

Research Article

Analysis of Volatiles of Rose Pepper Fruits by GC/MS: Drying Kinetics, Essential Oil Yield, and External Color Analysis

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Received 31 March 2022; Accepted 11 May 2022; Published 25 May 2022

Academic Editor: Ayon Tarafdar

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Condiments and culinary supplements are subjected to long-term storage and may undergo physical, chemical, and biological changes that can influence their quality. Thus, the objective of the present study was to analyze the drying kinetics of rose pepper (*Schinus terebinthifolius* Raddi) fruits in an oven with forced air circulation at different temperatures, namely, 45, 55, 65, and 75°C, and determine the effective diffusion coefficient and activation energy using different mathematical models. Furthermore, the effects of the different drying temperatures were analyzed for external color parameters and yield of essential oil contents by gas chromatography coupled to a mass spectrometer. Of the ten models used for fitting, Thompson's model was one with the best fitting to represent the drying of rose pepper fruits. The diffusion coefficient increases with the elevation of drying air temperature, described by the Arrhenius equation, with activation energy of 53.579 kJ·mol⁻¹. The color of the fruits decreased in lightness (L^*) with the increase in temperature. Of the thirty-eight terpenes identified, α -pinene and *cis*-ocimene were the most abundant, with the overall highest yield being found at a drying temperature of 45°C.

1. Introduction

Schinus terebinthifolius Raddi is a plant native to South America, especially Argentina, Paraguay, and Brazil, where it can be found throughout the Brazilian territory (from northeast to south), known as pink pepper or Brazilian pepper [1]. Its use in medicine is due to its antioxidant and antimicrobial activity, mostly manifested in the richness of its essential oils and phenolic compounds, such as tannins, alkaloids, saponins, sterols, and terpenes [2].

S. terebinthifolius has antihypertensive and vasodilating properties [3], antidiabetic, antioxidant, anti-inflammatory, and antiproliferative activities against tumors in human cells [4]. In cooking, pink pepper is considered an excellent

natural additive and substitute for artificial additives, presenting a sweet taste and light burning [5]. The promising antibacterial effect of pink pepper inhibits the growth of Gram-positive microorganisms associated with food, reinforcing the interest in the use of this product as a natural additive [6]. Plant products have high perishability due to the high moisture content after harvest. To ensure that these products can be stored, ensuring a constant supply of quality phytochemical raw material for the pharmaceutical industry and for consumers, medicinal plants must be to postharvest processes, such as drying [7].

Drying is still the most popular method for preserving agricultural products (fruits, vegetables, herbs, and spices), ensuring the microbial safety of various biological materials

TABLE 1: Mathematical models used to predict the drying phenomenon of agricultural products.

Models	Model	Equation number	Reference
Two Terms	$Rx = a^{k_0 * t} + b^{-k_1 * t}$	(2)	[12]
Two-term exponential	$Rx = a^{-k * t} + (1 - a)^{-k * a * t}$	(3)	[13]
Logarithmic	$Rx = a^{(-k * t) + c}$	(4)	[14]
Midilli	$Rx = a^{(-k * t^n)} + b * t$	(5)	[15]
Newton	$Rx = a^{-k * t}$	(6)	[16]
Page	$Rx = a^{-k * t^n}$	(7)	[17]
Thompson	$Rx = a^{(-a - (a^2 + 4 * b * t)^{0.5}) / 2 * t}$	(8)	[18]
Verma	$Rx = a^{(-k * t)} + (1 - a)^{(-k_1 * t)}$	(9)	[19]
Henderson and Pabis	$Rx = a^{(-k * t)}$	(10)	[20]
Wang and Sing	$Rx = 1 + a * t$	(11)	[21]

t : drying time (hours); k , k_0 , and k_1 : drying constants (h^{-1}); a , b , c , and n : coefficients in the models.

[8, 9]. The artificial drying method is the most suitable for reducing the moisture content of the products, as it provides better control and efficiency of the process [10]. Reducing the moisture content inhibits microbial growth and delays some biochemical deterioration reactions, in addition to facilitating transport and reducing cost, by reducing the volume and mass of the material [7]. The drying temperature is an important factor to be analyzed since according to the literature, high temperatures influence the quality and yield of essential oils. Thus, considering the importance of drying in food preservation during storage, the objective of this work was to analyze the drying kinetics of pink pepper (*S. terebinthifolius*): in an oven with forced air circulation, at temperatures of 45, 55, 65, and 75°C, for model selection and determination of effective diffusion coefficient, activation energy, fruit color parameters, and essential oil yield.

2. Materials and Methods

2.1. Drying Process and Kinetics. Rose pepper fruits were collected manually in the municipality of Santa Helena de Goiás, GO, Brazil (17° 48' 50" S; 50° 35' 49" W), and transported to the Laboratory of Post-Harvest of Plant Products of the Federal Institute of Education, Science and Technology Goian, Campus of Rio Verde, Goiás. The initial moisture content of the pepper was 12.0 g, determined according to [11], in an oven at $105 \pm 3^\circ\text{C}$, for 24 hours. The peppers were homogenized and placed in stainless-steel rectangular trays ($24 \times 10 \times 6$ cm) without perforation, with a layer thickness of approximately 3 cm, containing 25 g, in four replicates per temperature. Then, they were subjected to drying in an oven with forced air circulation at temperatures of 45, 55, 65, and 75°C, with a relative humidity of 41.19% (d.b), respectively. The trays were weighed periodically on semianalytical scales, with a resolution of 0.01 g, until the fruits reached the equilibrium moisture content, being recorded at 6.92, 6.09, 5.17, and 4.88 g, respectively, for the drying conditions of 45, 55, 65, and 75°C.

The temperature and relative humidity of the ambient air were monitored using a data logger, and the relative humidity inside the oven was obtained through the basic principles of psychrometry using the GRAPSI computer program. The drying curve was obtained for each temperature and drying

condition, relating the moisture content ratio along the drying time, using the following expression:

$$RX = \frac{X^* - X_e^*}{X_i^* - X_e^*}, \quad (1)$$

where RX is the moisture content ratio of the product, dimensionless; X^* is the moisture content of the product; X_i^* is the initial moisture content of the product; X_e^* is the equilibrium moisture content of the product.

Ten mathematical models frequently used to represent the phenomenon of drying of condiments were fitted to the experimental data of moisture content ratio during the drying of rose pepper fruits, further shown in Table 1.

The mathematical models were fitted by nonlinear regression analysis through the Gauss–Newton method, using Statistica7.0® software. The degree of fit of the models used was verified considering the significance of the regression coefficient through a Student's t -test, adopting a 5% significance level, the magnitude of the coefficient of determination (R^2), magnitude of the mean relative error (P), the value of the mean estimated error (SE), and the chi-square test (χ^2). Mean relative error below 10% was considered as one of the criteria for selecting the models, according to Mohapatra and Rao [22]. The mean relative error, mean estimated error, and chi-square test (χ^2) for each model were calculated according to the following expressions:

$$SE = \sqrt{\frac{\sum (Y - \hat{Y})^2}{DF}},$$

$$P = \frac{100}{N} \sum \frac{|Y - \hat{Y}|}{Y}, \quad (2)$$

$$\chi^2 = \frac{\sum_{i=1}^n (Y - \hat{Y})^2}{DF},$$

where Y denotes the experimental value; \hat{Y} denotes the value estimated by the model; N denotes the number of experimental observations; DF denotes the degrees of freedom of the model (number of experimental observations minus the number of coefficients of the model).

The Akaike information criterion (AIC) and Schwarz's Bayesian information criterion (BIC) were used as

additional criteria for selecting the best mathematical model to predict the phenomenon. AIC makes it possible to use the principle of parsimony in choosing the best model; that is, according to this criterion, the most parameterized model is not always better [23].

AIC (equation (3)) is used to compare nonnested models or when three or more models are being compared. Lower AIC values reflect better fit [24].

$$AIC = -2 \log \text{like} + 2p, \quad (3)$$

where p is the number of parameters; log like is the logarithm of the likelihood function considering the estimates of the parameters.

BIC (equation (4)) also considers the degree of parameterization of the model, and similarly, the lower the BIC value [25], the better the fit of the model.

$$BIC = 2 \log \text{like} + p \cdot \ln(n), \quad (4)$$

where p denotes the number of parameters and log like denotes the logarithm of the likelihood function considering the estimates of the parameters. n denotes the number of observations.

BIC is an asymptotic criterion whose adequacy is strongly related to the magnitude of the sample size. For the penalty applied to the amount of parameters, this will be stricter than that of AIC for small samples. The effective diffusion coefficient (D) for the drying of rose pepper fruits, for the different conditions, was calculated using the mathematical model of liquid diffusion for the spherical geometric shape, with eight-term approximation, according to the following expression:

$$RX = \frac{X^* - X_e^*}{X_i^* - X_e^*} = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp \left[-\frac{n^2 \cdot \pi^2 \cdot D \cdot t}{9} \cdot \left(\frac{3}{R}\right)^2 \right], \quad (5)$$

where RX is the moisture content ratio of the product (dimensionless); n is the number of terms; D is the effective diffusion coefficient, $\text{m}^2 \cdot \text{s}^{-1}$; t is the drying time, h ; R is the equivalent radius, m .

The equivalent radius (Re) is the radius of a sphere with the same volume of the fruits and was calculated by the following expression:

$$Re = \sqrt[3]{\frac{3 \cdot V_s}{4 \cdot \pi}}. \quad (6)$$

The volume of each rose pepper fruit was obtained by means of the relationship between the measurements of the three orthogonal axes (a : length, b : width, and c : thickness). The orthogonal axes were determined using the mean values of 15 measurements in rose pepper fruits, using a digital caliper with a resolution of 0.01 mm. From these values, the volume of the fruits was calculated using the following expression [26]:

$$V_s = \frac{\pi \cdot (a \cdot b \cdot c)}{6}, \quad (7)$$

where V_s is the volume of each fruit, m^3 ; a denotes the length, m ; b denotes the width, m ; c denotes the thickness, m .

The relationship of the diffusion coefficient with the drying air temperature was analyzed by the Arrhenius equation according to the following expression:

$$D = D_0 \exp \left(\frac{-E_a}{R \cdot T_{abs}} \right), \quad (8)$$

where D_0 is the preexponential factor, $\text{m}^2 \cdot \text{s}^{-1}$; E_a is the activation energy, $\text{kJ} \cdot \text{mol}^{-1}$; R is the universal gas constant ($8.314 \text{ kJ} \cdot \text{kmol}^{-1} \cdot \text{K}^{-1}$); T_{abs} is the absolute temperature, K^{-1} .

2.2. External Color Analysis. The rose pepper fruits were dried until reaching equilibrium moisture contents of 6.92, 6.09, 5.17, and 4.88 g, respectively, for the drying conditions of 45, 55, 65, and 75°C and subjected to color analysis with a Hunter Lab colorimeter, using the CIE- $L^*a^*b^*$ system (Commission International eL'Eclairage), to obtain the parameters' lightness (black 0 to white 100), a^* ($-a^*$ green to $+a^*$ red), and b^* ($-b^*$ blue to $+b^*$ yellow) [1].

2.3. Essential Oil Identification and Quantification. The extraction of essential oil (EO) was performed using samples of peppers dried at different temperatures of 45, 55, 65, and 75°C and samples of natural peppers as control. The samples were homogenized and crushed in a blender, totaling 30 g of pepper for each condition. The extraction of essential oil was carried out at the Laboratory of Natural Products of the Federal Institute of Education, Science and Technology Goiano, Campus of Rio Verde, Goiás, using the Clevenger apparatus, with hydrodistillation by steam drag, adapted to a round-bottom flask. For every 30 g of pepper, 500 mL of distilled water was added. The duration of the extraction was 3.5 h for each sample. The essential oil was extracted from the aqueous phase through liquid-liquid partition using dichloromethane. The hydrolate was washed three times with three 10 mL portions of dichloromethane. The extracted essential oil was dried with anhydrous sodium sulfate, and the yield (%) was calculated for each temperature. The oils were stored under refrigeration in amber glass vials (10 mL) sealed to prevent leakage and exposure to light and sent to the Centro de Investigação de Montanha (CIMO) of the Polytechnic Institute of Bragança for identification. The EOs analysis was performed on a Perkin Elmer gas chromatograph coupled to a mass spectrometry detector (GC/MS) system with a Clarus® 580 GC and a Clarus® SQ 8 S MS module equipped with DB-5MS fused-silica column ($30 \text{ m} \times 0.25 \text{ mm}$ i.d., film thickness $0.25 \mu\text{m}$; J&W Scientific, Inc.) [27]. The carrier gas was helium gas adjusted to a linear velocity of 30 cm/s. The oven temperature program was as follows: 40°C for 4 min, raised at 3°C/min to 175°C and then at 15°C/min to 300°C, and held for 10 min. The injector temperature was set at 260°C, with a transfer line at 280°C and an ion source at 220°C. The ionization energy was 70 eV, and a scan range of 35–500 μ with a scan time of 0.3 s was used. For each essential oil, 1 μL of sample diluted in HPLC grade n-hexane (1:100) was injected with a split ratio of 1:3. Identification of components was assigned by matching their mass spectra with NIST17 data and by determining the linear retention index

(LRI) based on the retention times obtained for a mixture of n-alkanes (C₈–C₄₀, Supelco) analyzed under identical conditions. Comparisons were also performed with published data and with commercial standard compounds, when possible. Quantification was performed using the relative peak area values obtained directly from the total ion current (TIC) values, and the results were expressed as the relative percentage (%) of total volatiles. The mean values for the parameters of color and yield of the oils were evaluated through an analysis of variance (ANOVA) followed by the Tukey test at a 5% significance level for homoscedastic samples and a Tahmane T2 for heteroscedastic samples.

3. Results and Discussion

3.1. Drying Kinetics. In Figure 1, the drying curves of rose pepper fruits are represented for the different temperatures of 45, 55, 65, and 75°C as a function of the moisture content. The drying rates were higher with the increase in drying temperature, and the time required for drying to occur for the same value of moisture content ratio increases as the drying temperature decreases. Similar behaviors were reported by Geng et al. [28] when studying the drying kinetics of fresh peppers and Kaur et al. [29] when studying the drying kinetics of sweet pepper. The slope of the curvature increases with increasing drying temperature and represents the fastest reduction in moisture content. The slope of the curvature increases with increasing drying temperature and represents the fastest reduction in moisture content. A similar behavior was observed by Kheto et al. [30] when performing the drying kinetics of red pepper.

Table 2 presents the values of the mean estimated error (SE) and mean relative error (*P*) for the ten models fitted for the drying of rose pepper fruits at different temperatures (45, 55, 65, and 75°C).

Comparing the values of the mean estimated error (SE), Wang and Sing and Verma models showed discrepant values for all temperatures under study, while Midilli and Thompson models obtained the lowest values. According to Mohapatra and Rao [22], for a model to be considered appropriate, it must have a mean estimated error (SE) as close to zero as possible and a mean relative error (*P*) lower than 10%. Pina et al. [31] used the same comparison to find the best math to represent the drying kinetics of red peppers. Regarding the mean relative error (*P*), of the ten models applied, Page, Midilli, Two Terms, and Thompson models showed *P* values below 10% for the temperatures of 45, 55, and 75°C, while for the temperature of 65°C, only Midilli and Two Terms models showed *P* values below 10%. Silva et al. [32] report that models with mean relative error (*P*) values above 10% should not be used to explain the drying phenomenon. Regarding the coefficient of determination (*R*²) (Table 3), the Wang and Sing model showed lower values for all the temperatures under study compared to the others. Page, Midilli, Two Terms, and Thompson models had coefficients of determination (*R*²) higher than 99% under all drying conditions. According to Mohapatra and Rao [22], coefficients

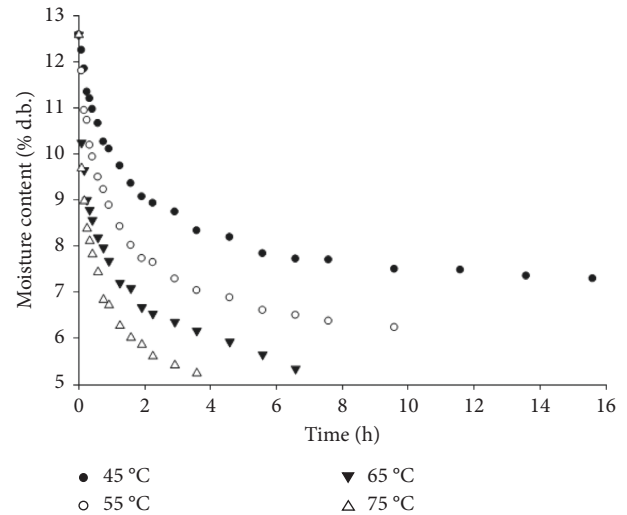


FIGURE 1: Moisture content of rose pepper (*Schinus terebinthifolius* Raddi) fruits along the drying time at temperatures of 45, 55, 65, and 75°C.

of determination (*R*²) higher than 90% are satisfactory in the drying process. Sitorus et al. [33] used the same parameters to choose the best model that fitted the kinetic drying of paddy in a fluidized bed. Madamba et al. [34] reported that this parameter alone does not constitute a good index for the selection of nonlinear models. The chi-square (χ^2) for the experimental data obtained varied from 0.022 to 1.633 (Table 3). The Midilli model had the lowest value for the temperature of 75°C, while Thompson had the lowest value for 45°C, Page for 55°C, and Two Terms for 65°C; all these models had the lowest values for chi-square (χ^2) compared to the others fitted. The smaller χ^2 values, the better the fit of the model.

To select the best model to describe the drying kinetics of rose pepper, some parameters were considered, including the Akaike information criteria (AIC) and Schwarz's Bayesian information criteria (BIC) [35]. These parameters were appropriately used by Souza et al. [36] in the drying kinetics of biofortified pulp of sweet potato (*Ipomoea batatas* L.) and by Gomes et al. [5] in the drying of the crushed mass of jambu (*Acmella oleracea*) for the selection of drying models. For the conditions studied, the Thompson model (Table 4) had lower values of AIC and BIC for the temperatures of 45, 55, and 75°C, and although the Thompson model did not show the best fit for the temperature of 65°C and with *P* > 10%, a single model with a satisfactory fit for all temperatures was chosen. In this case, the Thompson model was the most appropriate to describe the drying of rose pepper fruit.

Figure 2 shows the estimated data represented by the Thompson model for the different drying conditions, with an adequate fit for the analyzed conditions. Thompson model was the most recommended to represent the drying kinetics of "Carioca" common bean (*Phaseolus vulgaris* L.) according to a study conducted by Melo et al. [37] at temperatures of 55 and 65°C and also

TABLE 2: Values of mean estimated error (SE) and mean relative error (P) for the fitted models for drying of rose pepper fruits at temperatures of 45, 55, 65, and 75°C.

Models	45°C		55°C		65°C		75°C	
	SE	P	SE	P	SE	P	SE	P
Page	0.024	8.90	0.014	3.96	0.013	10.30	0.008	2.93
Logarithmic	0.037	12.25	0.042	34.33	0.059	31.05	0.049	16.92
Newton	0.080	34.48	0.071	36.80	0.109	38.25	0.083	30.43
Midilli	0.016	4.11	0.014	5.16	0.012	8.28	0.007	1.85
Wang and Sing	0.174	60.21	0.202	149.72	0.207	93.49	0.170	61.74
Henderson and Pabis	0.064	27.40	0.054	28.66	0.078	22.99	0.066	21.64
Two-term exponential	0.058	26.84	0.049	29.20	0.091	32.57	0.066	25.21
Two Terms	0.019	7.06	0.013	6.38	0.020	8.23	0.013	5.26
Verma	0.084	34.48	0.075	36.80	0.114	38.25	0.087	30.44
Thompson	0.015	5.92	0.010	7.61	0.019	10.36	0.008	2.59

TABLE 3: Values of the coefficient of determination (R^2) and chi-square (χ^2) during the drying of rose pepper fruits for the different conditions.

Models	45°C		55°C		65°C		75°C	
	R^2	χ^2	R^2	χ^2	R^2	χ^2	R^2	χ^2
Page	0.9969	0.097	0.9988	0.043	0.9982	0.112	0.9993	0.032
Logarithmic	0.9927	0.140	0.9894	0.392	0.9636	0.355	0.9722	0.193
Newton	0.9620	0.360	0.9668	0.384	0.8575	0.399	0.9094	0.318
Midilli	0.9986	0.049	0.9989	0.062	0.9985	0.099	0.9995	0.022
Wang and Sing	0.8166	0.657	0.7041	1.633	0.2954	1.020	0.5521	0.673
Henderson and Pabis	0.9770	0.299	0.9820	0.313	0.9335	0.251	0.9460	0.236
Two-term exponential	0.9810	0.293	0.9849	0.319	0.9083	0.355	0.9456	0.275
Two Terms	0.9982	0.085	0.9990	0.077	0.9960	0.099	0.9981	0.063
Verma	0.9620	0.394	0.9668	0.421	0.8575	0.437	0.9094	0.348
Thompson	0.9988	0.065	0.9994	0.083	0.9962	0.113	0.9992	0.028

TABLE 4: AIC and BIC values for the models fitted for the drying curves of rose pepper fruits under different air conditions.

Models	45°C		55°C		65°C		75°C	
	AIC	BIC	AIC	BIC	AIC	BIC	-89.62	-87.50
Page	-96.06	-92.65	-94.48	-91.35	-89.95	-87.28	-38.09	-35.26
Logarithmic	-80.23	-75.69	-63.06	-58.88	-40.61	-37.05	-23.74	-22.32
Newton	-47.52	-45.25	-46.11	-44.02	-21.71	-19.93	-86.30	-82.76
Midilli	-109.00	-103.33	-91.78	-86.56	-87.49	-83.04	0.61	2.74
Wang and sing	-10.79	-7.38	-1.11	2.02	3.40	6.08	-27.85	-25.73
Henderson and Pabis	-56.11	-52.70	-55.38	-52.24	-31.95	-29.28	-22.11	-23.85
Two-term exponential	-61.41	-58.00	-60.46	-57.33	-26.74	-25.85	-71.18	-67.64
Two Terms	-106.78	-101.11	-97.83	-92.60	-77.11	-72.66	-73.08	-70.25
Verma	-10.86	-10.41	-99.83	-95.65	-7.89	-7.53	-89.25	-87.12
Thompson	-114.83	-111.42	-101.36	-98.23	-84.55	-81.78	-89.62	-87.50

for the drying of crumb at temperatures of 30, 40, 50, 60, and 70°C [38].

The values of the effective diffusion coefficient increase with the increase in drying air temperature (Figure 3), a behavior also observed by Siqueira et al. [39]. The author also states that the increase in drying temperature and consequently the increase in diffusivity lead to greater speeds of water exiting from the center to the periphery.

The effective diffusion coefficient showed an increasing linear trend due to the increase in temperature used to dry the

product (Figure 3), with values of 2.22×10^{-11} , 4.164×10^{-11} , 6.760×10^{-11} , and $11.419 \times 10^{-11} \text{ m}^2 \cdot \text{s}^{-1}$ for the temperatures of 45, 55, 65, and 75°C, respectively. The higher the temperature, the faster the movement of water from the food to the environment. Similar results were found by Getahun et al. [40] in a study with chili peppers; the authors obtained values ranging from 7.204×10^{-11} to $3.062 \times 10^{-10} \text{ m}^2 \cdot \text{s}^{-1}$ for red pepper, 7.832×10^{-11} to $3.154 \times 10^{-10} \text{ m}^2 \cdot \text{s}^{-1}$ for brown, and 7.387×10^{-11} to $4.043 \times 10^{-10} \text{ m}^2 \cdot \text{s}^{-1}$ for green peppers. Deng et al. [41] observed diffusion values ranging from 1.33×10^{-10}

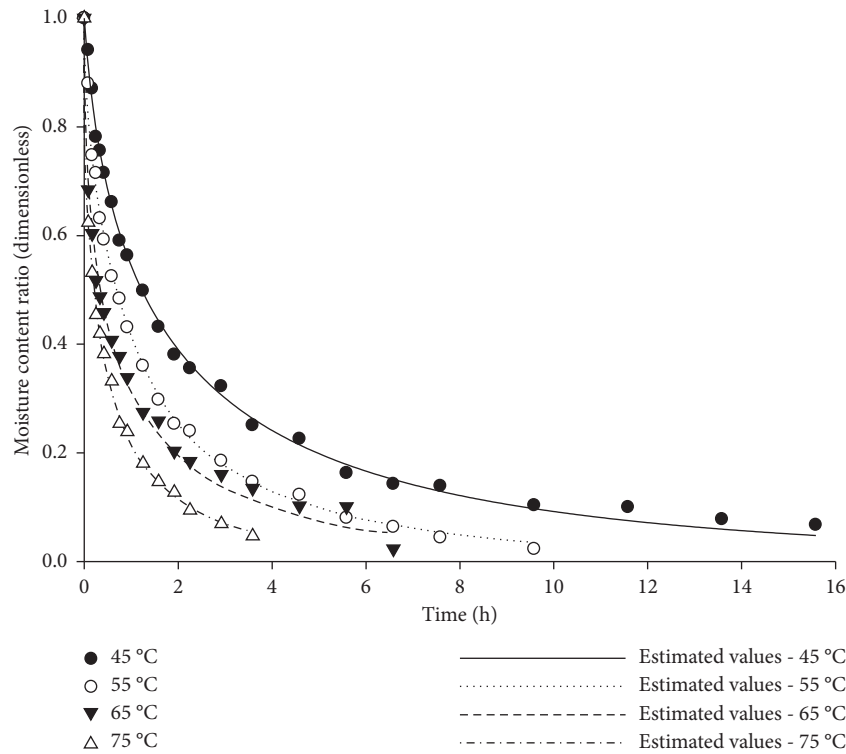


FIGURE 2: Drying kinetics estimated by the Thompson model for the drying of rose pepper (*Schinus terebinthifolius* Raddi) fruits at temperatures of 45, 55, 65, and 75°C.

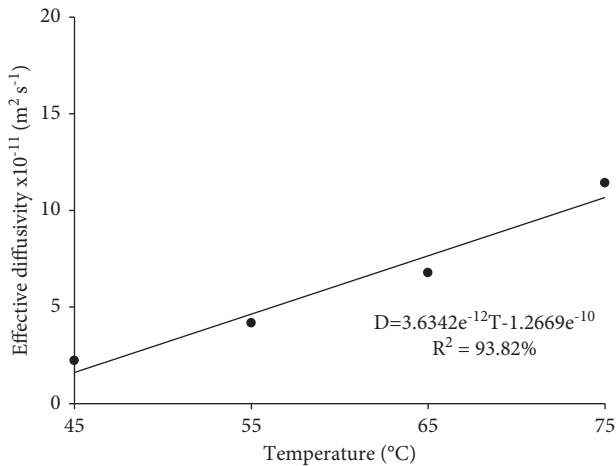


FIGURE 3: Mean values of the effective diffusion coefficient $\times 10^{-11}$ ($\text{m}^2 \cdot \text{s}^{-1}$) obtained for the drying of rose pepper fruits at temperatures of 45, 55, 65, and 75°C.

to $8.97 \times 10^{-10} \text{ m}^2 \cdot \text{s}^{-1}$ for red pepper (*Capsicum annuum* L.) at temperatures of 50, 60, 70, and 80°C. Kheto et al. [29] reported for sweet pepper (*Capsicum annuum* L.) at temperatures of 40, 50, and 60°C diffusion values of $0.114\text{--}6.86 \times 10^{-10} \text{ m}^2 \cdot \text{s}^{-1}$, $5.52\text{--}9.21 \times 10^{-10} \text{ m}^2 \cdot \text{s}^{-1}$, and $0.150\text{--}9.02 \times 10^{-10} \text{ m}^2 \cdot \text{s}^{-1}$.

The dependence of the effective diffusion coefficient of rose pepper fruits on drying air temperature was represented by the Arrhenius expression (Figure 4).

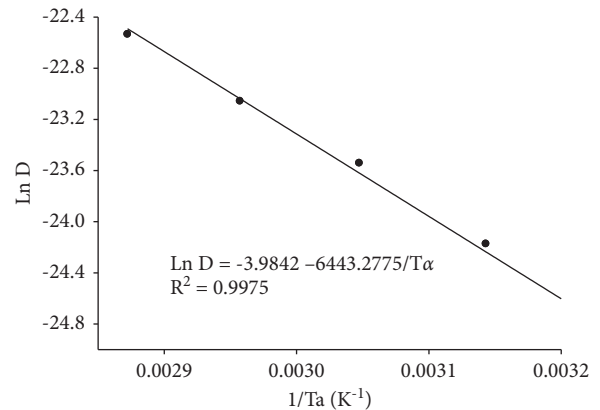


FIGURE 4: Arrhenius representation for the effective diffusion coefficient as a function of drying air temperature obtained during the drying of rose pepper (*Schinus terebinthifolius* Raddi) fruits at temperatures of 45, 55, 65, and 75°C.

TABLE 5: Values of the color coordinates L^* , a^* , and b^* of rose pepper both fresh and dried at 45, 55, 65, and 75°C.

Treatment	L^*	a^*	b^*
Fresh	36.53 ± 1.17^c	20.62 ± 1.57^a	19.56 ± 0.40^b
45°C	38.70 ± 2.06^{ab}	20.13 ± 2.08^a	18.78 ± 0.95^b
55°C	40.09 ± 1.44^a	19.45 ± 1.74^a	18.87 ± 0.55^b
65°C	39.24 ± 1.39^{ab}	19.85 ± 2.86^a	18.76 ± 0.56^b
75°C	37.56 ± 1.37^{bc}	20.12 ± 1.43^a	20.12 ± 1.43^a

Equal letters in columns do not differ by the Tukey test at a 5% significance level. L^* (lightness, black 0 to white 100), a^* ($-a^*$ green to $+a^*$ red), and b^* ($-b^*$ blue to $+b^*$ yellow).

TABLE 6: Mean values of the yield of essential oil of rose pepper.

Treatments	Yield (%)
Fresh	1.68 ± 0.06 ^c
45°C	4.47 ± 0.14 ^a
55°C	3.83 ± 0.20 ^b
65°C	3.10 ± 0.25 ^c
75°C	1.77 ± 0.07 ^d

*Equal letters do not differ by the Tukey or Tahmane T2 tests, at a 0.05 significance level.

TABLE 7: Essential oils composition of rose pepper fruits, expressed in relative percentage.

N	Compound	RT (min)	LRI *1	LRI *2	Rose pepper fruits essential oil relative %*3				
					Fresh	35°C	55°C	65°C	75°C
1	α -Pinene	11.29	940	932	21 ± 1^d	20.7 ± 0.2^d	57 ± 1^a	27 ± 1^c	37 ± 2^b
2	Sabinene	13.04	976	969	0.868 ± 0.003	0.9 ± 0.1	0.355 ± 0.002	0.47 ± 0.01	1.2 ± 0.1
3	β -Pinene	13.31	982	974	5.16 ± 0.03	6.6 ± 0.2	1.57 ± 0.03	4.3 ± 0.3	7.7 ± 0.2
4	β -Myrcene	14.02	996	988	3.7 ± 0.1	3.41 ± 0.04	2.7 ± 0.1	3.79 ± 0.03	2.3 ± 0.2
5	α -Phellandrene	14.68	1009	1002	0.135 ± 0.01	–	0.64 ± 0.02	0.21 ± 0.01	–
6	δ -3-Carene	14.77	1011	1010	12.8 ± 0.5^c	11.2 ± 0.3^d	11.07 ± 0.05^d	17 ± 1^a	15 ± 1^b
7	<i>cis</i> -Ocimene	15.07	1017	1032	29 ± 2^a	27.9 ± 1.1^a	6.6 ± 0.5^c	15.3 ± 0.1^b	3.3 ± 0.2^d
8	<i>p</i> -Cymene	15.70	1029	1025	4 ± 0.1^c	2.6 ± 0.1^e	7.1 ± 0.1^a	4.69 ± 0.03^b	3.4 ± 0.1^d
9	Limonene	16.01	1035	1024	8 ± 1^b	8 ± 1^b	9 ± 1^b	8.6 ± 0.05^c	11 ± 1^a
10	Terpinolene	18.64	1088	1086	0.517 ± 0.0004	0.82 ± 0.01	0.143 ± 0.001	0.8 ± 0.1	0.35 ± 0.01
11	α -Pinene oxide	19.23	1099	1096	0.186 ± 0.004	0.19 ± 0.02	0.69 ± 0.03	0.19 ± 0.01	0.2 ± 0.02
12	<i>cis-p</i> -Mentha-2,8-dien-1-ol	19.76	1110	1102	0.14 ± 0.01	0.085 ± 0.005	0.9 ± 0.1	0.32 ± 0.02	0.38 ± 0.03
13	<i>trans</i> -Verbenol	21.58	1147	1140	0.337 ± 0.005	0.061 ± 0.002	0.4 ± 0.01	0.45 ± 0.02	0.25 ± 0.01
14	Sabinol	21.78	1151	1142	0.15 ± 0.02	0.135 ± 0.002	0.6 ± 0.1	0.4073 ± 0.0001	0.31 ± 0.01
15	Terpinen-4-ol	23.28	1182	1174	0.157 ± 0.002	0.26 ± 0.01	–	0.32 ± 0.01	0.43 ± 0.02
16	α -Terpineol	23.52	1187	1186	0.26 ± 0.01	0.102 ± 0.001	0.9 ± 0.1	0.41 ± 0.02	0.21 ± 0.02
17	<i>p</i> -Cymen-9-ol	23.66	1190	1204	0.26 ± 0.02	0.19 ± 0.01	0.3 ± 0.1	0.4 ± 0.01	0.151 ± 0.005
18	Verbenone	24.36	1204	1205	0.91 ± 0.03	0.6 ± 0.04	0.94 ± 0.05	1.01 ± 0.02	0.52 ± 0.03
19	Eucarvone	24.64	1210	1243	0.71 ± 0.01	0.33 ± 0.02	0.18 ± 0.03	0.5 ± 0.04	0.18 ± 0.01
20	Hydroxycitronellol	31.12	1353	1359	0.46 ± 0.01	0.26 ± 0.01	0.71 ± 0.02	0.36 ± 0.04	0.044 ± 0.003
21	α -Ylangene	32.06	1374	1373	0.22 ± 0.03	0.15 ± 0.02	0.28 ± 0.02	0.29 ± 0.02	0.25 ± 0.02
22	β -Elemene	32.69	1389	1389	0.54 ± 0.01	0.686 ± 0.006	0.383 ± 0.005	0.614 ± 0.007	0.33 ± 0.03
23	α -Gurjunene	33.36	1404	1409	0.23 ± 0.01	0.33 ± 0.01	–	0.35 ± 0.01	0.25 ± 0.02
24	β -Caryophyllene	33.94	1418	1417	2.24 ± 0.15	3.1 ± 0.1	1.74 ± 0.03	2.8 ± 0.1	2.9 ± 0.16
25	γ -Elemene	34.34	1428	1434	0.32 ± 0.03	0.6 ± 0.03	0.8 ± 0.1	0.88 ± 0.04	0.91 ± 0.02
26	Humulene	35.35	1452	1436	0.254 ± 0.001	0.37 ± 0.04	0.28 ± 0.01	0.5 ± 0.1	0.47 ± 0.04
27	α -Humulene	35.46	1455	1454	0.39 ± 0.01	0.72 ± 0.05	0.09 ± 0.01	0.24 ± 0.01	0.37 ± 0.01
28	Germacrene D	36.44	1479	1480	0.79 ± 0.04	1.65 ± 0.05	0.113 ± 0.003	1.45 ± 0.05	3.76 ± 0.23
29	α -Muurolene	37.17	1496	1500	0.262 ± 0.003	0.31 ± 0.03	0.17 ± 0.01	0.35 ± 0.02	0.93 ± 0.05
30	γ -Cadinene	37.70	1510	1513	0.18 ± 0.02	0.21 ± 0.02	0.145 ± 0.002	0.3 ± 0.02	0.29 ± 0.03
31	δ -Cadinene	37.97	1517	1523	1.06 ± 0.01	1.38 ± 0.01	0.2585 ± 0.0001	1.1 ± 0.1	1.2 ± 0.1
32	Elemol	39.20	1548	1548	2.2 ± 0.1	3.1 ± 0.1	1.1 ± 0.1	2 ± 0.1	0.85 ± 0.01
33	Spatulenol	40.22	1574	1576	0.28 ± 0.01	0.32 ± 0.03	0.25 ± 0.02	0.27 ± 0.01	0.43 ± 0.01
34	Caryophyllene oxide	40.36	1578	1582	0.75 ± 0.03	0.72 ± 0.03	0.54 ± 0.02	0.9 ± 0.1	0.4 ± 0.01
35	γ -Eudesmol	42.28	1628	1632	0.26 ± 0.02	0.494 ± 0.005	0.567 ± 0.001	0.41 ± 0.01	0.37 ± 0.01
36	Alloaromadendrene oxide	42.85	1643	1641	0.095 ± 0.004	0.227 ± 0.004	0.6 ± 0.1	0.36 ± 0.02	0.546 ± 0.004
37	β -Eudesmol	43.16	1652	1650	1.26 ± 0.02	1.23 ± 0.03	0.151 ± 0.001	1.3 ± 0.01	0.69 ± 0.04
38	Dihydroeudesmol	43.27	1655	1658	0.09 ± 0.01	–	0.37 ± 0.01	0.21 ± 0.01	0.13 ± 0.01
	Monoterpene hydrocarbons				85 ± 5^a	82 ± 2^a	87 ± 2^a	82 ± 2^a	82 ± 5^a
	Oxygen-containing monoterpenes				3.4 ± 0.1^c	2 ± 0.1^d	5 ± 0.4^a	4.2 ± 0.2^b	2.5 ± 0.1^c
	Sesquiterpene hydrocarbons				7.3 ± 0.3^c	10.5 ± 0.4^b	5.4 ± 0.2^d	10.1 ± 0.6^b	13 ± 1^a
	Oxygen-containing sesquiterpenes				4.1 ± 0.2^b	5.1 ± 0.2^a	2.4 ± 0.1^c	4.2 ± 0.1^b	2.5 ± 0.1^c

*1LRI: linear retention index determined on a DB-5 MS fused-silica column relative to a series of n-alkanes (C₈–C₄₀). *2Linear retention index reported in the literature (Adams, 2017). *3Relative % is given as mean ± SD, n = 3. Equal letters do not differ by the Tukey or Tahmane T2 tests, at a 5% significance level.

The activation energy for the liquid diffusion process in the drying of rose pepper fruits for the temperature conditions studied (45, 55, 65, and 75°C) was 53.579 kJ·mol⁻¹. Xie et al. [42] observed values close to the present study of 54.30 kJ·mol⁻¹ for Wolfberry (*Lycium barbarum*, L.) at temperatures of 60, 65, and 70°C. Kheto et al. [29] reported for sweet pepper (*Capsicum annuum* L.) at temperatures of 40, 50, and 60°C activation energy of 22,256, 22,281, and 22,281 kJ·mol⁻¹. The discrepancy in the activation energy values for different agricultural products is naturally attributed to the physical and biological characteristics of the products [43].

3.2. External Color. Table 5 shows the color parameters of the rose pepper fruits under the different drying conditions as well as in their fresh form.

The luminosity of the samples (L^*) showed a decrease from the temperature of 65°C. Chromaticity (b^*) was red at all temperatures, with no difference between fresh fruits. The red color is the most significant quality parameter of pepper. Carotenoids, anthocyanins, betalains, and natural chlorophyll-like pigments designate the color of peppers [44, 45], while a^* at 75°C showed greater yellowish chromaticity, indicating loss of pigmentation.

3.3. Essential Oils. Table 6 shows the average values of the yield of essential oil of rose pepper. The fresh fruit had the lowest statistical essential oil yield, 1.68%, and the increase in temperature led to a decrease in yield. Thus, the best yield of essential oil was verified at the drying temperature of 45°C, which yielded 4.47%, followed by each increasing temperature.

The main factors that influence the extraction of essential oil are the amount of water present in the fruits as well as the drying temperature used. According to Guenther [46], the lowest yield of essential oil from fresh fruits is explained by the amount of water present in them, which causes agglutination of the oil, preventing the steam from penetrating more evenly into the plant tissues, which makes the removal of the essential oil difficult [47]. Another important factor that also influences the yield of essential oils is the temperatures used in fruit drying. Essential oils are heat-sensitive substances, especially at temperatures above 50°C, so increasing drying air temperature can volatilize compounds, resulting in lower extraction yield [48]. Other factors that also influence the yield of essential oils are presented by Gobbo-Neto and Lopes [49], for instance, plant development, temperature, solar radiation, altitude, and availability of water and nutrients.

Table 7 presents the data obtained from the GC/MS analysis of rose pepper fruits EO. It was possible to identify approximately 99.8% of the chemical composition of the essential oil corresponding to 38 individual compounds. The results are generally similar between drying temperatures and fresh sample processes, with slight variations in some significant molecules.

Regarding the terpenes group (mono-, di-, and sesquiterpenes), monoterpene hydrocarbons are present in the

highest amounts at 55°C (87%) and sesquiterpene hydrocarbons at 35°C drying temperatures (10.5%). The most abundant compounds identified at 55, 65, and 75°C were α -pinene, followed by limonene. In contrast, the EO of the fresh sample had *cis*-ocimene (29%) followed by δ -3-carene (12.8%) as the major molecules. Considering the statistical analysis, only the major molecules were subject to statistical analysis due to the rest being very low in relative percentage. Thus, the fresh samples showed statistically higher amounts of the major individual compounds, except for *p*-cymene. Inversely, the temperature of 75°C showed the lowest amounts of individual compounds except for limonene which might show a higher resistance to temperature. α -Pinene, the most abundant compound, showed an optimal drying temperature of 55°C, in which the amount was statistically higher than the other drying temperatures and fresh state. Regarding the overall groups of terpenes, the monoterpenes did not show statistical differences among the different treatments, while the oxygen-containing monoterpenes showed an optimal temperature of 50°C. The sesquiterpenes did surprisingly show statistically higher quantities at 75°C and lowest at 55°C, revealing a sturdy resilience to temperature, while the oxygen-containing sesquiterpenes showed statistically higher values at 35°C. The obtained results agree with other authors, reporting a prevalence of monoterpenes, presenting as major constituents δ -3-carene, limonene, α -phellandrene, α -pinene, myrcene, and *o*-cymene; sesquiterpenes appeared in lower quantity [50]. Still, Cavalcanti et al. [51] obtained α -pinene (44.9%) followed by β -pinene (15.1%) as the predominant molecules in rose pepper. This variation observed in essential oils produced by the same species can be explained by abiotic factors [52].

This work is important for the food industry, namely, for understanding the kinetics of drying rose pepper and its influence on the content of essential oils. These results are particularly relevant to optimizing the output of essential oil quantities or even to promoting specific molecules within the essential oil fraction. The applicability of essential oils is evergrowing, namely, as food preservatives [53].

4. Conclusions

Considering the drying kinetics, the Thompson model was selected to represent the drying kinetics of rose pepper fruits. The diffusion coefficient increases with the elevation of drying air temperature, being described by the Arrhenius equation, with activation energy of 53.579 kJ·mol⁻¹. In relation to the color parameters, the lightness (L^*) showed some variation related to increasing temperatures, as did b^* at 75°C. Thirty-eight terpenes were identified in the samples, with the highest yield of essential oil being found at the drying temperature of 45°C. Considering the individual molecules, the most abundant terpenes were α -pinene and *cis*-ocimene. The temperature of 45°C seems to be the most suitable to obtain most compounds from the essential oils due to not degrading the compounds with excessive heat, except for limonene, which has high resilience to temperature. Overall, the study contributed to the understanding of

the effects of temperature on the essential oils of rose pepper, which is a widely appreciated spice.

Data Availability

Data are available upon request.

Conflicts of Interest

The authors state no conflicts of interest regarding the paper.

Acknowledgments

The authors acknowledge the Laboratory of Post-Harvest of Plant Products, Laboratory of Natural Products, CAPES, FAPEG, FINEP, CNPq, CONAB, and IF Goiano, Campus of Rio Verde, for the indispensable financial support to conduct this study. The authors are also grateful to the Foundation for Science and Technology (FCT, Portugal) for financial support through national funds FCT/MCTES to CIMO (UIDB/00690/2020). L. Barros acknowledges FCT, P.I., for the national funding through the institutional scientific employment program contract. M. Carochi acknowledges FCT for the individual scientific employment program contract CEECIND/00831/2018. This work was funded by the European Regional Development Fund (ERDF) through the Regional Operational Program North 2020, within the scope of Project NORTE-01-0247-FEDER-113508: Bio4Drinks®, which T. Finimundy acknowledges.

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