Drying Kinetics of Tomato Slices in Solar Cabinet Dryer Compared with Open Sun Drying

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Drying performance of a solar cabinet dryer newly developed to dry tomato slices was compared with open sun drying under the climatic conditions of Montreal, Canada. The tomato slices of 4, 6 and 8 mm thicknesses was dried from 94% to 11.5% wet basis moisture content, respectively in 300, 420 and 570 minutes in solar cabinet but it took 435, 615 and 735 minutes in open sun drying. Four thin layer drying models were used to optimize the ‘goodness of fit’. The models were compared using coefficient of determination, chi-square and root mean square error. The page model was found to fit the experimental data better as compared to other models. The moisture diffusivity of tomato slices ranged from 4.25 to 7.67 x 10^{-7} m^{2}/s in solar cabinet drying and from 3.09 to 9.28 x 10^{-9} m^{2}/s in open sun drying. Influence of air temperature, relative humidity, solar insolation and wind velocity on drying kinetics of tomato slices was discussed. Analyses on colour, water activity, rehydration ratio and ascorbic acid were also reported.

Key words: Solar drier, tomato, drying kinetics

Tomato (Lycopersicon esculentum L. var) is one of the most widely used and versatile vegetable crops. It is highly seasonal and available in large quantities at a particular season of the year in most of the tropical countries. Due to market glut during peak season large quantity of tomato gets spoiled. Processing, preservation and storage of tomato during peak season can prevent the huge post harvest losses in tomato and make them available in the off season at comparatively lesser cost. Tomato and tomato products are rich in health valued food components such as carotenoids (Lycopene), ascorbic acid (Vitamin C), vitamin E, folate and dietary fiber (Davies and Hobson, 1981).

Dehydration processes offer an alternative way of using tomato for consumption and the dehydration of tomato has been practiced for many years as a means of preservation. Dried tomato in the form of slice or powder helps to develop new food materials for ready to eat products. Recently, there is a great demand for natural sun / solar dried organic or bio-cultivated tomato in the international markets. Fresh tomatoes are dried as halves, quarters, slices and powdered for making different products. Though different mechanical drying methods are available, they are expensive and many of them lead to poorer quality final product.

Among all the drying methods, sun drying is a well known method for drying agricultural commodities immediately after harvest especially in developing countries. However, sun drying is plagued with in-built problems since the product during drying is unprotected from rain, storm, windborne dirt, dust, and infestation by insects, rodents, and other animals. This may result in physical and structural changes in the product such as shrinkage, case hardening, loss of volatiles and nutrient components and lower water reabsorption during rehydration. Therefore, the quality of sun dried product is degraded and sometimes become not suitable for human consumption. Further the required drying time is too long in sun drying.

Mechanical drying is an energy consuming process in the post harvest processing of food products; hence more importance is given now-a-days to use solar energy. Solar energy is considered as an important alternative source of energy because of its abundant, inexhaustible and non-pollutant in nature compared with higher prices and shortage of fossil fuels (Basunia and Abe, 2001). Solar dryers are now becoming increasingly popular due to the fact that they dry products rapidly, uniformly, hygienically, the traits inevitable for industrial food drying processes (Diamente and Munro, 1993; Condori et al., 2001). Different solar dryers like direct, indirect and natural convection for tomato have been
reviewed by Ekechukwa and Norton (1998) and Farkas (2004). Although for commercial production of agricultural products, forced convection solar dryer provides a better control of drying air, they require additional energy for drying operation. Hence, natural convection solar dryer is highly preferred for drying food products especially when in thin layers.

The drying phenomena can be described using thin layer drying models mainly to estimate the drying times and moisture content of the food materials at any time after they are subjected to a known temperature and relative humidity (Torgul and Pehlivan, 2004). Many research studies have been reported on mathematical modelling and experimental studies conducted on thin layer drying process of various food products such as onion and pepper (Kiranoüdis, 1992), chilli (Hussain and Bala, 2002), carrot (Doymaz, 2004) and tomato (Sacilik et al., 2006). In modelling, generally, the investigators have reported the best model that fit the experimental data. However, little information is available on solar drying of tomato slices under Canadian climatic conditions. Therefore, a research study was undertaken to fabricate and evaluate a solar cabinet dryer for drying sliced tomatoes and compare its performance in terms of product quality vis a vis open sun drying in relation to weather parameters such as ambient air temperature, relative humidity, wind velocity and solar insolation. Also, it was desired to study the drying kinetics of tomato slices of different thicknesses using thin layer drying models.

Materials and Methods

Fresh Olympian Gold (#4799) green house grown, herbicide and insecticide free tomatoes of Canada were procured from local market and stored in a refrigerator maintained at 4°C until the drying experiments. Before the start of the experiment, tomatoes (size 65-75 g) were allowed to equilibrate with room temperature (20 ± 1°C) for one hour. The tomatoes were washed with potable water and sliced into circular discs of 4, 6 and 8 mm thicknesses using a hand operated adjustable mechanical slicer. The sliced tomatoes were dried using both Solar Cabinet Dryer (SCD) and open sun drying methods.

Drying in Solar Cabinet Dryer

The schematic diagram of solar cabinet dryer (Fig.1) is developed at the Department of Bioresource Engineering, McGill University, Canada. The dryer has a drying chamber, converged with an angle of inclination of 25° towards centre. At the converged section, a channel was fitted to drain the condensate collected from the inner sloping surface of drying chamber. Two chimneys of each 3.5 cm diameter and 50 cm height were fixed at both the sides for natural convection of air during drying. 100 g of sliced tomatoes were spread on a black surface coated tray and the samples were kept in the drying chamber of the solar cabinet dryer. The drying tray rested on a digital electronic balance with an accuracy of ± 0.01 g. Provisions were made to record the reduction of mass, product temperature, air temperature and relative humidity inside the drying chamber using a data logger (Agilent 34970A, USA) connected to a personnel computer (PC). Experiments were carried out between 9.00 and 17.00 h on bright sunny days.

Open Sun Drying

Sun drying experiments were carried out simultaneously with the SCD experiments between 9:00 and 17:00 h. Tomato slices in a single layer was kept in a black painted tray, which was placed on a digital electronic weighing platform of ± 0.01g accuracy. Using appropriate sensors, the data on the reduction in product mass, product temperature, ambient air temperature, relative humidity, wind velocity and solar insolation were recorded in the computer using a data logger (Agilent 34970A, USA).

Figure 1. Schematic view of solar cabinet and open drying setup
**Moisture Content**

The moisture content of the tomato samples was determined by using vacuum oven at 70°C for 24 h (AOAC, 1980). Triplicate samples were used for the determination of moisture content and the average values were reported.

**Equilibrium Moisture Content**

The equilibrium moisture content of the dried tomato samples was determined by drying at 60°C in a batch type cabinet dryer until it reached the constant mass (Prabhanjan, et al., 1995). The moisture at this condition was reported as the equilibrium moisture content of dried tomatoes.

**Mathematical Modeling**

The moisture ratio of tomato slices dried under solar cabinet dryer and by open sun drying at a given time, t was calculated using a relationship:

\[
\text{Moisture Ratio (MR)} = \frac{M_t - M_e}{M_i - M_e} = e^{-kt}
\]

**Effective Moisture Diffusivities**

Fick’s equation is widely used for explaining drying mechanism of solid food material involving diffusion of vapour (Sankat and Castaigne, 2004). When a material dries mainly in the falling rate period, then it could be assumed that the internal moisture diffusion occurs. Therefore, moisture diffusivity in tomato slices can be calculated from the experimental drying data using Fick’s second law for a slab shaped material. The solution to this equation developed by Crank (1975) can be applied for tomato slices of different thicknesses by assuming uniform initial moisture distribution as:

\[
\frac{M_{i}}{M_{e}} = 1 - \sum_{n=0}^{\infty} \left( \frac{8}{(2n+1)^{2}} \right)^{1/2} \left( \frac{L}{4D} \right)^{1/2} \sin \frac{(2n+1)\pi \theta}{2L} e^{-\left( \frac{2n+1)^{2} \pi^{2} \theta}{4D} \right)}
\]

Where,

- \(M_{i}\) and \(M_{e}\) are the initial and equilibrium dry basis moisture contents, %
- \(M_{t}\) is dry basis moisture content at any time 't'
- \(k\) is the drying rate constant per minute
- \(t\) is the drying time, min.

Since, the well known thin layer drying models related dimensionless moisture ratio as the dry basis moisture content versus drying time into a dimensionless moisture ratio versus drying time. The experimental moisture ratio versus drying time data were fitted in four thin layer drying models (Table 1) widely used to describe the drying characteristics of most food products and the best model was selected to describe the solar cabinet and open sun drying processes of tomato slices.

The regression analysis was performed using Excel software. The coefficient of determination \(R^2\) was used as primary criteria for selecting the model that best fit the experimental data. In addition to the coefficient of determination, the best fit of the experimental data was also selected based on various statistical parameters such as the reduced chi-square \(X^2\) as the mean square of the deviations between the experimental and predicted values for the models and root mean square error analysis (RMSE). To get the best fit of the experimental data, the coefficient of determination should be higher and the \(X^2\) and RMSE should be lower (Akpinar et al., 2006).

The statistical parameters were calculated by using the following relationships:

\[
R^2 = \frac{\sum_{i=1}^{n} (MR_{i,exp} - MR_{i,pre})^2}{\sum_{i=1}^{n} (MR_{i,exp} - \bar{MR}_{exp})^2}
\]

\[
X^2 = \frac{N - n}{n - 1} \sum_{i=1}^{n} (MR_{i,exp} - MR_{i,pre})^2
\]

\[
\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{n} (MR_{i,exp} - MR_{i,pre})^2}
\]

Where,

- \(MR_{i,exp}\) is the \(i^{th}\) experimentally observed moisture ratio values,
- \(MR_{i,pre}\) is the \(i^{th}\) predicted moisture ratio values,
- \(N\) is the total number of observations, and
- \(n\) is the number of constants in the model.

**Table 1. Thin layer drying models based on moisture ratio**

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Model</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis MR</td>
<td>MR = exp(-kt)</td>
<td>Lewis (1921), Akpinar et al., (2006)</td>
</tr>
<tr>
<td>Wang and Singh MR</td>
<td>MR = 1+ at + btf</td>
<td>Wang and Singh(1978), Sasilik et al. (2006)</td>
</tr>
</tbody>
</table>
The effective moisture diffusivity values were determined by plotting experimental drying data in terms of \( \ln \frac{M - M_f}{M_i - M_f} \) versus drying time \( t \). A plot of \( \ln \frac{M - M_f}{M_i - M_f} \) versus drying time gives a straight line with a slope \( \frac{1}{D_e} \). Knowing the tomato slice thickness and the slope from the above plot, the moisture diffusivity was calculated for different slice thicknesses.

**Rehydration Ratio**

The rehydration ratio of dried tomato slices was determined as the ratio of rehydrated mass to the initial dehydrated mass, which gives a measure of the ability of dried tomato slices to reabsorb water. A sample of 5 g of the dried tomato slices was placed in a 250 ml beaker containing 150 ml of boiling distilled water. The contents were boiled for 5 min to allow the slices to rehydrate. After rehydration, the free surface water on the tomato slice was removed before assessing the rehydrated mass (Prakash et al., 2004). Triplicate measurements were done and the average values are reported here.

\[
\text{Rehydration ratio} = \frac{W_r}{W_d} \quad (7)
\]

Where,

\( W_r \) - rehydrated sample mass, g
\( W_d \) - initial mass of the sample before rehydration, g

**Colour**

The colour of fresh and dried tomato slices was determined in terms of the tristimulus colour values \( L^*, a^* \) and \( b^* \) using Minolta Chromameter, CR-300 (Minolta Co., Japan). Where, \( L^* \) indicates lightness or darkness of the material; \( a^* \) is the colour coordinate in red-green axis +ve value redness, -ve for greenness; \( b^* \) is the colour coordinate in yellow-blue axis, +ve for yellowness and -ve blueness. The colour of the tomato slices was measured after calibrating the instrument with the white standard plate using \( D_{65} \) illumination and 2° standard observer.

**Water activity**

The water activity of fresh and dried tomato slices was measured at room temperature (23.4 ± 1°C) using a water activity meter (Aqua Lab, Model Series 3TE, USA). A mean of three measurements were reported here.

**Ascorbic acid**

Ascorbic acid content in fresh and dried tomatoes was measured by titration method (Ranganna, 1995). One gram of sample was soaked in 4% oxalic acid for ten minutes and it was ground using a pestle and mortar. The contents were filtered and the volume was made up to 100 ml with oxalic acid. Out of this, 10 ml aliquot was titrated against a dye solution containing 42 mg of sodium bicarbonate and 52 mg of 2, 6 dichlorophenol indophenol in 50 ml of water. The ascorbic acid contents in the samples were determined and the results were expressed in mg/100g dry matter.

**Statistical analysis**

All observations were reported as means of three replications. The data pertaining to colour, water activity, rehydration ratio and ascorbic acid content were statistically analyzed to determine the significant difference, if any between dried tomato slices using AGRES software package of Indian Agricultural Statistics Research Institute, New Delhi at 5% significance level. ANOVA under Completely Randomized Design and the mean separation by LSD method was carried out for all the experimental data.

**Results and Discussion**

**Variation in Product Temperature**

During the experimental period of 20 days in August'05, the average daily variations of solar radiation, wind velocity, ambient relative humidity and air temperature ranged from 312 to 795.6 W/m², 0 to 6.5 m/s, 16.0 to 31.9% and 27.7 to 30°C, respectively in Montreal, Canada (Fig.2). When drying 4 mm thick tomato slices, the product temperatures recorded were 42.65 - 63°C in solar cabinet dryer (SCD) and 27.3 - 37.5°C in open sun drying (Fig.3). The maximum temperature and minimum relative humidity recorded inside the drying chamber were 63°C and 5.5% when the corresponding ambient temperature and relative humidity were 30°C and 16%, respectively. For 6 mm thick tomato slices, the maximum product temperatures in SCD and open sun drying were found to be 58.7 and 34.5°C, respectively. It is observed that the maximum product temperature of 8 mm thick tomato L, a and b using Minolta Chromameter, CR-300 (Minolta Co., Japan). Where, L* indicates lightness or darkness of the material; a* is the colour coordinate in red-green axis +ve value redness, -ve for greenness; b* is the colour coordinate in yellow-blue axis, +ve for yellowness and -ve blueness. The colour of the tomato slices was measured after calibrating the instrument with the white standard plate using D_{65} illumination and 2° standard observer.
slices in SCD was 56.6°C and in open sun drying, it was 31.5°C.

From the Figure 3, it is clear that the product temperature inside the solar cabinet drying chamber was significantly higher when compared to the open sun drying. It might be due to two reasons: i) better absorption of solar energy by the product as most of the

Table 2. Estimated parameters and comparison criteria of moisture ratio for solar cabinet drying

<table>
<thead>
<tr>
<th>Model</th>
<th>Model constants</th>
<th>Tomato thickness, mm</th>
<th>$R^2$</th>
<th>$\frac{\d}{2}$</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis</td>
<td>$k = 0.3986$</td>
<td>4</td>
<td>0.877</td>
<td>0.07895</td>
<td>0.26862</td>
</tr>
<tr>
<td></td>
<td>$k = 0.2443$</td>
<td>6</td>
<td>0.844</td>
<td>0.08017</td>
<td>0.27075</td>
</tr>
<tr>
<td></td>
<td>$k = 0.1798$</td>
<td>8</td>
<td>0.808</td>
<td>0.11162</td>
<td>0.32518</td>
</tr>
<tr>
<td>Page</td>
<td>$k = 0.00207$</td>
<td>4</td>
<td>0.985</td>
<td>0.00071</td>
<td>0.02514</td>
</tr>
<tr>
<td></td>
<td>$k = 0.00176$</td>
<td>6</td>
<td>0.987</td>
<td>0.00074</td>
<td>0.02524</td>
</tr>
<tr>
<td></td>
<td>$k = 0.00040$</td>
<td>8</td>
<td>0.983</td>
<td>0.00096</td>
<td>0.02774</td>
</tr>
<tr>
<td>Henderson</td>
<td>$k = 0.5574$</td>
<td>4</td>
<td>0.967</td>
<td>0.10181</td>
<td>0.30182</td>
</tr>
<tr>
<td>and Pabis</td>
<td>$k = 0.3198$</td>
<td>6</td>
<td>0.940</td>
<td>0.16544</td>
<td>0.37657</td>
</tr>
<tr>
<td></td>
<td>$k = 0.2456$</td>
<td>8</td>
<td>0.909</td>
<td>0.58077</td>
<td>0.68162</td>
</tr>
<tr>
<td>Wang and Singh</td>
<td>$a = 0.0051$</td>
<td>4</td>
<td>0.979</td>
<td>0.01219</td>
<td>0.03231</td>
</tr>
<tr>
<td></td>
<td>$b = 7 \times 10^{-6}$</td>
<td>6</td>
<td>0.968</td>
<td>0.06445</td>
<td>0.24038</td>
</tr>
<tr>
<td></td>
<td>$a = 0.0032$</td>
<td>8</td>
<td>0.964</td>
<td>0.11984</td>
<td>0.30964</td>
</tr>
</tbody>
</table>

Generally, the drying temperature, relative humidity and wind velocity varied continuously during the drying period of 9:00 to 17:00 h. It was also observed that the product temperatures were mostly higher than that of ambient air temperature due to the absorption of solar radiation by the tomato slices and it was more pronounced in SCD than in open sun drying. However, the product temperatures were highly influenced by the weather parameters.

Drying characteristics of tomato slices

The change in moisture content of tomato slices with drying time in solar cabinet dryer (SCD) and in open sun drying is depicted in Fig.4. It is observed that the total drying time for 4, 6 and 8 mm thickness slices was 300, 420, 570 min, respectively in SCD while the corresponding values in open sun drying were 435, 615 and 735 min, respectively. For a given thickness, the solar cabinet dryer required shorter drying time when compared to open sun drying. In other words, drying time was reduced to about 68-77% for 4 - 8 mm thickness tomato slices in solar cabinet dryer when compared to open sun drying.

The drying time reduced significantly as per the thickness of slices decreased in both solar and sun drying, because the resistance to moisture movement is relatively higher in thicker slices than in thinner ones. This resistance is known to decrease the drying rate, which resulted in increased drying time of 8 mm thick slices. Generally, it is observed that the time required to reduce the moisture content of tomato slices to any required moisture level was dependent on the drying conditions that are influenced by weather parameters. Similarly, Sacilik et al. (2006) also observed that the drying characteristics of tomato slices in solar tunnel and open sun drying methods were highly influenced by weather parameters.
The newly developed solar cabinet with open sun drying setup and the dried tomato slices are shown in Figs. 5 & 6.

Figure 5. View of solar cabinet and open sun drying setup.

Figure 6. Dried tomato slices

A constant rate drying period was not observed in both the drying methods but only a falling rate drying period, which resulted in shrinkage of the dried samples. The mechanisms of mass transfer in food are complex in nature. However, the main mechanism of moisture movement is assumed to be by diffusion that may have both liquid and vapour diffusion components. Hence, the moisture diffusivity estimated from the experimental results is an effective parameter, which includes the effect of hypothesis with the unknown phenomena. The effective moisture diffusivity values were found to be 4.25 - 7.67 x 10^-7 m^2/s in solar cabinet dried slices and 3.09 - 9.28 x 10^-9 m^2/s in open sun dried tomato slices of 4 to 8 mm thicknesses.

Diffusivity is a function of material characteristics as well as drying temperature. Higher diffusivity values for slices dried in SCD might be due to relatively lesser shrinkage of slices when compared to sun dried slices that were practically observed, better circulation of air due to chimney and perhaps also due to higher temperature and lower RH prevailed in SCD. The experimental moisture diffusivity values were in comparison with the values reported by Sacilik, et al., (2006) for open sun dried tomato slices (1.31 x 10^-9 m^2/s), Ramesh, et al. (2001) for paprika and Velic, et al. (2004) for apple slices. However, the effective diffusivity values of SCD were higher than the values reported by Giovenelli, et al., (2002) as 2.26 -9.14 x 10^-9 m^2/s and these higher values in the present study might be due to the lesser tomato slice thickness used for the experiment compared to the reported values.

Mathematical modeling of drying characteristics of tomato slices

The summary of model parameters of four thin layer drying models that were used for expressing drying characteristics of tomato slices dried by solar and open sun drying methods and the statistical evaluation of models using three different criteria are presented in the Tables 2 & 3. As per the procedure of Akpinar et al. (2006), the quality of various models was evaluated using R^2, reduced ∆∧ and RMSE values. It is observed that the Page model satisfactorily described the drying kinetics of tomato slices dried both under SCD and by open sun drying methods. For Page model, the R^2 values varied from 0.983 to 0.987, ∆∧ varied from 0.000071 to 0.00096 and RMSE varied from 0.02514 to 0.02774 for tomato slices of different thicknesses dried in SCD.
Whereas in the case of open sun drying method, the $R^2$ values varied from 0.946 to 0.983, $\rho^2$ varied from 0.00104 to 0.00440 and RMSE varied from 0.03036 to 0.06384 depending upon thickness of tomato slices.

Page model was also reported to fit the thin layer drying data better than other models in many earlier studies such as Akpinar et al., (2006) for aromatic plants, Doymaz (2004) for carrots and Hossain and Bala (2002) for green chillies. Since the present drying study on tomato slices was also performed in thin layers using solar and open sun drying methods and thus the Page model was found to describe the drying characteristics better when compared to other models.

From the tables, it could be observed that apart from Page model, the other tested models namely Wang and Singh, Henderson-Pabis and Lewis models in that order of priority also described the drying characteristics of tomato slices reasonably well.

Therefore, the Page model was used to predict the moisture ratio of tomato slices dried in both SCD and open sun drying methods. The experimental and the predicted data values using Page model for moisture ratios of tomato slices dried in solar and open sun drying methods are shown in Fig. 7 (a & b). The established model provided a very good conformity between the experimental data and the predicted moisture ratios of the tomato slices (4, 6 and 8 mm) dried under solar cabinet dryer and open sun drying methods. It is observed that the predicted data are banded around the ideal trend line indicating the suitability of the model in predicting the drying behaviour of tomato slices both in solar cabinet dryer and by open sun drying.

**Colour**

The colour is an important quality attribute of the dried product from the consumer’s point of view. The changes in color of solar cabinet and open sun dried tomato slices for 4, 6 and 8 mm thicknesses are shown in Table 4. From the table, it is observed that the dried slices were darker ($L^*$ decreased) when compared to fresh tomato slice. Between the drying methods, the open sun dried slices were significantly darker ($P<0.05$) than the solar cabinet dried ones. Also, there was a significant difference in the $L^*$ value of the tomato slices studied and among them 8 mm dried slices were found to be more darker than the other thicknesses in both the methods.

Kerkhofs, (2003) observed that an increase in darkness ($L^*$) of tomatoes were observed after air drying. Olorunda (1990) also observed that an increase in drying time and temperature resulted in tomato tissue darkening.

**Table 4. Colour values of solar cabinet and open sun dried tomato slices**

<table>
<thead>
<tr>
<th>Methods</th>
<th>Treatments</th>
<th>'L*'</th>
<th>'a*'</th>
<th>'b*'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td></td>
<td>48.84</td>
<td>12.64</td>
<td>12.06</td>
</tr>
<tr>
<td>Open sun drying</td>
<td>4 mm</td>
<td>42.04</td>
<td>8.98</td>
<td>18.39</td>
</tr>
<tr>
<td></td>
<td>6 mm</td>
<td>41.53</td>
<td>8.44</td>
<td>18.13</td>
</tr>
<tr>
<td></td>
<td>8 mm</td>
<td>40.75</td>
<td>7.84</td>
<td>18.07</td>
</tr>
<tr>
<td>Cabinet solar dryer</td>
<td>4 mm</td>
<td>44.16</td>
<td>10.18</td>
<td>17.51</td>
</tr>
<tr>
<td></td>
<td>6 mm</td>
<td>43.03</td>
<td>10.03</td>
<td>17.22</td>
</tr>
<tr>
<td></td>
<td>8 mm</td>
<td>42.86</td>
<td>9.68</td>
<td>16.94</td>
</tr>
</tbody>
</table>

F-test: * * *  
$P<0.05$: 0.16 0.14 0.18  
CV%: 2.1 4.6 3.6  
SED: 0.72 0.65 0.87

Means with same letter are not significantly different

The open sun dried tomato slices had significantly lower 'a*' values of slices (7.84 - 8.98) when compared to solar cabinet (9.68 - 10.18) dried slices. The $L^*$ value was declined to about 28-37% after open sun drying.

But there was a significant increase in 'b*' values tending towards yellowness of the colour coordinate after drying the slices in both the methods. Overall, it is observed that the colour ($L^*$, $a^*$ & $b^*$) change was significantly lower in the solar cabinet dried tomato slices when compared to open sun dried slices. Similarly, Sacilik, et al. (2006) reported that the tomato slices dried under solar tunnel drier retained better colour than open sun dried slices due to the exposure of the tomato slices to solar radiations for a longer drying time.

It is also reported that during drying the red color of tomato gradually changed to brick - red and then to brown color in open sun drying (Sacilik et al., 2006). Also, Porretta and Sandei (1991) mentioned that higher color change in open sun drying was mainly due to the direct exposure of the tomato slices to solar radiation for a longer period that induced non-enzymatic browning or Maillard reaction.

**Water activity**

The water activity ($a_w$) of the fresh tomato slice was determined to be 0.92. After drying the water activity reduced to 0.502, 0.504 and 0.507 for solar dried slices and 0.526, 0.527 and 0.530 for open sun dried tomato slices of 4, 6 and 8 mm, respectively. It is observed that the water activity (Table 5) did not significantly vary with slice thicknesses and drying methods. Similarly, Beaudry et al. (2004) reported that there was no significant difference in water activity...
of the dried cranberries. As the experimentally determined water activity values of the dried tomato slices were lower than 0.60, they are considered to be safer and shelf-stable with respect to microbial growth as reported by Wang and Brennen (1991).

Rehydration ratio

The rehydration ratio of tomato slices (4, 6 and 8 mm thickness) was higher for SCD samples (3.25, 3.56 and 3.61) when compared to open sun dried (2.95, 3.15 and 3.24) slices (Table 5). The samples dried under SCD rehydrated better in light and heat compared to open sun dried slices. Similarly, Sacilik et al. (2006) reported that the rehydration ratio of the thin layer solar tunnel dried tomato was little higher (3.15) than the open sun dried tomato (3.10). The lower rehydration ratio for open sun dried slices might be due to long exposure time coupled with higher shrinkage of final product. Rehydration behavior has been considered as a measure of the induced damage in the material during drying (Lewicki, 1998).

From the table, it is observed that the rehydrated value of 4 mm thick tomato slice in SCD was on par with the rehydrated value of 8 mm thick slice in open sun drying method. Further, it is observed that the thicker slices (8 mm) rehydrated better than the thinner slices (4 mm) in each method. The overall variation in the rehydration characteristics of the dried product were influenced by the method of processing, sample constitution, preparation of the sample prior to rehydration and extent of the structural and chemical changes induced during drying as reported by Krokida and Maroulis (2001).

Ascorbic acid

The ascorbic acid content was measured on both fresh and dried samples at 4, 6 and 8 mm thicknesses as shown in Table 5. There was a significant reduction ($P < 0.05$) in ascorbic acid content in all the dried samples. Between the two drying methods, the reduction was significantly higher in open sun dried (75.15 - 86.95%) tomato slices of 4 - 8 mm thicknesses. From the data, it is observed that the ascorbic acid was very sensitive to oxidative heat damages as the reduction was significant in both the solar and open sun drying methods. This is confirmed with the result reported by Giovanelli et al. (2002) that the reduction in ascorbic acid content was mainly due to the temperature, exposure to direct sun light and the presence of air. Similarly, Gould (1983) mentioned that the ascorbic acid degradation was mainly due to the temperature at which the tomato products were heated in the presence of air. In a similar line, Gregory (1996) mentioned that the loss of ascorbic acid was primarily due to chemical degradation involving oxidation of ascorbic acid.

Also, significant loss of ascorbic acid has been reported in the previous studies using higher temperature and longer drying time. For example,
Lavelli et al., (1999) found that about 88% losses in ascorbic acid when tomatoes were dried at 80°C for 7 h to 10% moisture content. Similarly, Zanoni et al. (1998) reported that 40 and 80% loss of ascorbic acid when tomatoes were dried at 80 and 110°C, respectively.

**Conclusion**

The study concluded that dehydrated tomato slices could be produced using solar cabinet dryer. The time required to dry the slices were comparatively lower in solar cabinet dryer when compared to open sun drying method. The time required to dry 4 mm thickness tomato slice was lesser as compared to 6 and 8 mm thick slices. The moisture diffusivity was higher in solar cabinet dryer than in open sun drying. The Page model was found to be better in describing the drying kinetics of tomato slices dried in both solar cabinet and open sun drying methods. The colour, rehydration ratio and ascorbic acid retention were comparatively higher in solar cabinet dried tomato slices.

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**References**


