Performance of Heat Pump Drying Equipped with Natural Dehumidifier: A Review from the Perspective of Relative Humidity of the Drying Cabin

Putu Wijaya Sunu[1], I Made Suarta[2], I Made Rasta[3], I Dewa Gede Agus Triputra[4],
Si Putu Gede Gunawan Tista[5], Harie Satiyadi Jaya[6], and C. Bambang Dwi Kuncoro[7]

[1,2,3,4] Mechanical Engineering Department, Politeknik Negeri Bali, Bali, Indonesia
[5] Mechanical Engineering Department, Universitas Udayana, Bali, Indonesia
[6] Mechanical Engineering Department, Universitas Palangka Raya, Kalimantan Tengah, Indonesia
[7] Department of Refrigeration, Air Conditioning, and Energy Engineering, College Engineering, National Chin-Yi University of Technology, Taiwan
`wijayasunu@pnb.ac.id`

Abstract. Turmeric, scientifically referred to as Curcuma domestica VAL, is a rhizome plant that is highly esteemed for its culinary and medicinal attributes. Turmeric can be employed in three distinct forms: fresh turmeric, dried turmeric, or turmeric powder. Drying turmeric leads to the creation of dehydrated turmeric, which has a longer shelf life and allows for easier packaging. A heat pump drying system is a specific type of dryer system that can be employed for the purpose of drying turmeric. The objective of this study is to assess the performance features of drying thin layers of turmeric. This will be done by adding natural dehumidifiers during the drying process, which will be conducted at a temperature of 45°C. The drying will be carried out using a Trays cabin system with a capacity of 2100 g. This study examined the relative humidity of the drying cabin under a consistent drying time of 5 hours. The ultimate relative humidity in the cabin, both without and with a natural dehumidifier, was 73.5% and 60.67% respectively. The ultimate water content level of the dehydrated turmeric product inside the cabin, both without and with a natural dehumidifier, was 14.11% and 4.76% respectively.

Keywords: Drying Turmeric, Heat Pump System, Natural Humidifier, Relative Humidity

1 Introduction

Turmeric (Curcuma domestica Val.) is one of the medicinal plants commonly used in Indonesia's herbal and pharmaceutical industries. Turmeric has anti-inflammatory, antioxidant, and blood-clotting properties which help reduce pain and speed up the process of wound healing. Antioxidant is just one of many active constituents contained in turmeric. Curcuminoids are the most significant and main antioxidants in turmeric.

© The Author(s) 2024
A. A. N. G. Sapteka et al. (eds.), *Proceedings of the International Conference on Sustainable Green Tourism Applied Science - Engineering Applied Science 2024 (ICoSTAS-EAS 2024)*, Advances in Engineering Research 249,
https://doi.org/10.2991/978-94-6463-587-4_65

Stored turmeric can be made available even longer without deterioration due to chemical reactions and microorganism growth by decreasing the water content of agricultural or industrial products through drying processes (Moradi et al., 2019, 2020; Wijaya Sunu et al., 2023). The process of moisture removal operates through two concurrently used processes that include the direct application of heat to the product to initiate evaporation in the product and the process of transferring moisture from the product's surface to the surrounding atmosphere.

Drying is one of the oldest methods employed in the preservation of food including medicinal herbs. The drying method and operational conditions will have direct influence on the quality and cost of the dried product; hence, the selection of the drying method is very critical and needs considerable attention. A drying medium is very important because of its direct effects on the nutritional value, quality, and cost of the product being dried (Hamid et al., 2022). With more than 500 types of dryers reported in the technical literature, only some 100 types are commercially available. On the other hand, variations in dryer design have been needed because of the distinct physical characteristics of the product, diverse methods of heat input, wide-ranging operating temperature and pressure conditions, and distinct quality requirements for the dried product, among others (Mujumdar & Law, 2010).

Of all the techniques developed to the present date, hot air drying is one of the most advanced methods of drying. Such advantages of this form of drying, in terms of the increased speed of the drying process, show its relation to drawbacks such as color and flavor changes, and loss of nutrition value and loss of functional properties of the product (Ozkan et al., 2007). In addition, it supports innovations concerning the development of new drying methods, as in the case of integrating a refrigeration system directly with heat pump drying. Research has found the heat pump dryer system to be the solution (Chua et al., 2002; Lee et al., 2019). Many advantages are associated with the heat pump drying system. It can be used for the recovery of heat. Other conditions, like humidity and air temperature, are also possible to achieve under it, which also contribute to achieving better quality. Moreover, the drying can be done at fairly low temperatures. This is because the heat pump drying systems utilize dehumidified and low-temperature air as the drying medium.

Drying is among the most energy-demanding industrial processes, with the high proportion of energy consumption at a proportion of 10-20% in total. Nevertheless, requiring a great quantity, in many industrial drying processes, a lot of energy is released into the environment (Ogura et al., 2005). In the investigations reported in (Chapchaimoh et al., 2016; Erbay & Hepbasli, 2017; Hou et al., 2020; Tunckal & Doymaz, 2020). Heat pump dryer methodologies and equipment were used to dry comparably thin products like fruits, vegetables, and spice products sliced thinly in small and medium production lots. Batch dryers were used in this study. Food is loaded onto trays in cabinets to desiccate until fully dehydrated. However, generally, cabinet dryers have low turnover because they are relatively simple equipment, and the drying process is non-uniform within the drying chamber.

The application of heat pump drying is fast gaining acceptance into the industry due to this process because of its effective drying capacities and energy efficiency. The heat pump reuses the energy, and thus its draining is a two-in-one function of being energy efficient. The recent study will examine the implementation of a coconut fiber cooling system that plays as an absorber of humid air inside the cabinet and accelerating the dehumidification process.

2 Methodology

A fresh supply of turmeric was available at a local market in Denpasar, Bali, Indonesia. Before commencing each experiment, turmeric was peeled and sliced crossetionally into slices that were 2 mm thick using a cutting machine. The turmeric utilized in this investigation was unprocessed, weighing up to 2100 g, which had undergone the process of categorization. In this study, turmeric was categorized, measured, and positioned on a drying tray, with each tray weighing 350 g. The drying process was conducted utilizing a heat pump dryer, with drying durations of 5 hours at a constant cabin temperature of 45^0C. The residual weight of the turmeric was measured after 5 hours of the experiment and utilized to determine the moisture content of the dried product. Figure 1 illustrates the equipment employed in this study.

Figure 1. A heat pump drying unit

The fan propels heated air into the drying cabin with an average velocity of 1.8 m/s. The measurement instruments utilized in the present study included a K-type thermocouple, hygrometer, low and high-pressure gauges, anemometer, and stopwatch. The temperatures of the refrigerant R-134a and the air circuit at the inlet/outlet of the air ducting system were measured using k-type thermocouples. The sensors are affixed to either the exterior of the copper tubing that carries the refrigerant or insulated using thermal insulation. Meanwhile, the electrical system employs a thermostat unit equipped with a detecting light to control the on/off cycles of the refrigerant flow. The data was recorded using a data logger programmed to capture information every 5 minutes and saved in an external storage device.

3 Result and Discussion

The result of humidity time series data for a multi-tray dryer system, both with and without a dehumidifier, is revealed in Figure 2.

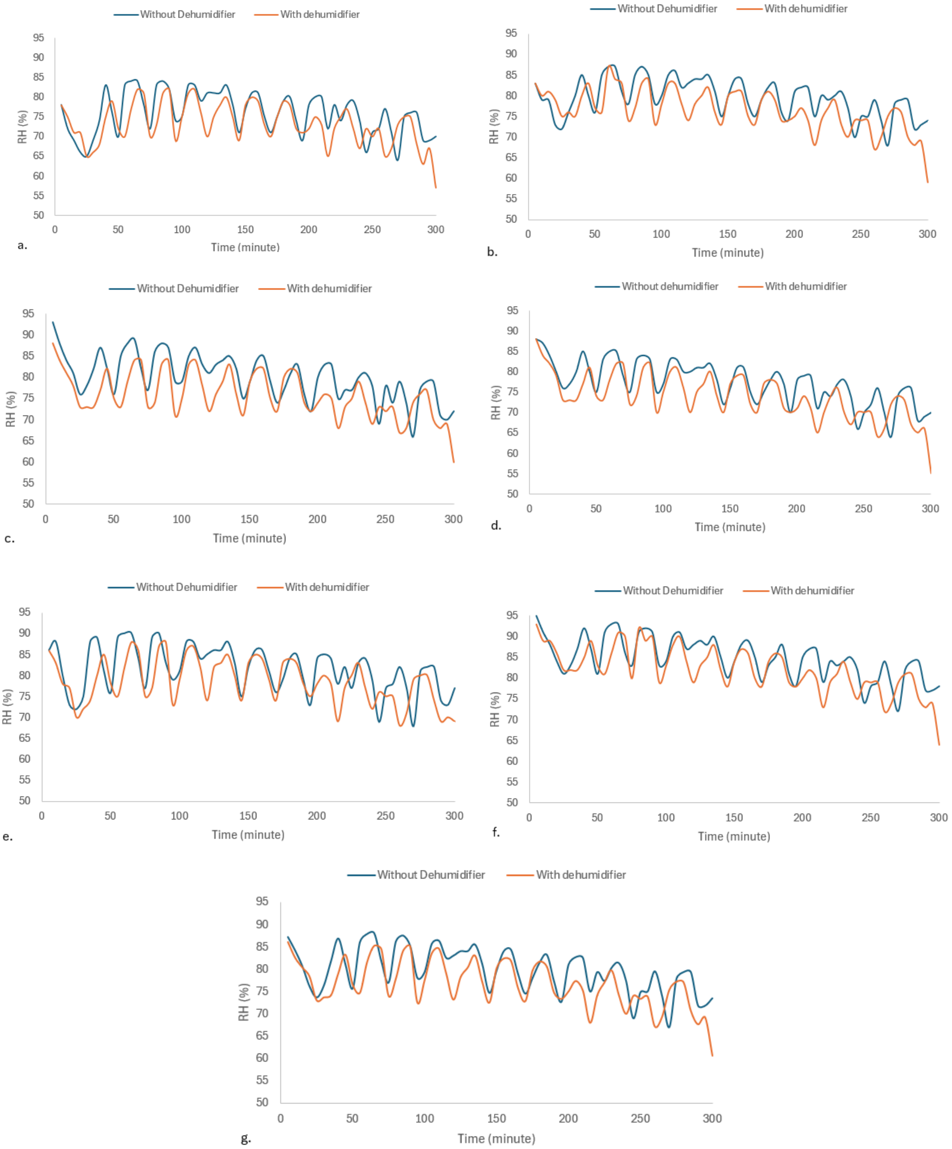

Figure 2. Time series of humidity. a. first tray; b. second tray; c. third tray; d. fourth tray; e. fifth tray; f. sixth tray; g. overall humidity of the dryer cabin.

The analysis of humidity time series data for a multi-tray dryer system from Figure 1, both with and without a dehumidifier, reveals significant insights into the drying process and the impact of dehumidification. Without a dehumidifier, the total relative humidity (RH) in the system fluctuates between 67% and 88%, starting at 87.17% and ending at 73.50%. In contrast, with the dehumidifier, the total RH ranges from 60% to 85%, beginning at 86.00% and concluding at a notably lower at 60.67%. This comparison demonstrates the dehumidifier's effectiveness in reducing overall moisture levels, particularly towards the end of the drying cycle. The data from Figure 1 reveals a distinct vertical humidity gradient across the six trays, correlating strongly with the hot air flow from bottom to top. The first (bottom) tray consistently exhibits the lowest humidity levels, ranging from 64% to 84% without the dehumidifier and 57% to 82% with it. This tray benefits from direct exposure to the incoming hot air, resulting in the most rapid and efficient drying. As we move upwards through the trays, there's a progressive increase in humidity levels, with the sixth (top) tray showing the highest and most persistent moisture content. Without the dehumidifier, the top tray's humidity ranges from 72% to 95%, while with the dehumidifier, it improves to a range of 64% to 93%. This gradient is a direct consequence of the hot air's path through the system; as it rises, it becomes increasingly saturated with moisture, reducing its capacity to absorb additional water vapor from the upper trays. The dehumidifier's impact is most pronounced in the upper trays, effectively mitigating this vertical humidity disparity and promoting more uniform drying across all levels.

A closer examination of individual tray performance provides further insights into the drying dynamics and the dehumidifier's role. In the variable without a dehumidifier, trays 1-3 show relatively quick drying patterns and lower overall humidity, with the second tray ranging from 68% to 87% RH and the third from 66% to 93% RH. The fourth tray exhibits a similar pattern to the third, while the fifth tray shows notably higher humidity levels, ranging from 68% to 90% RH. The introduction of the dehumidifier brings about several key improvements. First, it stabilizes humidity levels across all trays, reducing the magnitude of fluctuations observed in the non-dehumidified scenario. For instance, the second tray's range narrows to 59-87% RH, while the third tray improves to 60-84% RH. More significantly, the dehumidifier's effect becomes increasingly apparent in the upper trays, with the fourth tray showing a marked improvement from a range of 64-88% to 55-82% RH. The fifth tray, while still maintaining higher humidity than the lower trays, sees its range reduced from 68-90% to 68-88% RH. These improvements culminate in the top tray, where the humidity range drops from 72-95% to 64-93% RH with the dehumidifier in operation. This pattern of improvement underscores the dehumidifier's capacity to enhance drying efficiency, particularly in the more challenging upper regions of the dryer where hot air has already absorbed significant moisture. Moreover, the data reveals that all trays exhibit similar patterns of humidity fluctuation over time, with lower trays demonstrating more rapid responses to changes in air conditions. This responsiveness gradient further corroborates the impact of the vertical airflow on the drying process, highlighting the critical role of tray position in determining drying rates and efficiency.

The comprehensive analysis of this multi-tray drying system yields several crucial insights and potential possibilities for optimization. Foremost, the clear correlation between tray position and drying rate emphasizes the need for strategies to counteract the vertical humidity gradient. While the bottom trays dry efficiently due to their exposure to the hottest, driest air, the upper trays particularly the sixth tray struggle with persistent high humidity levels, indicating a need for improved air circulation or extended drying times for materials in these positions. The introduction of a dehumidifier proves to be a significant boon to the overall drying process, not only reducing total humidity levels but also promoting more uniform drying across all trays. This uniformity is particularly valuable for ensuring consistent product quality in industrial drying applications. Additionally, the time series data reveals fluctuations in humidity levels across all trays, indicating that the drying environment is dynamic and responsive to external factors or system adjustments. This responsiveness suggests that real-time humidity monitoring and adaptive control systems could further enhance drying efficiency by dynamically adjusting air flow, temperature, or dehumidifier operation in response to current conditions. Ultimately, this analysis underscores the complexity of multi-tray drying systems and the significant impact that airflow patterns and moisture management strategies can have on drying efficiency and product uniformity. By leveraging these insights, operators can fine-tune their drying processes to achieve optimal results, balancing energy efficiency with product quality to meet the demanding requirements of various agricultural applications.

4 Conclusion

The analysis of the drying system reveals significant insights into the drying process and the impact of dehumidification. The data clearly shows a vertical humidity gradient correlating with hot air flow, where bottom trays dry more efficiently than upper trays. The introduction of a dehumidifier markedly improves overall drying efficiency, reducing total humidity levels and promoting more uniform drying across all trays. Without a dehumidifier, total relative humidity fluctuates between 67-88%, compared to 60-85% with a dehumidifier. The analysis underscores the complexity of multi-tray drying systems and highlights the importance of moisture management in achieving optimal drying results to balance energy efficiency with product quality of agricultural applications.

Acknowledgment

The authors express gratitude for the financial assistance provided by Politeknik Negeri Bali, Kementerian Pendidikan, Kebudayaan, Riset dan Teknologi, Indonesia, under contracts 02226/PL8/AL.04/2024.

References

Chapchaimoh, K., Poomsa-Ad, N., Wiset, L., & Morris, J. (2016). Thermal characteristics of heat pump dryer for ginger drying. *Applied Thermal Engineering*, *95*, 491-498.

Chua, K. J., Chou, S. K., Ho, J. C., & Hawlader, M. N. A. (2002). Heat pump drying: recent developments and future trends. *Drying Technology*, *20*(8), 1579-1610.

Erbay, Z., & Hepbasli, A. (2017). Exergoeconomic evaluation of a ground-source heat pump food dryer at varying dead state temperatures. *Journal of Cleaner Production*, *142*, 1425–1435. https://doi.org/10.1016/j.jclepro.2016.11.164

Hamid, K., Sajjad, U., Yang, K. S., Wu, S. K., & Wang, C. C. (2022). Assessment of an energy efficient closed loop heat pump dryer for high moisture contents materials: An experimental investigation and AI based modelling. *Energy*, *238*, 121819. https://doi.org/10.1016/j.energy.2021.121819

Hou, H., Chen, Q., Bi, J., Wu, X., Jin, X., Li, X., Qiao, Y., & Lyu, Y. (2020). Understanding appearance quality improvement of jujube slices during heat pump drying via water state and glass transition. *Journal of Food Engineering*, *272*(October 2019), 109874. https://doi.org/10.1016/j.jfoodeng.2019.109874

Lee, B. H., Sian, R. A., & Wang, C. C. (2019). A rationally based model applicable for heat pump tumble dryer. *Drying Technology*, *37*(6), 691–706. https://doi.org/10.1080/07373937.2018.1454940

Moradi, M., Azizi, S., Niakousari, M., Kamgar, S., & Mousavi Khaneghah, A. (2020). Drying of green bell pepper slices using an IR-assisted Spouted Bed Dryer: An assessment of drying kinetics and energy consumption. *Innovative Food Science and Emerging Technologies*, *60*(November 2019), 102280. https://doi.org/10.1016/j.ifset.2019.102280

Moradi, M., Niakousari, M., & Mousavi Khaneghah, A. (2019). Kinetics and mathematical modeling of thin layer drying of osmo-treated Aloe vera (Aloe barbadensis) gel slices. *Journal of Food Process Engineering*, *42*(6), 1–13. https://doi.org/10.1111/jfpe.13180

Mujumdar, A. S., & Law, C. L. (2010). Drying technology: Trends and applications in postharvest processing. *Food and Bioprocess Technology*, *3*(6), 843–852. https://doi.org/10.1007/s11947-010-0353-1

Ogura, H., Yamamoto, T., Otsubo, Y., Ishida, H., Kage, H., & Mujumdar, A. S. (2005). A control strategy for a chemical heat pump dryer. *Drying Technology*, *23*(6), 1189–1203. https://doi.org/10.1081/DRT-200059337

Ozkan, I. A., Akbudak, B., & Akbudak, N. (2007). Microwave drying characteristics of spinach. *Journal of Food Engineering*, *78*(2), 577–583. https://doi.org/10.1016/j.jfoodeng.2005.10.026

Sunu, P. W., Anakottapary, D. S., Susila, I. D. M., & Kamal, D. M. (2023). Heat pump drying for turmeric: a preview. *Proceedings of the 5th International Conference on Applied Science and Technology on Engineering Science* - iCAST-ES; pages 342-345. https://doi.org/10.5220/0011770400003575

Tunckal, C., & Doymaz, İ. (2020). Performance analysis and mathematical modelling of banana slices in a heat pump drying system. *Renewable Energy*, 150, 918–923. https://doi.org/10.1016/j.renene.2020.01.040

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.