Effect of rotating tray drying on antioxidant components, color and rehydration ratio of tomato saladette slices

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ABSTRACT

A rotating tray drier was built and controlled for drying of tomato slices at different temperatures (45, 50 and 60 °C) and air velocities (0.6 and 1.2 m s⁻¹) with and without tray rotation. Drying curves were fitted using the Page mathematical model. Effective diffusivities for the different drying conditions correlated well with the chemical composition variables; lycopene, ascorbic acid and total polyphenols (TPP). The effect of drying conditions over quality of dried tomato slices was evaluated by quantifying their contents of lycopene, ascorbic acid and TPP, and measuring their color and rehydration ratio. The best drying conditions were 60 °C drying temperature and 0.6 m s⁻¹ air velocity with the use of tray rotation. These conditions minimized the degradation of lycopene (2.9%), ascorbic acid (17.3%) and TPP (2.1%) during drying. Tray rotation has a contribution on the α* color value, as well as on the lycopene and ascorbic acid concentrations (5% significance level).

1. Introduction

In recent years, tomato products have gained importance due to their antioxidant activity. Tomato is not only a source of antioxidant nutrients like vitamins A, C and E, but also contains a large amount of non-nutritive antioxidants including lycopene and polyphenolic compounds (Chang, Lin, Chang, & Liu, 2006). Tomato products are the main source of lycopene in the human diet. Studies have shown that lycopene protects against prostate cancer, breast cancer, atherosclerosis, reduces the oxidation of high density lipoprotein and helps reduce cholesterol levels in blood (Kerkhofs, Lister, & Savage, 2005; Xianquan, Shi, Kakuda, & Yueming, 2005).

The demand for a wide range of processed tomato products has increased remarkably both in the retail and the food-ingredient markets (Verlent, Hendrickx, Rovere, Moldenaers, & Van Loey, 2006). Among the processing methods for tomato preservation, drying is one of the most convenient since product water content is greatly lowered thus preventing microbial spoilage (Fellows, 2009, chap. 16). In addition, final product weight and volume are considerably reduced after dehydration, which may account for important savings in transport and storage costs (Doymaz, 2007).

Lycopene, ascorbic acid and total polyphenols content in tomato can be considered as good quality indicators of the drying process. During tomato thermal processing, these components are modified, thus affecting the color, sensorial, nutritional and functional quality of the dried product. Therefore, it is of paramount importance to minimize the losses of these compounds during tomato dehydration.

Lycopene constitutes approximately 83% of tomato pigments (Shi, Le Maguer, Kakuda, Liptay, & Niekamp, 1999), so its degradation during thermal processing may have an important effect on the color of the final product as well as on its nutritional and functional value. Lee and Chen (2002) reported that heating at 50 °C for 12 h did not affect lycopene concentration, whereas heating at 100 °C for 120 min caused a 78% reduction in lycopene. Marfil, Santos, and Telis (2008) studied the degradation kinetics of ascorbic acid in seedless tomato halves during dehydration at 50, 60 and 70 °C. The authors reported a rapid degradation rate of ascorbic acid which was dependant on the drying temperature with no significant ascorbic acid degradation in the first hour. In this study, it was concluded that maintaining temperatures below 60 °C can help to reduce ascorbic acid degradation during tomato dehydration.

Polyphenolic compounds, such as flavonoids and phenolic acids are a large group of secondary metabolites which are important in the human diet due to their potential health functionality (Chang et al., 2006). Fresh tomato possesses a significant amount of phenolic compounds; however, when subjected to thermal...
2. Materials and methods

2.1. Rotating tray dryer

A rotating tray dryer was designed and built at the Universidad Tecnológica de la Mixteca (Fig. 1). The operational characteristics of this equipment are: a) temperature between 20 and 60 °C, b) air velocity from 0 to 1.2 m s⁻¹, and c) the optional use of tray rotation.

In the present study, tomato slices, pre-treated with sodium metabisulfite, were dried at various temperatures and air velocity settings, with and without tray rotation. Color, rehydration ratio, lycopene, ascorbic acid and total polyphenols content were determined and treated as indicators of product quality. Experimental drying data were obtained during the falling period using Page mathematical model to predict drying curves (Sacilik, Keskin, & Elicin, 2006). Finally, this study assesses the contribution of tray rotation to the drying process. The correlation of the drying operational variables with tomato quality parameters was used to obtain an optimal final product in terms of its physical and chemical characteristics. This paper aims to contribute to the better knowledge of the tomato dehydration process using a rotating tray dryer.

2.2. Selection and preparation of tomato fruits

Saladette tomato (Lycopersicon esculentum) fruits were obtained from a greenhouse located in La Luz Nagore, Oaxaca, México. Tomatoes were selected based on color and size. Fruits were selected according to the USDA (1997) color scale with at least a 90% red surface. Only unbruised tomatoes with a similar mass (180–210 g) were used. Tomatoes were washed and cut into 6 mm-thick slices using a domestic manual slicer. Seeds were manually removed to prevent high variability in the dried product weight measurements.

2.3. Moisture determination

Moisture determination was performed in a Sartorius MA 45 thermobalance at 100 °C using seedless tomato slices with approximate weights of 5.0 ± 0.1 g.

2.4. Tomato dehydration and drying curves

Seedless tomato slices were immersed in a 10 g L⁻¹ sodium metabisulfite solution for 10 min at room temperature. Elsewhere, this salt was added both to prevent degradation of antioxidant components present in tomato and carrot slices as well as to increase water diffusion from the interior of the food to its surface (Latapi & Barret, 2006; Sra, Sandhu, & Ahluwalia, 2011).

The solution was then drained for 2 min. Drying of tomato slices was performed at 45, 50 or 60 °C, using air velocities of 0.6 or 1.2 m s⁻¹, with and without tray rotation at 20 rpm. Six slices were placed uniformly in each tray with a single layer arrangement. Drying curves were obtained by measuring the moisture loss of tomato slices with time. For tray rotation drying, samples were collected from two previously marked trays which were located opposite to each other. In the case of non rotational drying, tomato slices were sampled both from the top and from the bottom trays of the drying chamber. The samples were weighed in an analytical balance every 15 min and averaged. The drying was continued until a final moisture content of 10 ± 1 g per 100 g fresh tomato was reached. Drying curves were performed in triplicate. A representative drying curve plot is depicted in Fig. 2. Dried tomato slices...
were stored at –20 °C and protected from light for further determinations of lycopene, ascorbic acid, total phenols, color and rehydration ratio.

2.4.1. Mathematical modeling of drying curves

The Page mathematical model was used to describe tomato drying behavior (Sacilik et al., 2006):

$$MR = \exp(-kt^n)$$

where MR is the moisture removal parameter defined by the ratio of the moisture content at time $t$ ($M_t$) over the initial moisture content ($M_0$), $M_t/M_0$ (Sacilik et al., 2006). The $k$ and $n$ constants were obtained using InterReg software based on a Levenberg–Marquardt nonlinear regression method. Additionally, $R^2$ and $\chi^2$ values were obtained to determine the degree of correlation between the experimental and the calculated data.

2.4.2. Estimation of the effective diffusivity ($D_{eff}$)

For unsteady-state diffusion, Crank’s equation (Crank, 1979, chap. 4) can be used to obtain $D_{eff}$ values using falling-rate period data and assuming a uniform initial moisture distribution, Equation (2). This equation follows a linear curve with the slope containing the $D_{eff}$ parameter. $D_{eff}$ values were calculated for the different drying conditions.

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

2.5. Quantitation of chemical constituents

In this manuscript the concentration of each tomato chemical constituent is reported as milligrams per 100 g dry matter (DM).

2.5.1. Lycopene assay

Lycopene was extracted following the method developed by Fish, Perkins-Veazie, and Collins (2002). A 0.50 ± 0.01 g of tomato was ground in a mortar together with 1 mL of distilled water. Tomato pastes were transferred to light-protected glass tubes with the addition of 5 mL of a 0.5 g L$^{-1}$ butylated hydroxytoluene (BHT) solution in acetone; subsequently, 5 mL of 95% (v/v) aqueous ethanol and 10 mL of hexane were added. For lycopene extraction, the tubes were vortexed for 10 min. A supernatant aliquot (3.5 mL) was pipetted out and transferred to a quartz spectrophotometric cell. Absorbance was measured at 503 nm in a Perkin–Elsmer Lambda 35 UV/Vis spectrophotometer. The following equation was used to determine the amount of lycopene in tomato samples (Fish et al., 2002):

$$\text{Lycopene} = \frac{mg}{100 \text{ g sample}} = \frac{A_{503} \times 312}{g \text{ sample}}$$

2.5.2. Ascorbic acid assay

Sample extracts were prepared by maceration of 0.50 ± 0.01 g of tomato together with 25 mL of a 10 g L$^{-1}$ metaphosphoric acid solution. The mixture was then transferred to an amber bottle and stirred for 2 h; then, it was filtered through cotton wool. The content of ascorbic acid in 0.5 mL extract was quantified using the method of the reduction of 2,6-dichloroindophenol sodium salt (DCIP) (Julían-Loaeza, Santos-Sánchez, Valadez-Blanco, Sánchez-Guzmán, & Salas-Coronado, 2011).

2.5.3. Total polyphenols (TPP) assay

A mixture of 0.050 ± 0.002 g of dried tomato was extracted with 1 mL of methanol and vortexed for 30 min, after which the extract was filtered through cotton wool. The concentration of total polyphenols in the extracts was quantified using the Folin–Ciocalteu reagent method adapted for a BioTek ELx808 microplate reader equipment. A reaction mixture was prepared with 60 μL of extract, 720 μL of deionized water and 60 μL of the Folin–Ciocalteu reagent. This mixture was vortexed for 6 min at medium speed, followed by the addition of 600 μL of a 70 g L$^{-1}$ Na$_2$CO$_3$ aqueous solution. After the reaction was started, nitrogen was injected to displace oxygen and the mixture was vortexed for 5 min. When the reaction was completed, a 120 μL aliquot of the mixture was pipetted into a microplate well and incubated for 30 min at 40 °C. Subsequently, the absorbance was read using a 630 nm filter. Standards and samples were sheltered from light during the assays. TPP contents in the tomato samples were determined with a gallic acid calibration curve, and expressed as milligrams of gallic acid equivalents (GAE) per 100 g DM.

2.6. Color quantification

Color of tomato samples was determined with a HunterLab spectrophotometer (Ultra Scan Vis) using a D65 illuminant, a 10° viewing angle and a 0.9525 cm observation diameter. CIELAB color values ($L^*, a^*, b^*$) were measured at 10 different points and the average was calculated for each sample. An average of three tomato samples was considered for further data analyses.

2.7. Rehydration ratio

Dried tomato slices were weighed ($W_0$) and immersed for 50 min in distilled water (100 mL of water per gram of dried tomato) at room temperature. Following this, the water was drained during 2 min and the slices were weighed again ($W_1$) (Lewicki & Michaluk, 2004). The rehydration ratio was calculated as the ratio of the weight of gained water ($W_1 - W_0$) over the initial sample weight ($W_0$), Equation (4).

$$\text{Rehydration ratio} = \frac{W_1 - W_0}{W_0}$$

2.8. Statistical analysis

An ANOVA study was performed using Design Expert™ Version 6.0.10 software to determine the contribution of the independent variables (temperature, air velocity and rotation of trays) on both the tomato drying process and the quality of the final product using a significance level of 5%. Standard and sample measurements were performed in triplicate. In addition, Duncan’s multiple range method was used for comparison of means, considering a confidence level of 95% ($p < 0.05$). Linear correlations were performed to assess the relationships between variables following Pearson’s method.

3. Results and discussion

3.1. Drying times

The initial moisture content of tomato slices was 92.6 ± 0.4 g per 100 g fresh tomato. Drying processes were halted when a final moisture content of 10 ± 1 g per 100 g fresh tomato was reached. Total drying times were as follows: 345–390 min at 45 °C; 285–315 min at 50 °C; and 210–255 min at 60 °C.

Drying time decreased when air velocity was increased from 0.6 to 1.2 m s$^{-1}$. At higher air velocities the rate of water evaporation.
from the food increases thus causing a reduction in drying time (Foust, Wenzel, Clump, Maus, & Andersen, 1980, chap. 18). An ANOVA experimental design was performed to study the effect of the operating variables on the drying time. Temperature has the most important effect on drying time (88.47%), followed by tray rotation, which had a 6.4% contribution to the drying time. This contribution was higher than the corresponding contribution of air velocity (4.6%). Great variations in moisture content were observed for the top and the bottom samples for the non rotational experiments, which was possibly due to an uneven temperature distribution in the drying chamber. The tray rotation effect can be evidenced by following the drying curves for the top and the bottom samples in a non rotational drying run (Fig. 3). Under these conditions, temperature gradients of ±2.0 °C were measured within the drying chamber. In contrast, ±0.2 °C temperature gradients were registered during tray rotation drying. Therefore, it can be concluded that tray rotation drastically reduced the oven temperature gradients thus allowing a homogeneous and faster drying.

### 3.2. Mathematical modeling of drying curves

Table 1 lists the estimated Page model parameters ($k_p$ and $n$) as a function of the drying conditions, where $k_p$ is the Page drying rate constant. Individually, temperature had the highest contribution (83.2%) and air velocity had a low contribution (2.6%) on the drying rate constant, $k_p$. On the other hand tray rotation did not have a significant contribution over this $k_p$. In contrast, the effect of the three combined variables accounted for 12.8% contribution to the $k_p$. These results agree with other reports in the literature; Khattab (1997) reported that the $k_p$ constant was not only a function of temperature, humidity and air velocity, but also of the space coordinates which in our study were varied by means of the tray rotation parameter.

### 3.3. Drying rate

Since a falling-rate period dominates through the drying processes, the effective diffusivity ($D_{eff}$) during this period was determined. $D_{eff}$ is a parameter related to the internal mass transfer mechanisms during the falling-rate drying period; thus it can be used as an indicator of water molecular diffusion from the core of the tomato slice to its surface. The experimental values of $D_{eff}$ ranged from $1.35 \times 10^{-9}$ to $2.42 \times 10^{-8}$ m$^2$ s$^{-1}$ Khazaei, Chegini, and Bakhshtian (2008) obtained a $D_{eff}$ of $5.4 \times 10^{-10}$ m$^2$ s$^{-1}$ for the drying of 7 mm-thick tomato slices at 60 °C. Sacilik et al. (2006) reported $D_{eff}$ data for tomato halves dehydration which varied from $1.31 \times 10^{-9}$ to $1.07 \times 10^{-9}$ m$^2$ s$^{-1}$. The $D_{eff}$ values obtained in the present work are of the same magnitude to those obtained by Sacilik et al. (2006) and relatively high compared to the values reported by Khazaei et al. (2008). Considering the fact that high $D_{eff}$ values were obtained in studies that used salt pretreatments, Deymaz and Ismail (2011), the salt osmotic effect may be the cause for improved diffusive transport during drying.

The results indicate that temperature has the greatest contribution to the $D_{eff}$ parameter followed by tray rotation, with air velocity having the lowest effect on $D_{eff}$. The greatest tray rotation contribution to $D_{eff}$ (19.3%) was observed in the experiment performed at 60 °C and 0.6 m s$^{-1}$ air velocity, where the maximum $D_{eff}$ was obtained.

### 3.4. Color

Color is one of the most important quality parameters of tomato products. Changes in tomato color for different dehydration conditions were measured and used as indicators of product quality and process performance. Darkening intensity can be quantified using the CIELAB $L^*$ color parameter. Shi et al. (1999) observed severe tomato darkening (33.3%) occurring after a 90 °C drying process. Kerksfohs et al. (2005) reported a 26.7% darkening for tomato drying at 42 °C and 1.5 m s$^{-1}$. On the other hand, in our study, a maximum darkening (9.7%) was obtained for the drying process at 50 °C, 1.2 m s$^{-1}$ with no use of tray rotation (Table 2). Thus, only mild tomato darkening occurred during the experiments performed in this study.

An analysis of variance was performed to assess the effect of the operating variables on the CIELAB color values. Statistical analysis showed that tray rotation had no influence on the $L^*$ and $b^*$ parameters, but it had a 7.0% contribution to the $a^*$ value. In addition, the combined effect of tray rotation and air velocity contributed with 12.7% to the $a^*$ parameter (Table 3). Calculated $a^*/b^*$ values (Table 3) were similar to those reported by Shi et al. (1999) for vacuum drying at 55 °C and slightly superior to those reported for conventional drying at 90 °C.

### 3.5. Lycopene

Lycopene content in fresh and dried tomato slices was measured for different drying conditions. Average lycopene concentration in fresh tomato was $34.9 \pm 0.2$ mg per 100 g DM, while dried tomato concentrations ranged from $25.0 \pm 2.0$ to $33.9 \pm 0.7$ mg per 100 g DM (Table 4). The highest loss of lycopene (26.4%, average) occurred

![Fig. 3. Drying curves for two different sample locations in the drying chamber at 50 °C, 1.2 m s$^{-1}$ for non rotational drying (—— top; ——— bottom).](image-url)
in the drying experiments conducted at 50 °C without tray rotation (Table 4).

Zanoni, Peri, Nani, and Lavelli (1998) reported 12% lycopene loss in tomato dried at 110 °C. Statistical analysis indicated that temperature made the most important contribution to lycopene content variation (62.2%) followed by tray rotation (23.1%) (Table 3). When no tray rotation was used, drying strongly depended on the location of the sample in the drying chamber due to the oven temperature gradients. Duncan’s multiple intervals test on the data revealed that lycopene degradation was reduced by the effect of tray rotation in the 50 °C runs (independently of air velocity) and in the 45 and 60 °C runs at 0.6 m s⁻¹ air velocity.

3.6. Ascorbic acid

Ascorbic acid was determined in fresh and dried tomato slices for different drying conditions. The average content of this compound was 360.7 ± 1.1 mg per 100 g DM and ranged from 198.6 ± 1.7 to 298.9 ± 2.3 mg per 100 g DM (Table 4).

A maximum ascorbic acid loss of 45.2% was detected in the samples dried at 45 °C, 1.2 m s⁻¹ with tray rotation (Table 4). Kerkhofs et al. (2005) reported a reduction in the ascorbic acid content of up to 75% for tomato halves drying at 60 °C and 1.5 m s⁻¹. Zanoni et al. (2000) determined no ascorbic acid present after 160 min of tomato drying at 110 °C. Although temperature has the greatest effect on ascorbic acid content; long drying times also promote an ascorbic acid reduction, even at low temperatures such as those used in the present work (Table 4).

A Pearson correlation was used to assess drying time contribution on ascorbic acid content. An inverse correlation of −0.82 was found, which indicates that ascorbic acid degradation increases with drying time. Temperature had the largest contribution (72.0%) on the ascorbic acid content, followed by air velocity (21.1%) and tray rotation (2.5%) (Table 3). Duncan test results indicate that tray rotation had an effect on the ascorbic acid content at 45 °C and 50 °C; while at 60 °C, tray rotation was significant only at 0.6 m s⁻¹ air velocity (Table 4).

3.7. Total polyphenols (TPP)

The average TPP content in fresh tomatoes was relatively high, 6998.6 ± 14.9 mg per 100 g DM, compared with the content in other fruits such as plums, strawberries and grapefruits (Chun et al., 2005). Kerkhofs et al. (2005) reported similar TPP concentrations (682.1 ± 9.3 to 568.2 ± 21.7 mg per 100 g DM) in three New Zealand varieties. The TPP contents in dried tomato slices varied from 548.5 ± 11.3 to 685.1 ± 6.2 mg per 100 g DM (Table 4). The largest TPP degradation occurred at 45 °C, 1.2 m s⁻¹ without tray rotation (21.6%), whereas very low degradation (2.1%) occurred at 60 °C, 0.6 m s⁻¹ and the use of tray rotation (Table 4).

Kerkhofs et al. (2005) reported a 33.4% TPP loss during the drying of a flavouring tomato variety. On the other hand, no TPP losses during drying have been reported elsewhere (Chang et al., 2006; Dewanto, Wu, Adom, & Liu, 2002). During a tomato thermal process, the concentration of some simple phenols such as chlorogenic acid, caffeic acid and p-coumaric acid may increase, while more complex phenols such as ferulic acid, rutin and naringenin can be reduced (Re et al., 2002), thus resulting in a no measurable TPP degradation.

An ANOVA analysis showed that both temperature and air velocity had an important contribution on TPP content (Table 3). In addition, a Duncan test indicated that tray rotation had no contribution on TPP content (Table 4).

3.8. Rehydration ratio

Dried tomato rehydration was evaluated at different times ranging from 20 to 1440 min. A maximum rehydration ratio (4.8 ± 0.6 g H₂O per kg DM) was obtained for the experiment performed at 60 °C and 0.6 m s⁻¹. The rehydration ratio values

---

Table 2

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Air velocity (m s⁻¹)</th>
<th>Tray rotation (rpm)</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>a*[b*]</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>0.6</td>
<td>0</td>
<td>34.01 ± 0.60b</td>
<td>28.04 ± 1.12a</td>
<td>19.68 ± 0.36a</td>
<td>1.42 ± 0.06a</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>20</td>
<td>35.59 ± 1.12b</td>
<td>27.93 ± 1.13a</td>
<td>19.41 ± 0.87a</td>
<td>1.44 ± 0.09a</td>
</tr>
<tr>
<td>50</td>
<td>0.6</td>
<td>20</td>
<td>37.15 ± 0.38b</td>
<td>27.94 ± 1.15a</td>
<td>21.09 ± 0.85b</td>
<td>1.32 ± 0.08b</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>20</td>
<td>35.56 ± 0.46b</td>
<td>28.08 ± 0.43b</td>
<td>21.85 ± 1.00c</td>
<td>1.29 ± 0.06b</td>
</tr>
<tr>
<td>60</td>
<td>0.6</td>
<td>20</td>
<td>33.89 ± 1.05b</td>
<td>27.57 ± 0.99a</td>
<td>18.70 ± 0.78b</td>
<td>1.47 ± 0.08b</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>20</td>
<td>33.77 ± 1.08b</td>
<td>27.87 ± 0.37a</td>
<td>17.59 ± 0.35c</td>
<td>1.58 ± 0.04c</td>
</tr>
</tbody>
</table>

Fresh tomato CIELAB values: L* = 37.52, a* = 18.18, b* = 15.37. Data are expressed as mean of ten measurements of triplicate tests ± standard deviation. Means with different letters indicate significant differences (α = 0.05) at a given temperature and in the same column according to the method of Duncan’s multiples ranges.

Table 3

<table>
<thead>
<tr>
<th>Source</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>Lycopene</th>
<th>Ascorbic acid</th>
<th>Total polyphenols</th>
<th>Rehydration ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Temperature</td>
<td>55.3</td>
<td>54.0</td>
<td>38.7</td>
<td>62.2</td>
<td>72.0</td>
<td>50.6</td>
<td>59.0</td>
</tr>
<tr>
<td>B. Air velocity</td>
<td>0.9</td>
<td>8.7</td>
<td>1.5</td>
<td>0.1</td>
<td>21.1</td>
<td>34.2</td>
<td>30.8</td>
</tr>
<tr>
<td>C. Tray rotation</td>
<td>4.5</td>
<td>7.0</td>
<td>15.5</td>
<td>23.1</td>
<td>2.5</td>
<td>1.2</td>
<td>5.1</td>
</tr>
<tr>
<td>AB</td>
<td>18.5</td>
<td>9.7</td>
<td>36.1</td>
<td>6.2</td>
<td>2.9</td>
<td>1.1</td>
<td>3.4</td>
</tr>
<tr>
<td>AC</td>
<td>1.6</td>
<td>4.6</td>
<td>6.7</td>
<td>2.7</td>
<td>0.8</td>
<td>= 0.0</td>
<td>0.9</td>
</tr>
<tr>
<td>BC</td>
<td>0.5</td>
<td>12.7</td>
<td>0.1</td>
<td>5.8</td>
<td>= 0.0</td>
<td>= 0.0</td>
<td>0.6</td>
</tr>
<tr>
<td>ABC</td>
<td>18.7</td>
<td>3.8</td>
<td>1.4</td>
<td>4.0</td>
<td>0.8</td>
<td>0.2</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 2 CIELAB color values of dried tomato.

Table 3 Contribution effect (%) of the drying conditions on the color and chemical composition parameters.
3.9. Global correlations

ANOVA analyses were used to correlate the different parameters used in this work. In particular, the chemical composition variables were correlated with the CIELAB color and rehydration ratio parameters (Table 5). The darkening parameter, \( L^* \), had a poor correlation to the chemical composition data. Similarly, a poor correlation was observed between \( b^* \) and \( a^* / b^* \) values with the chemical composition variables. On the other hand a very high degree of relatedness was found between the \( a^* \) color value with both lycopene and ascorbic acid content (Table 5). The latter correlation can be explained considering that ascorbic acid is more reactive than lycopene, thus protecting lycopene from degradation (Nishino et al., 2011). Therefore, ascorbic acid oxidation during drying may be proportionally associated to an increase in lycopene degradation. This is the first time that ascorbic acid has been related with a CIELAB color parameter during tomato thermal processing. Lastly, \( k_p \) and \( D_{eff} \) had a good correlation with the chemical composition variables due to the strong dependence of drying on time and temperature.

4. Conclusions

The use of tray rotating dryer for tomato drying significantly improved the overall drying performance by influencing both drying rate and product quality. This was due to the fact that the use of tray rotation drastically reduced temperature variation within the drying chamber from 2 to 0.2 °C. Tray rotation had an important contribution on the variability of the tomato quality indicators used in this work: lycopene content (23.1%), ascorbic acid content (2.5%) and the \( a^* \) color value (7%). For example, ascorbic acid was better preserved at temperatures of 45 and 50 °C with the use of tray rotation. On the other hand, total polyphenols content was primarily affected by air velocity, whereas rehydration rate was not dependent on any of the operating conditions. In general, the contribution of the process variables to drying time was as follows: temperature > tray rotation > air velocity. The Page model resulted in a good fit to the experimental data. \( D_{eff} \) had a good positive correlation with the chemical composition variables (0.82–0.85). This implies that the increase in the water diffusion rate from the interior of the tomato slice reduced the degradation of lycopene, ascorbic acid and total polyphenols. This paper reports for the first time, the high correlation between the \( a^* \) CIELAB color value and both lycopene (0.90) and ascorbic acid (0.91) during tomato thermal treatments. Therefore, color determination, in addition to lycopene and ascorbic acid content, can be used as excellent tomato quality indicators in drying processes.

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