exhaust fan.

$$Q_b = m_f NK_f + P_e t \quad (8)$$

m_f (kg) is the weight of the LPG gas used, NK_f is the calorific value of the LPG fuel, P_e (kW) is the electrical power, and t (s) is the drying time.

3. RESULTS AND DISCUSSION

Based on the test results with heating for 480 minutes with varying numbers of exhaust fans, the relationship between heating time and turmeric water content was obtained as shown in Figure 3.

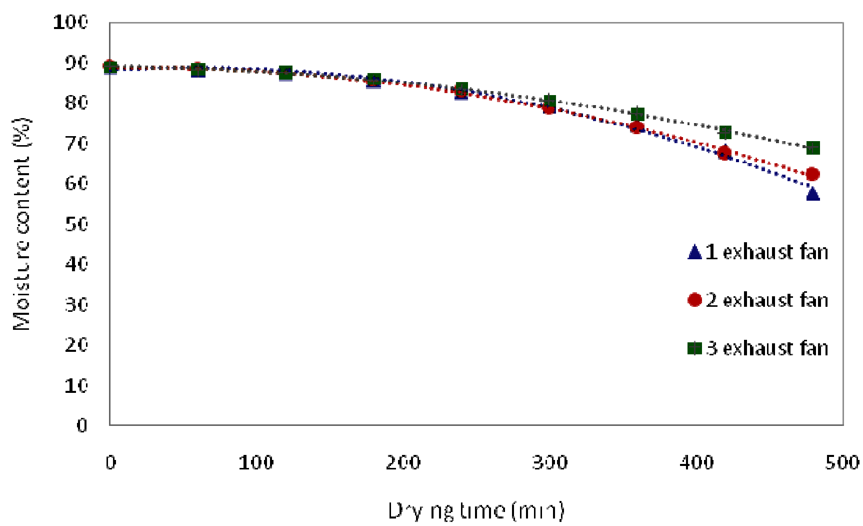

Figure 3. Effect of the number of exhaust fans on changes in the water content of turmeric

Variation in moisture content with turmeric drying time was observed during the 480-minute drying period. The results of the moisture content reduction showed the same trend for all amounts of exhaust fans; a similar occurrence was also observed in the turmeric drying conducted (Borah et al., 2017). Turmeric dried with 1 exhaust fan produces the lowest water content compared to using 2 and 3 exhaust fans. For the same drying time period, the use of a rotary dryer with 1 exhaust fan can reduce the moisture content from 0.9 to 0.65, while 2 and 3 exhaust fans can reduce the final moisture content to 0.69 and 0.75, respectively. This is due to the decrease in drying temperature when the exhaust fan is added, as shown in the following figure 4.

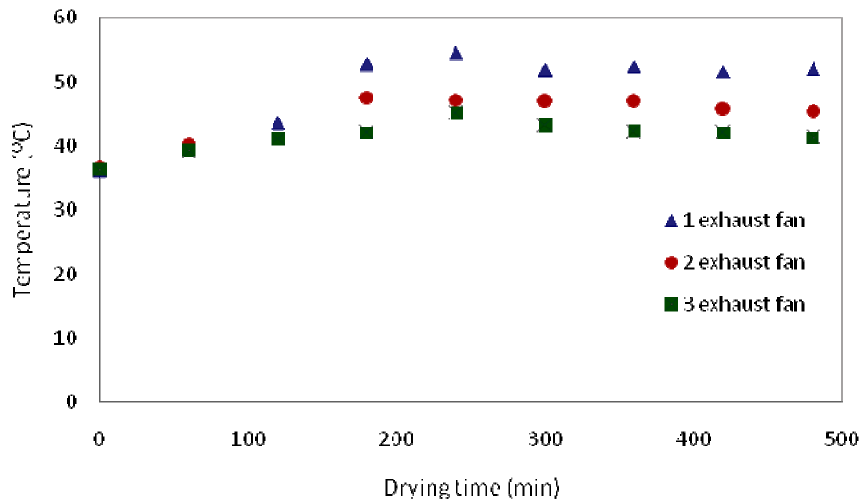

Figure 4. Drying temperature distribution

Drying temperature distribution is directly correlated with air flow rate. The airflow rate is influenced by the number of exhaust fans used. The decrease in the drying chamber temperature occurs because an increased number of exhaust fans leads to a higher airflow rate entering the drying chamber. Excessive airflow causes heat loss and a decrease in drying temperature, to prevent active compounds such as the degradation of active compounds such as curcumin(Nukulwar and Tungikar, 2020). From the test results, the use of 1 exhaust fan produces optimal turmeric drying temperature, while the use of 2 and 3 exhaust fans produces temperatures below the optimal range.

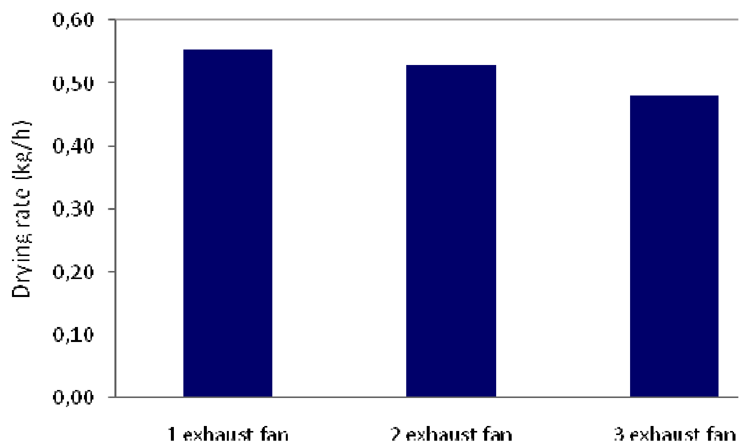

Figure 5. Effect of the number of exhaust fans and drying time on the drying rate

The drying temperature and air flow rate will influence the turmeric drying rate (Singh et al., 2010). Average turmeric drying rate was achieved with the use of one exhaust fan, at 0.55 kg/hour, followed by two exhaust fans (0.53 kg/hour), and the lowest occurred with three exhaust fans (0.48 kg/hour). Of the three configurations, the highest drying rate was achieved with a single exhaust fan. The decrease in drying rate in the three-exhaust fan configuration was also caused by excessively high airflow, which can cause casing hardening and reduce the moisture gradient between the material surface and the drying air. Consequently, moisture diffusion from the interior of the material is hampered, slowing the drying rate in later stages. These findings indicate that increasing the number of exhaust fans does not always improve drying efficiency.

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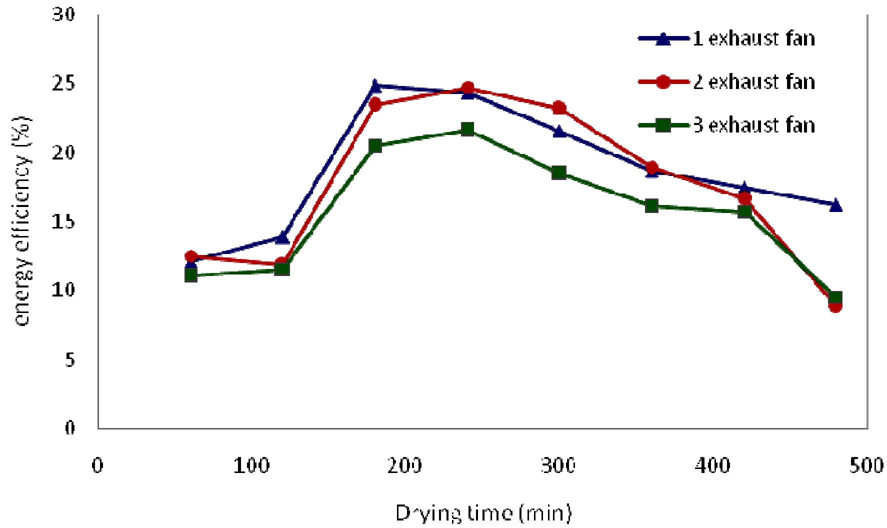

Figure 5. Effect of the number of exhaust fans on energy efficiency

Figure 5, shows the energy efficiency of turmeric drying as a function of drying time for three different exhaust fan configurations. Analysis shows a significant impact of the number of exhaust fans on the drying performance of the system. During the initial drying period (0–240 minutes), all configurations showed a trend of increasing energy efficiency, which was caused by the rise in the drying chamber temperature. After the temperature stabilizes, there is a trend of decreasing efficiency for all variations due to the reduction of moisture content in the material. The decrease in moisture content in the material results in an increased amount of energy required to release the remaining moisture (Alit and Susana, 2025). The use of 1 exhaust fan maintains relatively higher energy efficiency over a longer drying duration. The energy efficiency of turmeric drying using a rotary dryer ranges from 10.8-25.5%.

4. CONCLUSION

The drying airflow rate is one of the variables that determine the effectiveness of a rotary dryer. The airflow rate can be generated due to the number of exhaust fans used. This study shows that the number of exhaust fans affects the drying performance of turmeric in a rotary dryer system. The experimental results showed that the use of 1 exhaust fan provided the best results compared to configurations of 2 and 3 exhaust fans. Turmeric dried with 1 exhaust fan achieved the lowest moisture content for the same drying time compared to the use of 2 and 3 exhaust fans. For a drying time of 8 hours, a rotary dryer with 1 exhaust fan was able to dry turmeric from 89% moisture content to 57.8% with an average drying rate of 0.55 kg/hour. A rotary dryer with 1 exhaust fan produced an optimal temperature in the range of 50-60°C. In addition, this configuration was also able to maintain relatively higher energy efficiency. Energy efficiency during the drying process ranged from 10.8% to 25.5%. Thus, the use of one exhaust fan in a rotary dryer is the most optimal configuration to maintain a balance between drying quality and energy efficiency.

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