Study and Analysis of the Drying Kinetics of Jalapeño Pepper in a Convective Dryer

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Abstracts: The high moisture content in jalapeno peppers (Capsicum annuum L.) can cause the growth and reproduction of microorganisms, making processing and long-term storage difficult. The objective of the research is to evaluate the kinetics of jalapeño pepper drying in a convective dryer. for this reason, the drying of the jalapeño pepper was carried out in a dryer with hot air at temperatures of 40, 50 and 70°C; obtaining the drying kinetic curves, the drying time that was 18, 31 and 41 respectively; the effective diffusivity was 2.924E-10m2.s-1 for the temperature of 40°C, 7.521 E-9 m2.s-1 for 50°C and 1.307 E-9 m2.s-1 for 70°C; the degree of correlation (R2) between the moisture content and the drying time was 0.994 at 70°C with a root mean square error (RMSE) of 0.0429, R2 of 0.990 at 50°C with a RMSE of 0.0216 and R2 of 0.993 at 40°C with an RMSE of 0.0162, so it is concluded that the criteria for a good adjustment of the drying model between the experimental temperature, as well as between the humidity rate and the drying time are met.

Keywords: Jalapeño Pepper, Drying Kinetic, Effective Diffusivity, Convective Dryer.

1. INTRODUCTION

The jalapeño pepper of the genus Capsicum is commercially valued by the food industries; the total production was about 36.1 million tons in the world [1]. They are rich in bioactive compounds (capsaicinoids, gallic acid, caffeic acid, polyphenols, vitamins C, A, E, B1, B2) [2] [3]. Capsicum is a small genus that includes about 30 species, among which five are of considerable domesticated and economic importance, namely C. annuum, C. chinense, C. frutescens, C. baccatum and C. pubescens [4] [5]. Preliminary moisture content on a dry basis (db) for fresh jalapeno peppers ranges from 300-400%, which is extremely high for long-term processing and storage [6]. Therefore, the reduction of moisture in chilies to a safe level of 8 to 9 % (db) becomes mandatory before processing and storage [7]. The moisture content of fresh produce is reduced through the use of numerous drying techniques. Among the various drying techniques, hot air circulation around the product is commonly used [8]. Drying is one of the suitable preservation methods for food products that prevents the growth and reproduction of microorganisms and results in the reduction of many moisture-mediated spoilage reactions [9].

The jalapeño pepper has been recognized as an excellent source of antioxidants, being rich in ascorbic acid and other phytochemicals. The drying conditions, in particular the temperature and the drying method, lead to modifications that can cause quality degradation [10]. The jalapeño pepper is a highly perishable product, since it has a very short postharvest life, so it is necessary to adopt conservation techniques to prolong the useful life of the pepper and use it in all seasons [11]. Traditional sun drying is very slow (taking between 7 and 10 days depending on weather conditions), the final moisture content cannot be controlled, and a relatively low-quality dry product is obtained. This method has several drawbacks, such as being time consuming, prone to dust contamination, and attracting insects. Also, this drying technique is not suitable for countries with a long-wet season and little sunlight [12]. Drying conditions, including drying air temperature, relative air humidity, air velocity, sample thickness, and dryer types determine drying kinetics. Drying kinetic models are necessary to improve product quality and optimize the process [13].

The objective of the research is to evaluate the effect of temperature on the drying kinetics of jalapeño pepper, to contribute to knowledge in the field of food engineering and the Peruvian national agroindustry with the design of a new product.

2. MATERIALS AND METHODS

2.1. Experimental Equipment

The drying experiments were carried out using Alimentos Blanik BDA020 convective dryer of chinese origin, which consisted of a bottom heated hot air controllable electric heater, a centrifugal fan and 5 drying trays. This hot air dryer was cylindrical, approximately 0.32 m in radius and 0.26 m high, with a voltage of 220 V and a power of 250 Was can be seen in Figure 1.

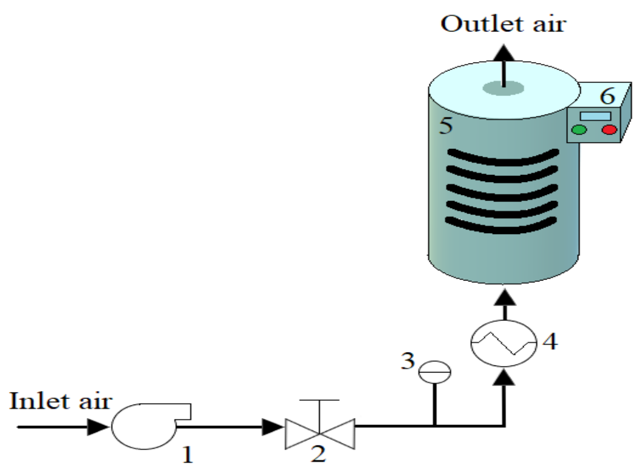

Figure 1: Schematic diagram of the tray drying system. (1. Blower; 2. Valve; 3. Relative humidity and temperature indicator; 4. Heater; 5. Tray column dryer and 6. Automatic thermoregulator)

2.2. Experimental Procedure

18 units of jalapeño peppers were purchased at the Miraflores organic farmers market in Peru in order to reduce biological and respiratory activities until the time of the experiment, these were placed in a no-frost refrigeration chamber at a temperature of 4.6-7.2 ° c. [14], then all the peppers were washed and the excess water was absorbed with paper tissues, then they were allowed to cool to room temperature and finally the width and length of the jalapeño peppers were measured with the foot of king before further processing. The initial moisture content of the chili samples was 73 ± 0.6% (w.b.) determined by a hot air oven at 105 °C for 12 h. These conditions were previously reported by (Suvarnakuta, Devahastin, and Mujumdar 2005). Then the jalapeño pepper samples had different thicknesses and were divided into 3 groups of 6 units with the codes A (A_1, A_2, A_3, A_4, A_5 y A_6), B (B_1, B_2, B_3, B_4, B_5 y B_6) and C (C_1, C_2, C_3, C_4, C_5 y C_6) that were kept in the Alimentos Blanik BDA020 convective dryer at a temperature of 70, 50 and 40 °C respectively and in all cases at an air velocity of 1.8 $m.s^{-1}$. Moisture loss was measured periodically with an interval of 60 min of drying with a SARTORIUS analytical balance calculated based on dry matter (db) [15].

2.3. Moisture Assessment

The experimental drying data were graphically analyzed in terms of the relationship of humidity with the drying time. Initially, the experimental drying data, which was measured in terms of moisture content (w.b.), was converted to dry basis (d.b.). Then, the moisture content on a dry basis was used to calculate the moisture ratio (MR) of the chili peppers at any time using the following equation;

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

Where MR, M_o, M_e y M_t are the moisture ratio, the initial moisture content (d.b.), the equilibrium moisture content (d.b.) and the moisture content (d.b.) at drying time t (min), respectively [16].

2.4. Effective Diffusivity of Moisture

Fick's second diffusion equation was used to calculate the effective diffusivity, considering constant moisture diffusivity, infinite slab geometry, and uniform initial moisture distribution [15]:

$$MR = \frac{8}{\pi^2}\sum_{i=0}^{\infty}\frac{1}{(2i+1)^2}\exp\left[-\frac{(2i+1)^2\pi^2 D_{eff} t}{4L^2}\right] \tag{2}$$

Where Deff is the effective diffusivity of moisture ($m^2.s^{-1}$), L is half the thickness of the samples (m), i is a positive integer and t is the time (s).

Considering that only the first term of the series is significant, then equation 2 is converted to equation 3 [17].

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \tag{3}$$

For long drying periods, equation 2 can be simplified as we noted in equation 4 [18].

$$\ln(MR) = \frac{8}{\pi^2} - \frac{\pi^2 D_{eff}}{4L^2} t \tag{4}$$

By plotting the logarithm of the experimental MR values (lnMR) versus the drying time, a straight line with a slope of $K = \frac{\pi^2 D_{eff}}{4L^2}$ was obtained and Deff was calculated with equation (5) [19].

$$D_{eff} = \frac{4L^2 K}{\pi^2} \tag{5}$$

2.5. Activation energy

The activation energy refers to the amount of energy required to initiate the diffusion of moisture during the drying process. This measurement provides us with information about how temperature influences this process, and this relationship can be expressed using the Arrhenius equation, identified as equation (6) [20].

$$D = D_0 \exp\left(\frac{E_a}{R(T)}\right) \tag{6}$$

In this equation, Ea represents the activation energy (in $m^2.s^{-1}$), T denotes the absolute drying air temperature in K, D_o stands for the Arrhenius factor ($m^2.s^{-1}$), and R corresponds to the universal gas constant (8.314 kJ mol^{-1}). Calculating the activation energy (Ea) involves creating a graph of lnDeff as a function of the inverse of temperature (1/T) [21]

2.6. Statistical Analysis

The correlation coefficient (R^2) with equation 7 and the root mean square error (RMSE) with equation 8 were determined to assess the fit between the model and the experimental data [22]. The highest R^2 and the lowest RMSE is what must be met for the model to be optimal [23].

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(\overline{MR}_{pre,i} - MR_{exp,i}\right)^2}\right] \tag{7}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2\right]^{1/2} \tag{8}$$

Where MR_{pre} – predicted MR; MR_{exp} – experimental value of the MR.

3. RESULTS

3.1. Drying Kinetics

During the drying of the jalapeño pepper, the weights of the different samples were taken sequentially to build the graphs corresponding to the drying kinetics by varying the moisture rate (MR) using equation 1, this procedure will be carried out with the temperatures of 70°C, 50°C and 40°C e.g. Figure 2.

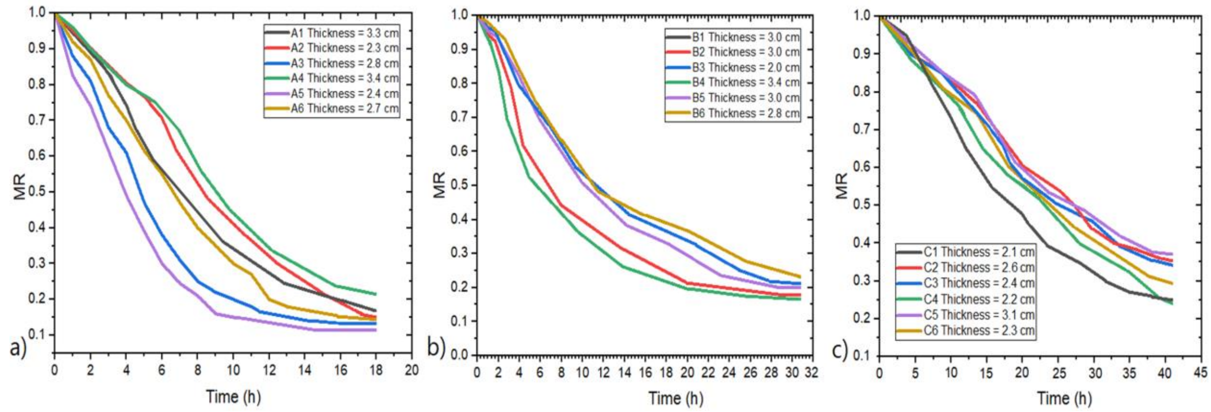

Figure 2: Drying kinetics of jalapeño pepper temperature vs time, a) 40 °C vs time (h) b) 50 °C vs time (h) c) 70°C vs time (h)

3.2. Moisture Rate in Jalapeño Pepper

Then figure 3 was made, containing the results of the Ln(MR) (moisture rate) with respect to time (h) in each experimental unit with temperatures of 70°C, 50°C and 40°C.

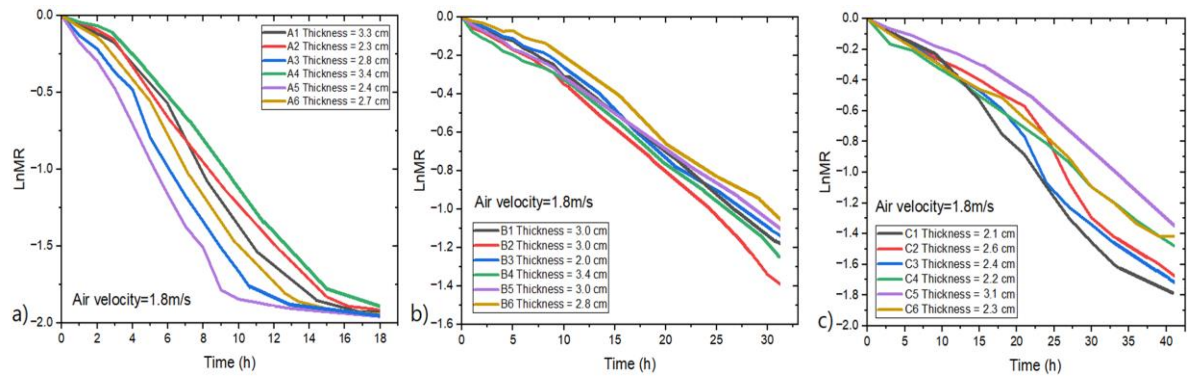

Figure 3: Variation of Ln(MR) vs drying time (h) of jalapeño pepper, a) Ln(MR) at 40°C vs drying time (h) b) Ln(MR) at 50°C vs drying time (h) c) Ln(MR) at 70°C vs drying time (h).

Table 2 shows the drying temperature, the drying time, its effective diffusivity, the R^2 and the RMSE, obtained after the experimental tests for each sample with its respective code.

Table 2: Variation of drying time of jalapeño pepper (Capsicum annuum L.) with respect to temperature

Group code	Temperature	Drying time	Effective diffusivity ($m^2.s^{-1}$)	R^2	RMSE	E_a ($kJ.mol^{-1}$)
A	70°C	18 hours	1.307 E^{-9}	0.994	0.0429	
B	50°C	31 hours	7.521 E^{-10}	0.990	0.0216	45.37
C	40°C	41 hours	2.924 E^{-10}	0.993	0.0162	

4. DISCUSSION

Regarding the models that best interpret the drying processes, the drying work of [24] is cited, which used a temperature of 40 °C, 50 °C and 60 °C for the drying of the Red chili pepper where the R^2 values were 0.991 with an RMSE of 0.048, 0.993 with an RMSE of 0.063 and 0.986 with an RMSE of 0.099 for each temperature respectively and finally the drying of the Green chili pepper in which the R^2 value at a temperature of 40 °C was 0.998 with a RMSE of 0.032, at a temperature of 50 °C it was 0.993 with a RMSE 0.051 and at a temperature of 60 °C the R^2 was 0.984 with a RMSE 0.099 having a high R2 and a low RMSE value, as in the research carried out in this article with the convective drying of jalapeño peppers by hot air where high R^2 values and low RMSE values were obtained with temperatures of 70°C with an R^2 0.994 and an RMSE of 0.0429, those of 50°C with an R^2 0.990 and an RMSE of 0.0216 and 40°C with an R^2 0.993 and an RMSE of 0.0162.

The highest value of moisture diffusivity was 1.307 $E^{-9}m^2.s^{-1}$ at an air temperature of 70 °C, while the lowest value was 2.924 $E^{-10}m^2.s^{-1}$ at an air temperature of 40°C. The Deff range of most food products was between 10^{-12} and 10^{-8} $m^2.s^{-1}$ [25]. Many investigations have reported a similar Deff range, as in the investigations by Abiodun et al., (Okunola et al. 2023) for Water Yam (10^{-9} to 10^{-8} $m^2.s^{-1}$), Incedayi [19] for red pepper (10 $E^{-8}m^2s^{-1}$), Handayani et al., [26] for red chilli ranging from 7.204 E^{-11} to 1.08 E^{-8} m^2s^{-1} and Hellismar et al. ., [27] for 'Cabacinha' pepper fruits (10^{-9}).

In the research carried out by Rasool et al., [28] it can be observed that the drying speed increases with the increase in temperature and the reduction of thickness, obtaining as maximum drying time at a temperature and a thickness of 60 °C, 7 mm, respectively, and a minimum drying time at a temperature and a thickness of 80 °C, 3 mm, respectively. This can be verified in this investigation because the maximum drying time was 41 hours at a temperature of 40°C and a thickness of 3.4 cm, and the minimum drying time was 18 hours at a temperature of 70°C and a thickness of 2.1 cm.

CONCLUSSIONS

- The effect of temperature on the drying kinetics of the jalapeño pepper was directly related to the drying time, so that at a higher temperature the drying time is shorter and vice versa.
- The effective diffusivity in the drying of pickled jalapeño pepper varied from 2.924 $E^{-10}m^2s^{-1}$ at 40°C to 1.307 $E^{-9}m^2s^{-1}$ at 70ºC using a convection hot air food dryer. What can be indicated is that the higher the drying temperature, the effective diffusivity is greater.
- The R^2 correlation coefficient was also found between the humidity rate or humidity proportion (MR) observed during the drying of jalapeño peppers with respect to time (h) at temperatures of 70ºC, 50ºC and 40ºC in which R^2 values of 0.994, 0.990, and 0.993 and an RMS of 0.0429, 0.0216 and 0.0162 respectively were obtained. Therefore, the criteria for a good adjustment of the drying model between the experimental temperature, as well as between the moisture rate and the drying time, are met.
- The energy required to carry out the drying process (referred to as activation energy, abbreviated as Ea) is closely related to the ingredients present, the characteristics of the tissue structure, specific surface area, diversity, the ripeness level of the products, and even the pre-treatments applied to the samples.

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REFERENCES

[1] [1] A. Arslan, Y. Soysal, and M. Keskin, “Mathematical Modeling, Moisture Diffusion and Color Quality in Intermittent Microwave Drying of Organic and Conventional Sweet Red Peppers,” AgriEngineering, vol. 2, no. 3, pp. 393–407, 2020, doi: 10.3390/agriengineering2030027.

[2] S. GA and M. MS, “Effect of Heat Treatment on Phenolic and Flavonoid Compounds and Antioxidant Activities of Some Egyptian Sweet and Chilli Pepper,” Nat. Prod. Chem. Res., vol. 04, no. 03, pp. 1–6, 2016, doi: 10.4172/2329-6836.1000218.

[3] E. S. P. Yap, A. Uthairatanakij, N. Laohakunjit, and P. Jitareerat, “Influence of hot air drying on capsaicinoids, phenolics, flavonoids and antioxidant activities of ‘Super Hot’ chilies,” PeerJ, vol. 10, 2022, doi: 10.7717/peerj.13423.

[4] E. R. Naves et al., “Capsaicinoids: Pungency beyond Capsicum,” Trends Plant Sci., vol. 24, no. 2, pp. 109–120, 2019, doi: 10.1016/j.tplants.2018.11.001.

[5] M. R. Rana, K. N. Sakib, M. Z. Islam, P. C. Das, and R. Ara, “Effect of pretreatments and temperature on rehydration kinetics of naga chili (Capsicum chinense),” Food Res., vol. 5, no. 4, pp. 38–45, 2021, doi: 10.26656/fr.2017.5(4).725.

[6] S. Arora, S. Bharti, and V. K. Sehgal, “Convective drying kinetics of red chillies,” Dry. Technol., vol. 24, no. 2, pp. 189–193, 2006, doi: 10.1080/07373930600559068.

[7] A. Anjaneyulu, A. B. Sharangi, T. K. Upadhyay, N. Alshammari, M. Saeed, and L. A. Al-Keridis, “Physico-Chemical Properties of Red Pepper (Capsicum annuum L.) as Influenced by Different Drying Methods and Temperatures,” Processes, vol. 10, no. 3, pp. 1–13, 2022, doi: 10.3390/pr10030484.

[8] A. Quraishi, P. S. Champawat, S. K. Jain, and K. Dhake, “Drying characteristics of green chilli and quality attributes of developed powder,” vol. 10, no. 9, pp. 1127–1133, 2021.

[9] T. Calado, A. Venâncio, and L. Abrunhosa, “Irradiation for Mold and Mycotoxin Control: A Review,” Compr. Rev. Food Sci. Food Saf., vol. 13, no. 5, pp. 1049–1061, 2014, doi: 10.1111/1541-4337.12095.

[10] E. M. A. El-hamzy and M. M. S. Ashour, “Effect of Different Drying Methods and Storage on Physico-chemical Properties , Capsaicinoid Content , Rehydration Ability , Color Parameters and Bioactive Compounds of Dried Red Jalapeno Pepper (Capsicum annuum) Slices,” Middle East J. Appl. Sci., vol. 06, no. 04, pp. 1012–1037, 2016.

[11] S. do N. Silva et al., “Prediction of Mathematical Models of the Drying Kinetics and Physicochemical Quality of the Chili Pepper,” J. Agric. Sci., vol. 10, no. 12, p. 377, 2018, doi: 10.5539/jas.v10n12p377.

[12] B. Sturm, W. C. Hofacker, and O. Hensel, “Optimizing the Drying Parameters for Hot-Air-Dried Apples,” Dry. Technol., vol. 30, no. 14, pp. 1570–1582, 2012, doi: 10.1080/07373937.2012.698439.

[13] S. Madhumita, D. Dibya, S. Pinaki, S. Sushmita, S. S. Kumar, and C. Runu, “Effect of drying kinetics on the quality of the green capsicum,” J. Med. Pharm. Allied Sci., vol. 10, no. 4, pp. 3464–3468, 2021, doi: 10.22270/JMPAS.V10I4.1473.

[14] H. Tavakolipour and M. Mokhtarian, “Drying of chili pepper in different conditions,” Proc. TheIRES 4th Int. Confererence, no. July, pp. 71–74, 2015.

[15] H. Darvishi, A. R. Asl, A. Asghari, M. Azadbakht, G. Najafi, and J. Khodaei, “Study of the drying kinetics of pepper,” J. Saudi Soc. Agric. Sci., vol. 13, no. 2, pp. 130–138, 2014, doi: 10.1016/j.jssas.2013.03.002.

[16] K. Limpaiboon, “Mathematical modeling of drying kinetics of bird’s eye chilies in a convective hot-air dryer,” Walailak J. Sci. Technol., vol. 12, no. 2, pp. 219–227, 2015.

[17] A. Sarimeseli, “Microwave drying characteristics of coriander (Coriandrum sativum L.) leaves,” Energy Convers. Manag., vol. 52, no. 2, pp. 1449–1453, 2011, doi: 10.1016/j.enconman.2010.10.007.

[18] A. Arslan, Y. Soysal, and M. Keskin, “Comparing hot air drying kinetics and color quality of organic and conventional sweet red peppers,” Mustafa Kemal Üniversitesi Tarım Bilim. Derg., vol. 5, no. 2, pp. 271–283, 2020, doi: 10.37908/mkutbd.747675.

[19] B. İncedayi, “Assessment of pretreatments on drying kinetics and quality characteristics of thin-layer dried red pepper,” Turkish J. Agric. For., vol. 44, no. 6, pp. 543–556, 2020, doi: 10.3906/tar-2001-62.

[20] R. Iglesias Díaz et al., “Drying kinetics of Moringa oleifera,” Rev. Mex. Cienc. Agríc, vol. 9, no. 5, pp. 935–947, 2018.

[21] Jam, F. A., Singh, S. K. G., Ng, B., & Aziz, N. (2018). The interactive effect of uncertainty avoidance cultural values and leadership styles on open service innovation: A look at malaysian healthcare sector. International Journal of Business and Administrative Studies, 4(5), 208-223.

[22] D. I. Onwude, N. Hashim, K. Abdan, R. Janius, and G. Chen, “Modelling the mid-infrared drying of sweet potato: kinetics, mass and heat transfer parameters, and energy consumption,” Heat Mass Transf. und Stoffuebertragung, vol. 54, no. 10, pp. 2917–2933, 2018, doi: 10.1007/s00231-018-2338-y.

[23] N. Afifah et al., “Foaming properties, microstructure, and mathematical model of foam mat drying of pasta sauce based on tomato,” Czech J. Food Sci., vol. 40, no. 2, pp. 130–137, 2022, doi: 10.17221/221/2021-CJFS.

[24] K. D. R. Ramarao, Z. Razali, and C. Somasundram, “Mathematical models to describe the drying process of Moringa oleifera leaves in a convective-air dryer,” Czech J. Food Sci., vol. 39, no. 6, pp. 444–451, 2021, doi: 10.17221/257/2020-CJFS.

[25] J. Carrera-Escobedo, O. Cruz-Domínguez, C. Guzmán-Valdivia, V. Carrera-Escobedo, M. García-Ruiz, and H. Durán-Muñoz, “Cost analysis of drying process by studying its kinetic parameters: A new study in Mexican chillies,” Czech J. Food Sci., vol. 38, no. 6, pp. 375–387, 2020, doi: 10.17221/96/2020-CJFS.

[26] E. J. Bassey, J. H. Cheng, and D. W. Sun, “Thermoultrasound and microwave-assisted freeze-thaw pretreatments for improving infrared drying and quality characteristics of red dragon fruit slices,” Ultrason. Sonochem., vol. 91, no. October, p. 106225, 2022, doi: 10.1016/j.ultsonch.2022.106225.

[27] S. U. Handayani, I. Mujiarto, A. P. Siswanto, D.Ariwibowo, I. S. Atmanto, and M. Mustikaningrum, “Drying kinetics of chilli under sun and microwave drying,” Mater. Today Proc., vol. 63, pp. S153–S158, 2022, doi: 10.1016/j.matpr.2022.02.119.

[28] H. W. da Silva, R. S. Rodovalho, M. F. Velasco, C. F. Silva, and L. S. R. Vale, “Kinetics and thermodynamic properties related to the drying of ‘cabacinha’ pepper fruits,” Rev. Bras. Eng. Agric. e Ambient., vol. 20, no. 2, pp. 174–180, 2016, doi: 10.1590/1807-1929/agriambi.v20n2p174-180.

[29] R. Sadin, G.-R. Chegini, and H. Sadin, “The effect of temperature and slice thickness on drying kinetics tomato in the infrared dryer,” Heat Mass Transf., vol. 50, no. 4, pp. 501–507, 2014, doi: 10.1007/s00231-013-1255-3.

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