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# Thin Layer Drying Characteristics of Tomato Slices in A Hot Air Dryer

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## ABSTRACT

The drying process of tomato slices were studied using a hot air dryer under five different levels of air temperature ranging from 50 to 70°C, at constant thickness of 5 ±0.2 mm, and a constant drying air flow rate of 0.07 $m^3$/sec. Tomato slices were sprayed before drying with 5% sodium chloride and left for 2 h to facilitate the release of moisture and preserve tomatoes during drying. Both the effective moisture diffusivity and activation energy were calculated. To find the best model for describing the drying curves, eight different thin-layer drying models were tested. The quality of dried tomato slices was assessed by estimating lycopene and ascorbic acid content. The results showed that the drying process of tomato slices took place during the falling rate period at all levels of temperature. Moisture content (MC) of tomato slices reduced from 751.79 %(d.b.) to 10% ±0.6 (d.b.) during a period of time ranging from 170 to 310minutes. The average values of effective moisture diffusivity varied from $9.9801\times10^{-10}$ to $1.8871\times10^{-9}$ $m^2s^{-1}$ and the activation energy was found to be 32.94 $kJ.mol^{-1}$. The statistical analysis of fit tests revealed that Diamante *et al.* model provided a satisfactory fit for the experimental data, and followed by Page model. Lycopene content in dried tomato slices is higher than that of fresh tomatoes. While ascorbic acid content decreased by increasing air temperature.

***Keywords:*** hot air – drying – tomato slices – modeling – lycopene.

## INTRODUCTION

Tomatoes (*Lycopersicon esculentum*) are considered among the most crucial vegetable crops grown globally, whether for fresh use or industrial purposes (Gaware *et al.*, 2010). The global productivity of tomatoes in 2020 amounted to about 186,821,216 tons, while the area cultivated with tomatoes in Egypt amounted to about 406,814 feddan, with a total productivity of about 6.7 million tons (FAO, 2020). Tomatoes are largely used in the fresh form, and some processes such as juice, puree, sauces, and canned varieties. In addition, it was used in dried form as an ingredient for pizza, spices, and in various vegetable dishes (Akanbi *et al.*, 2006).

Since tomatoes are an extremely perishable crop in fresh form, which leads to high waste and losses during the peak harvest period, and therefore it was necessary to find ways to preserve this crop, reduce losses, and create a state of balance between supply and demand, especially in the period when production declines (St George *et al.*, 2004).

One of the earliest techniques for protecting food from spoilage is drying. If packaged properly, the dried product can be preserved for a very long time without refrigeration (Durance and Wang, 2002). In the Mediterranean countries, solar drying is used to dry vegetables and fruits, as this method is characterized by simplicity and low costs, but it requires a long period of time for drying. In addition to low quality of the dried product, as it is subjected to contamination by dust and insects and is highly vulnerable to microbial and enzymatic activity (Andritsos *et al.*, 2003). Industrial dryers, such as solar dryers and hot air dryers (HAD), are employed to enhance the quality of such dried product. (Ertekin and Yaldiz, 2004).

Fresh tomatoes could be dried in the form of quarters, halves, slices of different thicknesses, or powders (Giovanelli *et al.*, 2002). The process of industrial drying of tomatoes is often carried out using high temperatures ranging from 60 to 110 degrees Celsius for a period of time up to 10 hours in the presence of oxygen to reduce MC of tomatoes to a level of less than 15% and thus some oxidative damage may occur (Toor and Savage, 2006). Due to the possibility of keeping dried tomatoes for a long period of time, it is possible to buy them when they are available in abundance and at a low price, then the drying process is carried out and stored, and thus they become of high economic value, well-known health and nutritional benefits of tomatoes also raise of these products value (Veillet *et al.*, 2009). Koca *et al.*, (2007) mentioned that some reactions may occur that lead to a deterioration in color, nutritional value, texture, and flavor of the dried products, and this effect could last throughout the storage period at a rate influenced by the storage conditions.

Drying is a complicated heat and mass transfer process in which heat is transferred to the product and then moisture is moved from the product to the surrounding medium (Sahin and Dincer, 2005). The HAD method is the most common method for drying tomatoes, due to its easiness and relatively low cost (Akanbi *et al.*, 2006). In this method, hot air with a temperature ranging from 50 to 80 $^{o}$C is pushed through the product to provide it with the necessary heat and reduce MC to the required level (Phongsomboon and Intipunya, 2009).

St. George *et al.*, (2004) stated that, some vegetables and fruits often contain a waxy outer layer to protect them from external and environmental factors. This waxy layer affects moisture movement from inside the fruit to outside, thus affecting the drying process. Before the drying process, a chemical treatment of fruits is often carried out to overcome the presence of the outer waxy layer. These different

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pretreatments were mentioned by Doymaz, (2007). Before drying, tomatoes are pre-treated with a variety of solutions: calcium chloride (Lewicki and Michaluk, 2004); sodium chloride (Sacilik *et al.*, 2006); sodium chloride-sucrose (Kross *et al.*, 2004).

Mathematical modeling of drying is used to create new drying systems or to develop and enhance current drying systems in addition to controlling the drying process. There are many mathematical models that are used to describe the drying characteristics of agricultural products in thin layers. These models can be divided into theoretical, semi-theoretical, and empirical models (Demiray and Tulek, 2012).

Bramley (2000); Southon (2000) and Franceschi *et al.*, (1994) mentioned that Lycopene (a $C_{40}$ carotenoid polyene) is the primary coloring matter responsible for the deep red color of ripe tomato and its products. In addition to being a source of coloring, lycopene has many health benefits. Lycopene is affected by thermal processes that take place on fruits and their products, such as heating and drying (Klaui and Bauernfeind, 1981).

Zanoni *et al.*, (1999) stated that lycopene content in tomato halves was not affected by drying at a temperature of 80 °C, while it decreased by 10% when using a temperature of 110 °C. High temperatures have a particular impact on the loss of ascorbic acid during drying process. Zanoni *et al.*, (1999) also mentioned that the degradation rate of vitamin C in tomatoes, at 80 and 110 ºC, was dependent of temperature and moisture content; and vitamin C was not detected in samples dried at 110 ºC and 50% moisture. Nevertheless, they found a 10% residue of vitamin C in samples dried at 80 C and 10% moisture.

Doymaz (2007) studied the characteristics of drying tomatoes at a temperature range of 55 to 70 ºC, using air at a constant speed (1.5 m $s^{-1}$). A comparison was made between tomatoes that were treated with ethyl-oleate alkaline solution and tomato samples that were not treated. During the experiments, the MC of tomatoes was reduced from 94.5% to a final MC of 11% (wet basis). The results also showed that the alkali treatment significantly raised the drying rate of tomatoes. In addition, Page model was the best in describing drying behavior under experimental conditions. The value of the effective moisture diffusivity was calculated, and it was in the range 5.65–7.53 $x10^{-10}$ $m^2s^{-1}$ for treated samples and 3.91–6.65 $x10^{-10}$ $m^2s^{-1}$ for untreated samples. The activation energy value ranged between 17.4 and 92.94 $kJ.mol^{-1}$.

The aim of the current research is to study the effect of air temperature on the drying characteristics of tomato slices using a laboratory dryer that works with hot air. Testing eight mathematical models and determining the best one in describing drying behavior of tomato slices under study conditions. Studying the effect of different levels of drying air temperature on moisture diffusion rate and calculating the activation energy for tomato slices. Finally, to examine the effect of the used levels of air temperature on the quality of dried tomatoes in terms of lycopene and ascorbic acid content.

## MATERIALS AND METHODS

### Materials:

Freshly harvested tomato fruits (Lycopersicon esculentum Mill) were bought from a market in Damietta governorate, Egypt. Bearing in mind that fruits are homogeneous in terms of color, size, and shape, in addition to being free from infections, and then they were packed in polyethylene bags and kept under refrigeration until it was used in laboratory experiments.

### Pre-treatment of tomatoes:

Before conducting drying experiments, tomatoes are cut into slices with average thickness of 5 ±0.2 mm using a manual vegetable slicing unit, then they are placed inside a tray and an amount of 5% sodium chloride is sprayed and left for two hours to facilitate the release of moisture and delay spoilage of tomatoes during drying.

The MC of fresh tomato slices was 94.24 (w.b.), while it decreased as a result of treatment with sodium chloride to 88.26 (w.b.).

### Hot air Dryer:

To conduct laboratory experiments, a thin layer hot air laboratory dryer was used in Food Processing Engineering Laboratory at Faculty of Agriculture, Mansoura University, which was designed and manufactured by Matouk *et al.*, (2001). The dryer contains a centrifugal fan with a capacity of 1.3 kW to supply the dryer with air at ambient temperature, and then air passes through a heating unit containing 6 heaters, each with a capacity of 1 kW, to raise air temperature to the level required for conducting experiments. The drying air temperature is controlled by a thermostat connected to a sensor. After heating, the air passes into the drying chamber containing a vertical cylinder containing a drying tray with a diameter of 270 mm and a perforated base to allow the heated air to pass through tomato slices to be dried.

### Drying procedure:

Before conducting the experiments, 250 ±10 grams of pre-treated tomato slices were alternately stacked in a thin layer not exceeding 2 cm inside the sample tray, to facilitate the passage of hot air through slices. The dryer was started at about 1 h before the drying experiments to achieve steady-state conditions before each drying run. Laboratory experiments were carried out using a constant air flow rate of 0.07 $m^3$/sec during all experiments. Five different drying air temperature levels of 50, 55, 60, 65, and 70 °C were used. During experiments, the sample tray is taken out of the dryer, weighed, and quickly returned to the dryer. The mass of sample was measured at 10-minute intervals until the end of every experiment. The drying experiment was continued for each experiment until a final MC of 10 ±0.6% (d.b.). Each run in the experimental work was conducted in three replicates.

### Instrumentations:

The initial MC of tomato slices was estimated using a laboratory electric oven (Binder, max 300ºC) at 70 ºC for 16 h according to AOAC (1990). The mass of samples used to estimate the MC was measured using a digital balance (AND EK-200GD) with an accuracy of ± 0.01 g. The mass of samples during the drying experiments was determined using digital balance (TR-6101) with (6000 ± 0.1 g). Temperature and velocity of the drying air inside the drying chamber were measured using an air velocity and temperature meter (9515, USA).

### Analysis of the drying data:

**Moisture Ratio (MR) and drying rate (DR) were calculated as follow:**

$$MR = \frac{M_t - M_f}{M_0 - M_f} \qquad (1)$$

$$DR = \frac{M_i - M_t}{t - i} \qquad (2)$$

**where**, **$M_o$ is the initial MC (%, d. b.), $M_f$ is the final MC (%, d. b.), $M_t$ MC at any time t (%, d. b.), $M_i$ is MC at the time i (%, d. b.), t and i are beginning and end period, (min). respectively.**

## Calculations of effective moisture diffusivity and activation energy:

According to Doymaz (2007) and Vega *et al.* (2007), the integrated equation of Fick's second law of diffusion for slab geometry was used to determine the effective moisture diffusivity for tomato slices as follow:

$$MR = \left(\frac{8}{\pi^2}\right)\exp\left[\frac{-\pi^2 D_{eff}\, t}{4L^2}\right] \qquad (3)$$

**where, $D_{eff}$ is the effective moisture diffusivity ($m^2s^{-1}$); t is the drying time (sec) and l is half thickness of tomato slices (0.0025 m in present study).**

By taking the ln of both sides the equation becomes as follows

$$\ln(MR) = (-0.21) - \left[\frac{\pi^2}{4L^2} D_{eff}\, t\right] \qquad (4)$$

The value of $D_{eff}$ obtained by displaying the relation between ln(MR) and time (t) ; the slope of the resulting straight line $k_o$ is equal to

$$K_o = \frac{\pi^2 D_{eff}}{4L^2} \qquad (5)$$

The drying properties of wet foodstuffs depend on the extent to which moisture is attached to the wet material. Activation energy is defined as the work required to remove one mole of moisture from the material at a given MC and constant components.

The effect of temperature change on the value of the effective moisture diffusivity can be illustrated by the Arrhenius equation (Doymaz, 2007; Arumuganathan *et al.* 2009; Tunde Akintunde and Afon, 2010)

$$D_{eff} = D_o \exp\left[\frac{-E_a}{RT}\right] \qquad (6)$$

**Where**

**$D_o$: pre-exponential factor of the Arrhenius equation ($m^2s^{-1}$)**
**$E_a$: activation energy ($kJ.mol^{-1}$)**
**T: the absolute temperature (ºK)**
**R: universal gas constant (8.314 $Jmol^{-1}K^{-1}$)**

By taking the ln of both sides, equation (6) becomes as follows

$$\ln(D_{eff}) = \ln(D_o) - \frac{E_a}{RT} \qquad (7)$$

Thus, the value of ($E_a$) can be calculated by plotting the relationship between (ln $D_{eff}$) and (1/T).

## Mathematical modeling of drying curves:

During this work the experimental MR values versus drying time were fitted by different drying models as follow:

- Lewis model (Lewis, 1921)

$$MR = \exp^{-kt} \qquad (8)$$

**Where, k is drying constant ($min^{-1}$); t is drying time (min)**

- Henderson and Pabis model (Henderson and Pabis, 1961)

$$MR = A_o \exp^{-kt} \qquad (9)$$

**Where, $A_o$ is coefficient of Henderson and Pabis model (dimensionless)**

- Page model (Page, 1949)

$$MR = \exp^{-kt^N} \qquad (10)$$

**Where, N is Page model coefficient (dimensionless)**

- Logarithmic model (Wang *et al.*, 2007)

$$MR = A_L \exp^{-kt} + C_L \qquad (11)$$

**Where, $A_L$ and $C_L$ are constants (dimensionless)**

- Wang and Singh model (Wang and Singh, 1978)

$$MR = 1 + At + Bt^2 \qquad (12)$$

**Where, A and B are constants (dimensionless)**

- Two-term model (Henderson, 1974)

$$MR = A_T \exp^{-k_o t} + B_T \exp^{-k_1 t} \qquad (13)$$

**Where, $A_T$ and $B_T$ are Two-term model coefficient (dimensionless); $k_o$ and $k_1$ are drying constants ($min^{-1}$)**

- The exponential linear combination model (Elfar *et al.*, 2022)

$$MR = A_e + B_e \exp^{-kt} + C_e\, t \qquad (14)$$

**Where, $A_e$, $B_e$ and $C_e$ are model coefficients (dimensionless)**

- Diamante *et al.* model (Diamante *et al.*, 2010)

$$\ln[-\ln(MR)] = A_d + B_d(\ln t) + C_d(\ln t)^2 \qquad (15)$$

**Where, $A_d$, $B_d$ and $C_d$ are coefficients (dimensionless)**

## Adequacy of the tested drying models:

Using Excel curve-fitting software (Office 365) and the Sigma plot 14.0 program, the tested models were fitted to the experimental data. For estimating the parameters of the examined models (Eqs. 8–15), non-linear regression analysis was used.

By calculating the coefficient of determination ($R^2$), standard error (SE), reduced chi-square ($\chi^2$), and root mean square error (RMSE), the examined models' adequacy for fitting the experimental data was assessed. The values of $\chi^2$and RMSE can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{n}(MR_{exp} - MR_{calc})^2}{n - z} \qquad (16)$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(MR_{exp} - MR_{calc}\right)^2\right]^{1/2} \qquad (17)$$

**where,**

**$MR_{exp}$: the experimental MR, (dimensionless)**
**$MR_{calc}$: calculated MR, (dimensionless)**
**n: number of observations**
**z: number of constants in the model**

The higher the $R^2$ values and the lower the SE, $\chi^2$and RMSE values, the better is the fitness.

## Quality evaluation of the dried tomato slices:

To evaluate the effect of air temperature levels on the quality of dried tomato slices, a comparison was made between fresh and dried tomatoes in terms of ascorbic acid and lycopene content. The **AOAC (1990)** method was used to estimate the amount of lycopene.

While the amount of ascorbic acid was measured using the 2,6-dichlorophenol indophenols dye method (Ranganna, 1986).

## RESULTS AND DISCUSSION

### Drying Characteristics of Tomato Slices:

The effect of different levels of air temperatures used for drying in the range from 50 to 70 °C on drying rate of tomato slices is shown in Figure (1).

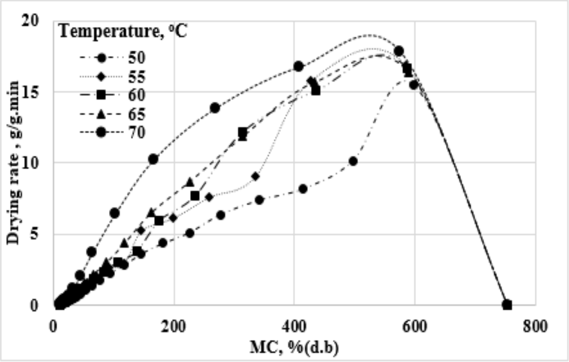


**Figure 1. Relation between DR and tomato MC at different air temperature.**

From figure (1) there is no constant drying rate period, and drying process was occurred during the falling rate period, in which the drying rate gradually decreases with the drying time, and this showed that diffusion was the main factor controlling the movement of moisture through tomato slices, and these results were consistent with the results obtained by Akpinar *et al.*, (2003) for pumpkin; Doymaz (2005) for okra and Demiray and Tulek (2012) for tomato slices.

It could also be noted that moisture removal rate was higher in the initial stages of drying process and then decreased with the progression of drying process. This was due to the high initial MC of tomato slices, which lead to a higher vapor pressure gradient, which then decreased with the progression of drying process. This increase in drying rate could be attributed to the opening of the physical structure of tomato slices, which lead to rapid evaporation of moisture and raised movement of moisture from the inner layers to the outside. This was consistent with the results obtained by Wang *et al.*, (2007). Additionally, there was a direct correlation between the rise in air temperature and the rate of drying.

Figure (2) showed the MC of tomato slices as a function of drying time at different levels of air temperature. From the figure, it could be seen that there was a clear decrease in moisture ratio (MR) with the increase of drying time.

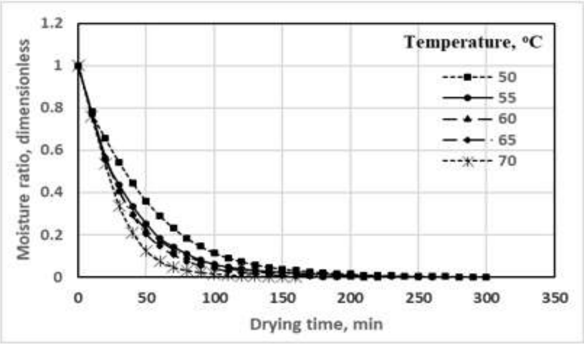


**Figure 2. Change in MR of tomato slices with drying time at different levels of drying air temperature.**

Also, there was an effect of air temperature on the total time required to reduce MC of tomato slices from 751.79 % (d.b.) to a final MC of 10 % ± 0.6 on a dry basis. The drying time was 310, 270, 230, 200 and 170 min. at air temperatures of 50, 55, 60, 65 and 70°C, respectively.

### Effective moisture diffusivities and activation energy of tomato slices:

The relationship showing the variation in ln (MR) with drying time at different levels of drying air temperature was drawn as shown in figure (3). In order to obtain the value of slope ($k_o$) in equation (5), the value of effective moisture diffusivity ($D_{eff}$) could be calculated.

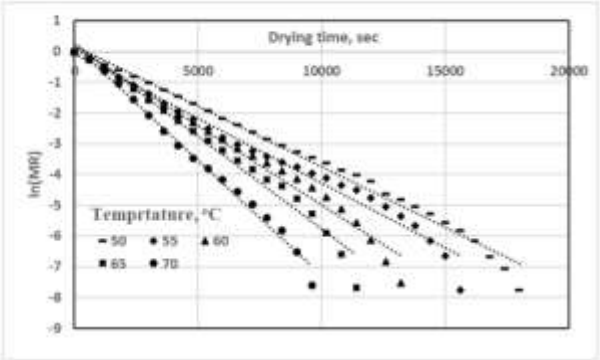


**Figure 3. Variation on ln (MR) of tomato slices with drying time at different levels of air temperature.**

Also, table (1) showed the obtained linear equations and the effective moisture diffusivity values at different drying air temperatures.

**Table 1. The calculated values of $D_{eff}$ for tomato slices at different levels of air temperature.**

| T, °c | Linear equation | $R^2$ | $D_{eff}$, $m^2/s$ |
|---|---|---|---|
| 50 | ln (MR) = 0.195705 - 0.000394 t | 0.9890 | $9.9801x10^{-10}$ |
| 55 | ln (MR) = -0.071202 - 0.000422 t | 0.9798 | $1.0689\ x10^{-9}$ |
| 60 | ln (MR) = 0.152147 - 0.000514 t | 0.9821 | $1.3020\ x10^{-9}$ |
| 65 | ln (MR) = 0.262029 - 0.000604 t | 0.9783 | $1.5299\ x10^{-9}$ |
| 70 | ln (MR) = 0.189598 - 0.000745 t | 0.9916 | $1.8871\ x10^{-9}$ |

The obtained values of the effective moisture diffusivity agree with the results obtained by previous researchers. Das Purkayastha *et al.*, (2013) found that moisture diffusivity ($D_{eff}$) for tomato slices was $5.453x10^{-10}$ to $2.0261\ x\ 10^{-9}\ m^2\ s^{-1}$. Akanbi *et al.*, (2006) also mentioned that the effective moisture diffusivity value of tomato dried at temperature from 45 to 75 C was in the range $3.72\times10^{-9}$ – $12.27\times10^{-9}\ m^2s^{-1}$. While Giovanelli *et al.*, (2002) stated that moisture diffusivity value of tomato dried at temperature from 60 to 110 C was in the range $2.3\times10^{-9}$–$9.1\times10^{-9}\ m^2\ s^{-1}$. Varadharaju *et al.*, (2001) also found that the value of moisture diffusivity for cherry tomatoe dried at 40 to 60 was in the range $0.87\times10^{-9}$–$1.0\times10^{-9}\ m^2s^{-1}$. Also, Arumuganathan *et al.*, (2009) mentioned that for food materials the effective moisture diffusivities ranged from $10^{-6}$ to $10^{-11}\ m^2s^{-1}$.

To calculate the value of activation energy, the relationship was drawn between logarithm of effective moisture diffusivity ln ($D_{eff}$) and reciprocal of temperature in Kelvin, as in Figure (4). From the resulting linear relationship, the value of activation energy for dried tomato slices using air temperature ranged between 50 and 70 °C was 30.003 kJ/mole. Doymaz (2007) found that the activation energy for tomatoes pre-treated with a solution of alkaline ethyl oleate was (17.40 kJ/mole) while it was (32.94 kJ/mole) for untreated tomatoes.

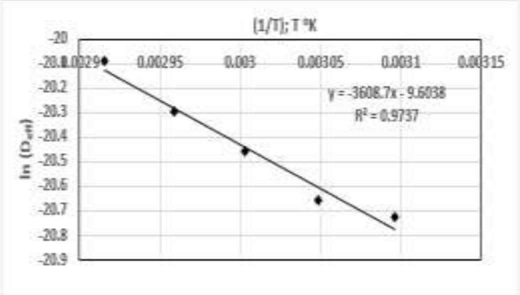


**Figure 4. Relationship between logarithm of effective moisture diffusivity ln ($D_{eff}$) and reciprocal of air temperature (1/T) °K.**

Also, Demiray and Tulek (2012) found that the activation energy for tomato slices dried at 60-100°C was 22.981 kJ/mole. Zogzas *et al.*, (1996) revealed that the values of activation energy for various food materials were within the range of 12.7 to 110 kJ/mol.

**Mathematical modeling:**

Eight thin layer drying models, namely, Lewis, Henderson and Pabis, Page, Logarithmic, Wang and Singh, two term, the exponential linear combination model and Diamante *et al.* model were examined for describing the drying process of tomato slices under the studied conditions to select the best model for describing drying behavior. Table (2) summarized constants, coefficients, and the statistical evaluation parameters of the examined models.

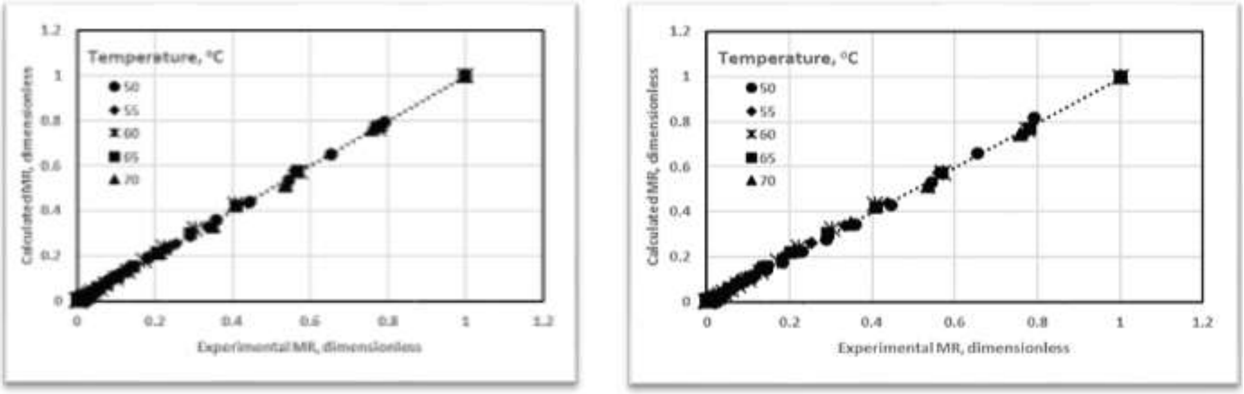
**Table 2. Statistical analysis of the eight examined models.**

| Model | T, °c | k | | | | $R^2$ | SE | $X^2$ | RMSE |
|---|---|---|---|---|---|---|---|---|---|
| Lewis | 50 | 0.0227 | | | | 0.9980 | 0.0123 | 0.000259517 | 0.015856 |
| | 55 | 0.0257 | | | | 0.9983 | 0.0118 | 0.000211492 | 0.014281 |
| | 60 | 0.0298 | | | | 0.9995 | 0.0069 | 8.14813E-05 | 0.008837 |
| | 65 | 0.0342 | | | | 0.9968 | 0.0174 | 0.000711049 | 0.026023 |
| | 70 | 0.0430 | | | | 0.9909 | 0.0311 | 0.001810191 | 0.041348 |
| Average | | | | | | 0.9967 | 0.015910 | 0.000615 | 0.0213 |
| | | k | $A_o$ | | | | | | |
| Henderson and Pabis | 50 | 0.0236 | 1.2162 | | | 0.9961 | 0.0200 | 0.003003987 | 0.053068 |
| | 55 | 0.0253 | 0.9313 | | | 0.9977 | 0.0126 | 0.000335004 | 0.017637 |
| | 60 | 0.0308 | 1.1643 | | | 0.9990 | 0.0100 | 0.001906047 | 0.0418 |
| | 65 | 0.0362 | 1.2996 | | | 0.9934 | 0.0306 | 0.005816271 | 0.072542 |
| | 70 | 0.0447 | 1.2088 | | | 0.9879 | 0.0422 | 0.002915857 | 0.05091 |
| Average | | | | | | 0.9948 | 0.023064 | 0.002795 | 0.0472 |
| | | k | N | | | | | | |
| Page | 50 | 0.0192 | 1.0272 | | | 0.9994 | 0.0071 | 5.52914E-05 | 0.0072 |
| | 55 | 0.0312 | 0.9629 | | | 0.9993 | 0.0075 | 6.21855E-05 | 0.007599 |
| | 60 | 0.0253 | 1.0299 | | | 0.9994 | 0.0082 | 7.19808E-05 | 0.008123 |
| | 65 | 0.0206 | 1.1004 | | | 0.9997 | 0.0056 | 3.33156E-05 | 0.00549 |
| | 70 | 0.0206 | 1.1571 | | | 0.9990 | 0.0106 | 0.000137297 | 0.011047 |
| Average | | | | | | 0.9994 | 0.007821 | 0.000072 | 0.0079 |
| | | k | $A_L$ | $C_L$ | | | | | |
| Logarithmic | 50 | 0.0207 | 0.9996 | -0.0038 | | 0.9996 | 0.0058 | 3.53572E-05 | 0.005661 |
| | 55 | 0.0281 | 1.0001 | 0.0040 | | 0.9997 | 0.0051 | 2.71015E-05 | 0.004919 |
| | 60 | 0.0295 | 1.0111 | 0.0018 | | 0.9995 | 0.0069 | 5.05166E-05 | 0.006648 |
| | 65 | 0.0306 | 1.0296 | -0.0064 | | 0.9990 | 0.0108 | 0.000123797 | 0.010301 |
| | 70 | 0.0362 | 1.0520 | -0.0153 | | 0.9959 | 0.0233 | 0.000579405 | 0.021974 |
| Average | | | | | | 0.9987 | 0.010393 | 0.000163 | 0.0099 |
| | | $A_T$ | $k_o$ | $B_T$ | $k_1$ | | | | |
| Two term | 50 | 0.5003 | 0.0210 | 0.4978 | 0.0210 | 0.9996 | 0.0060 | 4.28859E-05 | 0.006126 |
| | 55 | 0.9937 | 0.0284 | 0.0113 | 0.0051 | 0.9997 | 0.0050 | 2.72407E-05 | 0.004832 |
| | 60 | 1.0079 | 0.0297 | 0.0053 | 0.0058 | 0.9995 | 0.0069 | 5.26317E-05 | 0.006623 |
| | 65 | 0.5255 | 0.0312 | 0.5007 | 0.0312 | 0.9989 | 0.0110 | 0.000149347 | 0.010995 |
| | 70 | 0.5433 | 0.0379 | 0.4988 | 0.0379 | 0.9951 | 0.0236 | 0.00072061 | 0.023674 |
| average | | | | | | 0.9986 | 0.010509 | 0.000199 | 0.0105 |
| | | A | B | | | | | | |
| Wang and Singh | 50 | -0.0108 | $2.7x10^{-5}$ | | | 0.9461 | 0.0969 | 0.012723118 | 0.109215 |
| | 55 | -0.0123 | $3.7x10^{-5}$ | | | 0.9171 | 0.1171 | 0.017113756 | 0.126061 |
| | 60 | -0.0147 | $4.9x10^{-5}$ | | | 0.9375 | 0.1067 | 0.013795474 | 0.112454 |
| | 65 | -0.0166 | $6.3x10^{-5}$ | | | 0.9554 | 0.0956 | 0.01070374 | 0.098409 |
| | 70 | -0.0199 | $9.1x10^{-5}$ | | | 0.9563 | 0.1014 | 0.011764512 | 0.102261 |
| Average | | | | | | 0.9425 | 0.103565 | 0.013220 | 0.1097 |
| | | $A_d$ | $B_d$ | $C_d$ | | | | | |
| Diamante *et al.* model | 50 | -3.2395 | 0.6742 | 0.0413 | | 0.9997 | 0.0040 | 1.73992E-05 | 0.003971 |
| | 55 | -3.9138 | 1.1895 | -0.0272 | | 0.9995 | 0.0052 | 2.73224E-05 | 0.004939 |
| | 60 | -3.7580 | 1.0728 | -0.0053 | | 0.9991 | 0.0076 | 6.29949E-05 | 0.007424 |
| | 65 | -3.9764 | 1.1515 | -0.0065 | | 0.9997 | 0.0048 | 2.54746E-05 | 0.004673 |
| | 70 | -4.7978 | 1.6629 | -0.0662 | | 0.9992 | 0.0075 | 6.23349E-05 | 0.007207 |
| Average | | | | | | 0.9994 | 0.005828 | 0.000039 | 0.0056 |
| | | $A_e$ | $B_e$ | k | $C_e$ | | | | |
| The exponential linear combination model | 50 | -0.0276 | 1.0200 | 0.0199 | $9.61x10^{-5}$ | 0.9997 | 0.0053 | 3.0469E-05 | 0.005163 |
| | 55 | 0.0110 | 0.9943 | 0.0284 | $-3.48x10^{-5}$ | 0.9954 | 0.0049 | 0.000584013 | 0.022374 |
| | 60 | 0.0089 | 1.0057 | 0.0298 | $-3.51x10^{-5}$ | 0.9995 | 0.0069 | 5.19814E-05 | 0.006582 |
| | 65 | -0.0600 | 1.0780 | 0.0284 | 0.0003 | 0.9992 | 0.0096 | 0.000112404 | 0.009539 |
| | 70 | -0.1663 | 1.1925 | 0.0302 | 0.0011 | 0.9974 | 0.0192 | 0.000437388 | 0.018444 |
| Average | | | | | | 0.9982 | 0.009181 | 0.000243 | 0.0124 |

It was clear from tabulated data that at all levels of air temperature, there was a good agreement between experimental data and calculated values using the previous mathematical models, and this is confirmed by the high values of coefficient of determination ($R^2 \geq 0.9171$) and the low values of standard error (SE), reduced Chi-square ($\chi^2$) and root means square error (RMSE). Although all mathematical models gave high values for coefficient of determination at all levels of temperature, Page model and Diamanate *et al.* model gave the largest average values for coefficient of determination ($R^2 = 0.9994$).

Comparing Page model and Diamanate *et al.* model in terms of other statistical values, it could be noted that Diamanate *et al.* model gave the lowest values for standard errors (SE = 0.005828), reduced Chi-square ($\chi^2 = 0.000039$) and root means square error (RMSE = 0.0056). Also, from table (2) Wang and Singh model gave the lowest average values of coefficient of determination ($R^2 = 0.9425$) and the highest average values of standard error (SE = 0.103565), reduced Chi-square ($\chi^2 = 0.01322$) and root means square error (RMSE = 0.1097). So, it was reasonable to assume that Diamanate *et al.* model represented the drying behavior of tomato slices in a hot air dryer accurately and it was followed by Page model. Figure (5) showed comparison between the calculated and the experimental moisture ratio of Diamanate *et al.* model and Page model.

Table (2) also demonstrated that as air temperature rised, the drying constants (k) of Lewis model, Henderson and Pabis model, Logarithmic model, ($k_o$) of Two Term Model, (A and B) of Wang and Singh model all increased.



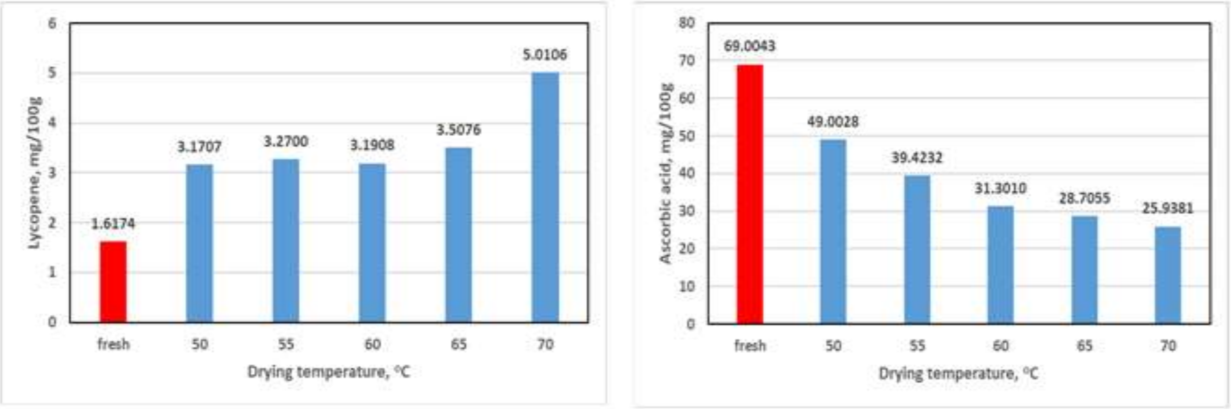
**a. Diamanate *et al.* model** **b. Page model**

**Figure 5. Relationship between the calculated and the experimental moisture ratio of Diamanate *et al.* model and Page model**

**Effect of drying temperature on some quality characteristics of dried tomato slices:**

Effect of drying temperature on the content of lycopene and ascorbic acid in dried tomato slices was shown in figure (6). It could be noted that content of lycopene in dried tomato slices was higher than that of fresh tomatoes, and the highest value of lycopene content was found in dried tomato slices at a temperature of 70 °C.

Tomato slices dried at 50, 55, 60, and 65 °C had an average lycopene content of (3.285 mg/100 g) that was 2.03 times greater than that of a fresh sample (1.6174 mg/100 g). While lycopene amount in samples dried at 70 °C (5.0106 mg/100 g) was 3.1 times greater than that in fresh samples. According to Goula and Adamopoulos, (2005), high-temperature processing stabilizes or slightly reduces the fruit's lycopene content.



a. Lycopene content b. Ascorbic acid content

**Figure 6. Effect of drying temperature on lycopene and ascorbic acid content of tomato slices.**

The previous figure showed that the higher the drying temperature, the greater loss in the ascorbic acid content, compared to the content of fresh samples (69.0043 mg/100 g solid weight). Ascorbic acid retention was nearly 71.01%, 57.13%, 45.36%, 41.59%, and 37.59% for samples dried at 50, 55, 60, 65, and 70 °C, respectively. As a result, the ascorbic acid reduction was the highest at 70 °C (62.41%) and the lowest at 50 °C (28.99%). The current study therefore suggests that tomato samples dried at 50 °C were better able to uphold the heat-labile ascorbic acid. Das Purkayastha *et al.*,

(2013) reported similar results for tomato slices and Mudgal and Pande (2009) for bitter gourd.

## CONCLUSIONS

The drying properties of tomato slices were studied using a hot air at air temperature ranging from 50 to 70 ºC. The constant drying rate period was not observed, while the tomato slices were dried during the falling drying rate period at all temperature levels. The moisture content of tomato slices was reduced from 751.79% on a dry basis to a final moisture content of 10% ± 0.6 on a dry basis over a period of time ranging from 170 to 310 minutes. The effective moisture diffusivity was in the range ($9.9801\times10^{-10}$ - $1.8871\times 10^{-9}$ $m^2s^{-1}$) and the activation energy value (32.94 kJ/mol.). Diamanate *et al*.'s model gave the best description of the experimental data, following Page's model. The lycopene content of fresh tomatoes was lower than that of dried tomato slices, while the ascorbic acid content decreased with increasing air drying temperature.

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# خصائص تجفيف طبقة رقيقة من شرائح الطماطم في مجفف الهواء الساخن

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## الملخص

تمت دراسة خصائص التجفيف لشرائح الطماطم باستخدام مجفف الهواء الساخن تحت خمسة مستويات مختلفة من درجة حرارة الهواء تتراوح من 50 إلى 70 $^{o}$م ، وسمك ثابت لشرائح الطماطم 5 ± 0.2 مم ، ومعدل تدفق ثابت لهواء التجفيف 0.07 م $^{3}$/ ثانية. تم رش شرائح الطماطم قبل التجفيف باستخدام 5٪ كلوريد الصوديوم وتركها لمدة ساعتين لتسهيل خروج الرطوبة والحفاظ على الطماطم أثناء التجفيف. تم حساب كل من معدل انتشار الرطوبة الفعالة $D_{eff}$ وطاقة التنشيط. تم اختبار ثمانية نماذج رياضية مختلفة لاختيار أفضلها لوصف منحنيات التجفيف. تم تقييم جودة شرائح الطماطم المجففة من خلال تقدير محتوى اللايكوبين وحمض الأسكوربيك. أوضحت النتائج أن عملية تجفيف شرائح الطماطم حدثت خلال فترة معدل التجفيف المتناقص عند جميع مستويات درجات الحرارة. انخفض المحتوى الرطوبي لشرائح الطماطم من 751.79٪ على اساس جاف إلى محتوى رطوب نهائي 10٪ ± 0.6 على اساس جاف خلال فترة زمنية تتراوح من 170 إلى 310 دقيقة. تراوحت القيم المتوسطة لمعدل انتشار الرطوبة الفعالة من $9.9801 \times 10^{-10}$ إلى $1.8871 \times 10^{-9}$ متر مربع / ثانية في مدى درجات الحرارة قيد الدراسة وقدرت طاقة التنشيط بـ 32.94 كيلوجول / مول. أشارت جودة اختبارات الملاءمة إلى أن نموذج Diamanate *et al.* أعطى افضل وصف للنتائج التجريبية ويلية نموذج Page. أوضحت النتائج أن محتوى اللايكوبين في شرائح الطماطم المجففة أعلى من محتوى الطماطم الطازجة. بينما انخفض محتوى حامض الاسكوربيك مع زيادة درجة الحرارة.

***الكلمات الدالة:*** الهواء الساخن – التجفيف – شرائح الطماطم – النمذجة – الليكوبين.