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Solar and Convective Drying: Modeling, Color, Texture, Total Phenolic Content, and Antioxidant Activity of Peach (*Prunus persica* (L.) Batsch) Slices

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Abstract: Peach is a fruit highly appreciated by consumers; however, it is highly perishable, so drying is an alternative to preserve its physical and chemical properties. In this study, the effect of drying in natural and forced convection at three different temperatures (40 °C, 45 °C and 50 °C) and solar drying with two air velocities (1 m/s and 3 m/s) on the color, texture, total phenol content and antioxidant capacity of peach (*Prunus persica* (L.) Batsch), were evaluated. The experimental data of the drying kinetics were adjusted to five different mathematical models (Page, Logarithmic, Two-term exponential, Wang and Singh, and Verma et al.). The model that best represented the experimental data in natural convection was the Wang and Singh model ($r^2 > 0.998$; $RMSE < 0.016$; $\chi^2 < 2.85 \times 10^{-4}$); in forced convection (45 °C and 50 °C), it was the Verma et al. model ($r^2 > 0.997$; $RMSE < 0.025$; $\chi^2 < 8.12 \times 10^{-4}$); and finally, for solar drying, it was the Logarithmic model at 3 m/s ($r^2 = 0.999$; $RMSE < 0.012$; $\chi^2 < 1.12 \times 10^{-4}$) and Wang and Sing model (1 m/s) ($r^2 = 0.998$; $RMSE = 1.31 \times 10^{-4}$; $\chi^2 = 1.92 \times 10^{-4}$). The highest color difference was in samples dried by the natural convection method. The highest values of hardness were obtained by the solar drying method. The value of chlorogenic acid increased with the temperature of natural convection, while the concentration of neochlorogenic acid increased with the temperature at forced convection. For solar drying, the values of chlorogenic acid were greater at 3 m/s; in contrast, the neochlorogenic acid was greater at 1 m/s.

Keywords: solar drying; peach; color analysis; phenolic content; antioxidant capacity

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1. Introduction

Peach (*Prunus persica* (L.) Batsch) is part of the Rosaceae family and is one of the world's most economically important fruit crops, with annual global production of over 20 million tonnes [1,2]. Mexico is the twelfth largest peach in the world producer with 220 thousand tonnes in 2021, and the Mexican states of Zacatecas, Michoacán, Puebla, Chihuahua, Morelos, and Durango are the leading peach producers [3]. Due to the fast softening and high moisture content, peach fruits have a short shelf-life, and drying methods could be alternatives to extend their storage life and ensure their quality parameters. Dried peaches are generally used in baking, pastry, fruit leather, and sauces; moreover, they are sources of beneficial vitamins, minerals, and bioactive compounds [4] and healthy dietary ingredients [5].

On the other hand, the drying method is one of the oldest techniques for food preservation, and it is one of the most common technologies for processing and preserving foods such as fruits and vegetables. Drying kinetics studies provide information that helps to understand the drying behavior under different conditions, mainly the temperature and velocity of hot air. However, there are other parameters, such as pretreatments [6], the effect of the incidence of direct solar radiation [7], vacuum [8], puffing [9], and microwaves [10], among others that also present an influence on the dried product. The effect of these parameters and determining each product influences the optimal quality parameters. For example, the difference in the temperature of the drying process has been explained in several studies, resulting in higher temperatures to achieve lower moisture content [11–13].

The mathematical modeling of the drying kinetics is crucial because it allows for obtaining characteristic parameters of the material's behavior during the drying process. For this purpose, there are numerous mathematical models, some based on water–food interaction theories while others are merely empirical [14]. Several studies have shown that temperature is one of the factors with the most significant effect on food's physical, chemical, and sensorial attributes, such as color, texture, bioactive compounds, vitamins, and antioxidant properties, among others.

Moreover, the predominant and conventional drying method is convective hot air drying. Furthermore, this conventional method is a process that consumes large amounts of energy, between 12% and 25% of the total energy of industrial processing [15]. Therefore, solar thermal drying could be an alternative to improve the efficiency of heat and mass transfer, such as low costs during its process. Furthermore, this kind of preservation method is a friendly alternative to the environment since it uses the free and clean energy of the sun. It also protects food from dust, rain, insects, rodents, and direct UV radiation if necessary. However, all thermal treatments could cause the reduction or loss of bioactive metabolites, specifically antioxidant compounds that may undergo degradation within their chemical structure, causing the loss of biological activities, one of the attributes that make fruits attractive [16].

Phytochemicals in plants and fruits are essential to their growth and protection. They are metabolites related to the morphological and sensory characteristics of fruits and also contribute to their taste and pigmentation, these bioactive compounds are characterized by the presence of one or several hydroxyl groups bonded to a six-carbon aromatic ring that can be linked to sugars, and they are also related to some of functional and nutraceutical properties in fruits; nevertheless, phenolic compounds are susceptible to heat and light altering their stability [17]. In the case of phenolic compounds, the values decrease when the drying air flow rate drop; generally, the increasing drying temperature causes a reduction in the antioxidant activity [18]. In addition, previous studies show that forced convection drying shows a more stable drying curve in less time than natural convection drying [19]. Several studies on drying methods in fruits have been carried out; however, there are few reports on the drying kinetics of convection and solar drying methods in the peach slides, such as their effects on the quality parameters and biological properties of dried peach slices.

Therefore, the objective of this study was to compare the drying kinetics, color, texture, total phenol content, and antioxidant activity of peach slices using different solar and convective drying methods at different air speeds and temperatures, respectively.

2. Materials and Methods

2.1. Raw Material and Reagents

Peach fruits (*Prunus persica* (L.) Batsch) industrially produced, were purchased fresh at the early maturity stage with fruit hardness around 9 N and preserved at room temperature (25–30 °C) from a local market in Cuernavaca, Morelos, Mexico, during the months of April to May 2022. The fruits were washed with 0.05% chlorinated water and stored at the laboratory at 5 °C for 2 days before the experiments. Then, peaches were conditionated to room temperature (25–30 °C) and sliced uniformly (average thickness: 1.8 mm thickness). The initial moisture content of the peach was 80.7 ± 2.5%, with color parameters of L: 55, a: −10, b: 50, and a value of 9° Brix.

The reagents Folin–Ciocalteu's phenol, p-iodonitrotetrazolium chloride, 2,2-diphenyl-1-picrylhydrazyl (DPPH), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), gallic acid, chlorogenic acid, neochlorogenic acid, formic acid, methanol, and acetonitrile (HPLC grade) were purchased from Sigma Aldrich (St. Louis, MO, USA). Ultra-pure water was prepared in a Milli-Q water filtration system (Millipore, Bedford, MA, USA).

2.2. Dryers Used in Experiments

The peach slice drying experiments were conducted in two different devices. The solar dryer (Figure 1a) consists of a drying chamber with a translucent glass cover; inside of drying chamber, there are three racks with a weight cell each to record weight loss in real time. This drying chamber is coupled to a fan and water–air heat exchanger. The water is heated by the solar collectors, passes through the heat exchanger and then to a thermal storage tank closing the circuit, and passes again through the solar collectors. An axial fan (12 V) with variable speed blows the air into the drying chamber. A photovoltaic panel (300 W) supplied the energy to pump the water and air.

(**a**) (**b**)

Figure 1. Mixed-mode tunnel-type solar dryer (**a**) and electric dryer (**b**).

On the other hand, the electric dryer (Figure 1b) consists of a bank of 4.5 kW electric resistors, a 1/20 hp centrifugal fan, a frequency inverter, and a drying chamber. Air is drawn in from the outside, heated through the heater bank, and fed into the drying chamber. Sensors for air temperature (Sensirion, Stäfa, Switzerland, SHT4x; −40 to 125 °C), water temperature (HOBO, S-TMB-M002; −40 °C to 100 °C), weight (DFRobot, HX711; 0 kg to 20 kg), and solar radiation (Eppley 8-4.8 pyranometer; sensitivity 8 $\mu V/Wm^{-2}$) were used for process monitoring.

2.3. Drying Procedure

For the convective drying experiments, fresh peach slices were prepared in 6 trays with 50 g each and were dried at 40 °C, 45 °C, and 50 °C in an electric dryer at natural and forced convection. For the solar drying experiments, 100 g of peach slices were placed in 8 trays and divided into two racks. Each shelf was placed on a weight sensor for registration in real time; the experiment was carried out at two air speeds: 1 m/s and 3 m/s.

The moisture content was calculated as follows:

$$M_{db} = \frac{W_w}{W_d} \quad (1)$$

where M_{db} is the moisture content in a dry basis, and this is expressed as the ratio of water content (W_w) to the weight of dry material (W_d). Moisture conte content was expressedon a dry basis, i.e. grams of water per gram of dry matter (g H_2O/g d.m.). The moisture ratio during drying is calculated as follows [20]:

$$MR = \frac{X_t - X_f}{X_0 - X_f} \quad (2)$$

$$X_t = \frac{m_t - m_g}{m_g} \quad (3)$$

where m_t and m_g are the mass of the sample at any time and the final dried matter; X_t, X_f, and X_0 are moisture content at any time, initial moisture content, and equilibrium moisture content, respectively.

The drying curves obtained were fitted with five mathematical models in Table 1. The model coefficients were determined statistically based on experimental data.

Table 1. Mathematical models used to fit experimental data.

Equation	Name	References
$MR = exp(-kt^n)$	Page	[21]
$MR = a\ exp(-kt) + c$	Logarithmic	[22]
$MR = a\ exp(-kt) + (1-a)\ exp(-kat)$	Two-term exponential	[23]
$MR = 1 + at + bt^2$	Wang and Singh	[24]
$MR = a\ exp(-kt) + (1-a)exp(-gt)$	Verma et al.	[25]

The goodness of fit was evaluated based on three descriptors: the coefficient of determination (r^2), reduced chi-squared coefficient (χ^2), and root mean square error ($RMSE$). The fit is better when the lower values of χ^2 and the $RMSE$ provides the deviation between the experimental and predicted values; preferably, it should be close to 0. The r^2, χ^2, and $RMSE$ descriptors were determined using the following equations:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{N}} \tag{4}$$

$$r^2 = \frac{\sum_{i=1}^{N}\left(MR_1 - MR_{pre,i}\right)\sum_{i=1}^{N}\left(MR_1 - MR_{exp,i}\right)}{\sqrt{\left[\sum_{i=1}^{N}\left(MR_1 - MR_{pre,i}\right)^2\right]\left[\sum_{i=1}^{N}\left(MR_1 - MR_{exp,i}\right)^2\right]}} \tag{5}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - Z} \tag{6}$$

where N is the total number of data values, Z is the number of drying constants, $MR_{exp,i}$ is the experimental values, and $MR_{pre,i}$, is the predicted moisture ratio value.

2.4. Color Measurement

Color parameters in drying peach slices were measured using a colorimeter (model CR30, Hangzhou CHNSpec Technology Co., Ltd., Hangzhou City, China), which was calibrated in CIE L a*b* space, and the color parameters were expressed in L (brightness–darkness), a* (redness–greenness), and b* (yellowness–blueness). Color change (ΔE) was calculated using the following equation:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \tag{7}$$

Fresh peach slices were used as the reference, and a larger ΔE denotes the color change.

2.5. Texture Analysis

Texture properties of peach slices dried by different drying methods were carried out using a universal texture analyzer (model EZ-SX, Shimadzu Co., Kioto, Japan). The needle displacement obtained the hardness by a textural analyzer software (Trapezium X, V1.4.0, 2013) through a three-point bending test (1 cm), downward compression polarity and displacement rate, and a limit of 1.0 cm/min. The hardness parameter was expressed as maximal strength. Nine tests were performed for each sample.

2.6. Extraction and Total Phenolic Content (TPC) Quantification

The ultrasonic-assisted extraction method was used for phenolic compound extraction [16]. First, 1 g of the dried sample was immersed in 50 mL of 50% aqueous methanol as solvent. Next, the samples were sonicated using a 130 W Ultrasonic Liquid Processor (GEX130PB, Sonics and Materials Inc., Newtown, CT, USA) with a 13 mm diameter probe at a frequency of 20 kHz. A cold-water bath maintained the temperature at 50 ± 0.5 °C. After applying the ultrasound process for 5 min, samples were filtered through a Whatman No. 4 filter paper using a Buchner funnel connected to a vacuum pump. Finally, extracts were collected into amber vials and stored in a refrigerator at 4 °C until the analysis.

TPC was determined by Folin–Ciocalteau method using the methodology reported by Medina-Torres [16]. The absorbance of samples was measured using a UV-visible spectrophotometer (Biomate 3S, Thermo Fisher Scientific, Inc., Wathan, MA, USA) at 765 nm. TPC analysis was performed in triplicate, and values were expressed as mg of gallic acid equivalents (mg GAE) per g of dry weight (dw) samples through a calibration curve of gallic acid (R^2 = 0.996). All measurements were performed in triplicate.

2.7. Antioxidant Capacity by DPPH and ABTS Assays

The antioxidant activity of dried peach extracts was determined using the DPPH radical scavenging activity assay, according to Pacheco [26]. Sample extract (100 µL) was added to 2900 µL of 0.1 mM DPPH prepared in methanol, then kept in the dark for 30 min at room temperature (25 °C). A UV-vis spectrophotometer (BioMate 3S, Thermo Fisher Scientific Inc., USA) was used to measure the absorbance of the reactions at 515 nm [27]. The ABTS method was performed according to Medina-Torres [16]. Antioxidant activities were expressed for DPPH and ABTS as microMol of Trolox equivalent (µM TE) per g of dry weight (dw) using a calibration curve of Trolox. All measurements were performed in triplicate.

2.8. Phenolic Compounds Identification by UPLC-PDA-ESI-MS/MS

Phenolic compounds of dried peach extracts were analyzed according to Herrera-Pool [27]. Chromatographic profiles were obtained using a Waters Acquity H Class UPLC (Milford, MA, USA) with a quaternary pump (UPQSM), an automatic injector (UPPDALTC), and a PDA λ photodiode array detector (UPPDALTC). The chromatographic separation was performed with a Waters Acquity UPLC BEH C18 column, 1.7 µm, 100 × 2.1 mm ID (Milford, MA, USA). The mobile phase comprised 0.1% formic acid in ultrapure water (A) and 0.1% formic acid in acetonitrile (B) [28]. The PDA reading λ was carried out from 190 to 400 nm. The analytical response absorbance was taken at 290 nm. The quantification of phenolic compounds identified in the samples was expressed as µmol of the analytical standards used. All measurements were performed in triplicate. The mass spectrometry (MS/MS) analysis was performed according to Herrera-Pool [27].

2.9. Statistical Analysis

Nine tests were performed for the texture analysis, while the TPC, antioxidant activity, and chromatographic results were conducted by triplicates from three independent experiments carried out using a randomized experimental design. Data were subjected to Analysis of Variance (ANOVA) and to LSD's means comparison test. Significance was established at $p \leq 0.05$. Data analysis was performed using the Statgraphics Centurion Version XVI software (Statistical Graphics Corp., Manugistics, Inc., Cambridge, MA, USA).

3. Results and Discussion

3.1. Drying Kinetics

The temperature and the mechanism of heat transfer are decisive in the drying process because these can have an effect on the final quality of the products. For example, the above can be seen in Figure 2; for the same temperature (40 °C) in the natural and forced convection drying methods, the drying time was reduced by 50% in the forced convection drying (840 min and 420 min with natural and forced drying, respectively). Furthermore, for forced convection drying at 50 °C, the drying time was 240 min, and the final humidity was 0.007 g H_2O/g d.m., while the natural convection presented the final moisture content of 0.008 g H_2O/g d.m. These results are similar to previous studies, where the drying process of peach puree takes approximately 500 min at 55 °C in natural convection [5].

The increase in temperature could raise the vapor pressure in the peach slices, which could remove the moisture from the interior in less time; the warmer the air, the more water it will hold before becoming saturated [28]. In all cases, an increase in temperature caused a higher drying rate; this may be seen clearly in Figure 3, where the normalized moisture content (MR) versus time. Similar results were observed in peaches and strawberries [11], hawthorn fruit [29], and peaches [30].

As can be seen in Figure 2e, in the case of solar drying, when the air velocity was 1 m/s, the average temperature was 40.5 °C. In comparison, when the speed was 3 m/s, the average temperature was 37.2 °C; this influenced the drying time, taking 60 min more at 3 m/s. The final moisture content was 0.015 g H_2O/g d.m. (3 m/s), followed by 0.010 g H_2O/g d.m. (1 m/s). It should be noticed that the samples used in all experiments had different initial moisture content.

The drying rate is influenced by the temperature and evaporation mechanism to which the food is subjected in a given time. Generally, the moisture content decreases fast until evaporation becomes limited [31]. Theoretically, the drying rate occurs in three periods; the first is when there is a constant surface evaporation rate (period of constant velocity) that ends when the transport of moisture to the surface is limited because the moisture content fails to saturate the surface as it did in the first moments (first period of decreasing rate). Subsequently, the drying rate is further reduced because the water is firmly bound to the food structure by physical and chemical interactions in the food (second period of decreasing rate) [28].

Figure 2b,d,f show the drying rate for the three methods used. In temperature-controlled experiments, the higher temperatures produced a faster drying rate, as reported in [20]. When the electric dryer was used in natural convection, the maximum drying rate was 0.025 g H_2O/g d.m min^{-1}, while in forced convection, it was more than two times higher (0.061 gH_2O/g d.m min^{-1}). On the other hand, in solar drying, the highest drying speeds were observed at an airflow of 3 m/s (0.053 gH_2O/g d.m min^{-1}), observing the influence of the airspeed on drying kinetics [32]. These results were similar to Tan [33]. They reported that the drying speeds of drying Blood-Flesh Peach at 50 °C and 0.5 m/s ranged from 0.04 to 0.1 gH_2O/g d.m min^{-1}. In the case of solar drying, the drying rate was higher than in all cases when the electric dryer was used. This resulted in a shorter drying time of up to 200 min at 1 m/s, while the drying time of natural convection was the longest (840 min) at 40 °C. In no case was a period of constant velocity observed; only periods of decreasing drying rate were observed, especially in solar drying. For the other drying methods, two periods of decreasing speed can be observed that can be distinguished from one another in a range of drying rates between 0.010 gH_2O/g d.m min^{-1} and 0.015 gH_2O/g d.m min^{-1}.

According to the results obtained, solar drying represents an interesting alternative from the point of view of processing time since it was possible to obtain a reduced drying time compared to drying in the electric dryer. The type of convection (natural or forced) is an important factor in the food drying process because it affects the drying time and, consequently, the characteristics associated with the quality of the dried products. Natural convection is a heat transfer phenomenon in which air movement is due to the difference in densities, while forced convection (caused by an external mechanism) allows a better heat transfer between the air and the food and, consequently, a higher mass transfer from the food to the air, resulting in a shorter drying time. Furthermore, it is worth mentioning that the temperatures reached with the solar dryer are suitable for drying a wide variety of foods.

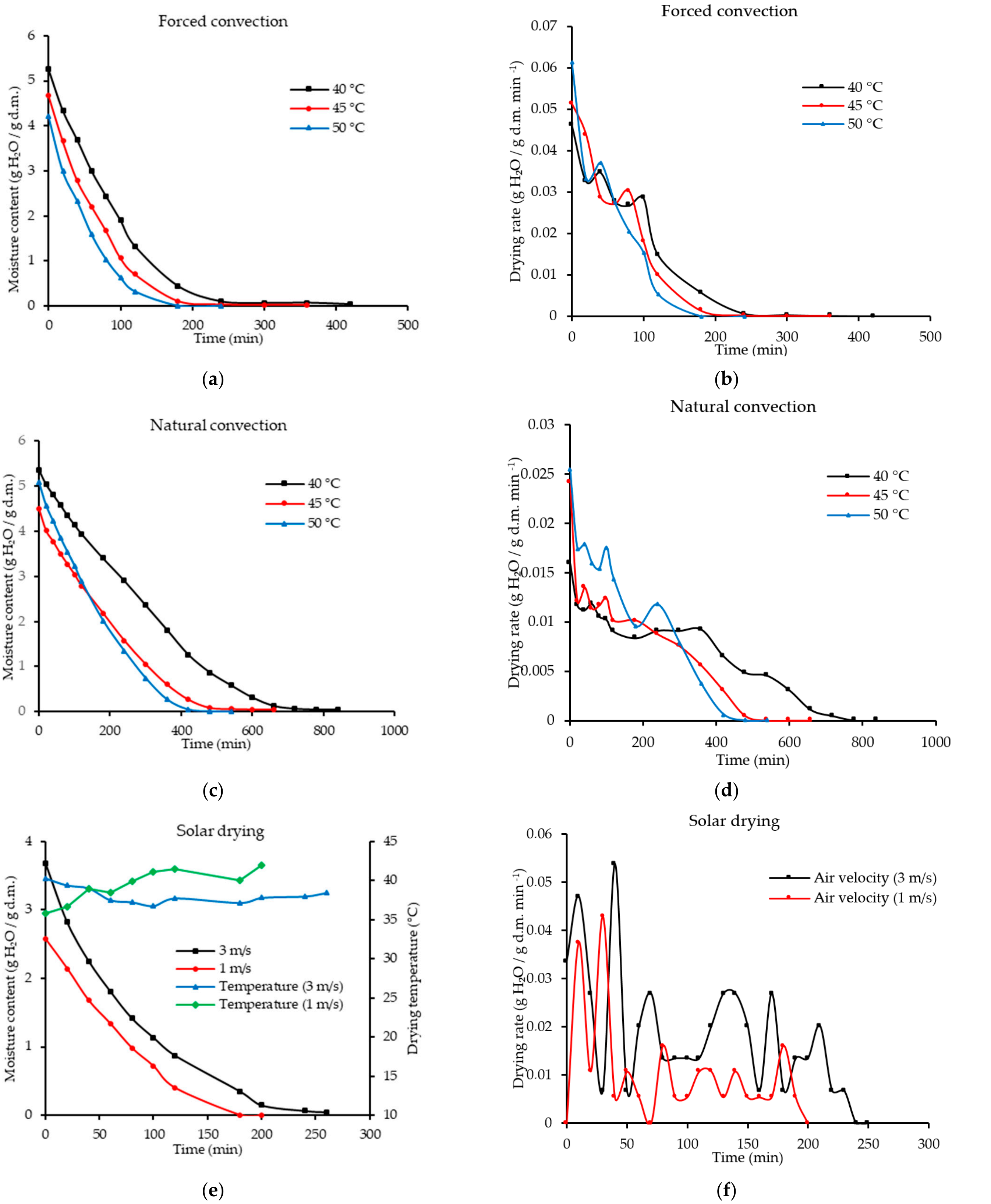

Figure 2. Drying kinetics of (**a**) forced convection and (**c**) natural convection; drying rate (**b**) forced convection, and (**d**) natural convection at different temperatures; solar drying kinetics (**e**) and drying rate (**f**).

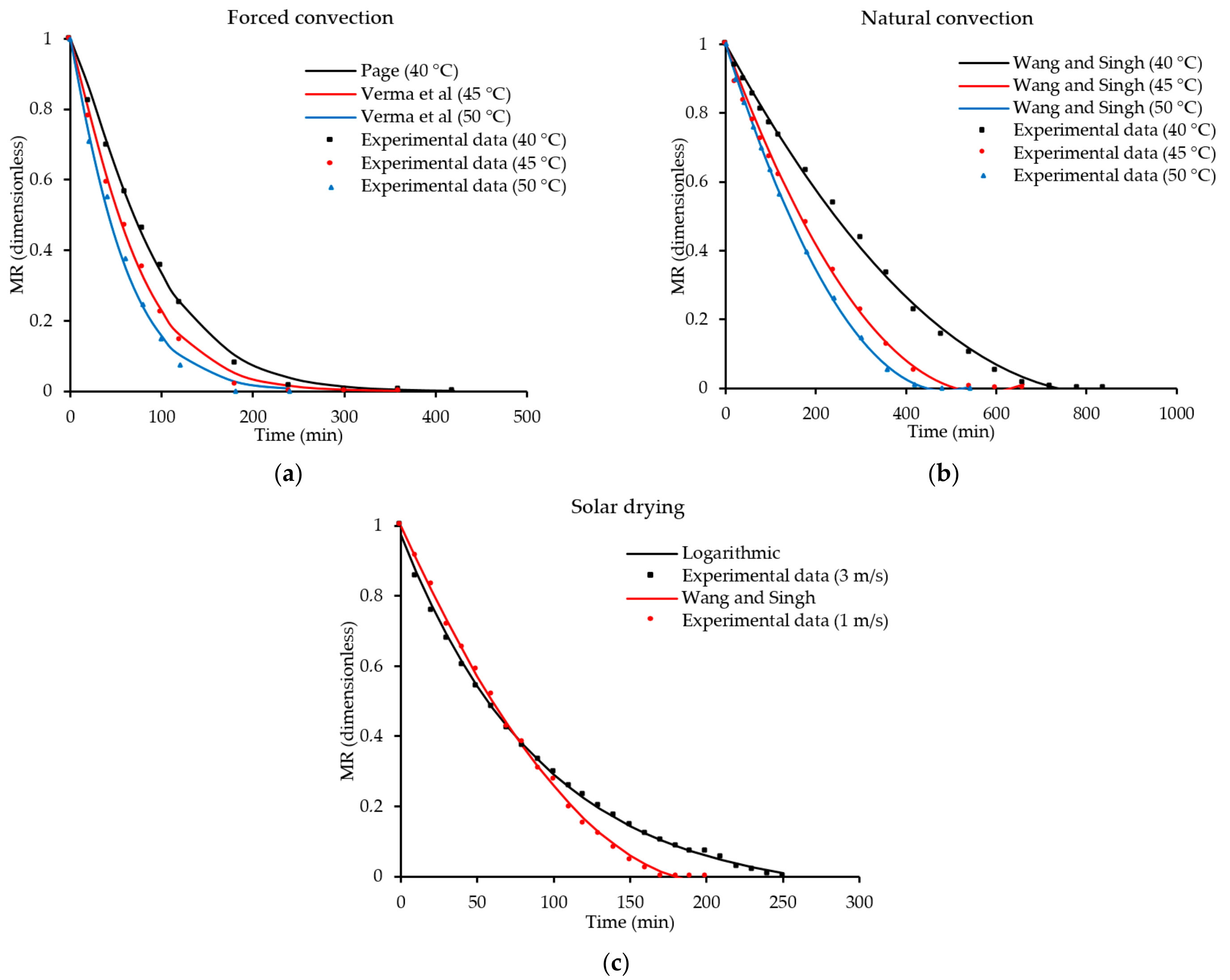

Figure 3. Mathematical fit of experimental drying data at different temperatures in (**a**) forced convection, (**b**) natural convection, and (**c**) solar drying [24,25].

3.2. Analysis of Thin Layer Models

Figure 3 shows the experimental data and the data predicted by the models used for the three drying modes. The predicted data were obtained by nonlinear regression analysis and curve fitting using the equations of the selected model [34]. The mathematical models were evaluated based on static parameters such as root mean square error (*RMSE*), chi-square (χ^2), and coefficient of determination (r^2). The results of the adjustment and statistical parameters are shown in Table 1. The models with the lowest *RMSE* and χ^2 values and the highest value of r^2 were considered the best-fitted model. The fit of the mathematical models and the goodness of fit statistical parameters are shown in Table 2.

According to Figure 3, the fit of experimental data to the models that showed the best statistical parameters can be observed. The plots show the moisture ratio for drying time. In the case of drying with controlled temperature and forced convection, the Verma et al. model was the most suitable to describe the experimental data for 45 °C y 50 °C with values of $r^2 > 0.996$, $RMSE < 0.025$, and $\chi^2 < 8.12 \times 10^{-4}$. While for 40 °C, the Page model was the most suitable for describing the experimental data with a value of $r^2 > 0.996$, $RMSE < 0.019$, and $\chi^2 < 4.13 \times 10^{-4}$.

Table 2. Statistical results and fitting models at different drying temperatures (natural and forced convection).

Models and Parameters		Natural Convection			Forced Convection			Solar Drying	
		Temperatures						Air Velocity	
		40 °C	45 °C	50 °C	40 °C	45 °C	50 °C	1 m/s	3 m/s
Page [21]	k	0.000	0.001	0.001	0.003	0.006	0.009	0.001	0.006
	n	1.332	1.244	1.278	1.248	1.190	1.165	1.417	1.064
	r^2	0.991	0.991	0.994	0.996	0.996	0.995	0.993	0.997
	RMSE	0.034	0.032	0.027	0.019	0.019	0.021	2.85×10^{-2}	2.07×10^{-2}
	χ^2	0.001	0.001	0.001	4.13×10^{-4}	4.20×10^{-4}	5.81×10^{-4}	9.01×10^{-4}	5.06×10^{-4}
Logarithmic [22]	a	1.276	1.159	1.187	1.072	1.055	1.062	1.302	1.049
	c	−0.265	−0.156	−0.174	−0.047	−0.036	−0.055	−0.257	−0.065
	k	0.002	0.004	0.004	0.010	0.013	0.016	0.005	0.007
	r^2	0.994	0.994	0.995	0.994	0.994	0.995	0.996	0.999
	RMSE	0.026	0.027	0.023	0.011	0.008	0.006	2.24×10^{-2}	0.012
	χ^2	8.09×10^{-4}	8.96×10^{-4}	6.68×10^{-4}	1.33×10^{-4}	7.92×10^{-5}	4.69×10^{-5}	5.88×10^{-4}	1.12×10^{-4}
Two-terms exponential [23]	a	1.828	1.757	1.799	1.768	1.704	1.000	1.915	1.500
	k	0.005	0.007	0.008	0.015	0.019	0.017	0.012	0.009
	r^2	0.989	0.991	0.993	0.996	0.996	0.991	0.988	0.997
	RMSE	0.037	0.033	0.028	0.017	0.016	0.024	3.49×10^{-2}	1.96×10^{-2}
	χ^2	0.002	0.001	0.001	4.56×10^{-4}	4.32×10^{-4}	1.2×10^{-3}	1.35×10^{-3}	4.29×10^{-4}
Wang and Singh [24]	a	−0.002	−0.004	−0.004	−0.007	−0.009	−0.012	−0.006	−0.006
	k	1.42×10^{-6}	3.08×10^{-6}	4.20×10^{-6}	0.000	0.000	0.000	0.000	0.000
	r^2	0.998	0.998	0.999	0.958	0.958	0.983	0.998	0.983
	RMSE	0.015	0.016	0.008	0.052	0.068	0.040	1.31×10^{-2}	4.47×10^{-2}
	χ^2	2.62×10^{-4}	2.85×10^{-4}	7.86×10^{-5}	0.003	0.006	0.002	1.92×10^{-4}	2.22×10^{-3}
Verma et al. [25]	a	14.685	1.000	−210.081	277.454	−12.286	18.146	237.569	0.618
	g	0.006	0.002	0.002	0.006	0.023	0.028	0.003	0.008
	k	0.006	0.002	0.002	0.006	0.024	0.027	0.003	0.008
	r^2	0.990	0.691	0.996	0.997	0.997	0.996	0.995	0.995
	RMSE	0.035	0.197	0.021	0.025	0.018	0.020	3.21×10^{-2}	1.52×10^{-2}
	χ^2	0.001	0.048	0.001	8.12×10^{-4}	4.34×10^{-4}	6.01×10^{-4}	1.2×10^{-3}	2.72×10^{-4}

In the case of drying at a controlled temperature and in natural convection, the Wang and Singh model was the one that best fitted the experimental data, with values of $r^2 > 0.998$, *RMSE* < 0.016, and $\chi^2 < 2.85 \times 10^{-4}$. Finally, for solar drying, the logarithmic model fitted better to the experimental data of drying at 3 m/s ($r^2 > 0.999$, *RMSE* < 0.001, and $\chi^2 < 1.12 \times 10^{-4}$), while the Wang and Singh model was the most suitable to describe de experimental data at 1 m/s ($r^2 > 0.998$, *RMSE* $< 1.31 \times 10^{-2}$, and $\chi^2 < 1.92 \times 10^{-4}$). Similar results were observed in the solar thermal drying of peaches reported by Nasri [35,36]; they reported a drying time between 120 and 180 min for low and high airflow, and the model that best fit the experimental data was the Two-Terms model.

3.3. Color Analysis

Color is one of the most important quality parameters in food products and generally can be considered an indicator of the pigment degradation of important compounds by enzymatic and non-enzymatic reactions during the drying process [34,35]. Figure 4 shows the evolution of the color as a function of the drying time. The peach slices dried by solar method at 3 m/s presented the highest redness color during the overall drying time, possibly due to the lower drying temperatures (37.2 °C). The most color difference was presented in the natural convection drying, which showed the highest darkness dried peach slices due to degradation of pigments, and samples gave less lightness. A similar effect also be found in forced convection drying, but the browning was slightly lesser because the drying time was less. According to Udomkun [37], the color change in the dried samples may be due to the browning that occurred during the drying process by the Maillard reactions, which generally increase at higher drying temperatures. Azam [32] mentioned that the reducing sugars could be susceptible to non-enzymatic browning reactions, and some disaccharides could also hydrolyze during heating.

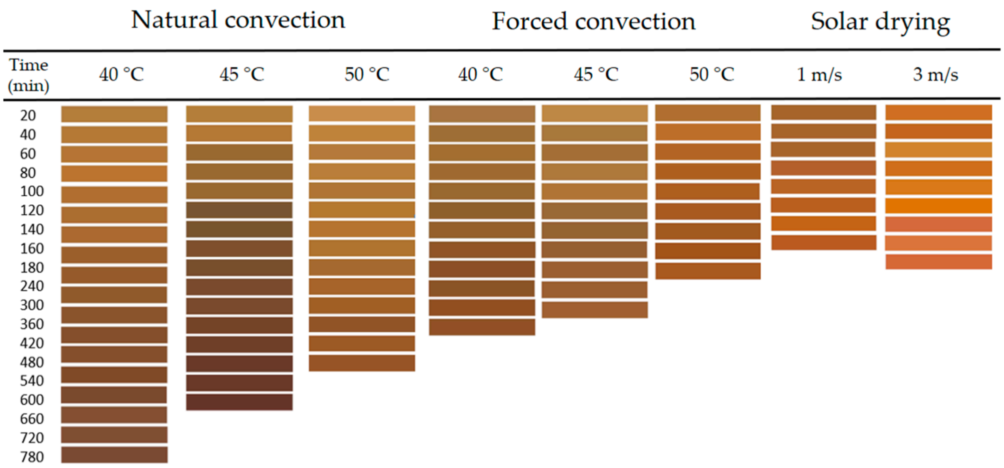

Figure 4. Color change as a function of time for different drying modes (natural convection, forced convection, and solar drying).

On the other hand, ΔE is the combination of the color change of all three-color parameters, and it is widely applied to analyze the color change of dried samples and for comparison between the initial color of fresh fruit and the final color of final fruit [33]. In this sense, it is important to mention that the early maturity stage of the fresh fruit used for drying processes was of great importance in color parameters; as it was expressed in the previous paragraph, a high content of sugar in the maturity stage could lead to a major browning production. The ΔE values of natural and forced convection drying were 35.62 ± 9.3, 33.91 ± 9.5, and 30.34 ± 8.4 and 14.41 ± 5.1, 16.86 ± 8.8, and 10.96 ± 0.6 at 40, 45, and 50 °C, respectively. Finally, the ΔE values of solar drying were 13.28 ± 7.6 and 17.13 ± 4.4 at 1 m/s and 3 m/s, respectively. The dried peach slices by natural convection drying presented the highest ΔE values, possibly due to increased drying time. In addition, the dried samples by forced convection and solar drying exhibited similar ΔE values. Therefore, solar drying may be an interesting alternative as a drying technique among the convection methods because it could give the redness color and less drying time. Similar results of color change were reported by Seerangurayar [7] for solar drying methods from *Pheonix dactylifera* L. fruits.

3.4. Hardness

The texture of dried fruits becomes an important quality affecting consumer acceptance and is one of the most important parameters associated with dried snack food [33]. In this sense, the hardness values of dried peach slices by natural convection, forced convection, and solar drying methods are presented in Table 3. The hardness values were from 4.83 to 11.35 N. The natural and forced convection drying showed similar behavior of hardness, which may be associated with the formation of more fragile structures during the drying processes. On the other hand, the highest values of hardness (10.85 and 11.35 N) were obtained by solar drying. This behavior of hard texture in the dried peach by solar drying may be due to the rapid migration of water molecules in a shorter drying time which could result in hardness fruit tissues and crispy textures for the consumers. Similar results of peach slices dehydrated by heat pump drying were presented by F. Wang [38]. Moreover, Çetin and Sağlam [39] mentioned that the textural properties of dried samples depend on the behavior of soluble solid phase and cellular matrix in the tissue by different interactions with water.

Table 3. Hardness, total phenolic content, ABTS, and DPPH antioxidant activity of extracts obtained from dried peach slices by natural and forced convection at different temperatures.

Treatment		Hardness (N)	ABTS (µmol Eq Trolox/g d.w.)	DPPH (µmol Eq Trolox/g d.w.)	TPC [1] (mg EAG/g d.w.)
Natural convection	40 °C	9.63 ± 1.97 [d]	99.79 ± 9.02 [b]	83.23 ± 9.38 [c]	54.50 ± 3.08 [cd]
	45 °C	4.83 ± 1.28 [a]	81.28 ± 5.63 [ab]	101.61 ± 12.15 [d]	52.14 ± 5.43 [cd]
	50 °C	9.78 ± 2.23 [d]	99.59 ± 14.97 [b]	91.12 ± 2.07 [cd]	53.79 ± 0.47 [cd]
Forced convection	40 °C	9.52 ± 0.58 [cd]	78.69 ± 9.11 [ab]	63.18 ± 2.32 [b]	40.32 ± 1.21 [ab]
	45 °C	8.22 ± 1.12 [bc]	94.22 ± 2.07 [b]	99.49 ± 3.58 [d]	58.52 ± 9.75 [d]
	50 °C	7.77 ± 1.10 [b]	104.64 ± 27.07 [b]	75.59 ± 8.85 [bc]	45.27 ± 1.08 [bc]
Solar drying	1 m/s	11.35 ± 1.53 [e]	59.16 ± 4.96 [a]	42.39 ± 6.35 [a]	35.03 ± 0.33 [a]
	3 m/s	10.85 ± 1.08 [de]	77.17 ± 0.39 [ab]	63.63 ± 1.98 [b]	39.84 ± 0.22 [ab]

[1] Total Phenolic Content. Values with the same letter in the same column were not significantly different at $p < 0.05$, determined by multiple comparisons of means by the LSD-Fisher test.

3.5. Total Phenolic Content and Antioxidant Activity

TPC values for the dried peach using different drying methods are presented in Table 3. The TPC value of fresh peach was 127.67 mg EAG/g d.w.

Percent loss in TPC contents as affected by the drying method ranged from 54.16 to 72.5% compared to the fresh product. The natural convection method at different temperatures did not present significant differences. However, TPC contents of the forced convection at different temperatures showed a dissimilar behavior, and this method at 45 °C presented the highest value of TPC. Moreover, an increase in the TPC contents of dried peaches might be ascribed to the formation of new phenolic compounds from their precursor at a specific temperature [40]. On the other hand, solar drying at 1 m/s presented the highest loss of TPC. This loss in TPC might be due to greater UV light degradation of antioxidant compounds. Similar results were reported by Rodríguez-Ramírez [41] on the solar drying of strawberries. These results of TPC suggest that the drying method could improve the release of compounds during the extraction method, such as phenolic acids.

The antioxidant activity by ABTS and DPPH assays is presented in Table 3. The antioxidant activity showed a similar trend as observed for TPC content. The ABTS values ranged from 104.64 to 59.16 µmol Eq Trolox/g d.w., while DPPH values ranged from 101.61 to 42.39 µmol Eq Trolox/g d.w.

The forced convection drying presented the highest value of ABTS (104.64 µmol Eq Trolox/g d.w.) at 50 °C, while the highest antioxidant activity (101.61 µmol Eq Trolox/g d.w.) by DPPH was natural convection at 45 °C. Moreover, the solar drying at 1 m/s presented the lowest values of antioxidant activity by ABTS (42.39 µmol Eq Trolox/g d.w.) and DPPH (35.03 µmol Eq Trolox/g d.w.) assays. This variation in the antioxidant activity may be due to various factors such as other compounds with antioxidant capacity, new components formed, deactivation of oxidative and hydrolytic enzyme release, and degradation by UV radiation.

3.6. Phenolic Compounds Identification and Profile

The identification of phenolic compounds performed by UPLC-DAD-MS/MS showed the presence of two significant compounds identified as chlorogenic acid and neochlorogenic acid in all dried samples for both wavelengths evaluated (350 and 290). Additionally, procyanidin dimer B type and catechin were observed at a wavelength of 350, and quercetin-3-O-rutinoside, quercetin-3-O-hexoside, Kaempferol-3-O-rutinoside, and isochamnetin-3-O-rutinoside were observed at a wavelength of 290, the lasted ones in minimal concentrations Figure 5.

The major compounds (chlorogenic and neochlorogenic acid) were quantified in each sample subjected to drying methods and presented in Table 4. The results indicated that chlorogenic acid was shown in all treatments in higher concentrations than neochlorogenic acid. For natural convection, the concentration of chlorogenic acid was higher at higher temperatures, reaching the highest concentrations of all treatments; this could be related to the stability of chlorogenic acid in systems with reduced water [41]. The phenolic compounds in the forced convection method increased the concentration of both phenolic acids with the temperature. The higher concentrations in this method were presented at 50 °C. In addition, the lowest concentrations of chlorogenic and neochlorogenic acids were shown in the solar drying. This behavior was similar to the TPC content and antioxidant activity. On the other hand, it has been reported that the content of bioactive compounds and the physical characteristics (including color) change considerably between different varieties and the maturity of the fruit during growth and fertilization conditions. In contrast, some other compounds do not show such noticeable changes [42].

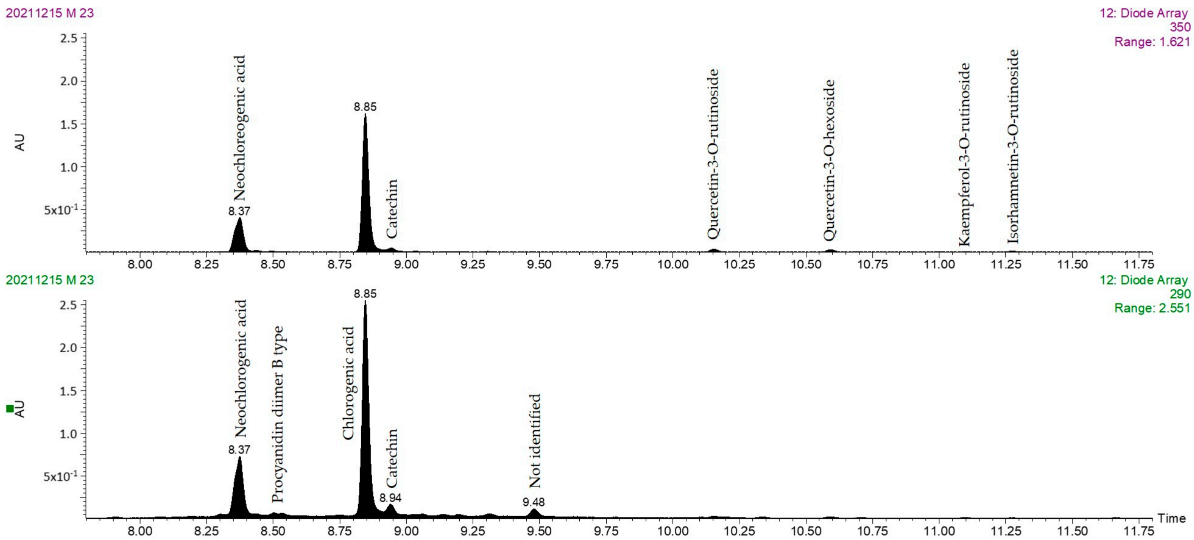

Figure 5. Mass chromatogram obtained from the control sample of the identification analysis performed by UPLC-PDA-MS/MS.

Table 4. Chlorogenic and neochlorogenic acids content of extracts obtained from dried samples of peach slices obtained at different temperatures of natural and forced convection.

Treatment		Chlorogenic Acid (μmol/L)	Neochlorogenic Acid (μmol/L)
Natural convection	40 °C	822.41 ± 66.98 d	585.01 ± 71.27 c
	45 °C	653.73 ± 65.06 bc	354.41 ± 2.44 a
	50 °C	938.67 ± 34.03 e	558.92 ± 9.67 bc
Forced convection	40 °C	678.48 ± 30.89 c	390.37 ± 50.01 a
	45 °C	741.84 ± 18.84 cd	391.74 ± 9.31 a
	50 °C	813.04 ± 12.73 d	501.09 ± 1.94 b
Solar drying	1 m/s	522.13 ± 7.89 a	334.73 ± 20.97 a
	3 m/s	567.54 ± 33.14 ab	319.54 ± 13.07 a

Values with the same letter in the same column were not significantly different at $p < 0.05$, determined by multiple comparisons of means by the LSD-Fisher test.

4. Conclusions

In this study, the drying kinetics of peach slices were investigated using an electric and solar dryer under different operating conditions. Likewise, the effect of these drying modes on the phenol content and the antioxidant capacity of the dried samples were analyzed.

The highest drying rates were observed in solar drying at both tested temperatures, followed by the drying kinetics in the electric dryer in forced convection and the drying kinetics in natural convection. It is worth mentioning that a fluctuation in the drying speed is observed in the solar drying experiment because this process is carried out in a transitory state, that is, in non-stable conditions. This is due to the natural variations in the incident solar radiation, due to cloudiness and relative humidity that can affect the incident solar radiation on the dryer. These same variations cause a variation in the temperature inside the drying chamber and, consequently, a fluctuating drying rate. The models that best describe the experimental data obtained were the Wang and Singh model for the experiments carried out in natural convection in all cases; the Page and Verma et al. models fit better to the experimental data obtained in forced convection; and finally, the logarithmic model and the Wang and Singh model were more suitable for data obtained for solar drying. High drying rates mean shorter drying kinetics. Periods of constant velocity were not observed in any case. The TPC content and antioxidant activity were reduced in the dried peach slices.

Finally, all samples identified two compounds (chlorogenic acid and neochlorogenic acid) by the UPLC-DAD-MS/MS method. Chlorogenic acid was the compound in the highest concentrations for drying methods. In this sense, solar drying showed advantages in terms of drying speed, color, and texture; however, the antioxidant compounds were affected, possibly due to the effect of UV rays on them. This opens a new possibility for research on the design of solar dryers and the use of selective films to filter UV rays to conserve bioactive compounds beneficial to health. Moreover, performing the evolution kinetics of antioxidant compounds can improve the understanding of their behavior during drying. In addition, the findings can provide a guide to finding the best technology and drying method to improve the quality of dried peach.

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