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INFRARED DRYING OF LEMON SLICES

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ABSTRACT

A study was carried out to test and evaluate the use of infra-red radiation as heat energy source for drying lemon slices. A laboratory scale dryer was developed and tested at the laboratory of Agric. Eng. Dept. Fac. of Agric. Mansoura Univ. The experimental treatments included three different levels of radiation intensity (0.973, 1.093, and1.161 kW/m^2), three different air temperatures (40, 50 and 60°C) and constant air velocity of 1 m/sec. The drying behavior was simulated using two different thin layer models (Lewis's and Henderson, and Pabis's). The studied models were compared with the obtained drying data, and the most suitable model for predicting the change in lemon moisture content during drying process was then assessed. Final quality of the dried lemons was also determined. The results show that, both studied models could describe the drying behavior of lemons satisfactorily. However, Lewis's model considered more proper for describing the drying behavior and predicting the changes in moisture content in terms of precision and application simplicity. The quality tests of the dried lemons showed that, radiation intensity of 0.973 kW/m^2 with air temperature of 50°C recorded the best dried lemon quality in terms of higher retention of ascorbic acid (Vitamin C), citric acid and total soluble sugars.

INTRODUCTION

Citrus, Citrus., is considered as one of the most important crops in all countries of the world. In Egypt, citrus rank third after cotton and rice. It is primarily valued for the fruit, which is either eaten alone (sweet orange, tangerine, grapefruit, etc.) as fresh fruit, processed into juice, or added to dishes and beverages (lemon, lime, etc.). (Manner *et al.,* 2006)

Citrus is a major export product of Egypt. The total cultivated area for citrus fruit is about 529,290.5 feddan and total production is estimated 2,149,349 ton/year. The average volume of citrus exported to various countries during 1997–2000 ranged from 205,800 to 210,500 tons. (Biosecurity, 2002)

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. (Sharma *et al.,* 2005)

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 (Mongpraneet *et al.,* 2002).

Experimental studies on infrared drying of various food products including vegetables and fruits have been reported by (Ginzburg, 1969). Application of infrared radiation to food processing has gained momentum due to its inherent advantages over hot-air heating. Infrared processing has been tried in baking, roasting, thermal treatments (blanching, pasteurization, sterilization, etc.) and drying of foodstuffs. In general, far infrared radiation is advantageous for food processing because most food components absorb radiative energy in the FIR region (Sandu, 1986).

Hot-air drying is the most commonly employed commercial technique for drying of biological products.(Mazza and Lemaguer, 1980). Dehydrated whole and sliced limes are unique products, consumed mainly in the Middle East and gulf area. However, there is no readily available information about the drying of lime fruit using infrared heating, and its effect on the changes that occur in their quality and flavor profile as a result of processing.

The general objective of the present work was to study and evaluate the use of infrared radiation as a source for heat energy drying lemon slices as a new approach for decreasing the drying time and enhancing the product quality.

MATERIALS AND METHODS

Materials:

Tested crop:

Freshly-harvested lemon fruits *(Citrus aurantifolia)* were used for conducting the experimental work. The initial moisture content of the freshly harvested lemon ranged from 88% to 92% (dry basis). Lemon was cut into slices (4:6) mm thickness and the drying runs were stopped when the final moisture content reached about ~5 % (d.b.).

Structure of the laboratory scale infrared dryer:

Fig. (1) illustrates a schematic view of the laboratory scale dryer used during the experimental work.

As shown in Fig. (1) the drying bed consists of three drying chambers. Each chamber constructed of an iron frame of 40 × 70 × 50 mm (L × W × H). The base of each chamber is made of stainless steel wire net and used for accommodating a drying tray. The three drying trays are supported inside the dryer body in vertical position under the heat source with distances of 15 mm between the trays and the heat sources.

For heating and temperature controlling of the dryer, two (1 kW) ceramic Infrared heaters were fixed over two iron blades and assembled of the top of each drying chamber facing the drying tray. For controlling the distance between the ceramic heaters and the drying trays, screw rods are used to allow movement of the heaters up and down. To control the radiation intensity of the infrared heaters, a set of dimmers are used.

For moisture carrying process a hot air stream was passed in parallel to the lemon samples at each tray. The air heating circuit of each drying chamber consists of 2 kW electric heaters fixed over the surface of an iron net in order to increase the area of air contact with the heating source.

The air temperature control was consisted of a precise digital thermostat for stopping and connecting the heaters and keeping the pre-adjusted temperature constant throughout each experimental run.

For air supply three identical axial flow fans model OLMO are used. Each fan is assembled in one side of each drying chamber facing the heater. The drying air is supplied equally to each drying chamber using a speed control electric switch.

Experimental Treatments:

The experimental treatments are included the following:

1-Three levels of infrared radiation intensity (0.973, 1.093, and 1.161 kW/m^2).

2-Three levels of inlet air temperature (40, 50, and 60° C) and constant air velocity at 1 m/sec are used as recommended by *(Sharma* et al., *2005; Arafa, 2007)*.

Test procedure and measurements:

After it is clear that, the radiation intensity, air temperature and air velocity are stabilized, the lemon samples distributed uniformly as a single layer on the tray which is then placed directly inside the drying bed. At the same time three sub samples each of 10-20 g are taken to determine the initial moisture content using the drying oven method as recommended by (AOAC, 1995).

The observation on mass loss changes for lemon slices were recorded every 10 min until the end of each drying run (until the moisture content of the lemon reached ~5% (d.b.).

In order to minimize the experimental errors of each run, it is replicated three times, and the average is considered.

Measurements and Instrumentation

Moisture content determination:

Initial and final moisture contents of lemon fruits are determined by the method described in A.O.AC. (1995) with an electric oven adjusted at 70°C for 16 hours.

1-Radiation intensity measurement:

A radiation sensor with data recorder (model H-201) is used for the measurement of radiation intensity.

2-Air velocity measurement:

A TRI – SENSE temperature / humidity / air velocity meter is used for measuring the air velocity with an accuracy of 0.01 m/s. The unit is a self – contained direct reading portable instrument.

3-Quality evaluation tests:

The quality evaluation tests of the dried lemon slices included; determination of ascorbic acid, citric cid, and total soluble sugars.

4-Temperature measurement:

A temperature meter model (Trotec 2000S) connected with an Iron – Constantan thermocouple type (T) is used to measure air and sample temperatures.

The examined drying models for simulating the drying data:

The obtained data of the laboratory experiments are employed to examine the applicability of the two studied thin layer drying models (Lewis's and Henderson, and Pabis's equations) on describing and simulating the drying data, as follows:

1-Lewis's model:

$$MR = \exp(-k_L\, t) \qquad (1)$$

$$MR = \frac{M - M_f}{M_o - M_f}$$

Where,

MR	=Moisture ratio, dimensionless	
M	=Instantaneous moisture content during drying process,	% (d.b)
M_0	=Initial moisture content of lemon samples,	% (d.b)
M_f	=Final moisture content of lemon samples,	% (d.b)
k_L	=Drying constants,	min^{-1}
t	=Drying time,	min

Lewis's model has been applied to fit the drying data of sliced lemons after converting its form to the logarithmic form relating the moisture ratio (MR) with the elapsed drying time (t) as follows:

$$\text{Ln MR} = (-kt)$$

The analysis was conducted based on using the final moisture content (M_f) for calculating the moisture ratio (MR).

2-Henderson and Pabis's model:

$$MR = A.\exp(-k_h\, t) \qquad (2)$$

Where,

A, k_h =Drying constants.

Henderson and Pabis's model has been also applied to fit the drying data of the lemon slices after converting its form to the exponentially form and calculating the constants (k_h and A).

RESULTS AND DISCUSSION

1 - Influence of drying parameters on the change in lemon moisture ratio:

Fig. (2) illustrates the change in lemon slices moisture ratio as related to the drying time at different levels of drying air temperature and radiation intensity. It evidently that, the reduction in moisture ratio of lemon varied with the experimental treatments and it was increased with the increase of radiation intensity, and the drying air temperature.

Fig. (2) Lemon slices moisture ratio as related to drying time at different radiation intensity and different drying air temperatures.

Analysis of thin layer drying using Lewis's equation:

The values of drying constant (k_L) for the Lewis's model (1) could be obtained from the exponential relationship between the moisture ratio (MR) of the tested sample versus drying time (t) for all studied drying parameters as shown in Fig. (3). The computed values of the drying constant (k_L) are listed in table (1).

Fig. (3): Determination of the drying constant; (k_L) of Lewis's equation at the maximum radiation intensity of 1.161 kW/m^2 and minimum and maximum heating air temperatures.

Table (1): Drying constant (k_L) for Lewis's equation at different levels of radiation intensity and air temperatures.

Infrared radiation intensity kW/m^2	Drying constant, k_L		
	Air temperature °C		
	40	50	60
0.973	0.0143	0.0164	0.0194
1.093	0.0256	0.0308	0.0385
1.161	0.0416	0.0521	0.0681

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 the studied parameters (I and T) with the drying constant (k_L) at constant air velocity of 1 m/sec. The analysis showed that, the nature of dependence could be expressed by the following equation:

$$k_L = 0.18952\,(I) + 0.00074\,(T) - 0.20685 \qquad ...(3)$$

[$R^2 = 0.8920$; SE = 0.00678]

Where,

k_L = Drying constant, 1/min
T = Drying air temperature, °C
I = IR radiation intensity, kW/m^2

Analysis of thin layer drying of lemon slices using Henderson and Pabis's equation:

The values of drying constant (k_h) and (A) for Henderson and Pabis's model (2) could be obtained from the exponential relationship between (MR) versus drying time (t). The exponent of the drying curve represents the drying constant (k_h) while the intercept represents the constant (A) as shown in Fig.(4). The computed values of the drying constants (k_h and A) are listed in table (2).

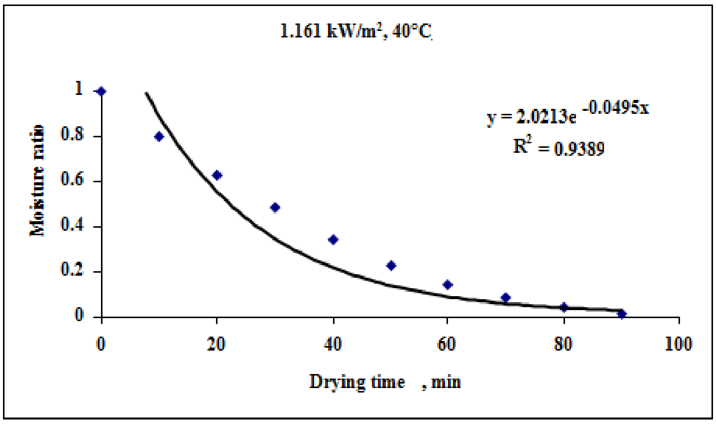

Fig. (4): Determination of the drying constant; (k_h,A) of Henderson and Pabis's equation at the maximum radiation intensity of 1.161 kW/m^2 and the minimum heating air temperature of 40°C.

As shown in table (2) the drying constant (k_h) increased with the increase of drying air temperature (T) and the increase of radiation intensity (I). The dependence of drying constant (k_h) of equation (2) on the experimental parameters was further studied using the multiple regression analysis. The obtained relationship could be presented as follows:

$$K_h = 0.24445(I) + 0.00099\,(T) - 0.27279 \qquad (4)$$

[$R^2 = 0.8912$; SE = 0.00884]

Table (2): Drying constant (k_h) at different levels of drying air temperature and radiation intensity.

Infrared radiation intensity kW/m^2	Drying constant, k_h		
	Air temperature °C		
	40	50	60
0.973	0.0127	0.0187	0.0228
1.093	0.0263	0.0370	0.0440
1.161	0.0495	0.0681	0.0816

Meanwhile, the drying constant (A) was calculated for different combinations of drying air temperatures and radiation intensity and listed in table (3).

Table (3): The calculated drying constant (A) of equation (2).

Infrared radiation intensity kW/m^2	Drying constant, A		
	Air temperature °C		
	40	50	60
0.973	1.1608	1.3683	1.4817
1.093	1.5940	1.7483	1.9850
1.161	2.0213	2.2861	2.6466

It clearly reveals that, the values of constant (A) increased with the increasing of drying air temperature (T) and the increase of the radiation intensity (I). The dependence of drying constant (A) of equation (2) on the experimental parameters was tested using multiple regression analysis. It was found that, the drying constant (A) is depending upon the drying air temperature and infrared radiation intensity (I).

The nature of dependence could be expressed by the following equation:

$A = 5.03937 (I) + 0.02229 (T) - 4.72478$ ...(5)

[$R^2 = 0.9448$; SE = 0.1278]

Applicability of the drying models:

Lewis's model:

The results of simulation analysis indicated that, equation (2) described the drying behavior of lemon slices satisfactorily as indicated by the high values of coefficient of determination and low values of standard error (SE). Figs (5 and 6) show the measured and predicted values of moisture content at the minimum and the maximum levels of drying air temperature and radiation intensity.

Henderson and Pabis's model:

The results of simulation analysis indicated that, Henderson and Pabis's model also described the drying behavior and predicted the change in moisture content of lemon slices satisfactorily as indicated by the high values of coefficient of determination and low values of standard error. Figs. (7 and 8) reveal the measured and the predicted values of moisture content at the minimum and the maximum levels of drying air temperature and radiation intensity.

Fig. (5): Measured and predicted values of lemon slices moisture content using Lewis's model at (T) 40°C and (I) 0.973 kW/m^2.

Fig. (6): Measured and predicted values of lemon slices moisture content using Lewis's model at (T) 60°C and (I) 1.161 kW/m^2.

Fig.(7):Measured and predicted values of lemon slices moisture content using Henderson and Pabis's model at (T) 60°C and (I) 1.161 kW/m^2.

Fig.(8):Measured and predicted values of lemon slices moisture content using Henderson and Pabis's model at (T) 40°C and (I) 0.973 kW/m^2.

Comparative evaluation of the studied drying models:

A comparison study for the two drying models (Lewis's and Henderson and Pabis's models) was conducted to assess the most proper drying model for simulating and describing the drying behavior of lemon slices under the studied range of experimental parameters. In general, the overall average of the obtained coefficient of determination (R^2) and the standard error (SE) for the observed and predicted moisture content revealed that, both studied models could describe the drying behavior of sliced lemons satisfactory. On the other hand, Lewis's model could be considered more proper model in terms of precision and application simplicity for describing the drying behavior of lemon slices and predicted the change in moisture content during the laboratory drying process.

3-Lemon Samples Quality:

Total soluble sugar:

Fig. (9) illustrates the changes in total soluble sugar as related to radiation intensity and air temperature. As shown in the figures the total soluble sugar was ranged from 0.83 to 1.21%. However, the taste of the dried sliced lemon is the limiting factor for quality acceptance of the dried sliced lemons and varied for different consumers.

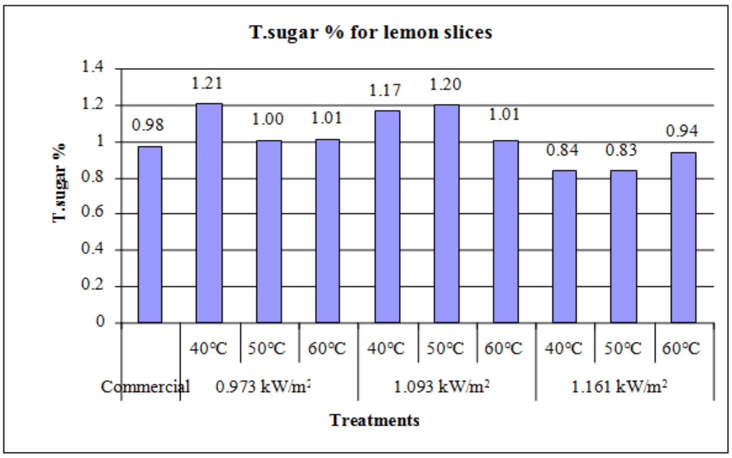

Fig. (9): Changes in the total soluble sugar for lemon slices at different levels of infrared radiation intensity and drying air temperature.

Citric acid:

Fig. (10) presents the percentage of citric acid. The dried sliced lemon showed higher citric acid percentage for all treatments as compared with the control sample dried under direct sun rays. The recorded percentages of citric acid ranged from 0.88 to 1.7% in comparison with 1.24% for the control sample. The figure also shows that, the radiation intensity of 0.973 kW/m^2 and air temperature of 50°C provided the highest percentage of citric acid (1.67%).

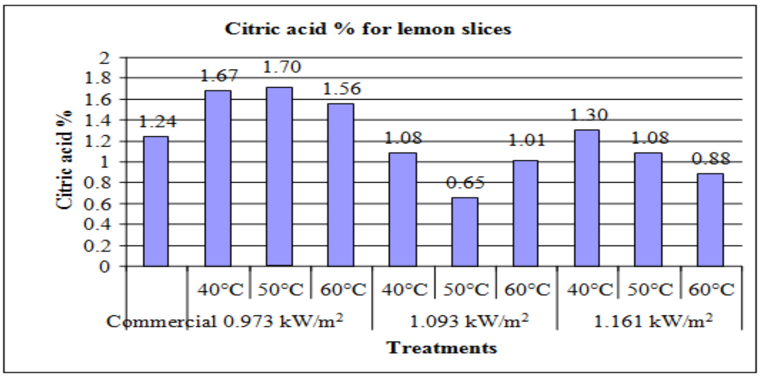

Fig. (10): Changes in citric acid for lemon slices at different levels of infra-red radiation intensity and drying air temperature.

Ascorbic acid (Vitamin C):

Fig. (11) presents the change in ascorbic acid of the dried lemon slices as related to different levels of radiation intensity and air temperature. The figure shows that, the commercial natural dried lemon under direct sun rays revealed lower level of ascorbic acid (48.9 mg/100 g dry matter) as compared with the ascorbic acid of the dried sliced lemons. As shown in the figure the ascorbic acid in the lemon slices treatment ranged from (39.6 to 63.4 mg/100 g dry matter). Meanwhile, radiation intensity of 0.973 kW/m^2 and air temperature of 50°C performed the highest retention for the ascorbic acid (63.4 mg/100 g dry matter).

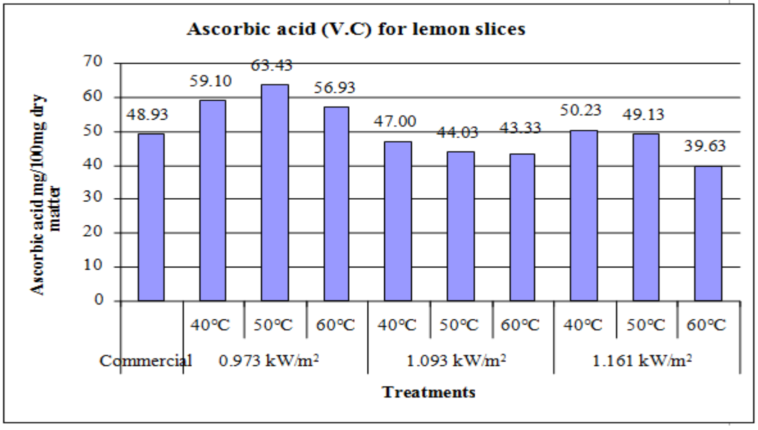

Fig. (11): Changes in ascorbic acid for lemon slices at different levels of infrared radiation intensity and drying air temperature.

CONCLUSIONS

1- The reduction in moisture ratio of lemon slices varied with the experimental treatments and it was increased with the increase of radiation intensity, and drying air temperature.
2- The drying constant (k_L) of Lewis's model increased with the increase of drying air temperature and radiation intensity.
3- The drying constants of Henderson and Pabis's model (k_h, A) increased with the increase of drying air temperature and the radiation intensity.
4- Both studied models could describe the drying behavior of lemon slices. However, the Lewis's model considered more proper for describing the drying behavior and predicting the changes in moisture content of lemon slices in terms of precision and application simplicity.
5- The percentages of total soluble sugar ranged from 0.83 to 1.21%, and the dried lemon slices provided the highest citric acid and ascorbic acid percentages at radiation intensity of 0.973 kW/m^2 and air temperature of 50°C as compared with the control sample dried under direct sun rays.

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تجفيف شرائح الليمون باستخدام الأشعة تحت الحمراء

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أجريت دراسة لإختبار وتقييم استخدام الأشعة تحت الحمراء كمصدر للطاقة الحرارية لتجفيف شرائح الليمون باستخدام مجفف معملي يعمل بالأشعة تحت الحمراء، تم تصنيعه واختباره بمعمل هندسة التصنيع بقسم الهندسة الزراعية- كلية الزراعة – جامعة المنصورة، وشملت المتغيرات التجريبية ثلاثة مستويات لشدة الإشعاع (٩٧٣.٠- ١.٠٩٣ – ١.١٦١ كيلو وات\م^{٢} وثلاث مستويات لدرجة حرارة الهواء المستخدم في حمل الرطوبة من الثمار (٤٠-٥٠-٦٠) درجة مئوية، مع تثبيت سرعة الهواء المستخدم عند مستوي ١ م\ث واختبار الشرائح بسمك يتراوح من ٤ الي ٦ مم. وقد أجريت التحليلات الرياضية للنتائج المتحصل عليها باستخدام معادلتين لوصف سلوك التجفيف لليمون المجفف في طبقة رقيقة وهما معادلتي (Lewis's and Henderson & Pabis's). أظهرت النتائج المتحصل عليها وصف كلا المعادلتين لسلوك التجفيف لثمار الليمون الكامل بصورة مرضية إلا أن معادلة (Lewis's) قد أعطت نتائج أكثر دقة للتنبؤ بالتغير في المحتوي الرطوبي لليمون كما أن تطبيق تلك المعادلة كان أكثر سهولة مقارنة بمعادلة (Henderson & Pabis's). من ناحية أخري أظهرت نتائج اختبارات الجودة لشرائح الليمون المجفف أن شدة الإشعاع 0.973 كيلووات\م^{٢} عند درجة حرارة الهواء ٥٠ درجة مئوية قد أعطت أفضل النتائج من حيث الحفاظ علي أعلي نسبة لفيتامين (C)، حمض السيتريك وكذلك السكريات الكلية الذائبة.

قام بتحكيم البحث

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