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DRYING AND STERILIZATION OF TOMATO SLICES USING INFRARED RADIATION

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ABSTRACT : Experiments were carried out to assess the utilization of infrared radiation for drying and sterilizing tomato slices using an infrared dryer. To fulfill the objective of this research work, some operating parameters affecting the performance of the infrared dryer were taken into consideration: Three different levels of infrared intensity (0.973, 1.093, and 1.161 kW/m^2), three different inlet air temperatures (40, 50 and 60°C) and three different tomato slices thicknesses (3, 5 and 7mm). The experimental work included the use of the simple exponential model (Lewis's 1921) for describing the drying behavior and predicting the changes in moisture content of tomato slices during the drying process. Evaluation of the infrared dryer was carried out taking into consideration tomato slices moisture ratio and final dried tomato slices quality. The obtained data reveal that the final dried tomato slices quality in terms of ascorbic acid, total phenolic content, lycopene pigment and antioxidant activity were in the optimum region with the use of the infrared dryer under conditions of 0.973 kW/m^2 radiation intensity, 50 ^{0}C air temperature and 5 mm tomato slices thickness. The findings illustrated that the investigated model (Lewis's 1921) could describe the drying behavior of tomato slices satisfactory.

Key words: Dehydration, infrared, tomato, drying model, moisture ratio.

INTRODUCTION

Tomato is an important agricultural commodity worldwide. Tomato crop is noted to be the second most important vegetable crop next to potato. It is a source of vitamins A and C and mineral salts, such as K and Mg. It is the main vegetable grown and most widely consumed and is therefore of strategic importance.

Tomato (*Lycopersicon esculentum Mill.*), along with playing an important role in human nutrition is the most commercially produced vegetable in the world that is consumed in both fresh and processed form, such as tomato paste, ketchup, pickles, etc. Tomatoes are cultivated in many countries around the world. It is considered the most important vegetable crops grown in Egypt for exportation and local consumption. Tomato is the most important horticultural crop in Egypt. It is grown in all governorates and throughout the year within the three seasons; winter, summer and Nili (fall). It occupies the first place among horticultural crops in terms of volume of production. The tomato production is 7.7 million Mg representing 36% of the total vegetable production (in 2015). It also occupies the first place in terms of cultivated area with about 469 thousand feds (197 thousand ha) representing 22.1% of the total area of vegetables (**Siam and Abdelhakim, 2018**).

To increase the shelf life of tomatoes, different preservation techniques are being employed; however, the success of these methods depends on how it meets certain requirements of the product quality for consumption. Many developing countries still face enormous challenges of post-harvest losses of tomatoes due to inadequate processing and storage facilities. Tomatoes produced in the peak seasons are either

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consumed fresh, sold at relatively cheap prices, or are allowed to go waste **(Abano and Sam-Amoah, 2011; Corrêa *et al*., 2012; Hussein *et al*., 2016; Ismail and Akyol, 2016)**.

Drying is a very common preservation method used in foodstuffs. The quality of the final products is strongly dependent on the technique and the process variables used. The reduction of water activity by moisture removal leads to a significant reduction of weight and volume, minimizing packaging, transportation and storage costs. Drying also alters other physical, biological and chemical properties of foods **(Demirhan and Özbek, 2010)**. Dehydration of foods is aimed at producing a high-density product, when adequately packaged has a long shelf time, after which the food can be rapidly and simply reconstituted without substantial loss of flavor, color, taste and aroma. Water removal from agricultural and food materials is very energy intensive. The efficiency of drying with respect to both energy and time is an important economic consideration **(Sorour and El-Mesery, 2014).**

New and innovative techniques that increase the drying rate and enhance product quality have achieved considerable attention in the recent past. Drying by infrared radiation is one among them, gaining popularity because of its inherent advantages over conventional heating. Infrared radiation has significant advantages over conventional drying such as, higher drying rates with significant energy savings, and uniform temperature distribution. Therefore, it can be used as an energy saving drying process. **Sadin *et al*. (2014)** investigated thin layer drying of tomato slices in the infrared dryer. Drying rate increased with increasing temperature and reduction thickness and thus reduced the drying time. The effective diffusivity increased with increasing temperature and with increasing thickness of the samples. The effective diffusivity values changed from 1.094×10^{-9} to 4.468×10^{-9} m^2/s and for activation energy varied from 110 to 120 kJ/mol. **Kocabiyik *et al*. (2015)** stated that infrared drying of tomato provided good nutrient retention and low cost of energy. Therefore, infrared radiation can be suggested in both nutritional and operational aspects in terms of drying tomato slices. At present, it was applied in different driers using infrared radiators. The mechanism of these radiators, as an energetic advance that can give high drying efficiency, clean environment, space saving, etc.

However, research which quantitatively analyzed heating and drying by infrared radiation are limited in the literature **(Corrêa *et al*., 2012; Matouk *et al*., 2014 and Hussein *et al*., 2016)**.

Given the importance of studies on drying, the objective of this investigation is to study and evaluate the use of infrared radiation as a heat energy source for drying and sterilizing tomato slices as a new approach for decreasing the drying time and enhancing the product quality.

MATERIALS AND METHODS

The main experiments were carried out through the year of 2020 in Agricultural Engineering Institute workshop in Dokki, Cairo, Egypt. Agricultural Research Center (ARC).

Materials

Freshly-harvested tomato fruits (*Lycopersicon Esculentum* L.) available in the local market was selected visually for ripeness, size and physical damage for the present investigation. The average diameter and mass of tomato fruits were 5.55 cm and 125.8 g, respectively. Tomato fruits was sliced at 3,5 and 7 mm thicknesses using a hand tool slicer with control mechanism for slice thickness. To determine the initial moisture content of the samples, four samples, were dried in a German electric oven 1.2 kW (BINDER) at 105^0C for 24h **(Abano *et al.*, 2013)**. The average initial moisture content of tomato slices was found to be 93.5% (wet basis).

The Laboratory Scale Infrared Dryer

Fig. 1 illustrates a schematic view of the laboratory scale infrared dryer used during the experimental work. The laboratory scale infrared dryer consists of the following main parts:

Drying bed

The drying bed consist of one drying tray. The tray constructed of iron frames of 45´* 44´* 50 cm (L´* W´* H) and the base of the tray is made of the stainless steel wire net.

Infrared heating system

For heating and temperature control of the dryer, two (1 kW) ceramic Infrared heaters (German-750°C) were fixed over two iron blades and assembled into the sealing of drying chamber facing the drying tray.

Air heating and air temperature control system

For moisture removal from the drying chamber, two electric heaters were used for air heating of drying chamber. The heating circuit of drying chamber consists of two 1 kW– Italian electric heaters.

Drying air supply and distribution

One identical axial flow fan model OLMO – 10 W – 1300 rpm was used for suction of heated air in a parallel direction over the surface of drying tray.

Methods

Experiments were carried out to study and evaluate the performance of the infrared dryer under different operational parameters.

Experimental Treatments

The experimental treatments include the followings:

- Three different levels of infrared radiation intensity of (0.973, 1.093, and 1.161 kW/m^2).
- Three different levels of inlet air temperature of (40, 50 and 60 °C).
- Three different levels for tomato slices of (3, 5 and 7 mm).

Measurements

Radiation intensity measurement

A radiation sensor with data recorder (model H-201) was used for measuring of radiation intensity. This unit is a self-contained direct reading portable instrument.

Air velocity measurement

A TRI-SENSE air velocity meter (model YK- 2005AH) was used for measuring the air velocity over the surface of drying tray with an accuracy of 0.01 m/s. The unit is a self – contained direct reading portable instrument.

Temperature measurement

The air temperature was measured inside the drying chamber by means of a thermostat ELIWELL, equipped with a sensor located above the surface of the drying tray, and when the temperature of the heaters reaching the required level, the heaters will automatically disconnected.

Mass measurement

The mass of samples was recorded using a digital balance (Sartorius Gmbh Gottinge) made in Germany, with an accuracy of 0.01g. The balance was used for determining the mass changes of tomato slices throughout all experimental runs. The scale is located in a separated chamber, located under the drying chamber.

The examined drying model for simulation of the drying data

The obtained data of the laboratory experiments was employed to examine the applicability of thin layer drying model (**Lewis's, 1921**) for describing and simulating the drying data. The examined drying model could be presented as follows:

Lewis's model:

$$MR = \frac{M - M_f}{M_o - M_f} = exp\,(-K_L\ t) \quad \ldots\ldots\ldots (1)$$

Where:

MR - Moisture ratio, dimensionless.

M - Instantaneous moisture content during the drying process, % (d.b.).

Mo - Initial moisture content of tomato slices, % (d.b.).

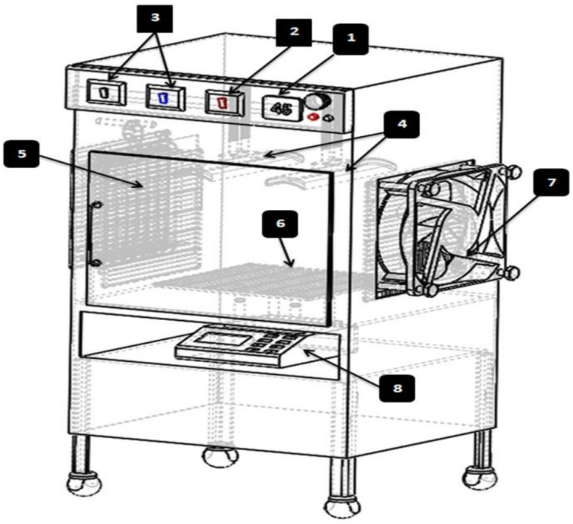
Mf - Final moisture content of tomato slices, % (d.b.).

K_L - Drying constants, min-1.

t - Drying time, min.

Measurement of dried tomato slices quality

Dried tomato slices quality was measured in terms of ascorbic acid, total phenolic content, lycopene pigment and antioxidant activity at different levels of infrared radiation intensity, drying air temperature and slices thickness.



No.	Part name	No.	Part name
1	Thermostat	5	Electric heaters
2	Fan switch	6	Samples tray
3	Electric dimmers	7	Axial flow fan
4	Infra-red heaters	8	Digital balance

Fig. 1. Schematic view of the developed infrared dryer

RESULTS AND DISCUSSION

Effect of Some Drying Parameters on Tomato Slices Moisture Ratio

Figs. 2, 3 and 4 illustrated the change in tomato slices moisture ratio as related to drying time at different levels of drying air temperature, radiation intensity and slices thickness. As shown in the figures, the reduction in moisture ratio of tomato slices varied with the experimental parameters. It was increased with the increase of radiation intensity and the drying air temperature. Whilst it was decreased as tomato slices thickness increased.

Analysis of Tomato Slices Drying Using Lewis's Model

The values of drying constant (k_L) for the Lewis's model could be obtained from the exponential relationship between (MR) of the tested sample versus drying time for all studied drying parameters as shown in Figs. 5 and 6. The computed values of the drying constants are listed in Table 1.

As shown in Table 1, the drying constant (k_L) increased with the increase of drying air temperature and the increase of radiation intensity.

A multiple regression analysis was employed to relate (I, T and T_h) with the drying constant (k_L) at constant air velocity of 1 m/s. The analysis showed that, the nature of dependence could be expressed by the following equation:

K_L = - 0.11651 + 0118659 I + 0.000635 T – 0.00166 Th …………… (2)

$R^2 = 0.94149$, SE 0.00295

Where:

K_L - Drying constant,

T - Drying air temperature, ^{0}C

I - IR radiation intensity, kW/m^2

Th - Slices thickness, mm.

R^2 – Coefficient of determination

SE = Stander error

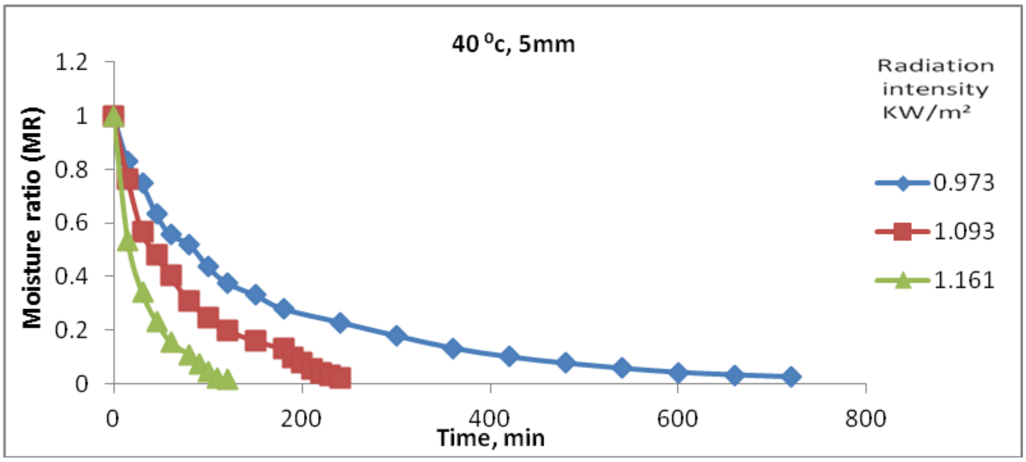


Fig. 2. Tomato slices moisture ratio as related to drying time at different levels of radiation intensity, air temperature 40°c and slices thicknesses 5 mm.

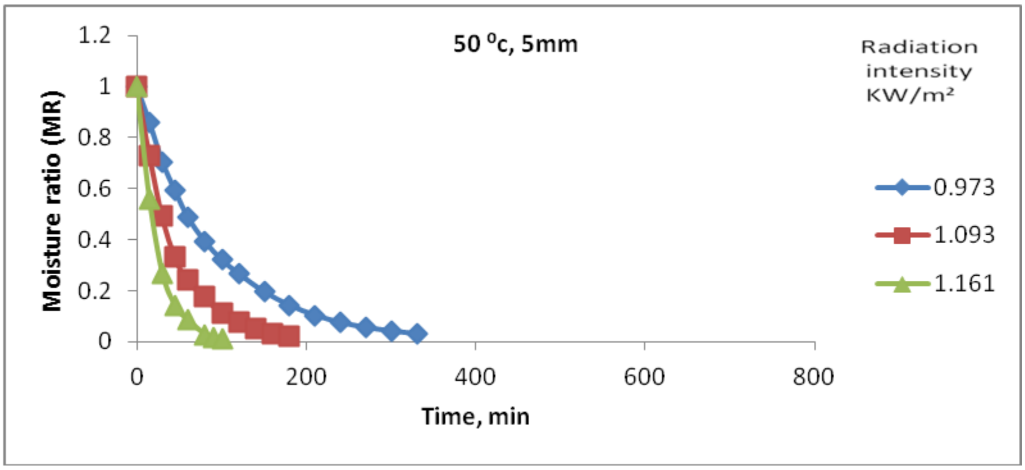


Fig. 3. Tomato slices moisture ratio as related to drying time at different levels of radiation intensity, air temperature 50°c and slices thicknesses 5 mm.

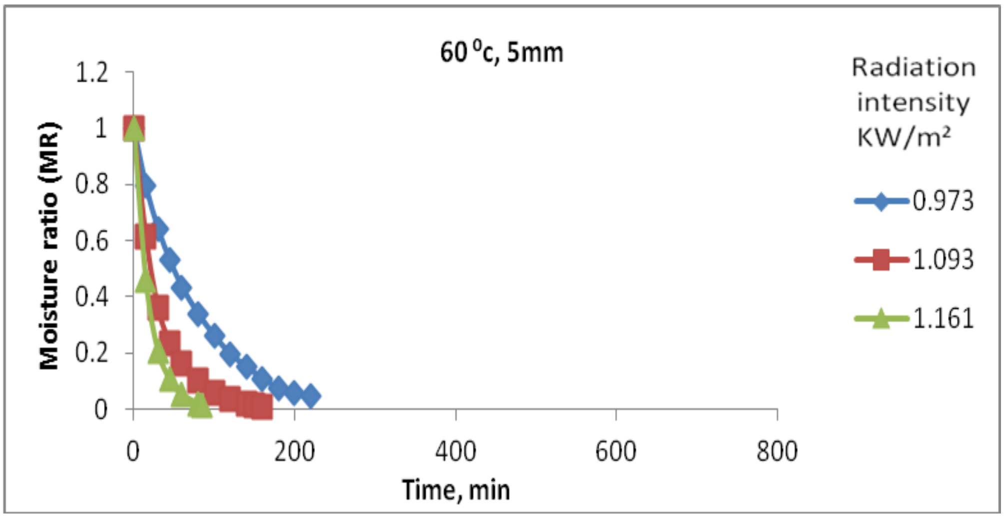


Fig. 4. Tomato slices moisture ratio as related to drying time at different levels of radiation intensity, air temperature 60°c and slices thicknesses 5 mm.

The Fitting curves examine the applicability of Lewis's model in simulating the laboratory experimental drying data showed that, equation (2) described the drying behavior of tomato slices satisfactorily as indicated by the high values of coefficient of determination (R^2) and low values of slandered error (SE). Figs. (7 and 8) show the observed and calculated moisture ratio at the minimum and the maximum levels of drying air temperature, radiation intensity and slices thickness.

Dried Tomato Slices Quality

Ascorbic acid (Vitamin C)

Fig. 9 illustrated the changes in ascorbic acid of tomato slices at different levels of infrared radiation intensity, drying air temperature and slices thickness. As shown in the figure the range of ascorbic acid of tomato slices was from 220 to 80 mg/100g. Also, the recorded values of ascorbic acid ranged from 220 to 155, from 150 to 80 and from 190 to 110 mg/100g at radiation intensity of 0.973, 1.093 and 1,161 kW/ m^2 respectively.

In general, the tomato samples dried at radiation intensity of 0.973, air temperature of 50°C and slices thickness of 5mm recorded the highest ascorbic acid content of 220 mg/100g.

Total phenolic content

Fig. 10 illustrated the changes in total phenolic content of tomato slices at different levels of infrared radiation intensity, drying air temperature and slices thicknesses.

As shown in the figure the range of total phenolic content of tomato slices was from 10.22 to 7.44 mg/100g. Also, the recorded values of total phenolic content ranged from 10.22 to 8.01, from 9.93 to 7.89 and from 10.01 to 7.44 mg of gallic acid/g dry weight at radiation intensity of 0.973, 1.093 and 1,161 kW/m^2, respectively.

In general, the tomato samples dried at 0.973 kW/m^2, air temperature of 50^0C and slices thickness of 5mm recorded the highest total phenolic content of 10.22 mg of gallic acid/g dry weight.

Lycopene pigment

Fig. 11 illustrated the changes in lycopene pigment of tomato slices at different levels of infra-red radiation intensity, drying air temperature and slices thickness. As shown in the figure the range of lycopene pigment of tomato slices was in 52.3 and 36.2 mg/100g. Also, the recorded values of lycopene ranged from 52.3 to 36.2, from 49.1 to 37.1 and from 51.5 to 40.9 mg/100g at radiation intensity of 0.973, 1.093 and 1,161 kW/m^2, respectively. In general, the tomato samples dried at 0.973 kW/m^2, air temperature of 50°C and slices thickness of 5mm recorded the highest lycopene content of 52.3 mg/100g.

Antioxidant activity

Fig. 12 illustrated the changes in antioxidant activity of tomato slices at different levels of infra-red radiation intensity, drying air temperature and slices thickness. As shown in the figure the range of total antioxidant activity of tomato slices was in 94.86 and 90.99 %. Also, the recorded values of antioxidant activity ranged from 94.86 to 90.99, from 93.86 to 91.7 and from 93.98 to 91.08 %at radiation intensity of 0.973, 1.093 and 1,161 kW/m^2, respectively. In general, the tomato samples dried at 0.973 kW/m^2, air temperature of 50°C and slices thickness of 5mm recorded the highest antioxidant activity of 94.86%.

Conclusion

The experimental results revealed the following:

- The current investigation confirmed the effectiveness of drying tomato slices by infrared radiation
- The reduction in moisture ratio of tomato slices was varied with the experimental treatments and it was increased with the increase of radiation intensity, and the drying air temperature.
- The drying constants (k_L) of Lewis's model increased with the increase of drying air temperature and the increase of the radiation intensity and decreased with the increase of slices thickness.
- The drying constants of Lewis's model (k_L) was found to be directly proportional to air temperature and radiation intensity.
- The studied Lewis's model could describe the drying behavior of tomato slices satisfactorily as indicated from the higher coefficient of determination for the model.
- The tomato samples dried at 0.973 kw/m^2, air temperature of 50^0C and slices thickness of 5 mm recorded the highest ascorbic acid of 220 mg/100g, total phenolic of 10.22 mg/g, lycopene of 52.3 mg/100g, and antioxidant activity of 94.86%.

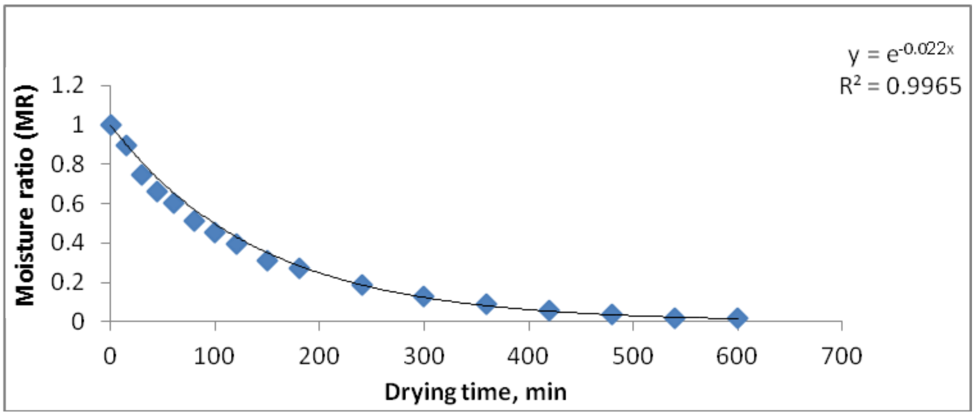


Fig. 5. Determination of the drying constant; (k_L) of Lewis's equation at the minimum radiation intensity of 0.973 kW/m^2, air temperature of 40 ^{0}C and 3 mm slice thickness

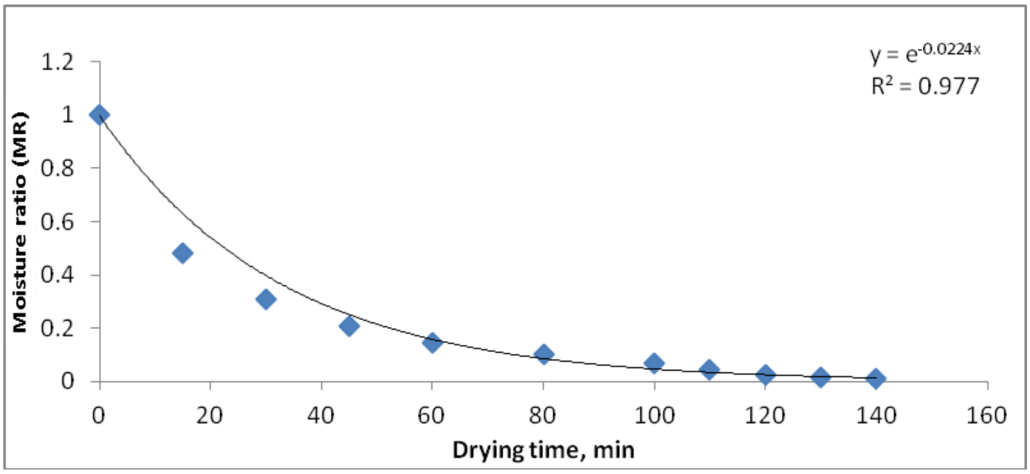


Fig. 6. Determination of the drying constant; (k_L) of Lewis's Equation at the maximum radiation intensity of 1.161 kW/m^2, air temperature of 40 °C and 7mm slice thickness

Table 1. Drying constant (k_L) for Lewis's equation at different levels of radiation intensity, air temperature and slices thickness

Infra-red radiation Intensity, kW/m^2	Thickness, mm	Air temperature, °C		
		40	50	60
	3	0.0228	0.0259	0.0277
0.973	5	0.0204	0.0233	0.0255
	7	0.0176	0.0192	0.0224
	3	0.0314	0.0396	0.0445
1.093	5	0.0297	0.0367	0.0424
	7	0.0258	0.0316	0.0388
	3	0.0388	0.0487	0.0598
1.161	5	0.0357	0.0454	0.0557
	7	0.0317	0.0409	0.0514

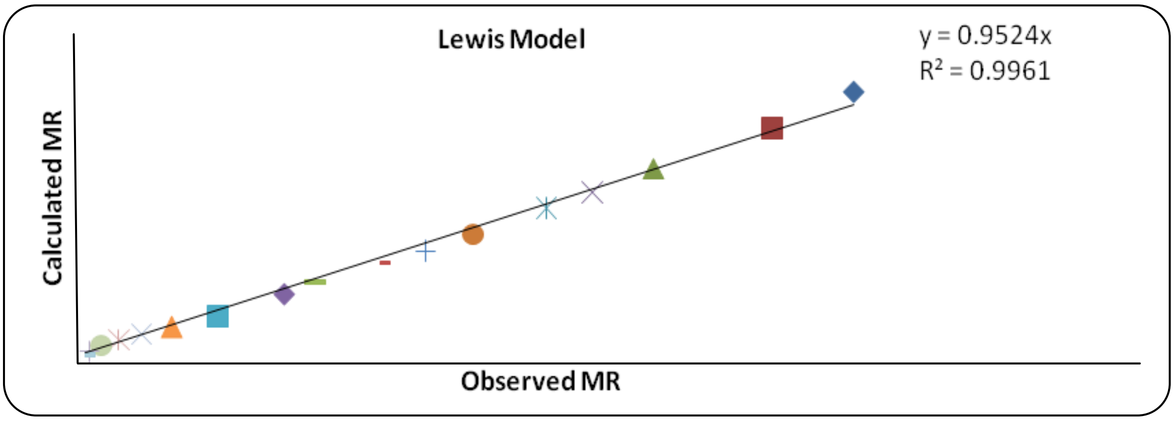


Fig. 7. Observed and calculated values of tomato slices moisture ratio using Lewis's model at (T) 40^{0}C, (I) 0.973 kW/m^2 and 3 mm slices thickness

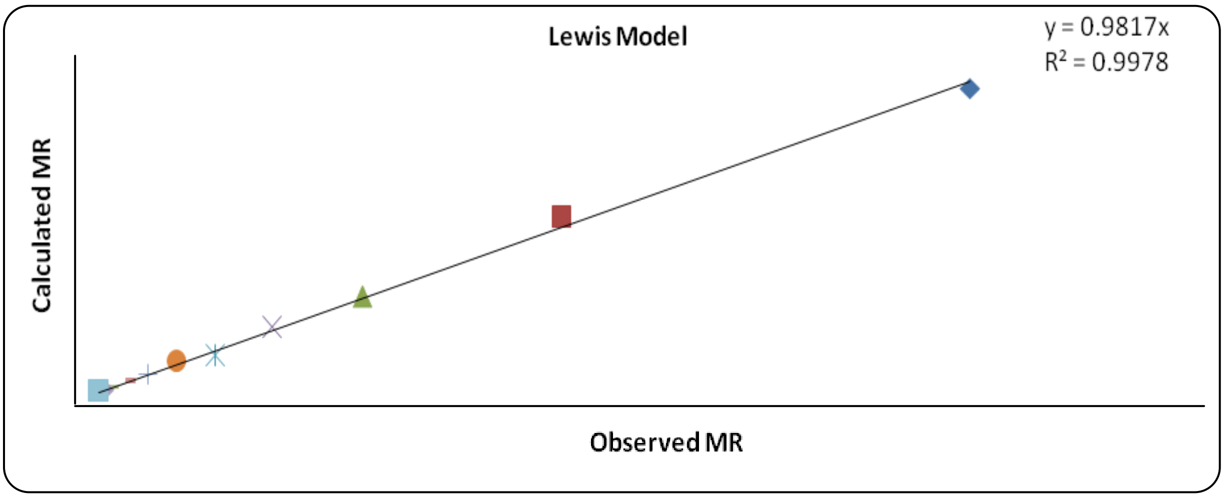


Fig. 8. Observed and calculated values of tomato slices moisture ratio using Lewis's model at (T) 40^{0}C, (I) 1.161 kW/m^2 and 7 mm slices thickness

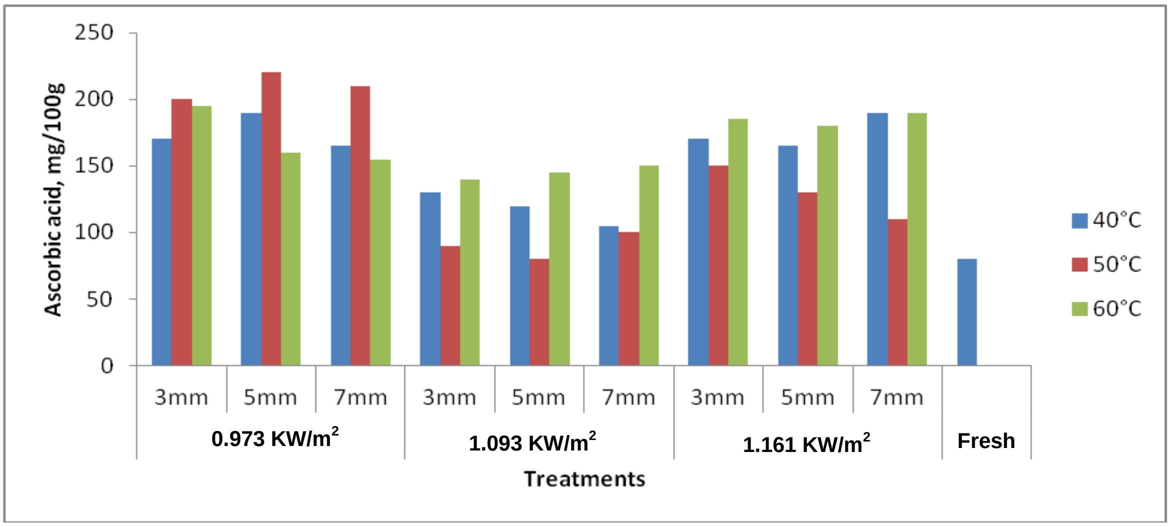


Fig. 9. The changes in ascorbic acid of dried tomato slices at different levels of infrared radiation intensity, drying air temperature and slices thicknesses

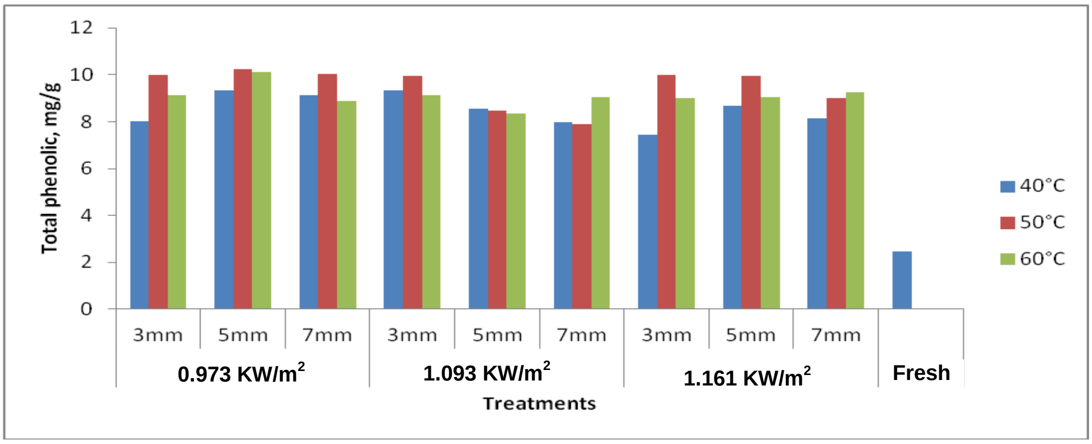


Fig. 10: The changes in total phenolic content of dried tomato slices at different levels of infrared radiation intensity, drying air temperature and slices thickness

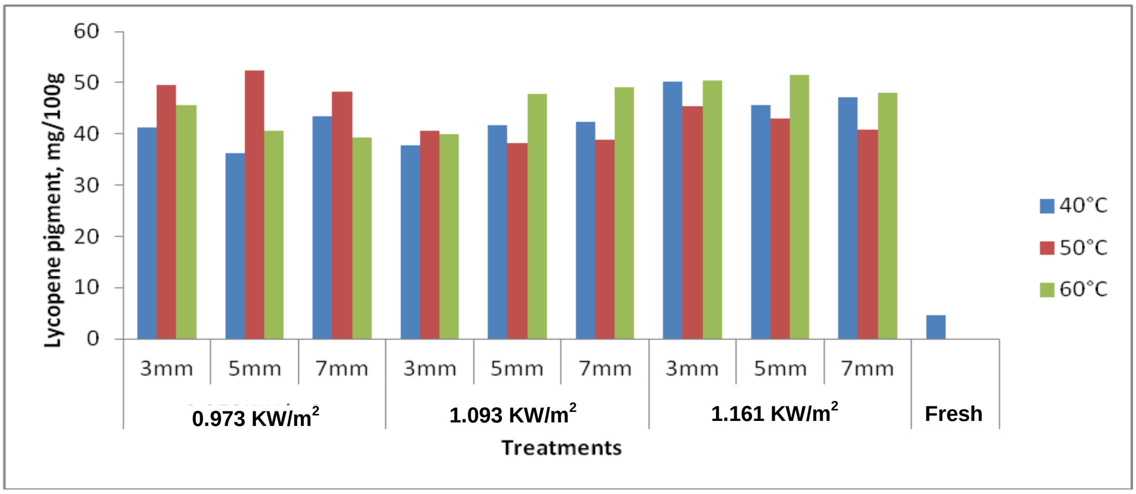


Fig. 11. The changes in lycopene pigment of dried tomato slices at different levels of infrared radiation intensity, drying air temperature and slices thickness

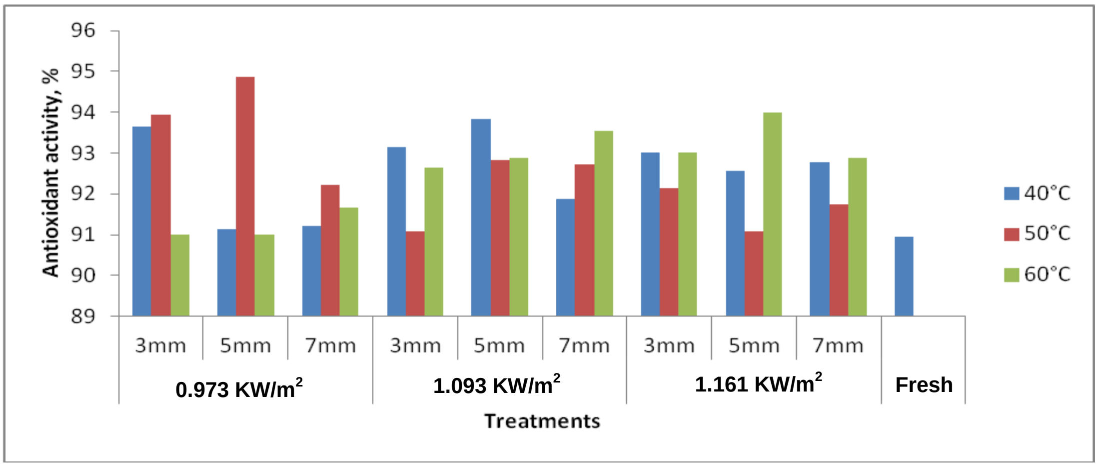


Fig. 12. The changes in antioxidant activity of dried tomato slices at different levels of infra-red radiation intensity, drying air temperature and slices thickness

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تجـفيـف وتعقيـم شـــــرائـح الطمـــاطـــم بـاســــتخـدام الأشـــــعة تحـــت الحمــــراء

هند أحمد على ابراهيم[1] ـ محمد محمد مراد حسن[2] ـ محمود مصطفى على على [2]ـ محمد مصطفى الخولى[1]

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أجريت هذه الدراسة لاختبار وتقييم استخدام الأشعة تحت الحمراء كمصدر للطاقه الحرارية لتجفيف شرائح الطماطم باستخدام مجفف تم تصنيعه في ورشة خاصة بمدينة القاهرة، وشملت المتغيرات التجريبيه ثلاث مستويات لشده الاشعاع هي: (0.973 ، 1.093 ، 1.161 كيلو وات/م^2)، وثلاث مستويات لدرجه حراره الهواء المستخدم في حمل الرطوبه هي: (40، 50 ، 60 درجه مئوية) وثلاث مستويات لسمك شرائح الطماطم هي: (3 ، 5 ، 7 مم) مع تثبيت سرعه الهواء المستخدم عند 1 م/ث وقد اجريت التحاليل الرياضية للنتائج المتحصل عليها باستخدام معادلة لوصف سلوك تجفيف شرائح الطماطم وهى معادلة (لويس 1921). تم تقييم الأداء أخذاً في الاعتبار كلا من نسبة الرطوبة لشرائح الطماطم المجففة إضافة الى جودة شرائح الطماطم المجففة الناتجة. أظهرت النتائج المتحصل عليها ما يلى: أعطت معادله (لويس1921) نتائج دقيقة للتنبؤ بالتغير في المحتوي الرطوبي لشرائح الطماطم، أظهرت اختبارات الجودة لشرائح الطماطم المجففة ان شدة الإشعاع 0.973 كيلو وات/م^2 عند درجة حرارة 50 درجة مئوية وسمك شرائح 5 مم قد أعطت أفضل النتائج من حيث الحفاظ علي أعلي نسبة لمضادات الاكسدة والليكوبين.

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