International Journal of Engineering and Technology, Vol. 15, No. 3, August 2023

Influence of Drying Temperature on Drying Kinetics and Appearance of Avocado Slices in Heat Pump Drying Process

Nguyen Thi Thuy Dung* and Nguyen Van Thuan

Abstract—**The avocado is a nutritious fruit that originated from tropical countries such as Central and Southern America, and Southeast Asia. From the commercial point of view, it is an important fruit with a total world production is around eight million tons in 2020. Fresh avocados can be consumed directly or stored before advanced processing. The drying technique can be applied as an efficient post-harvesting technique to prolong the storage time of avocados. In this paper, heat pump drying experiments were performed to evaluate the influence of drying conditions on the drying time, the moisture diffusion coefficient, and the color change of avocado slices. It was obtained that color change can be decreased by increasing the drying temperature from 35 ºC to 50 ºC. Additionally, the effective moisture diffusivity was enhanced approximately two times by increasing temperature. It was suggested that a drying temperature of 50 ºC should be used for the heat pump drying system operation and design to shorten drying time and prevented the quality of avocado. Additionally, empirical models were established to describe the drying behavior of avocados. The results indicated that the Page model can reflect well the evolution of moisture content over time with determination coefficient R^2 greater than 0.996.**

Index Terms—**Avocado, heat pump, drying kinetics, drying process, thin-layer drying model**

I. INTRODUCTION

Avocado (Persea Americana) is a tropical fruit that is planted in Southern and Central America and in Southeast Asia countries. In Vietnam, avocado growing areas are concentrated in the Western Highlands (Daklak, Dak Nong, Lam Dong, Gia Lai, and Kon Tum provinces) with a total area of nearly 8000 hectares and some provinces in the Northwest. The nutritional value of avocado powder is varied with an avocado pulp containing 67 to 78% moisture, 13.5 to 24.0% lipid, 0.8 to 4.8% carbohydrate, 1.0 to 3.0% protein, 0.8 to 1.5% ash, 1.4 to 3.0% fiber and an energy density of 140 to 228 kcal [1]. Avocado has 4 times more nutritional value than any other fruit except banana, contains protein (1% to 3%), and high content of vitamins, fat, folic acid, calcium, potassium, magnesium, sodium, phosphorus, sulfur, and silicon, and vitamins E, B1, B2 and D [2]. With high nutritional values, avocado has many applications, especially in the pharmaceutical, food, and cosmetic sectors. In the pharmaceutical industry, avocados have been used to stimulate hair growth, heal wounds, treat dysentery and diarrhea, and as a diuretic [3]. Avocado extracts have been reported to have anticancer, antifungal, and antioxidant preservation [4]. Compared to cold storage, drying can be considered as a low-energy consumption preservation technique that can prolong the storage time. There are several research works on drying avocados with different drying methods such as hot air drying, freezing drying and modified air drying that can be found in the literature. In the work of Temu *et al.* [5], the slices of avocado with the thickness of 2mm and 5mm were dried in a drying oven at drying temperatures of 50 ºC, 60 ºC and 70 ºC. The results show that the drying rate in the first drying period increases linearly with the drying temperature. Additionally, the drying rate decreases when the slice thickness turned from 2 mm to 5 mm. Compared with the hot air drying, the avocado samples obtained from the freezing drying process had lower equilibrium moisture values, no signs of browning, and higher protein and fat content [6]. However, the freezing drying time is approximately 72 hours, significantly longer than hot air drying processes. To shorten the drying time and avoid the oxidation reaction, the sliced avocado was dried in a modified air environment [7]. Besides, from the latest research results of Özbek1 [8], avocado samples with a thickness of 2 cm were dried by hot air-assisted radio frequency (HA-RF), drying settings at electrode gap of 80 mm. The drying kinetics of hot air-assisted radio frequency were compared to drying with Hot Air (HA). The experimental results indicated that HA-RF drying method was better than HA drying and freeze-dried. Particularly, the HA-RF can shorten drying time and provides higher total phenolic content and lower color change compared to HA drying.

The results of drying avocado slices showed that although the drying temperature is moderate, the modified air drying method and HA-RF drying gives a better appearance to products compared to hot air drying. It can be concluded that the freeze-drying, modified air-drying techniques and HA-RF drying can advance product quality but at a high cost compared to hot air drying.

This article presents our attempts to investigate the drying kinetic and appearance of avocado slides at low temperatures in a heat pump dryer. Following this introduction section, the drying apparatus and experimental procedure are presented. Afterward, by analyzing the mass evolution of the sample, the effective moisture diffusivity is determined. Additionally, the color change of the sample is reported. Finally, several conclusive remarks are drawn activities. However, avocado is a very difficult fruit to process since the ripened avocados are easily been broken, and it is difficult to be transported to remote provinces or export. If the post-harvest preservation is processed improperly, the taste of avocado is bitter and its color becomes brown. In addition, the nutrition that appeared

Manuscript received April 12, 2023; revised May 16, 2023; accepted June 20, 2023.

Nguyen Thi Thuy Dung is with the Faculty of Mechanical Engineering, University of Transport and Communications, Hanoi, Vietnam and also with School of Mechanical Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam.

Nguyen Van Thuan was with School of Mechanical Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam.

*Correspondence: nttdung_ktn@utc.edu.vn (N.T.T.D.)

DOI: 10.7763/IJET.2023.V15.1226

in avocados is easily oxidized when placed in the air, this process occurs strongly at high temperatures for a long time. To improve the commercial and nutritional values of avocados, finding the proper post-harvest preservation technologies for avocados is an important research question. There are two popular methods of preserving avocados: cold storage and drying.

This article presents our attempts to investigate the drying kinetic and appearance of avocado slides at low temperatures in a heat pump dryer. Following this introduction section, the drying apparatus and experimental procedure are presented. Afterward, by analyzing the mass evolution of the sample, the effective moisture diffusivity is determined. Additionally, the color change of the sample is reported. Several conclusive remarks are drawn. Finally, a empirical Page model describing dimensionless moisture changes over time at drying temperatures of 35 °C, 40 °C, 45 °C and 50 °C has been suitable selected, in accord with R^2.

II. MATERIALS AND METHODS

A. Experimental Apparatus

In this work, a heat pump dryer was fabricated in the Thermal Engineering Group, School of Mechanical Engineering in the frame of Project B2021-BKA-12 supported by the Vietnamese Ministry of Education and Training. The maximal drying capacity of the dryer is 10 kg of fruit per batch. The heat pump dryer works with R134a refrigerant. The main component of the heat pump dryer is a compressor (model AW5532EK—Kulthorn Kirby Public Company Limited, Thailand) with an electrical capacity of 3 HP. The air is circulated in the system by using a centrifugal fan (380 VAC—1 kW). The air is cooled down and dehumidified in the evaporator of the heat pump before being reheated in the condenser. Afterward, the air flows into the drying chamber to absorb the moisture from the drying product and then enters the evaporator for completing the circulation of the drying agent. The drying chamber with a dimension of 1000 mm × 1000 mm × 1000 mm (H × W × D) is integrated into the dryer. The fabricated dryer is shown in Fig. 1. The experimental apparatus can work in a range of temperatures from 25 °C to 55 °C, and a range of air velocity from 0.5 m/s to 2.0 m/s by using an inverter.

B. Experimental Procedure

The fresh avocados bought from the local market used in the study are Boots varieties planted in Da Lat Province. After being purchased, they were washed, peeled, and cut into thin slices with a thickness of 2 mm. All drying samples were stored in the fridge and used for experiments on the same day. The drying sample with an initial mass of 200 g is spread on one layer of the sample tray. We conduct the heat pump drying experiment with four different drying temperatures: 35 °C, 40 °C, 45 °C and 50 °C. The air velocity is kept constant at 1m/s. The change in material mass was monitored during the drying process with a time interval of 20 min. Each experiment was repeated triply. The drying will stop when the mass of the drying material remains constant. The initial moisture content of the drying sample is determined by performing the drying at 105 °C for two hours in a GMP-500 drying cabinet.


(a)

(b) (c)

Fig. 1. The heat pump system (a), the drying chamber (b), and trays (c) fabricated in this project.

C. Data Analysis

1) Moisture content and moisture ratio

The moisture content of the drying sample X is calculated as

$$X = \frac{M_w}{M_s} \tag{1}$$

where M_w and M_s are the mass of liquid water and the dried solid of the samples, respectively. The mass of the dried solid M_s is determined from the initial moisture content as in

$$M_s = \frac{M_0}{1 + X_0} \tag{2}$$

From the temporal moisture content of the sample, the dimensionless moisture ratio is computed as

$$MR = \frac{X - X_e}{X_0 - X_e} \tag{3}$$

where X_e is the equilibrium moisture content obtained from the sample mass when the drying process finishes.

2) Effective moisture diffusivity

The moisture transport inside the avocado slices is a complicated process. It is controlled by multiple physical and morphological properties such as the capillary pressure, the internal liquid-vapor transition, the absolute and relative permeabilities, and the sorption isotherm of the drying product. To simplify the transport phenomenon model, moisture transport is assumed to be solely driven by the moisture content gradient. Thus, the conservation equation of moisture is written based on Fick’s second law [9].

$$\frac{\partial X}{\partial \tau} = \nabla.\left(D_{eff}\nabla X\right) \qquad (4)$$

where is the effective moisture diffusivity. Crank (1975) gave analytical solutions for the isothermal drying process of a slap with the assumption of constant effective moisture diffusivity [10].

$$MR=\frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{\left(2n\text{-}1\right)^2}exp\left(-\left(2n\text{-}1\right)^2\frac{\pi^2 D_{eff}\tau}{L^2}\right) \qquad (5)$$

In Eq. (5), L is a haft of sample thickness, by neglecting the high order number in the series, Eq. (5) can be approximated as

$$MR=\frac{8}{\pi^2}exp\left(-\frac{\pi^2 D_{eff}\tau}{L^2}\right) \qquad (6)$$

After rearrangement, Eq. (6) can be written in logarithm form

$$ln\left(MR\right)=ln\left(\frac{8}{\pi^2}\right)-\frac{\pi^2 D_{eff}\tau}{L^2} \qquad (7)$$

It means that the effective moisture diffusivity can be determined from the slope of the linear correlation between the natural logarithm of moisture ratio and time.

3) Change the color of the pattern

The sample color is examined by using a colorimeter CS-210 (CHN SPEC, China). Using the CIELAB color space, the sample color is characterized by three parameters *L*, *a*, and *b*. In these parameters, *L* indicates the lightness of the sample, ranging from 0 (black) to 100 (white); *a* varies from −60 (green) to 60 (red), and *b* shows the color change from yellow (−60) to blue (60). The color deviation of the dried sample compared to fresh ones is evaluated by ΔE [11].

$$\Delta E=\sqrt{\left(L_{dried}-L_{fresh}\right)^2+\left(a_{dried}-a_{fresh}\right)^2+\left(b_{dried}-b_{fresh}\right)^2} \qquad (8)$$

4) Empirical models

Empirical models have been used to describe the drying of agricultural products. They were widely applied for the drying process of vegetables and fruits sliced in thin-layer [12, 13]. In this study, the Lewis (Newton), Henderson-Pabis, and Page models have been used in this study.

Newton model:

$$MR = exp(-k.\tau) \qquad (9)$$

Henderson - Pabis model:

$$MR = a.exp(-k.\tau) \qquad (10)$$

Page model:

$$MR = exp(-k.\tau^n) \qquad (11)$$

where k is the experimental coefficients, a and n are constant in the drying models, τ is the drying time. These parameters are fitted from the experimental data based on the criterion of the coefficient of determination (R^2).

III. RESULTS AND DISCUSSION

A. Influence of Drying Temperature on Drying Kinetic

The influence of drying temperature on the moisture content evolution is shown in Fig. 2. In general, when the drying process commences, the moisture ratio decreases fastly and linearly. It means that the drying rate remains at a high magnitude. At the end of the drying process, the moisture ratio reduces slowly. This experimental result is completely consistent with the theory. Additionally, the results show that as the temperature increases from 35 °C to 50 °C, the drying process is significantly faster. The equilibrium moisture content obtained with high drying temperatures is lower compared to that with low drying temperatures. Conclusively, a high drying temperature leads to a fast and thorough drying process.

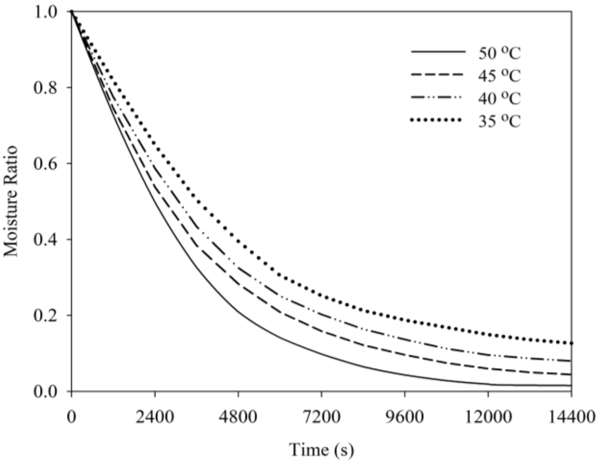

Fig. 2. Influence of drying temperature on drying kinetics.

B. Effective Moisture Diffusivity Determination

The moisture diffusivity is important in the drying process to characterize the moisture transfer in the material. Based on Eq. (7), the effective moisture diffusivity is determined for each drying temperature and the results are presented in Fig. 3. The moisture diffusivity increases from $1.91.10^{-10}$ to $4.07.10^{-10}$ m^2/s, corresponding to the change of drying temperature from 35 °C to 50 °C. The research results are consistent with published data where the moisture diffusivity of fruit varies in range from 10^{-12} to 10^{-6} m^2/s [14].

C. Effect of Temperature on The Color of Drying Product

The results of the color measurement are shown in Table I. As can be seen, the color deviation becomes lower when the drying temperature increases from 35 °C to 50 °C. It implies that a better appearance can be obtained at 50 °C compared to other lower drying temperatures. This can be explained that at low drying temperatures, the drying velocity is low resulting in a longer drying time. Therefore, the contact time between the wet surface of the sample and the air is largely leading to a strong browning reaction of polyphenol oxidase. With high drying temperatures, the sample surface is completely dried in a short time. Thus, the oxidation reaction does not occur significantly.

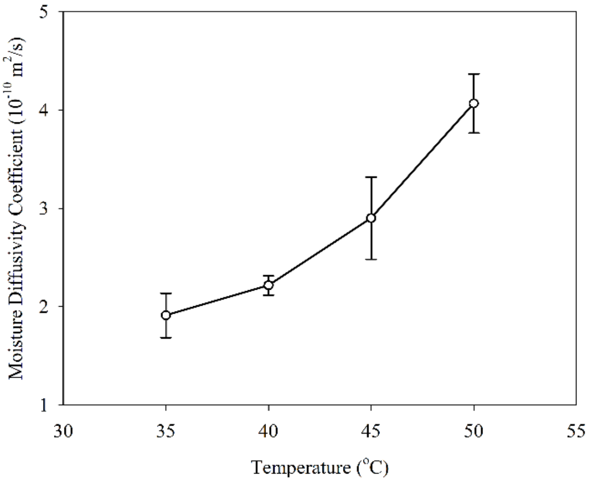

Fig. 3. Influence of drying temperature on moisture diffusivity.

TABLE I: COLOR CHANGE OF THE SAMPLE

Drying Temp.	Sample	*L*	*Δa*	*Δb*	*ΔE*
35 °C	Fresh	75.04	−2.77	58.42	**37.41**
	Drying	47.95	9.80	35.88	
40 °C	Fresh	74.86	−3.37	57.82	**30.87**
	Drying	53.15	15.1	45.96	
45 °C	Fresh	72.71	−4.62	55.72	**23.58**
	Drying	54.70	7.45	46.65	
50 °C	Fresh	74.08	−2.70	57.31	**12.98**
	Drying	64.63	6.02	59.04	

TABLE II: VALUES OF THE DRYING CONSTANTS DETERMINED BY REGRESSION METHOD FOR AVOCADO SLICES

Drying Temp.	Model	*a*	$k \times 10^{-5}$	*n*	R^2
	Newton		1.494		0.9903
35 °C	Henderson-Pabis	1.039	1.548		0.9920
	Page		0.621	1.199	0.9978
	Newton		1.591		0.9942
40 °C	Henderson-Pabis	1.022	1.603		0.9947
	Page		1.02	1.102	0.9963
	Newton		1.73		0.9963
45 °C	Henderson-Pabis	1.016	1.756		0.9971
	Page		1.207	1.084	0.9973
	Newton		1.927		0.9947
50 °C	Henderson-Pabis	1.026	1.972		0.9954
	Page		1.022	1.152	**0.9984**

D. Empirical Modeling of Drying Curve

The regression analysis was performed aiding Matlab Computer Program. The coefficient of determination (R^2) was the primary criterion for selecting a suitable equation to describe the drying curve model. The statistical analysis results applied to three models at drying air temperatures of 35 °C, 40 °C, 45 °C, and 50 °C and 2 mm thickness avocado slices are given in Table II. The best model describing the thin layer-drying characteristic was chosen as the one with the highest R^2 value.

As can be seen in Table II, the Page model seems to be better than the other two models for representing the experimental data. In addition, the model fitting shows that the prediction ability of the empirical models is improved with higher drying temperatures. These observations are in good agreement with the published data [5, 15].

IV. CONCLUSION

In this paper, experimental research on drying avocado slices in a heat pump dryer has been presented. The results show that the drying agent temperature has a great influence on the drying kinetics, the effective moisture diffusivity, and the color deviation of avocados. Particularly, the moisture diffusivity is enhanced by drying temperature increasing. Additionally, at the low drying temperature, the color change value *ΔE* is greater compared to the high drying temperature. It implies that a drying temperature of 50 °C can be chosen for the heat pump dryer operation and design. Additionally, the empirical model, i.e. Page model, can be used to pave the way for designing and operating the dryer.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Nguyen Thi Thuy Dung conducted the research, analyzed the data, and wrote the paper; Nguyen Van Thuan conducted experimental research; all authors had approved the final version.

FUNDING

This research is funded by University of Transport and Communications (UTC) under grant number T2022-CK-009.

REFERENCES

[1] H. Rafidah, Y. Ando, I. Amin, Y. Shirai, and H. Mohd Ali, “Enhanced polyphenol content and antioxidant capacity in the edible portion of avocado dried with superheated-steam,” *International Journal of Advanced Research*, vol. 2, issue 8, pp. 241–248, 2014.

[2] P. F. Duarte, M. A. Chaves, C. D. Borges, and C. R. B. Mendonca, “Avocado: Characteristics, health benefits and uses,” *Cienc. Rural*, vol. 46, n. 4, pp. 747–754, 2016.

[3] A. DerMarderosian and J. A. Beutler, *The Review of Natural Products: the Most Complete Source of Natural Product Information*, 8th Ed., Lippincott Williams & Wilkins, 2002

[4] Q. Y. Lu, J. R. Arteaga, Q. Zhang, S. Huerta, V. L. W. Go, and D. Heber, “Inhibition of prostate cancer cell growth by an avocado extract: Role of lipid-soluble bioactive substances,” *The Journal of Nutritional Biochemistry*, vol. 16, issue 1, pp. 23–30, 2005.

[5] A. Temu, “Effect of temperature and slice size on avocado pulp drying rate and oil yield,” *Tanzania Journal of Engineering and Technology*, vol. 34, no. 2, 2013.

[6] S. Mujaffar and T. A. Dipnarine, “The production of a dried avocado (Persea Americana) power,” in *Proc. International Conference on Emerging Trends in Engineering & Technology (IConETech-2020)*, 2020.

[7] V. T. Nguyen, T. T. H. Tran, V. D. Nguyen, and H. N. Nguyen, “Experimental study on sliced avocados drying in modified air,” in *Proc. the AUN/SEED-Net Joint Regional Conference in Transportation, Energy and Mechanical Manufacturing Engineering*, 2022, pp. 1001–1011.

[8] H. N. Özbek1, B. Koç, D. K. Yanık, and F. Gögüs, “Hot air-assisted radiofrequency drying of avocado: Drying behavior and the associated effect on the characteristics of avocado powder,” *Journal of Food Process Engineering*, 2022.

[9] M. A. M. Khraisheh, T. J. R. Cooper, and T. R. A. Magee, “The transport mechanism of moisture during air drying processes,” *Transactions of the Institution of Chemical Engineers* , vol. 75, issue 1, pp. 34–39, 1997.

[10] J. Crank, *The Mathematics of Diffusion*, 2nd ed. Oxford University Press, London, 1975, pp. 69–88.

[11] F. Salehi and M. Kashaninejad, “Effect of drying methods on rheological and textural properties and color changes of wild sage seed gum,” *Journal of Food Science and Technology*, vol. 52, no. 11, 2015.

[12] E. K. Akpinar, "Determination of suitable thin layer drying curve model for some vegetables and fruits," *Journal of Food Engineering*, vol. 73, no. 2006, pp. 75–84, 2005.

[13] Z. Erbay and F. Icier, "A review of thin layer drying of foods: Theory, modeling, and experimental results," *Critical Reviews in Food Science and Nutrition*, vol. 50, no. 5, pp. 441–464, 2010.

[14] D. I. Onwude, N. Hashim, R. B. Janius, N. M. Nawi, and K. Abdan, "Modeling the thin-layer drying of fruits and vegetables: A review," *Comprehensive Reviews in Food Science and Food Safety*, vol. 15, pp. 599–618, 2016.

[15] A. Bicer and F. Kar, "The effect of different drying methods temperatures on drying time and vitamin C in pineapple, kiwi, and avocado fruits," *Journal of the Turkish Chemical Society Section B: Chemical Engineering*, vol. 3, no. 1, pp. 9–18, 2020.