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Effect of convective drying on color, water activity, and browning index of peach slices

Efecto del secado convectivo sobre el color, actividad de agua e indice de oscurecimiento en rebanadas de durazno

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Abstract

Color is one of the most critical food quality parameters since it impacts consumer acceptability. The influence of peach drying at varied temperatures (50, 55, and 60 °C), air velocities (0.3, 0.6, and 0.9 $m\cdot s^{-1}$), and processing periods (6, 6.5, and 7 h) on color change, water activity, total soluble solids, and browning index was studied. A 2^3-randomized experimental design was used to investigate the effect of various operating factors. The drying kinetics were primarily controlled by temperature and airflow rate, with higher temperatures and airspeed resulting in a shorter drying time. The water activity ranged from 0.33 to 0.41, and the lowest color change (ΔE) was 18 at 55 °C, 0.3 $m\cdot s^{-1}$, and 6 h. The color parameters showed the best result at 55 °C and 60 °C at 3 $m\cdot s^{-1}$. Furthermore, temperature and air velocity increased the browning index and total soluble solids. These results may be valuable to dry peach producers.

Keywords: Convective drying, drying kinetics, colorimetry, dehydrated peaches.

Resumen

El color es uno de los parámetros de calidad alimentaria más críticos, ya que influye en la aceptabilidad por parte del consumidor. Se estudió la influencia del secado de durazno a distintas temperaturas (50, 55 y 60 °C), velocidades del aire (0,3, 0,6 y 0,9 $m\cdot s^{-1}$) y periodos de procesado (6, 6,5 y 7 h) sobre el cambio de color, la actividad del agua, los sólidos solubles totales y el índice de oscurecimiento. Se utilizó un diseño experimental aleatorizado de 2^3 para investigar el efecto de diversos factores operativos. La cinética de secado estuvo controlada principalmente por la temperatura y la velocidad del flujo de aire, siendo las temperaturas y la velocidad del aire más elevadas las que dieron lugar a un tiempo de secado más corto. La actividad del agua osciló entre 0,33 y 0,41, y el menor cambio de color (ΔE) fue de 18 a 55 °C, 0,3 $m\cdot s^{-1}$ y 6 h. Los parámetros de color mostraron el mejor resultado a 55 °C y 60 °C a 3 $m\cdot s^{-1}$. Además, la temperatura y la velocidad del aire aumentaron el índice de oscurecimiento y los sólidos solubles totales. Estos resultados pueden ser valiosos para los productores de durazno seco.

Palabras clave: Secado convectivo, cinéticas de secado, colorimetría, duraznos deshidratados.

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1 Introduction

Peach (*Prunus persica* L.) fruit originates in China and has excellent nutritional value, such as vitamins A, B1, B2, C, proteins, calcium, etc. (Africano *et al*., 2015). This fruit is grown worldwide, including Asia, Europe, Africa, and America (Naseer *et al*., 2016), and the worldwide production is 24,994,352 tons (Food and Agriculture Organization of the United Nations [FAO], 2023). The worldwide most important producers are China, Spain, and Italy. In Mexico, there is peach production in most of the country, with nearly 19 million hectares (Solleiro & Mejia, 2018). Despite having a high total sugar content and being firm, the fruit does not unfortunately fulfill marketing standards at the end of the agricultural cycle, which justifies the search for value-adding processing alternatives that will profit farmers financially. Peaches must also be processed quickly to prevent rotting because of how perishable they are due to their high moisture content. In this sense, drying preservation is one of the options (Figeroa González *et al*., 2011).

Drying improves food stability by reducing its water content and, consequently, its microbiological activity (Tonguido Borja, 2011). The quality of dehydrated products is increasingly relevant regarding microbiological stability and organoleptic characteristics. Hence, each food requires special drying conditions depending on the physical or chemical attributes that must be preserved. Convective drying removes water by flowing hot, dry air over the material's surface. The air temperature can be varied to optimize drying time and will depend on the sensitivity of specific physical and chemical product characteristics to be preserved (Zhu & Shen, 2014). The most important physical properties of products that probably will change with drying are color, flavor, texture, shrinkage, and chemical changes affecting bioactive compounds.

Valéroe *et al*. (2006) and Mínguez-Mosquera *et al*., (2006) studied the interactions between fruit color and human perception of food acceptability, including color-taste, color-olfactory, and color-flavor; in this context, the color becomes a quality index indicating quality and deterioration. Tlatelpa-Becerro (2022) presents the solar drying behavior of Cecina from Yecapixtla, Morelos in an indirect solar dryer, observing significant effects on pH, salinity and density levels compared to traditional drying. conclude that solar drying provides better color, thickness and presence of intramuscular fat. There are many studies on the drying kinetics of various fruits, Ewa *et al*. (2013) investigated the convective drying process of peaches in a laboratory dryer at three temperatures (50, 60, and 70 °C) and two airflow velocities (1.0 and 1.2 m·s^{-1}) and concluded that the velocity has less effect on drying rate than temperature. El Broudi *et al*., (2022) evaluated a hybrid indirect solar dryer (at 40, 50, 60 and 70°C) for the processing of pomegranate arils, calculated the optimal water activity, net isosteric heat of sorption, effective moisture diffusivity, bioactive compounds and sensory evaluation. The results showed that the color is best preserved at 40°C. However, indirect convective solar drying at 50°C was the most appreciated by consumers in the sensory evaluation test. García-Valladares, *et al*. (2022) evaluated the effect of drying Carambolo in a solar dryer with natural convection using four different covers: glass, acrylic, polycarbonate and polyethylene. They obtained samples with a humidity between 2.2% and 5.9% and water activity ranging between 0.310 and 0.414. The polycarbonate cover dryer presented less degradation of the bioactive compounds and color. Roknul Azam *et al*. (2019) studied the effect of different drying modes on Peach skin quality and moisture distribution, texture, rehydration ratio, color, and microstructure. Mireles Bañuelos *et al*. (2019) worked on the dehydration process in peaches using natural and forced convection in a solar dryer to compare the method's efficiency and the product's physical characteristics. On the other hand, Rossi Bilesky, *et al*. (2018) performed peach drying kinetics using two variables: temperature and fruit geometry, at four different temperatures (60, 70, 80, and 90 °C) and showed that the increase in the fruit contact area to external environment facilitates the water loss of the fruit. Another study analyzed the effects of convective drying on the cell wall and morphology of peach slices (Liu *et al*., 2020). Recently, Demirel & Ismail (2017) reported a study on the color of nectarine slices in a microwave dryer at 50 and 70 °C with an air velocity of 2 m·s^{-1} finding better results at 70 °C.

Drying is a process that modifies organoleptic properties; therefore, it is necessary to study the effect of the operating conditions on the color of dried peaches and to find the conditions that best preserve their properties. The main objective of this experimental work was to study the drying kinetics of peach and identify the most appropriate drying conditions (temperature, time, and air velocity) in a laboratory electric dryer that would least affect the color change and obtain the best values of water activity, moisture content, and total soluble solids content.

2 Materials and methods

2.1 Raw material

Peaches were acquired from the Cuernavaca, Mor., Mexico, the local market between April to May

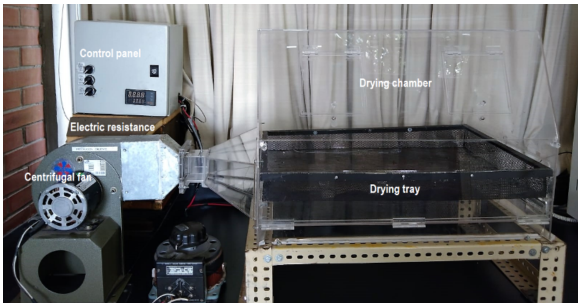

Fig. 1 Photo of forced convection electrical dryer utilized in the experiments.

2021. Peaches were selected having a uniform orange color and firm consistency. They were treated with a chlorine solution (100 ppm) to remove dirt and were then stored at -5 ± 0.5° C before dehydration; the initial moisture content was 82.1±1.16 % (w.b.).

2.2 *Description of the drying*

To perform the experiments, we used an electrical dryer (Fig. 1), which has 0.35 m^2 of effective drying area, the maximum flow capacity of the blower is 570 $m^3 \cdot h^{-1}$, and the heating system is composed of three electric resistances of 1500 W each. An electrical motor of 1/20 hp powered a centrifugal fan to provide the airflow.

2.3 *Experience procedure*

Fresh peaches, without pretreatment, were cut into slices (thickness 2 mm; width 40 mm; length 50 mm) and placed on the drying 6 trays with ~15 slices (50 g) in a single layer, totaling 300 g of peach for each experiment. Every 20 minutes, the samples were weighed during the first 2 hours and every 60 minutes during the following hours. Moisture content was determined using a moisture analyzer (OHAUS, MB45 ±0.001 g) at 105 °C of peach samples (~3 g), and it was measured before and after the experimentation, getting initial and final moisture content. The water activity (aw) was obtained at room temperature (25 °C), where the samples were chopped into small sections and uniformly distributed in the sample holder of the water activity meter (Rotonic Higrolab CI).

The experiments were performed with air velocities of 0.3, 0.6, and 0.9 $m \cdot s^{-1}$; the temperatures implemented were 50, 55, and 60 °C. The air velocity was measured utilizing an anemometer Dwyer 473B-1 (0.2-25 $m \cdot s^{-1}$), and the drying temperature was measured with a PT100 sensor (-100-200 °C).

2.4 *Analytical methods*

2.4.1 *Color*

The color parameters of the sample were measured with a portable colorimeter (NR60CP), taking values every 20 minutes during the first 2 hours and then every hour until the end of the experiment. The parameters were measured in only one sample for each experiment, data were recorded in triplicate, and the values were averaged. The equipment was calibrated using CIE L a*b* space, and the color parameter was enunciated in L* (brightness-darkness), a* (redness-greenness), b* (yellowness-blueness), H (hue angle) property of color, and C (Chroma) saturation. Hue and Chroma were calculated following the equations:

$$Hue = \tan^{-1}(b*/a*) \tag{1}$$

$$Chroma = \sqrt{a*^2 + b*^2} \tag{2}$$

The samples were weighed and photographed using a camera (Nikon D5100) at regular intervals until the samples reached a constant weight. Then, the color difference ΔE of the randomly selected samples was calculated using the following equation.

$$\Delta E = \sqrt{\Delta L*^2 + \Delta a*^2 + \Delta b*^2} \tag{3}$$

Where, $\Delta L* = L*_o - L*_f$, $\Delta a* = a*_o - a*_f$ and $\Delta b* = b*_o - b*_f$, comparing color parameters between raw (o) and dried sample (f).

2.4.2 *Browing index*

The browning index (BI) was assessed by color space CIE L*a*b* coordinates, according to the methodology used by Santos Souza *et al.* (2015); this was calculated at the same time as ΔE, by the equation:

$$BI = \frac{100(A - 0.31)}{0.172} \tag{4}$$

where A is:

$$A = \frac{a* + (1.75)L*}{(5.645)L* + a* - (3.021)b*} \tag{5}$$

2.4.3 *Total soluble solids*

The total soluble solids, or sugar content, in the fruits, was obtained by testing the degrees Brix by a refractometer (WZ-119/ATC) using the methodology mentioned by Kassem *et al.* (2011) with some modifications, measuring the refractive juice index of the raw peach and peach dried, 30 mL of distilled water were mixed with 10 g of dried peach and crushed; then the refractive juice index was measured.

Table 1. Mathematical models applied to drying curves.

Model name	Model	Reference
Midilli and Kucuk	$MR = ae^{-ktn} + bt$	Midilli *et al.* (2002)
Logarithmic	$MR = ae^{-kt} + c$	Toğrul and Pehlivan (2002)
Two-Term exponential	$MR = ae^{-kt} + (1-a)e^{-kat}$	Sharaf *et al.* (1980)
Henderson & Pabis	$MR = ae^{-kt}$	Henderson and Pabis (1961)
Newton	$MR = e^{-kt}$	Jayas *et al.* (1991)

2.4.4 *Drying kinetics*

The moisture content (dry basis) was calculated using the following equation (Mühlbauer & Müller, 2011):

$$M_{db} = \frac{m_w}{m_d} \tag{6}$$

where M_{db} is the ratio of water mass (m_w) to dry matter mass (m_d). Kinetic models for thin layer drying processes considered for this study are listed in Table 1.

The kinetic model was fitted using R 4.2.2 software. Model selection was made using the Akaike Information Criterion (AIC):

$$AIC_i = -\log L_i + 2p_i \tag{7}$$

where L_i and p_i are the likelihood and the number of parameters for each model, and n is the number of observations. The selected model is the one with the lowest AIC.

The goodness of fit of the selected model was assessed through bias, the root mean square error (RMSE), and residual standard error (RSE). The chosen model has the bias closest to cero and the lowest RMSE and RSE

$$Bias = \frac{1}{n}\sum_{i=1}^{n}(MR_i - \hat{MR}_i) \tag{8}$$

$$RMSE = \frac{1}{n}\sum_{i=1}^{n}(MR_i - \hat{MR}_i) \tag{9}$$

$$RSE = \frac{1}{n}\sqrt{\sum_{i=1}^{n}(MR_i - \hat{MR}_i)} \tag{10}$$

were MR_i represents the experimental data and $\hat{MR}_i$ represents the fitted data.

2.4.5 *Moisture ratio*

The moisture ratio was estimated by using the following equation:

$$MR = \frac{M - M_e}{M_o - M_e} \tag{11}$$

where M is the moisture content of the peach throughout the drying process, M_o is the initial moisture content, and M_e is the moisture content stabilized.

Table 2. Experimental values of response variables for randomized experimental design.

Independent variables	Coded variables	(-1)	(+1)
Temperature (°C)	X_1	50	60
Air velocity ($\mathrm{m \cdot s^{-1}}$)	X_2	0.3	0.9
Time (h)	X_3	6	7

2.4.6 *Experimental design*

To explore the effect of the operating variables on peach drying a 2^3 factorial design with a single replicate was performed. The factors and levels of the experiment are shown in Table 2.

R 4.2.2 software was used to create the design table and data analysis. Lenth Plots were considered to assess the significant effects on the response variables, using the margin error (ME) and simultaneous margin error (MSE) limits at approximately 95 % as references. Effects between these ME and SME limits probably would be active; over SME are considered active, and below ME, effects are not significant. The response variables were the final moisture content (Y_1), water activity (Y_2), lightness (Y_3), a (Y_4), b (Y_5), Chroma (Y_6), Hue (Y_7) BI (Y_8), °Brix (Y_9) and color difference (Y_{10}) of the dried peach. Each response has its statistical model, where the general equation is:

$$\begin{aligned} Y_i =& \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \beta_{12} X_{i12} + \beta_{13} X_{i13} \\ &+ \beta_{23} X_{i23} + \beta_{123} X_{i123} + \varepsilon_{ijk} \end{aligned} \tag{12}$$

Where

$$X_1 \begin{cases} \text{-1 if temp.=50 °C} \\ \text{1 if temp.=60°C} \end{cases}$$

$$X_2 \begin{cases} \text{-1 if air vel.=0.3 m s}^{-1} \\ \text{1 if air vel.=0.9 m s}^{-1} \end{cases}$$

$$X_3 \begin{cases} \text{-1 if time=6 h} \\ \text{1 if time=7 h} \end{cases}$$

Constant β_0 is the mean of all treatments; β_1, β_2, β_3 are the main effects for the i-th level of each factor; β_{12}, β_{13}, β_{23} are the two-factor interaction effects; β_{123} is the three-factor interaction effect and ε_{ijk} are independent $N(0,\sigma^2)$.

Table 3. Physicochemical characteristics of fresh peaches.

Analysis	Mean values± standard deviation
Moisture content (w.b)	82.1 ± 1.16
Total solids (° Brix)	17.9 ± 1.16
Water activity	0.989 ± 0.001
Lightness	52.98 ± 6.09
a*	8.71 ± 1.2
b*	33.01 ± 4.57
Chroma	34.5 ± 4.57
Hue angle	75.12 ± 2.03
BI	104.5 ± 9.47
Total soluble solids	13.66 ± 1.53

3 Results

3.1 Measurement of initial peach physicochemical conditions

Table 3 shows the physicochemical characteristics evaluated before drying experiments.

3.2 Drying kinetics

Data shown in Fig. 2 suggest that, at tested drying conditions, air velocities of 0.6 and 0.9 m·s^{-1} have similar drying rates above 55 °C, but at an air velocity of 0.3 m·s^{-1}, the temperature effect is evident, and drying rates are lower at lower temperatures. According to the results observed in the literature, temperature is the most critical factor for moisture removal from foods (Zhihan *et al.*,2021; Fenglin *et al.*, 2013); this is because the relative humidity of the air tends to decrease as air temperature increases, which enhances the potential for moisture removal from foods. Additionally, the convection of hot air passing over the peach slices makes moisture removal more efficient. There is an effect in peach drying process time regarding temperature; the lower the temperature is, the longer the drying time. Also, at 60° C, the drying process ends around t = 250 min, regardless of the airflow value.

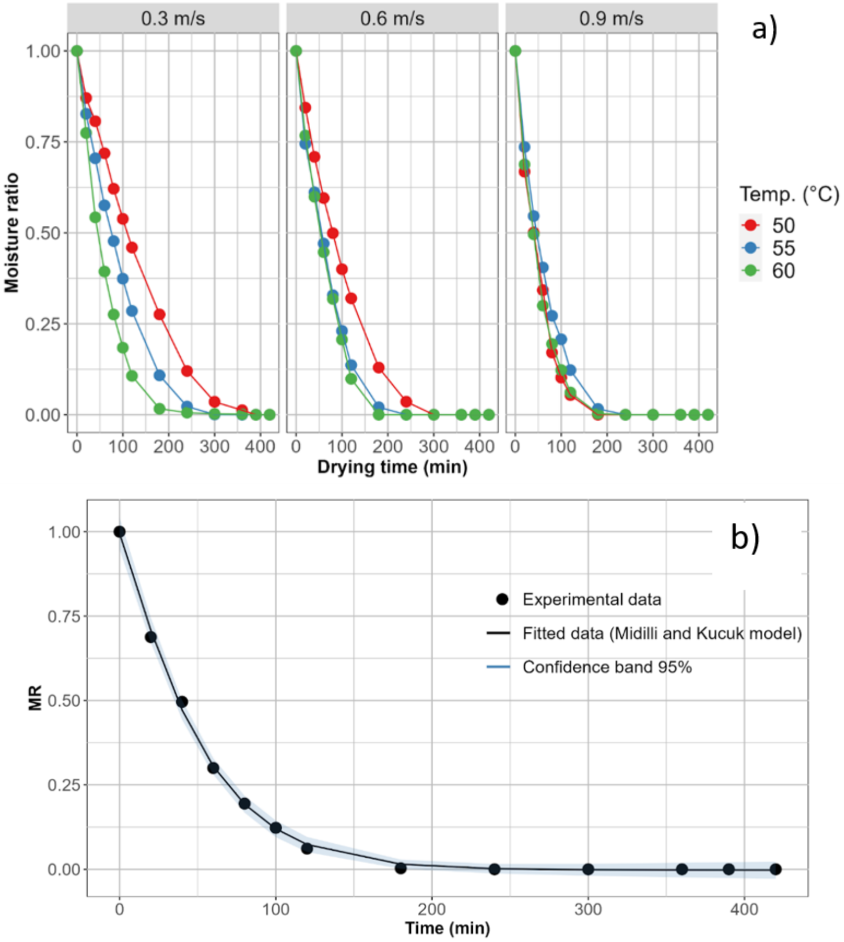

Fig. 2 a) Drying kinetics at different airflow rates (0.3, 0.6, and 0.9 m s^{-1}) and drying temperatures (50, 55, and 60°C); b) mathematical fit of experimental data.

Table 4. Model parameters, model selection and model goodness of fit criterion in different drying parameters.

Model parameters, model selection and model goodness of fit criterion										
	0.9 ms^{-1} and 60 °C					0.3 m s^{-1} and 50 °C				
Kinetic model	Model parameters	AIC	RSE	RMSE	Bias	Model parameters	AIC	RSE	RMSE	Bias
Midilli	$\hat{a}$ =0.995 $\hat{k}$ = 0.013 $\hat{n}$ = 1.104 $\hat{b}$ = -3.795×10^{-5}	-96.016	0.015	0.013	-3.26×10^{-4}	$\hat{a}$ = 0.975 $\hat{k}$ = 1.53×10^{-3} $\hat{n}$ = 1.292 $\hat{b}$ = -8.922×10^{-5}	-61.581	0.018	0.015	-1.78×10^{-4}
Logarithmic	$\hat{a}$ = 1.033 $\hat{k}$ = 0.018 $\hat{b}$ = -0.026	-91.019	0.017	0.015	-2.49×10^{-10}	$\hat{a}$ = 1.169 $\hat{k}$ = 0.005 $\hat{b}$ = -0.151	-52.132	0.027	0.024	-1.05×10^{-10}
Two-term exponential	$\hat{a}$ = 1.592 $\hat{k}$ = 0.025	-100.189	0.013	0.013	-0.002	$\hat{a}$ = 1.584 $\hat{k}$ = 0.024	-52.853	0.027	0.025	-0.009
Henderson & Pabis	$\hat{a}$ = 1.013 $\hat{k}$ = 0.020	-85.061	0.020	0.019	-0.005	$\hat{a}$ = 1.011 $\hat{k}$ = 0.020	-63.171	0.022	0.020	-0.004
Newton	$\hat{k}$ = 0.020	-86.028	0.020	0.020	-0.004	$\hat{k}$ = 0.020	-64.419	0.019	0.021	-0.002
	0.3 m s^{-1} and 55 °C					0.3 m s^{-1} and 60 °C				
Kinetic model	Model parameters	AIC	RSE	RMSE	Bias	Model parameters	AIC	RSE	RMSE	Bias
Midilli	$\hat{a}$ =0.982 $\hat{k}$ = 3.48×10^{-4} $\hat{n}$ = 1.227 $\hat{b}$ = -3.333×10^{-5}	-63.348	0.017	0.014	-5.57×10^{-4}	$\hat{a}$ = 0.999 $\hat{k}$ = 7.49×10^{-3} $\hat{n}$ = 1.181 $\hat{b}$ = -4.010×10^{-6}	-80.699	0.008	0.007	-3.71×10^{-4}
Logarithmic	$\hat{a}$ = 1.066 $\hat{k}$ = 9.49×10^{-3} $\hat{b}$ = -0.046	-53.661	0.026	0.023	1.74×10^{-10}	$\hat{a}$ = 1.039 $\hat{k}$ = 0.016 $\hat{b}$ = -0.013	-59.099	0.020	0.018	1.614×10^{-9}
Two-term exponential	$\hat{a}$ = 1.734 $\hat{k}$ = 0.014	-62.548	0.019	0.017	-0.006	$\hat{a}$ = 1.713 $\hat{k}$ = 0.022	-82.548	0.009	0.008	-0.001
Henderson & Pabis	$\hat{a}$ = 1.033 $\hat{k}$ = 0.011	-47.407	0.035	0.031	-0.010	$\hat{a}$ = 1.029 $\hat{k}$ = 0.017	-58.762	0.022	0.020	-0.005
Newton	$\hat{k}$ = 0.010	-47.607	0.035	0.033	-0.007	$\hat{k}$ = 0.016	-58.107	0.023	0.022	-0.007

Model parameters for kinetic models under these experimental settings were estimated for the following situations: 1) at 60 °C and 0.9 m·s^{-1} because at this temperature, the drying time is identical independent of the airflow; and 2) at 50, 55, and 60 °C with 0.3 m·s^{-1} because at this airflow the temperature affects the drying rate and drying time. Midilli and Kucuk model was the most representative and best fit the experimental data in all cases. Therefore, this model is the one that best adequately describes the drying kinetics of peach slices and could be used for further calculation and prediction of the dehydration behaviour of peach slices under the described experimental conditions. It is essential to model the dehydration kinetics and understand the operational variables in the drying kinetics. Assessing the AIC selection criteria, Midilli and Kucuk model is one of the lowest; in terms of goodness-of-fit, it is the model with the lowest difference between the predicted and observed data and the model with the smallest bias. Fig. 2 shows the model fitting and confidence band (Delta method). The estimated parameters of all assessed models are displayed in Table 4. In the case of the Midilli and Kucuk model, a and n are dimensionless drying constants and b is a parameter for the model. The most important parameter is k, the constant of drying velocity. During experiments, an increase of two orders of magnitude in the constant of drying velocity (k) at higher airflows and temperatures was observed. This means that the drying rate increases by increasing the value of these two parameters.

3.3 *Experimental design*

Single replicate was performed for the experiments, and effects on the response variables Y_1, Y_2, $\ldots$, Y_{10} where evaluated using Lenth plots. As seen in Fig. 3, the effects of any of the factors or interactions are unlikely to be significant since all lie below margin error limits (ME) under the studied conditions, except for the three-way interaction in Chroma, Lightness, and b responses. This demonstrates that the drying process is over at 6 h, and no change in final variables is observed. Nevertheless, the effect of temperature and airflow rate was observed from kinetic data.

According to the results shown, there is no significant effects of the selected factors under studied conditions, so it is considered necessary, in a future study, to evaluate this factors in a different experimental region with a wider separation between the values to determine which of these factors has a more significant effect on the drying kinetics and final color of the sliced peach slice samples.

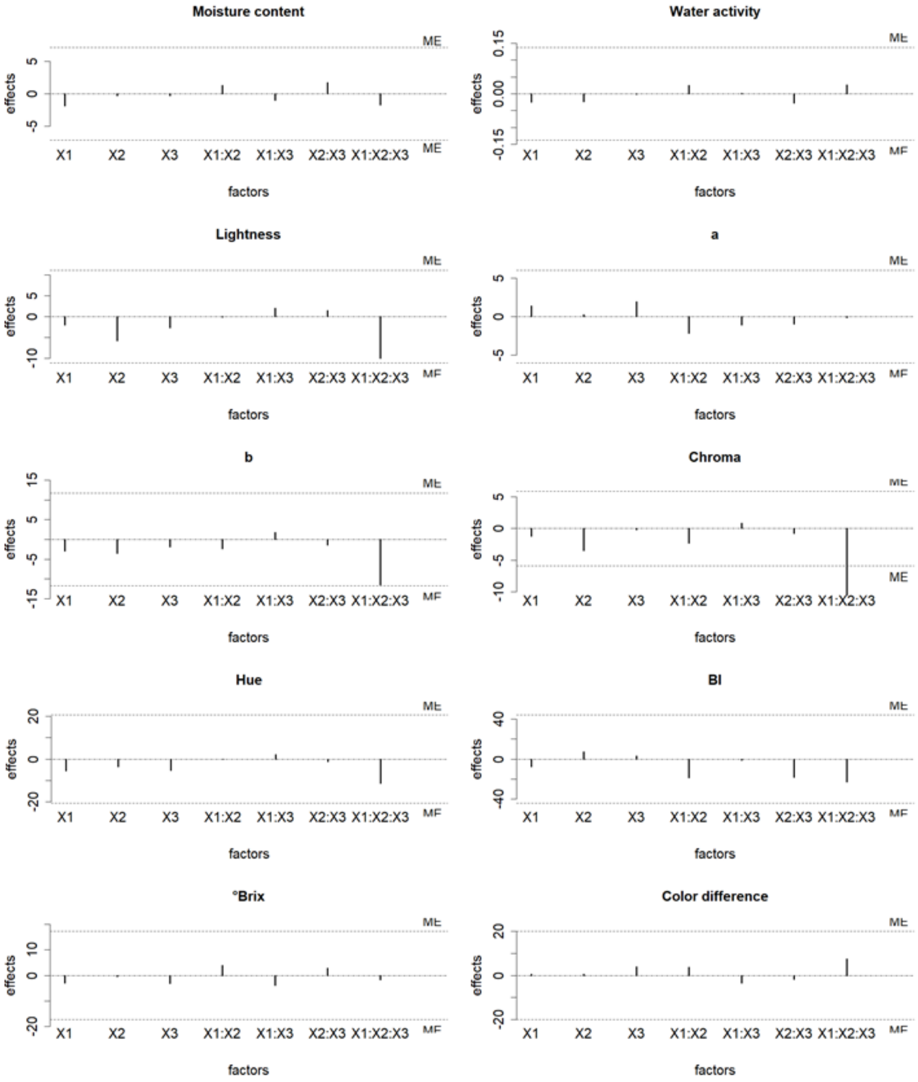

Fig. 3 Lenth plots of effects for responses Y1 to Y10.

3.4 *Influence of drying time, temperature, and air velocity on moisture content*

Fig. 4 shows the relationship between moisture content, airflow, and temperature. Experimental moisture content values are 8.9 H_2O/g d.m., where the lowest moisture content was obtained at 60 °C and 0.3 m·s^{-1} (0,063g H_2O/g d.m.) The lowest moisture content was observed at higher temperatures due to the increased potential for moisture transfer between the peach and hot air. Zhu & Shen (2014) studied the influence of the drying temperature, air velocity, and thickness of peach slices in convective drying. They showed similar results where higher temperatures presented lower moisture content and shorter drying time. According to the results, at higher temperature the lower the final moisture content was achieved; however, if the airflow rate is high and at a constant temperature, the drop in moisture content will be more pronounced, and the drying time will be shorter (Johnson & Mukhain, 2016). This behaviour is observed in Fig, 2; when the air velocity is higher (0.9 m·s^{-1}), the moisture content decreases faster than 0.3 m·s^{-1} and 0.6 m·s^{-1}; similar results were shown by Hansmann *et al.* (1998) in their study where dried peach at different air velocities (2 m·s^{-1}, 3 m·s^{-1} and 4 m·s^{-1}) where the drying rate increased when the air velocity augmented, obtaining less drying time at 4 m·s^{-1}.

3.5 *Water activity*

Fig. 4 shows how final water activity is affected by air velocity, temperature, and drying time in peach samples. Water activity (aw) is essential for food microbiological stability, avoiding decomposition and loss. The raw value of the fresh peach slices was 0.989. The highest aw values were obtained at 0.3 m·s^{-1} and 50 °C, after ~250 min (0.452). The aw showed values between 0.351 and 0.452, smaller values at 60 °C, 0.9 m·s^{-1}, and a longer drying process (7 h).

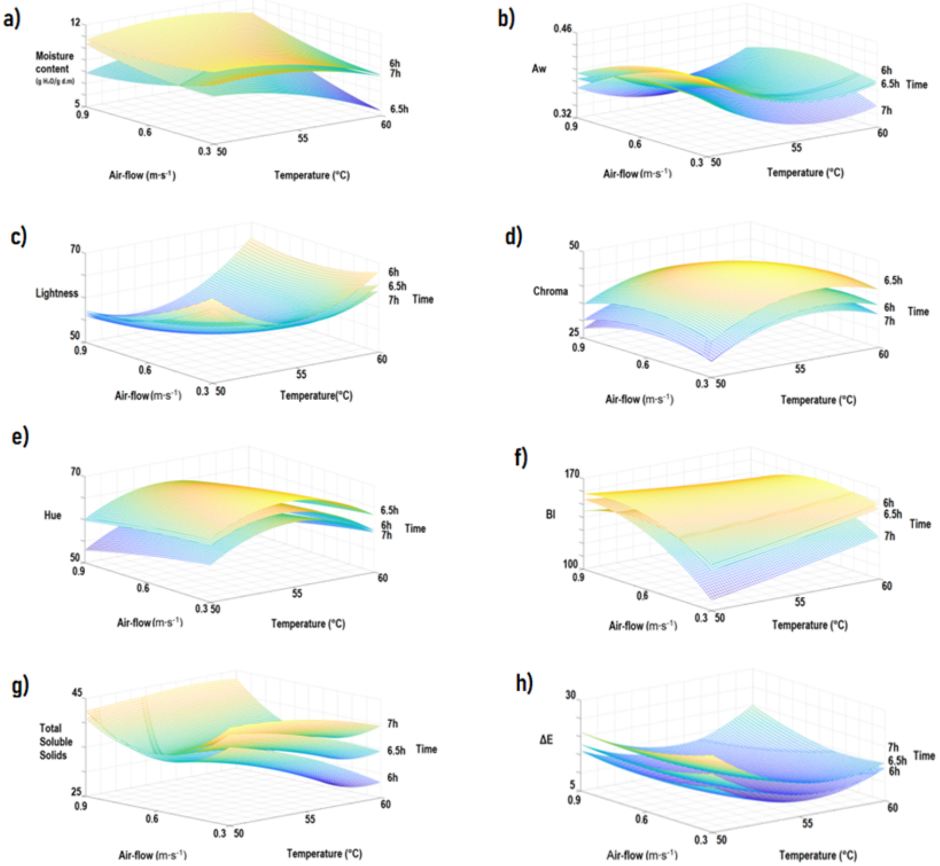

Fig. 4 Surface Response as a function of airflow and temperature at three different drying times (6 h,6.5 h,7 h) of a) Moisture content, b) Aw, c) Lightness, d) Chroma, e) Hue, f) BI, g) Total Soluble Solids and h) Color Difference.

The reduction of *aw* implies a decrease in the partial vapor pressure of water in the food, which reflects the decrease in the moisture content in it. A lower value in water activity may be related to the reduction of surface sites available for water adsorption due to physical structural changes in peach slices during the drying process. Similar behavior has been reported by Dipersio *et al*., (2004) for peach drying; they showed that aw decreased from 0.97 to 0.37. Bacterial and fungal growth occurs when aw is between 0.6 and 1 (Mühlbauer & Müller, 2011). These low reported water activity values are considered to be in a range of greater stability from a microbiological point of view, given that enzymatic, non-enzymatic and lipid oxidation reactions are at their lowest levels (López-Vidaña *et al*., 2021; Piazola-Jacinto *et al*. 2019).

3.6 Lightness

Fig. 4 shows how the luminosity decreased as the airflow increased from 0.3 m·s^{-1} to 0.9 m·s^{-1}; in contrast, it grew at higher temperatures (60 °C) and is higher when the drying time is minor (6 h). This behaviour can be related to the increase in the degree of the Browning Index. However, Hasman *et al*. (1998) demonstrated the opposite effect in the drying process of peaches; they report that the luminosity increased as the airflow rate increased from 2 m·s^{-1} to 4 m·s^{-1} at 65 °C (fresh sample = 52.18; dried sample = 29.57). According to Guiné *et al*. (2011), the decrease in luminosity is due to increased temperature and drying time. Similar results were reported by Dadali *et al*. (2007) in the kinetics of the color difference of spinach by microwave drying, demonstrating how luminosity decreased from 39 to 30 with drying time. Cruz *et al*. (2015) described this behavior in luminosity during apple drying at 60 °C, reported a decrease from 79 to 69, and attributed the changes in color to the polyphenol oxidase enzyme. Ávila & Silva (1999) studied the color change in peach puree and reported that it loses its yellowness as the b value decreases and becomes redder as the a* value increases. Roknul Azam *et al*. (2019) reported a decrease in lightness when comparing different drying methods on the quality attributes of peaches. According to their results, the initial luminosity value was 52.98 and decreased to 56.19 for drying with hot air, 51.55 for microwave drying, and 58.15 for radiofrequency drying.

3.7 Chroma

As shown in Fig. 4, Chroma values increased with the temperature (from 50 °C to 60 °C) and air flow rate (from 0.3 m·s^{-1} to 0.9 m·s^{-1}). The a* values increased from 8.71 to 33, and the b* values increased from 33.01 to 47.52, indicating a yellow and red color increase in the dried samples. On the other hand, chroma values ranged from 22.05 to 51.42 from an initial value of 34.5. When chroma values decrease, the dried peach becomes darker at first impression; however, this is because the red color has increased and not the yellow color, so the peach slice is no longer yellow enough and therefore, the perception is a darkening of the peach slice (Tan *et al*. 2022). This decrease was observed at higher temperatures and for extended periods of time. Polat *et al*. (2021) reported a decrease in chroma parameters from 65 to 60 using the peach puree's convection and microwave drying processes. The augment in chroma value is related to the rise in the browning index.

3.8 Hue

Hii *et al*. (2014) state that low Hue angle values indicate the samples' browning. As seen in Fig. 4, the Hue angle decreased with increasing airflow from 0.3 m·s^{-1} to 0.9 m·s^{-1}. On the other hand, when the temperature rises from 50 °C to 55 °C and the airflow increases from 0.3 m·s^{-1} to 0.6 m·s^{-1}, the hue angles increase, indicating less browning. Therefore, an increase in hue angle shows that the color of the peach sample tends toward yellowing, whereas a decrease in hue angle means that the peach color tends toward red (Karaaslan *et al*., 2021). For example, the initial hue angle of peach slices was 75.12 (Table 2); however, this value increased with increasing airflow, meaning that the sample's color changed from red to yellow (hue average of 58.06).

3.9 Browning index

The browning index is determined in sugar-containing foods and relates to the purity of the brown color. According to Pepa *et al*. (2021), during the heating time, the samples increased a scarcely yellow color, then the samples turned red, and finally, a brown color was observed. The initial browning index of peach slices was 104.5 (Table 2); however, this value increased from a minimum of 109.43 to a maximum of 188.3. Although the Lenth plot showed that the factors did not influence the response variable, Fig. 4 shows how the browning index increased slightly as airflow and drying temperature increased from 0.3 m·s^{-1} to 0.9 m·s^{-1} and from 50 °C to 60 °C, respectively. According to Fig. 4, the lowest browning index was obtained with a drying temperature of 50 °C, an airflow of 0.3 m s^{-1} and 6 h of drying time. Similar behavior was obtained by Hatami *et al*. (2017) in the solar drying of plantain slices; however, they reported that the lightest airflow (0.016 kg·s^{-1}) caused the highest values of browning in dried plantain slices. According to Hii *et al*. (2010), the formation of brown or black pigments, such as melanoidins, contributes to color changes during drying. Phuon *et al*. (2022) reported the effect of different drying processes on orange peel under drying conditions during the convective drying process (50 °C; 1 m·s^{-1}; 4.5 h), being higher when the two different drying techniques (convective and microwave) were used (112 and 103, respectively).

3.10 Total soluble solids

Food color is considered an indicator of pigment degradation by enzymatic and non-enzymatic reactions during the drying process. The caramelization of the sugar contents is a non-enzymatic reaction that oxides the products' total soluble solids (sugar content) (García-Moreira *et al*., 2023). Total soluble solids value in the fresh sample was 13.66 °Brix; however, an increment in total soluble solids was observed at 0.9 m·s^{-1} for every experiment. While Fig. 4 shows similar values in every experiment in 0.9 m·s^{-1}, when the air velocity is 0.3 m·s^{-1}, it shows a slight tendency to augment if the temperature decreases (60 °C to 50 °C). This contrasts with the results of Polat *et al*. (2021) during the application of different drying techniques on peach puree, which reported that the total soluble solids in the fresh peach pure was 9 °Brix, and it increased until 50 °Brix in convective drying and until 70 °Brix in microwave drying. Also, Fig. 4 shows how the total soluble solids increased as the drying time increased from 6 h to 7 h. Also, 0.9 m·s^{-1} is the best condition to increase the total soluble solids; the color redness increases when the total soluble solids increase.

3.11 Color difference

The difference between the fresh and dried samples can be evaluated by the total color difference (ΔE). The ΔE values ranged from 11.61 to 28.22; these values could be unattractive in appearance or not, this depends on the final color because it could improve (in this case, more yellow and lightness), or darkening could occur. The highest ΔE value was 28.22 at 50 °C, 0.3 m·s^{-1}, and 7 h. According to Hii *et al*. (2010), the factors that contribute to color changes during drying are pigments, Maillard reactions, and enzymatic browning; these factors can produce changes from yellow to red color and oxidation of carotenoids by oxygen in the air formation of brown or black pigments increment.

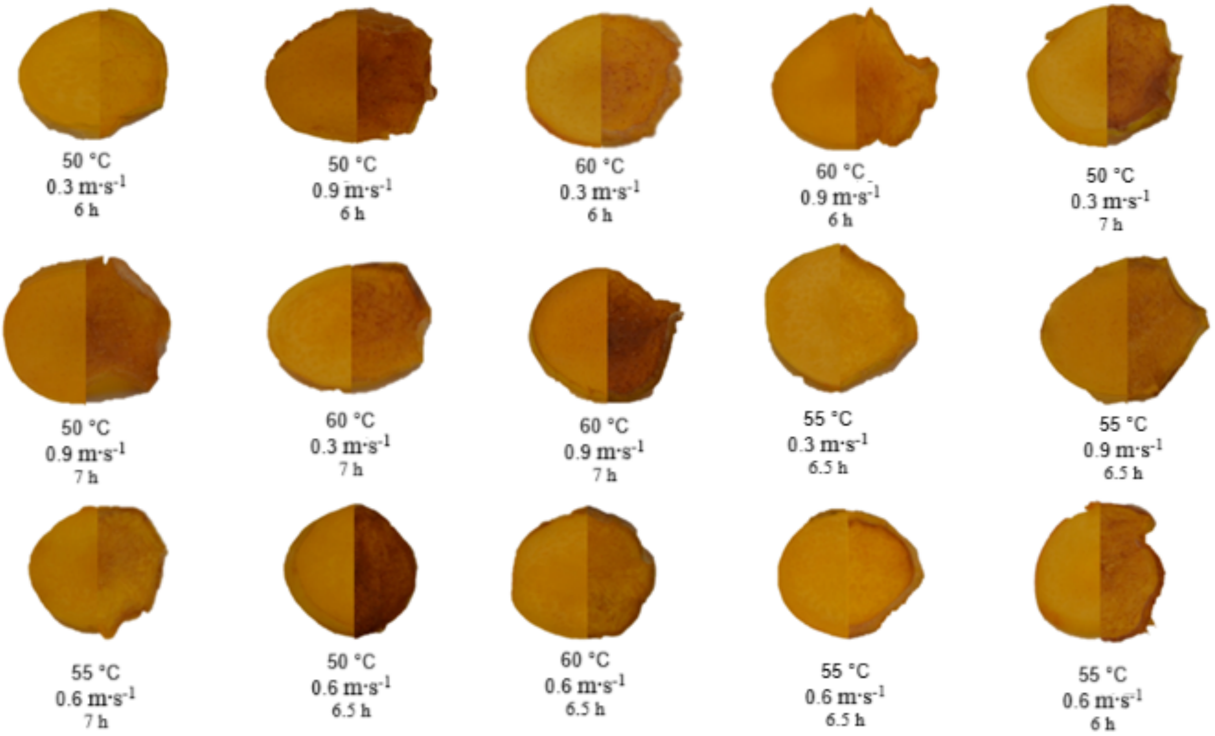

Fig. 5 Comparison of peach slices before (left) and after (right) drying process.

The behavior of color presents a tendency to red in every case; this is because when the peaches are exposed to high temperatures, an augment to red exists. However, the yellowness also increased when the temperature increased, but the red color caused a visible difference (Krokida *et al*. 1998). For example, Polat *et al*. (2021) reported low color difference values (18) on peach puree with a higher microwave on air temperature, while in convective drying, the values were up to 20 units. On the other hand, Roknul Azam *et al*. (2019) reported high color difference in peach by using microwave-assisted hot air drying (26.64), hot air-assisted radio frequency drying (22.10), hot air drying (17.38), and infrared drying (16.46). Their results showed that the drying time affected the color difference.

Figure 5 shows the color difference from the drying process's beginning and end. The left side presents the initial condition of the slices and the right side the final condition of the peach slices. The comparison has been analyzed in the same sample to the objective to obtain a real comparative.

Conclusions

The differences in the physicochemical parameters are essential for the final quality of the product and the customer's acceptance; comparing different drying conditions provides information that can offer better-quality dried products. In the experimental conditions tested, Midilli and Kucuk model describes the drying kinetics in all tested conditions. Moisture removal was higher at higher temperatures, and moisture content decreased faster when airflow increased. At 60 °C, the drying time is regardless of the airflow. The results show that the highest air velocity gave a similar drying time for all temperatures evaluated, while the temperature influenced the drying time for the lowest velocity. The water activity was reduced in a range of 0.351- 0.452 which ensures the microbiological stability of the food. Lightness, Chroma, and browning augment as the airflow and the drying temperature rise in all cases. Total soluble solids at high temperatures show high quantities even in different conditions, improving their quality in appearance. In addition, a higher temperature and drying time promote a higher amount of total soluble solids in the samples. Most of the parameters above got better results with 0.6 $m \cdot s^{-1}$ of airflow, 55° C and 6.5 h. These results can help dry peach producers ensure stability and color quality. Since the first contact between the consumer and a food product is through sight, color is one of the most important sensory characteristics, so this type of study may be of interest to food producers seeking to preserve these physicochemical attributes of quality.

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