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Drying characteristics of Thompson seedless grapes using infra-red dryer.

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ABSTRACT

The drying characteristics of Thompson seedless grape ***(vitis vinifera L.)*** were investigated using laboratory scale infra-red dryer at four levels of intensity of infra-red radiation (0.861, 0.973, 1.039 and 1.161 kW/m^2). The drier was also equipped with three axial flow fans to supply air with at three different temperatures (40, 50 and 60 ^{o}C) and constant velocity of 2 m/s over the samples to carry the evaporated moisture. The results showed that the moisture content of dried grapes was decreased from (287.15 ±1, %d.b.) to (19.83 – 12.37, % db). It has been found that, both air temperature and infra-red radiation intensity affects rate of drying. Two drying models: Lewis model and Henderson and Pabis's model were examined. The models were compared using the statistical coefficients such as (R), (SE), (χ^2), (MBE) and (RMSE). Lewis's model was the best model for describing the drying curves of Thompson seedless grapes. A diffusion model was used to describe the moisture transfer and the effective diffusivity at each drying temperature and radiation intensity. The effective diffusivity ranged from (2.2393x10^{-9}) to (2.3033x10^{-10} m^2/s) and was significantly affected by radiation intensity. The average value of activation energy was (3.2051 kW/kg). The seedless Thompson grape dried at radiation intensity of (0.973 kW/m^2) and air temperature of (60 °C) recorded the highest quality of the dried samples in terms of, total soluble solid, total sugar, reducing sugars and remained Residual sulphur (SO$_2$).

Keywords*:* Drying characteristics, infra-red dryer, effective diffusivity, activation energy.

INTRODUCTION

After harvest, time of conservation of fruit under natural conditions is too limited to conserve fruits. For example, grapes one of the most wasted fruits. Losses of moisture and microbial decline were highly susceptible. Two processes are commonly used to extend the consumption time of grapes fruit, the cooling and drying process. The duration of dried grapes is longer than in the cooling process. The drying process of the grapes is generally slow due to the resistance of the skin (Margaris and Ghiaus, 2007).

(Wang *et al*., 1997) and (Yang *et al*., 2009) reported that, grape is a non-climatic fruit growing on the *Vitis* genus ' perennial and deciduous woody vines. This includes large quantities of phytochemicals which provide health benefits, including phenolics, flavonoids, anthocyanins, and resveratrol. Vitamins, phenols, carotenoids and flavonoids are antioxidant compounds. Among the last group, the most important are flavones, isoflavones, flavanones, flavonols, anthocyanins, and catechins, with significant antioxidant activity. It has been proposed that the high content of grapes in phenolics, flavonoids and anthocyanins be responsible for their health benefits.

Grapes have relatively high content of sugar and moisture, which cause high sensitivity during storage to microbial spoilage. Therefore, in a few weeks after harvest, they have to be consumed or processed to reduce economic losses. In most grape-growing countries, drying grapes was the main processing method. Traditionally, raisins are obtained by sun drying during 8–10 days, which reduces the moisture content. This is a low cost drying method, but it is considered as a risky method cause of damage occurred by infection with dust and insects (Pangavhane and Sawhney, 2002).

On the other hand, hot air drying can generally cause damage to food's texture, colour, taste and nutritional value due to high temperatures (60–75 ^{o}C) and long drying times (2–3 days) (Singh *et al*., 2012).

Doymaz (2006) reported that, dipping black grape in ethyl oleate plus potassium carbonate solution gives the shortest drying time (25 h) at 60 °C with an air velocity of 1.1 m/s.

Pahlavanzadeh *et al.* (2001) was examined the drying behavior of Iranian seedless white grapes (sultana) in a batch process using a laboratory air dryer with different air temperatures and pre-treatment solutions contained various alkaline materials with different concentrations. He found that, dipping grapes in an alkaline solution increases the drying rate substantially. The drying time was ranged from 450min to 900 min. That is depends on the air temperature and pre-treatment. The shortest drying time and best quality of raisins were resulted to dipping in a 5% potassium carbonate solution and air temperature of 42 °C.

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Infrared drying method could be considered as a process which decreases the drying time by providing heat through infrared radiation. This heating method is particularly suitable for thin layer drying of materials which exposed to radiation with a large surface area. Recently, the applications of infrared heating in food drying were particularly interested due to the improvements in the constructions of infrared generating units which have an efficiency ranged from 80% and 90%, with emitted radiation in narrow wavelength range (Sandu, 1986).

For foods with high moisture content, water absorption of infrared energy is an important variable that affects the kinetics of drying. In other words, the material's radiation properties change as a result of the moisture content changes. The decreasing of moisture content increases reflectivity and decreases absorptivity. Also, humid porous materials are penetrated by radiation to some depth and their transmissivity depends on the moisture content. On the other hands, solid materials generally absorb infrared radiation in a thin layer of surface (Lampinen *et al*., 1991).

(Sakai and Hanzawa, 1994) stated that, Infrared radiation is transmitted through water at short wavelength, while at long wavelength; it is absorbed on the surface. Thin layer drying therefore appears to be more efficient at far-infrared radiation (FIR) (25–100 µm), while drying of thicker bodies should give better results at near-infrared radiation (NIR) (0.75–3.00 µm). Also, they reported that, infrared radiation has Features in comparison with convective heating such as, higher coefficients of heat transfer, less in drying time and low cost of energy as resulting of air transparency to infrared radiation; so it can be performed at ambient air temperature.

The purpose of this work was to investigate the effect of infra-red radiation intensities assisted with hot air at different temperatures which passed over the samples on the drying characteristics and quality of Thompson seedless grape by examining the applicability of Lewis model and Henderson and Pabis's model on describing the drying behavior. The present study also aimed to calculate the effective moisture diffusivity and activation energy. The quality of the dried grapes is specified by the criteria of final moisture content, TSS, reducing sugar and remained SO_2.

MATERIALS AND METHODS

Freshly harvested Thompson seedless grapes (Banaty) were obtained directly from the field during the summer season (2017). It had initial moisture content 287.15 ±1 % d.b. (74.17 ±1% wb). The grape clusters were cleaned with running fresh water, and then separated to single grapes (grains). The total soluble solid (TSS) of fresh grapes was 21.1%.

Preparation of samples:

For ensuring the uniformity of the grapes used for different field test, the berries of the freshly harvested grape were cut into bunches and cleaned with fresh water to free it from dust and foreign materials. Chemical pre-treatments were applied to reduce the skin resistance and hence improving moisture diffusion through the waxy cuticle. These pre-treatments were immersing grapes in a 0.2% solution of sodium hydroxide (NaOH) at temperature of 90oC for (1 min). After immersion, the samples were taken out from NaOH solution and washed under fresh water until full removal of alkaline then, the grape samples were immersed in a (3%) solution of sodium Meta bi-sulphite for (5 min) (Matouk et al., 2019).

prior to each experimental run, the radiation intensity, air temperature and air velocity were adjusted in presence of samples and left until stable operation condition while, the pre-treated grapes were distributed uniformly as a single layer on a perforated tray which was then placed directly inside the drying bed. At the same time three sub Samples (5 g for each) were taken from the pre-treated grapes and kept in tins to determine the initial moisture content.

The changes in samples weight were recorded every 5 min for the first hour, every 10 min for the next two hours and then every 20 min until constant weight. In order to minimize the experimental errors of each run, it was replicated three times, and the average was considered.

Instrumentations:

An electric oven (Model Binder, max 300oC) was used to determine the initial moisture content. A sample of 5 g was weighed and placed into the aluminum tins. The initial moisture content was determined by air-drying the samples of grapes at 70 oC for 16 h according to (AOAC, 1995). The initial moisture content was determined in three replicates. In this study, the average initial moisture content of the fresh pre-treated grapes was 287.15 ±1 % d.b. (74.17 ±1% wb).

A 200 ±0.01 g capacity digital balance (model AND EK-200GD) was used for determining the weight of the samples during the determination of initial moisture content of the grapes. Meanwhile, a 6000 ± 0.1 g capacity digital balance (model TR-6101) was used during drying experiments.

A radiation sensor with data recorder (model H-201) was used to measure radiation intensity.

Air temperature and air velocity meter (model 9515, USA) was used to measure both of air temperature and air velocity during the experimental work.

Drying process:

Drying experiments were performed in a laboratory scale infra-red dryer developed by Matouk et al., (2014a) and installed in the Food Processing Engineering Laboratory, Agricultural Engineering Department, Faculty of Agriculture, Mansoura University, Dkahlia, Egypt.

The dryer consisted of three similar drying chambers which included a shelf with 700 mm long, 500 mm wide and 400 mm high. Each shelf had drying tray made of stainless-steel wire net with 400 mm long and 100 mm wide to accommodate three replicates. The three trays were situated at 200 mm from each IR lamp as recommended by (Utgikar et al., 2013).

1- The dryer frame
2- Fan's switch
3-Dimmers of infra-red heaters
4- Infra-red heater
5- Thermostat
6- Tempered glass
7- Sample's tray
8- Axial flow fan
9- Electric heater
10- Wheels

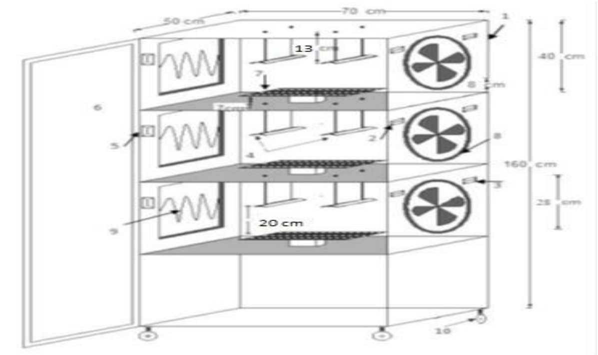


Fig. 1. Schematic view of experimental infra-red dryer.

As it can be seen in (Figure 1), two (1000 W, 750°C) German ceramic Infra-red heaters are fixed with two iron blades which assembled into the sealing of each drying chamber facing the drying tray. To adjust the distance between the ceramic heaters and the grape samples, two screw rods are welded to the iron blades to allow movement of the heaters up and down. A set of dimmers were used to control the radiation intensity of the infrared heaters, two (1000 W) Italian electric heater were used for heating the air passing through each drying chamber. The heating circuit of each chamber consists of two electric heaters with digital thermostat for temperature control. Also, three identical axial flow fans were used for suction of heated air in a parallel direction over the surface of each drying tray. The velocity of the air was measured before and after each axial fan and adjusted at 2 m/s.

Mathematical modeling of drying curves:

The moisture ratio (MR) of samples was calculated using by the following equation:

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

Where:

M_t is the moisture content at any time % (d.b.), M_o is the initial moisture content % (d.b.), M_f is the final moisture content % (d.b.).

The obtained data of the laboratory experiments was employed to examine the applicability of the two studied thin layer drying models (Lewis's model (1921) and Henderson and Pabis's model 1961) for describing and simulating the drying data.

Lewis's model may be written as:

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

Where:

k_L is the drying constant (1/ min) and t is the drying time (min).

The values of drying constant (k_L) for Lewis's model (1) could be obtained from the slope of linear correlation between Ln (MR) of the tested sample versus drying time (t).

Also, Henderson and Pabis's model can be written as:

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

Where:

k_h is the drying constant (min^{-1}) and A is constant depending on the samples shape (dimensionless)

The values of drying constant (k_L) and (A) for Henderson and Pabis's model (2) could be obtained from the exponential relationship between (MR) of the tested sample versus drying time (t).

Analysis of drying data:

In order to select the proper model which represent the drying data of grapes, statistical analysis were examined. The coefficient of determination (R^2) was one of the primary criteria for selecting the best model. In addition to R^2, the various statistical parameters such as standard error (SE), reduced chi square (χ^2), mean bias error (MBE) and root mean square error (RMSE) were used to determine the quality of the fit.

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{obs.,i} - MR_{calc.,i})^2}{N - n} \qquad (3)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(MR_{calc.,i} - MR_{obs.,i}) \qquad (4)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{calc.,i} - MR_{obs.,i})^2\right]^{1/2} \qquad (5)$$

Where

$MR_{obs;i}$ stands for the observed moisture ratio found in any measurement and $MR_{calc;i}$ is the calculated moisture ratio for this measurement. N and n are the number of observations and constants, respectively (Pangavhane *et al.*, 1999; Sarsavadia *et al.*, 1999).

Determination of effective diffusivity:

The effective diffusivity is an important transport property in modeling drying process of food and other materials, which is a function of temperature and moisture content in material. Fick's second law of diffusion equation, symbolized as a mass-diffusion equation for drying agricultural products in a falling rate period. The solution of diffusion equation for slab geometry is solved by Crank (1975), and supposed uniform initial moisture distribution, negligible external resistance, constant diffusivity, and negligible shrinkage:

$$\ln(MR) = \ln\left(\frac{6}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}\, t}{r^2}\right) \qquad (6)$$

Where:

D_{eff} is the effective diffusivity (m^2/s) and r is the radius of samples (m).

The effective diffusivity is obtained by plotting the experimental drying data in terms of ln (MR) versus time (s). From Eq. 7, a plot of ln (MR) versus time gives a straight line with a slope of (K), in which:

$$K = \left(\frac{\pi^2 D_{eff}}{r^2}\right) \qquad (7)$$

Determination activation energy:

For the calculation of activation energy which is the energy in order to activate moisture diffusion, modified form of Arrhenius equation as derived by Dadali and Ozbek (2008) show the relationship between the effective diffusivity and the IR power level to sample weight:

$$D_{eff} = D_o \exp\left(\frac{-E_a\, m}{p}\right) \qquad (8)$$

Where:

D_0 is the pre-exponential factor of Arrhenius equation (m^2/s), E_a is the activation energy (W/kg), p is the IR power level (W), and m is the sample weight (kg).

Quality evaluation of the Raisins:

The quality evaluation tests for the produced raisins during the performance tests of the infra-red dryer included raisin moisture content, total soluble solids, total sugars, reducing sugars and remained So_2. All tests were conducted at the laboratories of the Food Technology Research Institute, Agricultural Research Center (A.R.C) according to AOAC (2012) and Ranganna S., (1977).

RESULTS AND DISCUSSION

Grapes drying behavior:

Figures (2) to (3) showed that, the reduction of moisture contents as related to the drying time, were affected by both of radiation intensity and air temperature. Also, the reduction of moisture contents was obtained during the falling rate drying period in which the drying curves fitted exponentially.

This action is common for most of fruits and vegetable crops as resulted to the limitation of the moisture diffusion from interior the grape toward the surface before evaporating in which still happening until the temperature of the grape reaching the drying air temperature (Pangavhane *et al*., 2000; Yaldiz *et al*., 2001 and Togrul and Pehlivn, 2004).

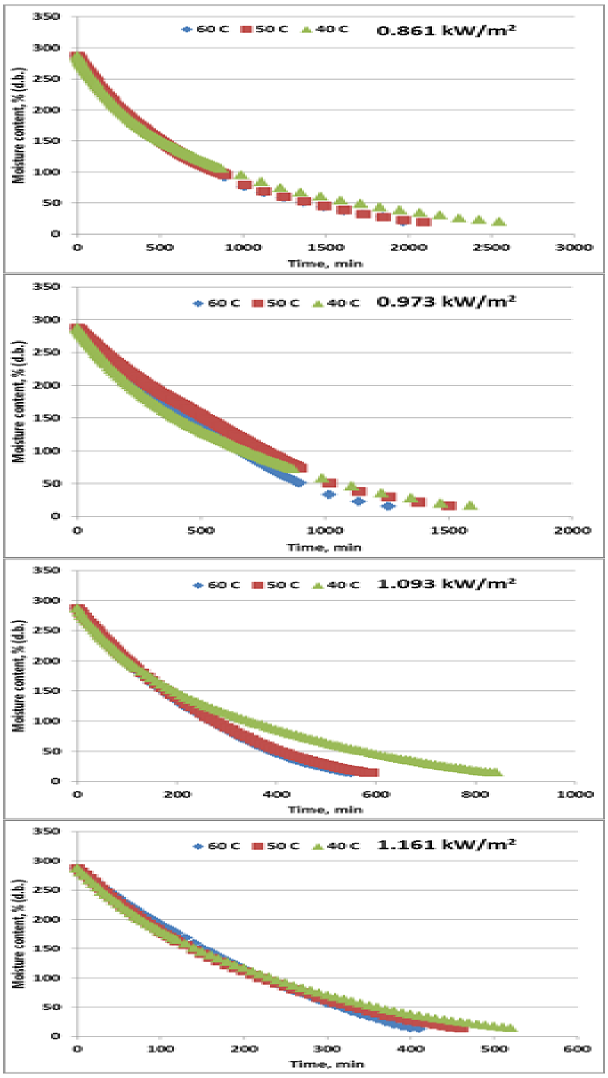


Fig. 2. Change in grapes moisture content as related to drying time at different levels of air temperature.

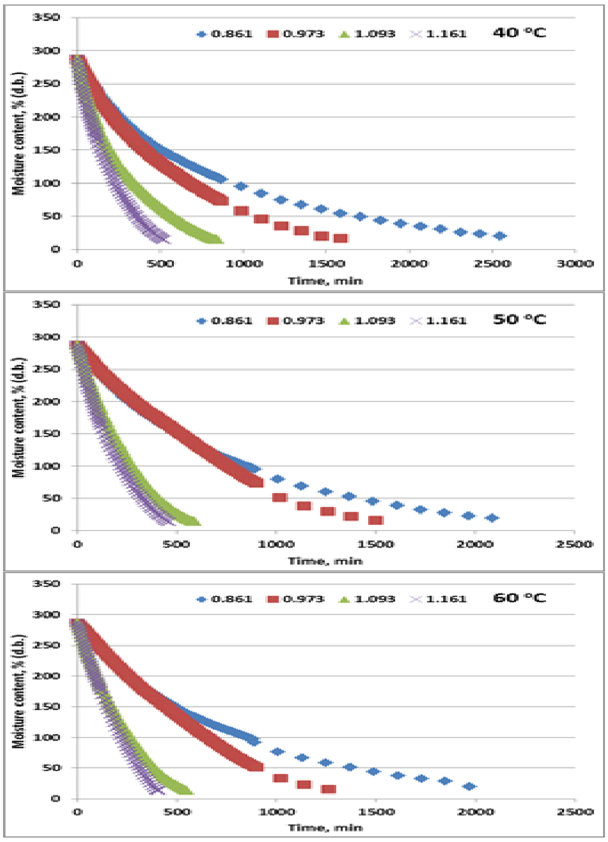


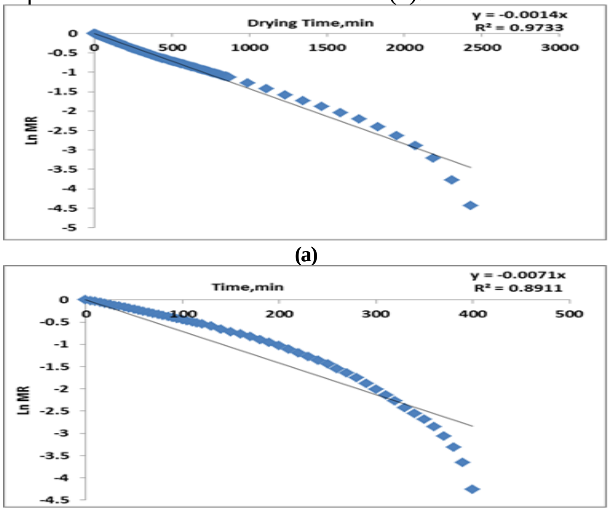
Fig. 3. Change in grapes moisture content as related to drying time at different levels of intensity of infra-red radiation.

Analysis of Thompson grapes drying using Lewis's equation:

The values of drying constant (k_L) were computed by using the linearization form of equation (1) as follow:

$$\mathbf{Ln\ (MR) = -\ k_L\ t} \qquad \mathbf{(9)}$$

Figure (4) represent the linear correlation at the minimum and the maximum inlet air temperatures and radiation intensity used for the experimental work (40oC and 0.861 kW/m2) and (60 oC and 1.161 kW/m2).The computed values of the drying constant (k_L) for all the experimental runs were listed in Table (1).



(a)

(b)

Fig. 4. Determination of the drying constant (k_l) of the Lewis's model, a: (40°C and 0.861 kW/m²) and b: (60 °C and 1.161 kW/m²)

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

A multiple regression analysis was also used to relate the studied parameters (RI and T) with the drying constant (k_L) at constant air velocity of 2 m/sec. The nature of dependence could be expressed by the following equation:

$$K_L = 0.018525\ RI + 3.625\text{x}10^{-5}\ T - 0.016937 \qquad (10)$$

$$(R^2 = 0.8998;\ r = 0.9486;\ SE = 0.000827)$$

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

	0.861	0.973	1.093	1.161
Air temperature °C	**Radiation intensity, kW/m²**			
40	0.0014	0.0017	0.0041	0.0064
50	0.0015	0.0018	0.0054	0.0069
60	0.0016	0.002	0.0058	0.0071

Analysis of Thompson grapes drying using Henderson and Pabis's model:

Figure (5) illustrates the method of determining the drying constants (kh) and (A) of Henderson and Pabis's model (2) and Table (2) presented the obtained data at different levels of radiation intensity and inlet air temperature.

As shown in the Table (2) the values of the drying constant (Kh) and (A) increased with the increasing of inlet air temperature (T) at all levels of radiation intensity (IR) and it was also increased with the increase of radiation intensity (IR) at all levels of inlet air temperature (T).

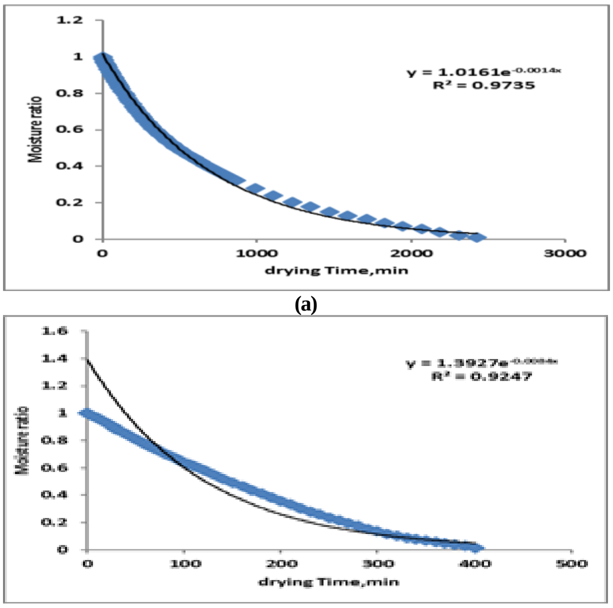
A multiple regression analysis was also used to relate the studied parameters (IR and T) with the drying constant (kh and A) at constant air velocity of 2 m/sec. The nature of dependence could be expressed by the following equations:

$$K_h = 0.020696\ IR + 6.54\text{x}10^{-5}\ T - 0.02020247 \qquad (11)$$

$$(R^2 = 0.89244;\ SE = 0.000976;\ r = 0.94469)$$

$$A = 1.032419\ IR + 0.005925\ T - 0.15582 \qquad (12)$$

$$(R^2 = 0.92984;\ SE = 0.040594;\ r = 0.964282)$$



(b)

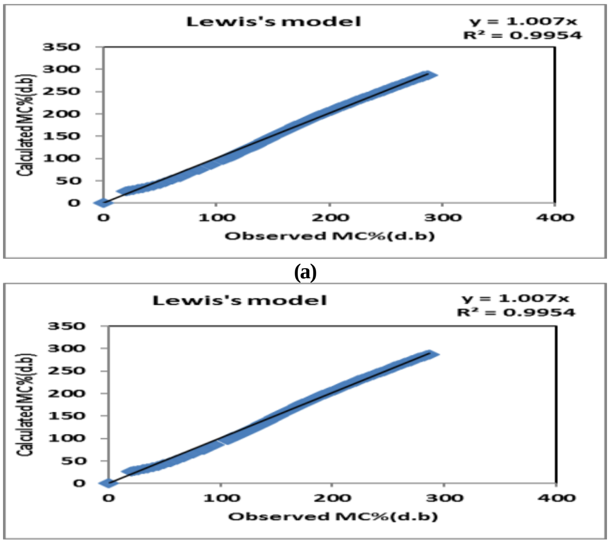
Fig. 5. Determination of the drying constants; (k_h, A) of the Henderson and Pabis's model a: (40°C and 0.861 kW/m²) and b: (60 °C and 1.161 kW/m²).

Table 2. Drying constants (k_h) and (A) of the Henderson and Pabis's model at different levels of radiation intensity and inlet air temperature.

Air temp. °C	Radiation intensity, kW/m²							
	0.861		0.973		1.093		1.161	
	K_h	A	K_h	A	K_h	A	K_h	A
40	0.00144	1.0161	0.00178	1.02579	0.00444	1.20611	0.00621	1.29173
50	0.00167	1.0571	0.00201	1.09561	0.00614	1.31763	0.00782	1.32310
60	0.00175	1.0890	0.00221	1.16475	0.00674	1.36733	0.0084	1.39268

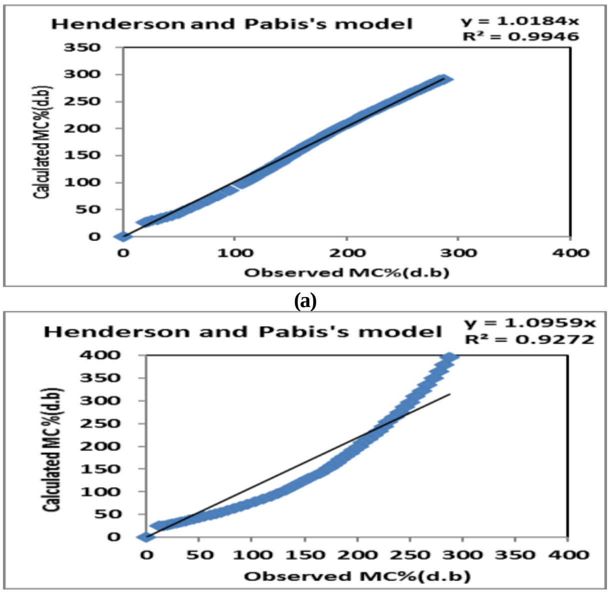
Comparative evaluation of the studied drying models:

A comparison study for the two drying models (Lewis's and Henderson and Pabis's models) was conducted (at 45o plot) to assess the most proper drying model for simulating and describing the drying behavior of Thompson seedless grape under the studied range of experimental parameters. Figures (6 and 7) show the relation between the observed and calculated moisture content at the minimum and the maximum inlet air temperatures and radiation intensity used for the experimental work (40oC and 0.861 kW/m2) and (60 oC and 1.161 kW/m2) for both studied models.



(b)

Fig. 6. Observed and calculated values of moisture content using Lewis's model, a: (40°C and 0.861 kW/m²) and b: (60 °C and 1.161 kW/m²)



(b)

Fig. 7. Observed and calculated values of moisture content using Henderson and Pabis's model, a: (40°C and 0.861 kW/m²) and b: (60 °C and 1.161 kW/m²)

In general, the overall average of the obtained coefficient of determination (R^2) and the standard error (SE) for the observed and calculated moisture content revealed that, both studied models could describe the drying behavior of Thompson seedless grape satisfactory.

On the other hand, calculation the coefficient of determination (R^2) and (SE) for nonlinear models are not a good decision making tool, it is necessary to analyze different statistical parameters. In addition to (R^2) and (SE) the various statistical parameters such as; reduced chi-square (χ^2), mean bias error (MBE) and root mean square error (RMSE) were used to determine the quality of the fit. Table (3) shows coefficient of determination (R^2), chi-square (χ^2), mean bias error (MBE) and root mean square error (RMSE) of Lewis model and Henderson and Pabis's model.

As shown in Table (3), Lewis model have the highest value of coefficient of determination (R^2) and the lowest values of standard error (SE), chi-square (χ^2), mean bias error (MBE), root mean square error (RMSE). So one may say that Lewis's model was the most proper model in describing the drying behavior of Thomson seedless grapes under the examined conditions.

Table 3. Values of coefficient of determination (R^2), standard error (SE), chi-square (χ^2), mean bias error (MBE) and root mean square error (RMSE) of Lewis model and Henderson and Pabis's model.

IR, k W/m^2	T, °C	Lewis model					Henderson and Pabis model				
		R^2	S. E.	χ^2	MBE	RMSE	R^2	S. E.	χ^2	MBE	RMSE
0.861	40	0.9954	0.015517	0.00077	-0.01210	0.02767	0.9946	0.015855	0.00087	-0.01434	0.02922
	50	0.9973	0.013368	0.00118	-0.02774	0.03415	0.9858	0.021765	0.00347	-0.05056	0.05839
	60	0.9945	0.01726	0.00212	-0.03918	0.04589	0.982	0.023839	0.00445	-0.05820	0.06610
0.973	40	0.9975	0.013266	0.00189	-0.03508	0.04323	0.9821	0.014398	0.00231	-0.03941	0.04758
	50	0.9833	0.03697	0.00685	-0.07319	0.08239	0.9641	0.045904	0.01191	-0.09717	0.10811
	60	0.9826	0.039414	0.00913	-0.08644	0.09508	0.9685	0.046537	0.01341	-0.10468	0.11470
1.093	40	0.9875	0.030168	0.00338	-0.04578	0.05783	0.9742	0.036871	0.00541	-0.06230	0.07282
	50	0.9788	0.044604	0.00856	-0.07508	0.09188	0.9543	0.056438	0.01397	-0.09494	0.11655
	60	0.9745	0.048558	0.01033	-0.08553	0.10090	0.9428	0.062348	0.01763	-0.11077	0.13082
1.161	40	0.9819	0.039474	0.00366	-0.03834	0.06005	0.9832	0.036754	0.00563	-0.06439	0.07387
	50	0.9783	0.043765	0.00741	-0.06347	0.08533	0.9527	0.055325	0.01422	-0.09556	0.11720
	60	0.9647	0.058182	0.01396	-0.09052	0.11705	0.9272	0.073300	0.02591	-0.13391	0.15795
average		0.98469	0.03338	0.00577	-0.05604	0.07012	0.96763	0.04078	0.00993	-0.07719	0.09111

Calculation of effective diffusivity:

The effective diffusivity was calculated using Equ. (7) And is shown in Figure (8), the Deff values of Thomson seedless grapes of IR drying at 0.861 to 1.161 kW/m2 ranged from 2.2393x10-9 to 2.3033x10−10 m2/s.

The obtained results showed that, the Deff values increased greatly with increasing IR power level. This may be due to, the increasing of power level which caused a rapid rising in temperature of the product, and Consequently increasing the vapor pressure.

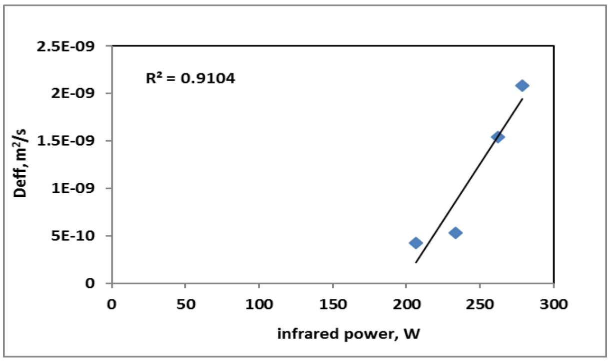


Fig. 8. Variation of effective diffusivity with power levels.

This result in agreement with those reported by (Zogzas *et al.*, 1996, Sharma *et al.*, 2005, Shi *et al.*, 2008, Celma *et al.*, 2009 and Doymaz, 2012).

The effect of IR power on effective diffusivity is defined by the following equation:

$$D_{eff} = 2\times10^{-11}\,p - 5\times10^{-9} \qquad (R^2 = 0.9104) \qquad (13)$$

Calculation of activation energy

The activation energy can be determined from the slope of Arrhenius plot, ln(Deff) versus m/p as mentioned in equ. (8). The ln(Deff) as a function of the sample weight/infrared power level was plotted in Figure (9). The slope of line is (−Ea) and the intercept equals to ln (D0).

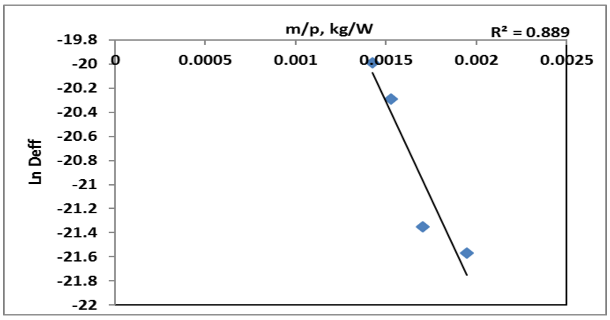


Fig. 9. Arrhenius-type relationship between ln (D_{eff}) and the sample weight/infrared power (m/p).

The results show a linear relationship due to Arrhenius type dependence. Equation (14) shows the effect of sample weight/power level on Deff of samples with the following coefficients:

$$D_{eff} = 1.8314\times10^{-7}\exp(-3205.1\ m/p), \qquad (14)$$
$$(R^2 = 0.889)$$

The estimated values of D0 and Ea from modified Arrhenius type exponential Equation (14) are 1.8314×10−7 m2/s and 3.2051 kW/kg, respectively.

Examination of the dried grapes:

Table (4) shows the final moisture content (% d.b.) of grapes at different levels of inlet air temperature and radiation intensity.

Table 4. The final moisture content (% d.b.) of grapes at different levels of inlet air temperature and radiation intensity.

Air temperature.	**Radiation intensity, kW/m^2**			
°C	**0.861**	**0.973**	**1.093**	**1.161**
40	19.83	16.47	14.4	14.28
50	19.153	15.81	14.09	13.74
60	19.03	15.51	13.46	12.37

As shown in table (4), the dried grapes shows high levels of final moisture content for the grapes dried at 0.861 kW/m2 at all levels of inlet air temperature, it was also noticed that samples dried at 1.093 and 1.161 kW/m2 showed undesirable color which indicates that the samples were burned. So, it was decided that the best treatment for drying the Thompson seedless grapes was 0.973 kW/m2 and inlet air temperature of 60 oC

Quality of the dried grapes:

Results in table (5) show the principal of chemical analysis of fresh grapes and dried grapes (Raisins) for infrared drying method.

Table 5. Chemical analysis of fresh grapes and dried grapes (Raisins) for the infra-red drying method.

samples	**Test results %**				
	Moisture ,(%w.b)	**T.S.S %**	**Total sugar, g/100g**	**Reduction sugar%**	**So$_2$, ppm**
Fresh grape	74.17	21.1	19.63	18.76	ND
IR dried raisin	15.51	74.6	68.54	51.28	1705.911

Data in table (5) indicated that the moisture content, T.S.S, reduction sugar and total sugars of fresh grape were 74.17 %, 21.1%, 18.76% and 19.63 %, respectively on fresh weight basis. These results mean that the grapes were harvested at the optimum time for collection and production of raisins, since total soluble solids must be not less than 20% according to the Egyptian Standard of dried grapes (Raisins) No., 285/2005.

The results also show that the sugar content of fresh grapes was higher than 19%, which indicated a good level for high quality dried grapes in terms of color changes during the drying process. Meanwhile, after the drying process, the results in table (5) also showed that the moisture content of dried grapes with infrared drying method was 18.36 % d.b. (15.51 %, w.b.). This level of moisture content represents an optimum level of dried grapes (raisins) which usually not over than 21.9 % d.b. (18%, w.b.) according to the Egyptian Standard of dried grapes (Raisins) No., 285/2005.

Table (5) also shows that the total soluble solids (T.S.S.) were higher than 66% and total sugars represent 91.8% of T.S.S. values. This means that, the predominate of solids in the dried grapes were sugars. Also, these high total sugars content of raisins maintain shelf life and keep high quality of the product.

CONCLUSION

The reduction in moisture content of Thompson seedless grapes varied with the experimental treatments and it was increased with the increase of radiation intensity, and inlet air temperature.

1- The drying constant (kL) of Lewis's model increased with the increase of drying air temperature and radiation intensity.

2- The drying constants of Henderson and Pabis's model (kh, A) increased with the increase of inlet air temperature and the radiation intensity.

3- Both studied models could describe the drying behavior of Thompson seedless grapes. However, the Lewis's model considered more proper for describing the drying behavior and predicting the changes in moisture content of Thompson seedless grapes in terms of precision and application simplicity.

4- The effective diffusivity was calculated and was found to vary between 2.2393x10-9 to 2.3033x10−10 m2/s and was significantly affected by radiation intensity.

5- The average value of activation energy also be calculated and its value was 3.2051 kW/kg.

6- The seedless Thompson grape dried at radiation intensity of 0.973 kW/m2and air temperature of 60 °C recorded the highest quality of the dried samples in terms of, T.S.S., total sugar, reducing sugars and remained SO2.

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خصائص تجفيف العنب صنف طومسون باستخدام مجفف يعمل بالأشعة تحت الحمراء

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تم اجراء الدراسة لتحديد خصائص تجفيف العنب صنف طومسون باستخدام مجفف معملي يعمل بالأشعة تحت الحمراء كمصدر للطاقة الحرارية عند أربعة مستويات لشدة الإشعاع (٠,٨٦١ ـ٠,٩٧٣ ـ١,٠٩٣ – ١,١٦١ كيلو وات\م^{٢}) ومزود بثلاث مراوح محورية لتحريك الهواء فوق العينات للمساعدة في ازالة الرطوبة المتبخرة من العينة وتم ضبط درجة حرارة الهواء المار فوق العينات على ثلاث مستويات هي (٤٠-٥٠-٦٠) درجة مئوية، مع تثبيت سرعة الهواء المستخدم عند مستوي ٢ م\ث. وأثناء التجارب تم خفض المحتوى الرطوبي للعنب من ٢٨٧,١٥ ±١% الى محتوى رطوبي نهائي تراوح بين (١٢,٣٧ – ١٩,٨٣)% على اساس جاف وقد لوحظ أن لكلا من شدة الاشعاع ودرجة حرارة الهواء المار فوق العينة تأثير واضح على معدل التجفيف .وقد أجريت التحليلات الرياضية للنتائج المتحصل عليها باستخدام معادلتين لوصف سلوك التجفيف للعنب المجفف في طبقة رقيقة وهما معادلتي (Lewis's and Henderson & Pabis's). أظهرت النتائج المتحصل عليها وصف كلا المعادلتين لسلوك التجفيف لثمار العنب بصورة مرضية إلا أن معادلة (Lewis's) قد أعطت نتائج أكثر دقة للتنبؤ بالتغير في المحتوي الرطوبي للعنب .تم حساب كلا من معامل الانتشار والذي وجد أنه في المدى (٢,٢٣٩٣x١٠$^{-٩}$ - ٢,٣٠٣٣ x ١٠$^{-١٠}$ م^{٢}/ث) وحساب القيمة المتوسطة لطاقة التنشيط والتي كانت (٣,٢٠٥١ كيلووات/كجم) . من ناحية أخري أظهرت نتائج اختبارات الجودة للعنب المجفف أن شدة الإشعاع 0.973 كيلووات\م^{٢} عند درجة حرارة الهواء ٦٠ درجة مئوية قد أعطت أفضل النتائج من حيث المحتوى الرطوبي النهائي ونسبة المواد الصلبة الكلية ونسبة السكريات والكبريت المتبقي.