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Thin Layer Infrared Drying of Crimson Seedless Grapes

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ABSTRACT

The drying characteristics of crimson grape *(vitis vinifera L.)* were investigated using laboratory scale infra-red dryer at four levels of infra-red radiation intensity (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 over the samples to carry the evaporated moisture. The passing air was adjusted at three different temperatures (40, 50 and 60 °C) and constant air velocity of 2 m/s. During the experiments, grapes were dried to final moisture content (19.96 – 13.87) % from 292.46 ±1 % dry basis. It has been found that, both air temperature and infra-red radiation intensity affect the course and rate of drying. The gained data were fitted to two thin layer drying models: Lewis model and Henderson and Pabis's model. The examined models were compared using R^2, SE, χ^2, MBE and RMSE. Lewis's model is the best for describing the drying curve of Crimson seedless grapes. A diffusion model was used to describe the transfer of moisture and the effective diffusivity at each drying temperature and radiation intensity. The effective diffusivity; varied between 6.8632x10^{-11} to 6.4057x10^{-10} m^2/s and was significantly affected by radiation intensity. The average value of activation energy was 4.2515 kW/kg. The Crimson seedless 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, TSS, total sugar, reducing sugars and remained SO$_2$.

Keywords: Thin layer drying, Infrared drying, Grape drying, effective diffusivity, activation energy

INTRODUCTION

Grape is among the most widely grown fruits in the world. The global production of table grapes increased by over 71% from 15.7 million ton in season 2000 to nearly 27 million ton in season 2014. Egypt ranks fourth in grape production all over the world after China, India and Turkey. Grape's production in Egypt increased from one million ton in season 2000 to 1.4 million ton in season 2014 with an increasing percentage of 40% and the Egyptian production of grapes represent 5% of the global production according to FAO and OIV (2016).

The non-climacteric grape is grown on woody vines that are perennial and deciduous and belong to the genus *Vitis*. It is rich in phytochemicals such as (flavonoids, phenolics, anthocyanins, and resveratrol), which are good for human health. Grapes also contain antioxidant compounds such as (vitamins, phenols, carotenoids, and flavonoids) which includes (flavones, isoflavones, flavanones, anthocyanins, flavonols, and catechins) which are very important and exhibit substantial antioxidant activity (Wang et al., 1997). The health advantages of grapes have been attributed to their high phenolic, flavonoid, and anthocyanin content (Yang et al., 2009).

After harvest, Fruit can only be preserved for a short time under natural circumstances. For example, Grapes are among the most perishable fruits. They are liable for moisture loss and microbial deterioration. In general, cooling and drying are utilized as two processes to extend the consuming time of grapes. Dried grapes have a longer shelf life than cooled grapes. Due to the resistance of the grape's skin, the drying process under natural conditions typically takes a long time. (Margaris and Ghiaus, 2007)

Grapes have a very high sugar and moisture content, making them extremely susceptible to microbial destruction during storage. They must be consumed or transformed into other products within a few weeks following harvest to minimize economic losses. Converting grapes into raisins by drying is a major processing method in almost all grape-growing countries. Grapes is traditionally dried in the sun for 8 to 10 days to produce raisins, which significantly lowers the water content. Despite the low cost of this drying method, there is a chance of damage by dust and insect infection. (Pangavhane and Sawhney, 2002). Hot air drying is an alternative but due to the high temperatures (60–75 °C) and prolonged drying times required in the process (2–3 days), dehydration may destroy the color, texture, taste, and nutritional content of food (Singh et al.,2012).

In a laboratory drier, (Doymaz, 2006) investigated the thin layer air drying process of black grapes using different pretreatments. Grapes were dried by heated air at (60 °C) with an air velocity of (1.1 m/s). Black grapes dipped in potassium carbonate an ethyl oleate solution dried in the shortest time (25 hours).

In a batch process using a lab air dryer (Pahlavanzadeh et al.,2001) investigated the drying process of Iranian white seedless grapes (sultana) using different alkaline materials in pretreatment at different concentrations, and various air temperatures. Dipping grapes in an alkaline solution increased, the drying rate substantially. Grapes dried in 450– 900 min depending on air temperature and pretreatment. Grapes soaked in a potassium carbonate solution of (5% at 42 °C) resulted in the best quality dried product and required the shortest drying time.

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Due to its advantages, including (short drying time, greater energy saving potential and the reasonable quality of the dried product), infrared drying has become more popular recently. It is also less expensive than vacuum and microwave drying methods. When IR is utilized for drying or heating a material, it is absorbed by the solid material in its outer surface layer. However, radiation can penetrate moist, porous materials to a certain depth depending on their moisture content (Abukhalifeh et al., 2005). The infrared drying method has high energy efficiency and more energy savings than conventional and other drying methods (Toğrul, 2005).

Infrared dryers may be assisted with heated air system to increase the drying rate and the dryer efficiency. Matouk et al. (2014) conducted and manufactured a laboratory scale dryer to evaluate the use of infra-red radiation as heat energy source for drying lemon slices. The experimental treatments included three different levels of radiation intensity (0.973, 1.093, and1.161 kw/m2), three different air temperatures (40, 50 and 60°C) and air velocity of 1 m/sec. The results showed that the best level of radiation intensity for drying the whole lemon is 1.093kW/m2 and for the slices is 0.973 Kw/m2 at air temperature of (50° C).

Sakai and Hanzawa, (1994) mentioned that, infrared radiation with a short wavelength is transmitted through the water, while at a long wavelength; it is absorbed on the surface. Therefore, it implies that drying thin layers is more effective using FIR (far infrared radiation 25-100 µm), whereas drying thicker bodies should give better results at NIR (near-infrared radiation 0.75-3.00 µm).

This work aim to examine the effect of infra-red radiation intensity assisted by hot air flowing over the samples at various temperatures on the drying characteristics and quality of Crimson seedless grape by examining the applicability of Lewis model and Henderson and Pabis's model on describing the drying data. This study also aimed to calculate the activation energy and the effective moisture diffusivity. The quality of the dried grapes is specified by the criteria: Final moisture content, T SS, reducing sugar and remained SO_2.

MATERIALS AND METHODS

Freshly harvested ripe crimson grapes were obtained directly from the field during the summer season (2017). It had initial moisture content of 74.52 ±1 % (W. b.). The grape bunches were cleaned under running water before being split into individual grapes. The total soluble solid (TSS) of fresh grapes was 19.7%.

Preparation of samples

In order to reduce skin resistance and increase moisture diffusion through the waxy cuticle, chemical pre-treatments were used. These pre-treatments included immersing grapes in a 0.2% solution of sodium hydroxide (NaOH) at a temperature of 90ºC for 1 min. After immersion, the samples were taken out from the NaOH solution and washed under tap water until full removal of alkaline. The grape samples were immersed in a solution of sodium meta bisulfite (3%) 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 conditions while the pre-treated grapes were uniformly distributed as a single layer on a perforated tray which was then placed directly inside the drying bed. At the same time, three sub samples each of 5 g were taken from the pre-treated grapes and kept in tins to determine the initial moisture content.

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

Instrumentations:

An electric lab oven (Binder, max 300ºC) used for estimating the (IMC) initial moisture content of fresh grapes at (70 ºC for 16 h) according to (AOAC, 1995). To obtain accurate data for initial moisture content, three replicates were taken. The fresh treated grapes used in this study had an average initial moisture content of 292.46 1% d.b. (74.52 1% wb).

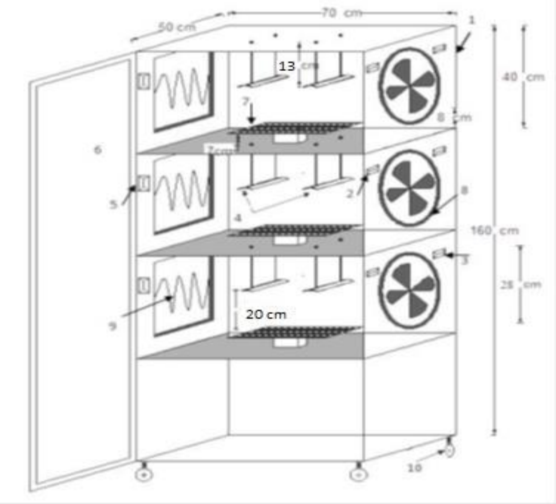
A 200 ± 0.01 g capacity digital balance (AND EK-200GD) was used for massing grapes during the initial moisture content determination. Nevertheless, another digital balance (TR-6101) with (6000 ± 0.1 g) was used during drying experiments.

A radiation sensor with a data recorder (H-201) was used for measuring the intensity of radiation. Air velocity and temperature meter (9515, USA) was used for measuring both air velocity and temperature during the experimental work.

Drying Experiments:

The experimental work was performed in a lab scale infra-red dryer developed by Matouk et al., (2014). The dryer installed in the Food Processing Eng. Lab., Ag. Eng. Dept., Agriculture Faculty, Mansoura University, Dakahlia, Egypt.

The dryer consists of three drying shelves. Each shelf was (700 mm long, 500 mm wide and 400 mm high). Each shelf had three similar trays made of stainless-steel wire net 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 the experimental infra-red dryer

As it can be seen (Figure 1), two German ceramic infra-red heaters (1000 W, 750°C) are fixed with two iron blades, which are assembled into the sealing of each drying chamber facing the drying trays. For adjusting the distance between the ceramic heaters and the grape samples, two screw rods are welded with the iron blades to allow movement of the heaters up and down. To control the radiation intensity of the infrared heaters, a set of dimmers were used. Two Italian electric heaters (1000 W) were used for heating the air passing through each drying chamber. The heating circuit of each chamber consists of two electric heaters with a digital thermostat for temperature control. Also, three identical axial flow fans were used for the 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.

Grapes drying models:

Moisture ratio (MR) of grape samples was calculated using the following model:

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

Where: M_t: the moisture content at any time % (d.b.)
M_o: the initial moisture content % (d.b.)
M_f: 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:

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

Where:
k_L: the drying constant (1/ min)
t: the drying time (min).

The values of constant (k_L) in model (1) could be calculated 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:

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

Where:
k_h: the drying constant (min^{-1})
A: constant depending on the shape of the sample (dimensionless)

The constants (k_L) and (A) in equation (2) could be calculated from the exponential relationship between (MR) and drying time (t).

Analysis of drying data:

To select the proper model which represents the drying data of crimson grapes, statistical analyses were examined. 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 assess 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:
$MR_{obs;i}$: the observed moisture ratio found in any measurement
$MR_{calc;i}$: the calculated moisture ratio for this measurement.
N the number of observations
n the number of constants, (Pangavhane et al., 1999; Sarsavadia et al., 1999).

Effective diffusivity:

Diffusion is generally accepted to be the main method during the movement of water, to the surface to be evaporated in most studies carried out on drying. Fick's second law of diffusion model, is symbolized as a mass diffusion model 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 water distribution, constant diffusivity, small external resistance, and less shrinkage:

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

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

The effective diffusivity, is calculated by plotting the experimental data in terms of Ln (MR) against the drying time (t). From Equation (7), a plot of Ln (MR) against 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 of the activation energy:

To calculate the activation energy, a modified form of (the Arrhenius equation) as derived by (Dadali and Ozbek, 2008) show the relation between the effective diffusivity and the infrared (IR) power level to sample mass:

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

Where:
D_0: the pre-exponential factor of the Arrhenius equation (m^2/s),
E_a: the activation energy (W/kg),
P: the infrared power level (W),
m: the sample mass (kg).

Quality evaluation of the Raisins:

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

RESULTS AND DISCUSSION

Drying behavior of grapes:

Figures (2 and 3) show the change in crimson grape's moisture content, (MC) as related to the time of drying, (t) at different levels of inlet air temperature and radiation intensity. The change in moisture content of grapes varied with the experimental treatments and it was increased by increasing both the intensity of radiation, and air temperature.

However, the constant drying rate period was not detected for all studied levels of inlet air temperature and radiation intensity. Meanwhile, all the drying processes carried out during the falling rate drying period in which the rate of evaporation tended to fall as the moisture content decreased and the drying curve decays exponentially toward the equilibrium or the final moisture content. This phenomenon is common for most fruits and vegetable crops since at the beginning of the drying process, the moisture diffusion from inside the grape toward the surface where it evaporates has been limited. This condition continues until the temperature of the grape reaches the drying air temperature as mentioned by Yaldiz et al. (2001) and Togrul and Pehlivn (2004).

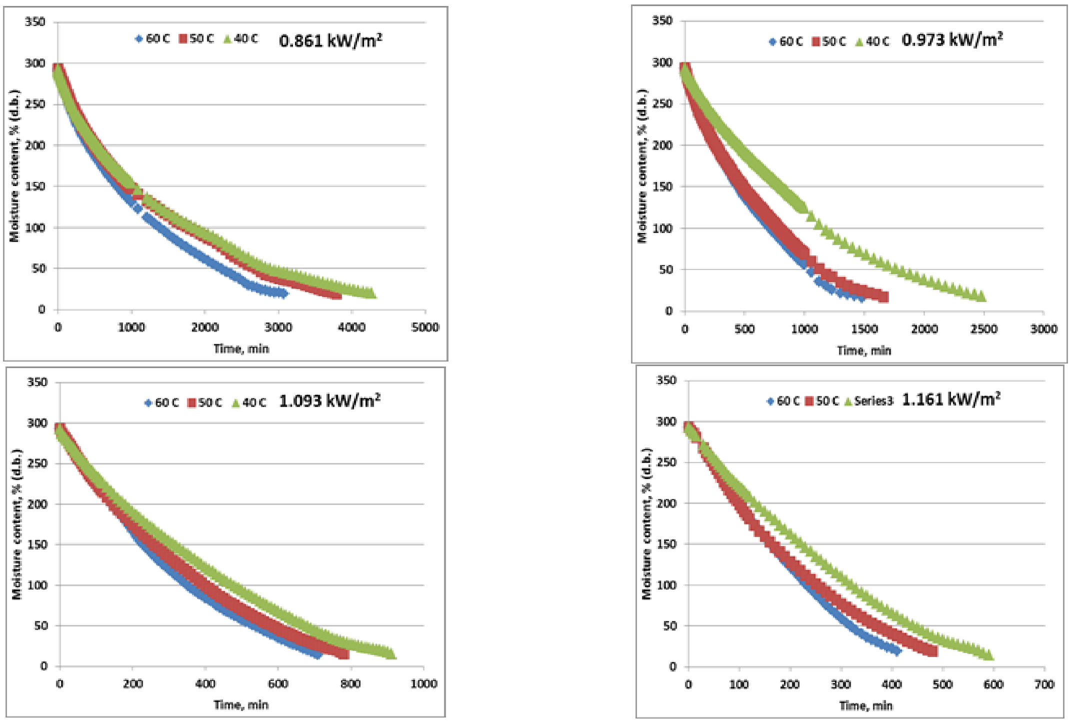


Fig. 2. Change in crimson grapes moisture content as related to drying time and air temperature.

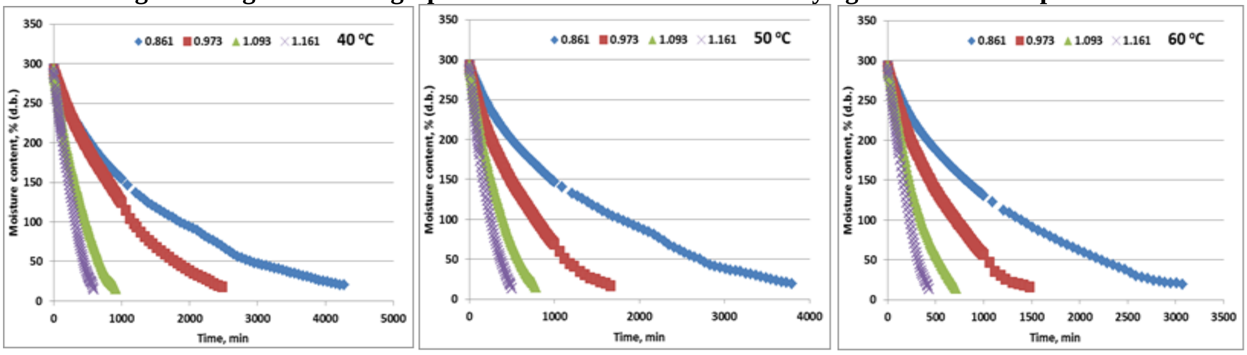


Fig. 3. Change in crimson grapes moisture content as related to time of drying and intensity of radiation.

Analysis of crimson grapes drying using Lewis's equation:

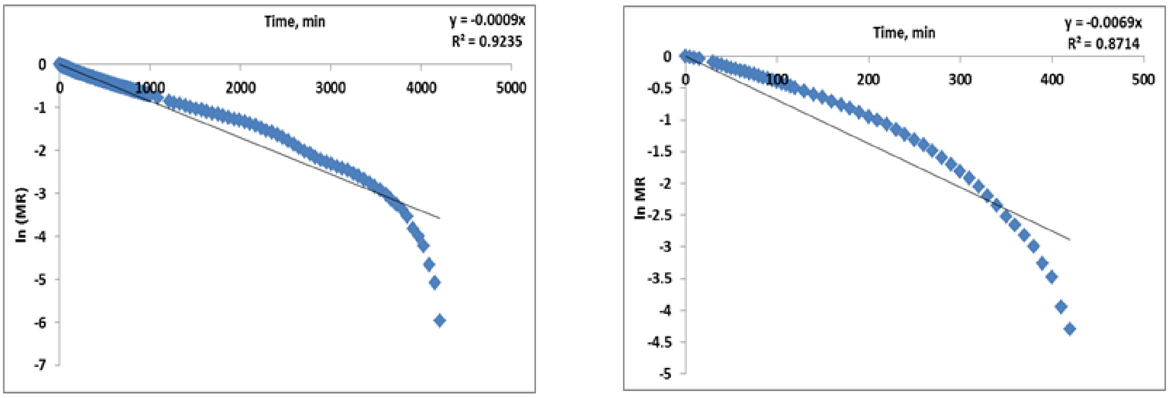
The drying constant values (k_L) were computed by using the linearization form of equation (1) as follows:

$$Ln(MR) = -k_L\, t \qquad (9)$$

Figure (4) represents the linear correlation at the minimum and the maximum inlet air temperatures and radiation intensity used for the experimental work (40°C and 0.861 kW/m^2) and (60 °C and 1.161 kW/m^2).The computed values of the drying constant (k_L) for all the experimental runs were listed in Table (1).

Table 1. The constant of drying (k_L) for Lewis's model at varies levels of radiation intensity and air temperature.

Air temp. °C	Radiation intensity, kW/m^2			
	0.861	0.973	1.093	1.161
40	0.00085	0.00122	0.00341	0.00500
50	0.00094	0.00181	0.00389	0.00604
60	0.00114	0.00250	0.00428	0.00687



(a) **(b)**

Fig. 4. Calculation of the constant (k_l) of Lewis's model, a: (40°C and 0.861 kW/m^2) and b: (60 °C and 1.161 kW/m^2)

Table (1): shows that, the drying constant (k_L) increased by increasing of both inlet air temperature and radiation intensity.

A multiple regression analysis was also used to relate both inlet air temperature and radiation intensity (IR and T) with the drying constant (k_L) at a constant air velocity of 2 m/sec. The nature of dependence could be expressed as follow:

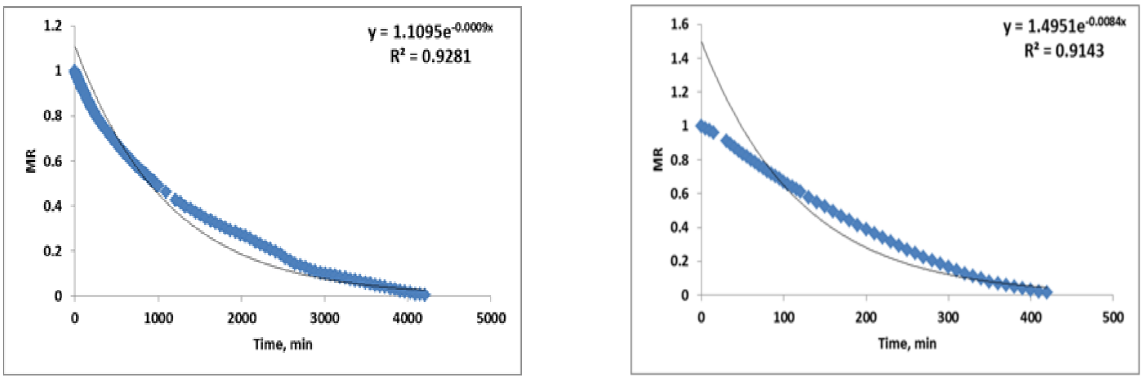
$$\mathbf{K_L = 0.0162569\ IR + 5.3875x10^{-5}\ T - 0.0161441} \qquad \mathbf{(10)}$$

$$\mathbf{(R^2 = 0.9247 \quad ; \quad r = 0.9616 \ ; \quad SE = 0.0006315)}$$

These results agree with Matouk et al., (2014) **and** Matouk et al., (2015)**.**

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

Figure 5 illustrates the method of determining the drying constants (k_h) and (A) of Henderson and Pabis's model (3) and Table (2) presented the obtained data at different levels of radiation intensity and inlet air temperature.



(a) (b)

Fig. 5. Calculations of the constants; (k_h and 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 Henderson and Pabis's model at varies 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	0.00089	1.10946	0.00139	1.15637	0.00397	1.29847	0.00599	1.32090
50	0.00097	1.13097	0.00201	1.17934	0.00446	1.33173	0.00705	1.37535
60	0.00123	1.16270	0.00227	1.21614	0.00493	1.35096	0.00836	1.49514

As noted in Table (2), the values of the drying constants (K_h and A) increased by increasing both inlet air temperature and intensity of radiation (IR). Also, multiple regression analysis was used for relating both the studied parameters (IR and T) with the constants of drying (k_h and A) at a constant air velocity of (2 m/sec). The nature of dependence could be expressed as follow:

$$\mathbf{K_h = 0.0199\ I8\ IR + 5.6875x10^{-5}\ T - 0.01956242} \qquad \mathbf{(11)}$$

$$\mathbf{(R^2 = 0.9069 \quad ; \quad SE = 0.0008625 \quad ; r = 0.9523)}$$

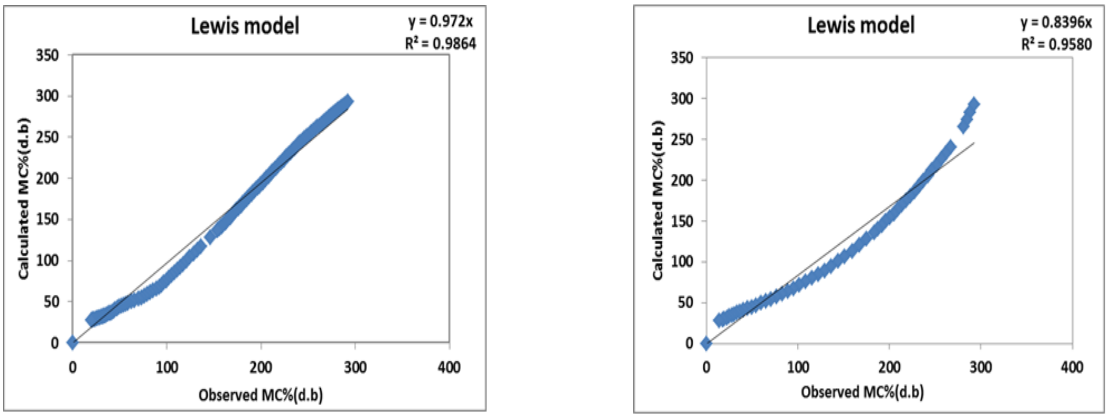
$$\mathbf{A = 0.906796\ IR + 0.0042466\ T + 0.12155257} \qquad \mathbf{(12)}$$

$$\mathbf{(R^2 = 0.930664 \quad ; \quad SE = 0.03457253 \quad ; r = 0.96471)}$$

The analysis described above revealed that the constants (k_h and A) were dependent on air temperature (T) and radiation intensity (IR). These results agree with Matouk et al., (2014) and Matouk et al., (2015)

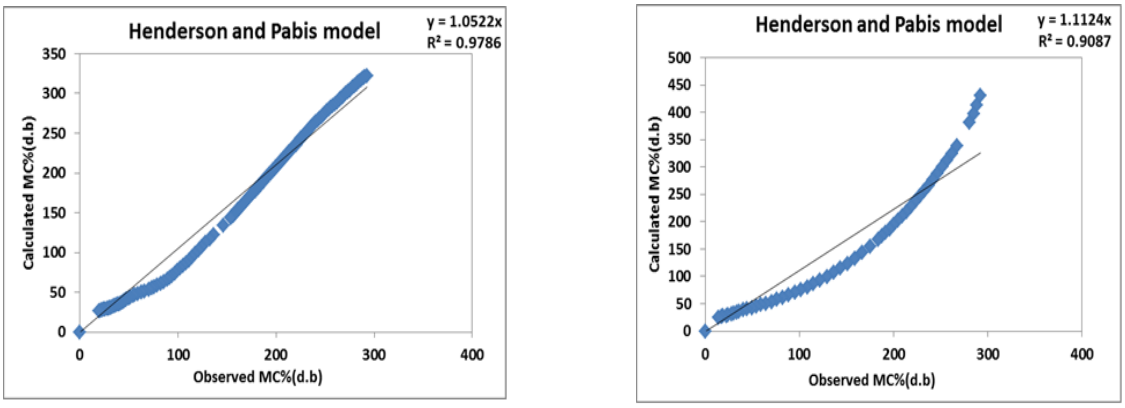
Comparative analysis of the drying models under study:

A comparison analysis for the two examined drying models was conducted (at 45° plot) to decide the most proper drying equation for simulating and describing the drying process of the crimson 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 (40°C and 0.861 kW/m²) and (60 °C and 1.161 kW/m²) for both studied models.



(a) (b)

Fig. 6. Calculated and observed moisture content for Lewis's model, a: (40°C and 0.861 kW/m²) and b: (60 °C and 1.161 kW/m²)



(a) **(b)**

Fig. 7. Calculated and observed moisture content for Henderson and Pabis's model, a: (40°C and 0.861 kW/m^2) and b: (60 °C and 1.161 kW/m^2)

In general, the standard error, (SE) for the calculated and observed moisture content, as well as the average coefficient of determination (R^2) showed that both studied models could adequately predict the crimson seedless grape's drying behavior.

On the other hand, determining the coefficient of (R^2) and (SE) for nonlinear models are not a good decision-making tool, so other statistical parameters such as (reduced chi square χ^2; mean bias error MBE; and root mean square error RMSE) were determined as shown in table (3).

Table 3. Values of determination coefficient (R^2), standard error (SE), chi-square (χ^2), mean bias error (MBE) and root mean square error (RMSE) for both examined models.

IR, kW/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	0.9864	0.03053	0.00289	-0.03965	0.05355	0.9786	0.03508	0.00405	-0.04911	0.06327
	50	0.9861	0.03067	0.00318	-0.04242	0.05622	0.9783	0.03482	0.00441	-0.05205	0.06596
	60	0.9779	0.03613	0.00483	-0.05576	0.06925	0.9601	0.04405	0.00769	-0.07239	0.08707
0.973	40	0.9694	0.04644	0.00926	-0.08314	0.09587	0.9360	0.05920	0.01590	-0.10964	0.12519
	50	0.9861	0.03116	0.00533	-0.06165	0.07272	0.9667	0.03910	0.00929	-0.08329	0.09560
	60	0.9635	0.03381	0.00624	-0.06968	0.07869	0.9305	0.04364	0.01113	-0.09387	0.10460
1.093	40	0.9668	0.05586	0.01254	-0.09530	0.11142	0.9352	0.06906	0.02019	-0.12100	0.14073
	50	0.9555	0.04848	0.01024	-0.08836	0.10062	0.9208	0.06047	0.01636	-0.11110	0.12651
	60	0.9631	0.04450	0.01100	-0.09373	0.10423	0.9754	0.03865	0.00971	-0.08830	0.09734
1.161	40	0.9621	0.05957	0.01705	-0.11324	0.12964	0.9241	0.07473	0.02805	-0.14433	0.16507
	50	0.9774	0.04522	0.01186	-0.09711	0.10803	0.9459	0.05900	0.02000	-0.12433	0.13907
	60	0.9580	0.06209	0.01972	-0.12160	0.13911	0.9087	0.07957	0.03347	-0.15695	0.17954
average		0.9710	0.04371	0.00951	-0.08014	0.09328	0.9467	0.05311	0.01502	-0.10053	0.11583

As noted in Table (3), Lewis model has the highest value of the coefficient of determination (R^2) and the lowest values of (SE, χ^2, MBE, and RMSE). So, it may say that Lewis's model is most proper model for describing the drying process of crimson grapes under the examined conditions.

Calculation of the effective diffusivity

The effective diffusivity was determined using Equation (7) and illustrated in Figure (8), the values of D_{eff} for crimson grapes of IR drying at 0.861 to 1.161 kW/m^2 ranged from 6.8632x10^{-11} to 6.4057x10^{-10} m^2/s.

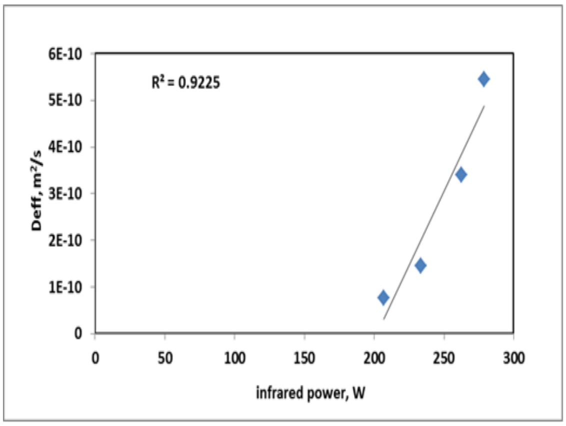


Fig. 8. Changes in the effective diffusivity with power levels.

It can be noticed that, the effective diffusivity values (D_{eff}) increased by increasing infrared power levels (IR). This may be because the product's temperature goes up quickly as a result of the increase in power level, which in turn raised the vapour pressure. As result, it led to faster drying. The obtained values of D_{eff} from this work lie within in general range (10^{-12} to 10^{-8} m^2/s) for drying of food materials (Zogzas et al., 1996). As expected, the values of D_{eff} increased with the increase of output power as was similar to the results for onion slices (Sharma et al., 2005), blueberry (Shi et al., 2008), tomato byproducts (Ruiz et al., 2009) and pomegranate seeds (Doymaz, 2012). The effect of IR power on effective diffusivity may be described by the following equation:

$$\mathbf{D_{eff} = 6\times10^{-12}\, p - 1\times10^{-9} \qquad (R^2 = 0.9225) \qquad (13)}$$

It also can be noticed that the effective diffusivity was affected by the infrared power level.

Calculation of the activation energy

The activation energy could be calculated from the slope of Arrhenius plot between Ln (D_{eff}) against m/p as illustrated in equation (8). The Ln (D_{eff}) as a function of the sample mass/infrared power level, was plotted in Figure (9) where the slope of the straight line is representing the value of (−Ea) while the intercept represents the value of Ln (D_0).

The results noted a linear relation due to Arrhenius type dependence and equation (14) shows the effect of sample mass/power level on D_{eff}:

$$D_{eff} = 2.4525\times10^{-7} \exp(-4251.5\ m/p) \qquad (R^2=0.9941) \qquad (14)$$

The calculated values of (D_0) and (Ea) from the modified Arrhenius type exponential Equation (14) are (2.4525×10^{-7} m^2/s and 4.2515 kW/kg) respectively.

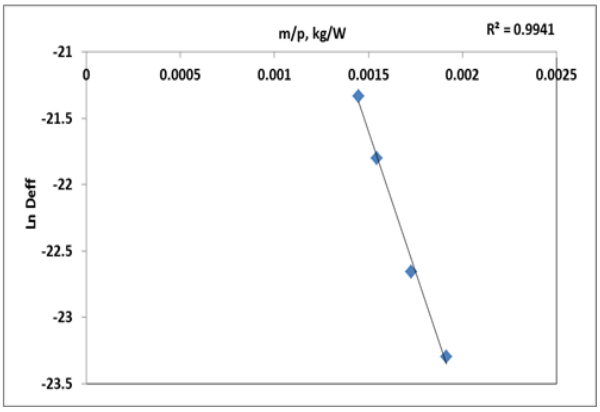


Fig. 9. Relation between Ln (D_{eff}) and the sample mass/infrared power (m/p).

Examination of the dried grapes

Table (4) shows the final moisture content (% d.b.) of crimson grapes at the studied levels of inlet air temperature and radiation intensity. As it can be noticed in table (4), the dried grapes show high levels of final moisture content for the grapes dried at 0.861 kW/m^2 at all levels of inlet air temperature. It was also noticed that samples dried at 1.093 and 1.161 kW/m^2 showed undesirable color which indicates that the samples were burned. So, it was decided that, the best treatment for drying the crimson grapes is 0.973 kW/m^2 and inlet air temperature of 60 ºC.

Table 4. Final moisture content (% d.b.) of crimson grapes at varies levels of intensity of radiation and air temperature.

Air temp. °C	Radiation intensity, kW/m^2			
	0.861	**0.973**	**1.093**	**1.161**
40	19.96	17.50	15.38	14.82
50	19.27	16.79	15.07	14.01
60	19.10	16.61	14.39	13.87

Quality of the dried grapes

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

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

samples	Test methods	Test results %				
		Moisture, (%w.b)	TSS, %	Total sugar, g/100g	Reduction sugar%	So$_2$, ppm
Fresh grape	AOAC (2012) & Ranganna (1997)	74.552	19.7	17.04	16.40	ND
IR dried raisin		16.61	75.8	71.87	54.93	2865.18

Data in table (5) indicated that the moisture content, TSS, reduction sugar and total sugars of fresh grape were 74.552 %, 19.7%, 16.40% and 17.04 %, respectively on fresh mass 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 close to 20% according to the Egyptian Standard of dried grapes (Raisins) No., 285/2005.

The results also show that the sugar content of fresh Crimson grapes was 17.04 %, 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 raisins was 16.61 (% w.b.), for. This level of moisture content represents the 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 (TSS) were higher than 66% and total sugars represent 94.8 % of TSS 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

1- Both inlet air temperature and intensity of radiation affect the reduction in moisture content of crimson grapes.
2- The constant (k_L) of Lewis's model increased by increasing the temperature of drying air and intensity of radiation.
3- The constants of Henderson and Pabis's model (k_h, A) increased with the increase of both inlet air temperature and radiation intensity.
4- Both studied models described the drying process of crimson grapes. However, Lewis's model is considered more proper for describing the drying process and predicting the changes in moisture content of crimson grapes in terms of precision and application simplicity.
5- The effective diffusivity was calculated and was found to vary between $6.8632\text{x}10^{-11}$ to $6.4057\text{x}10^{-10}$ m^2/s and was significantly affected by radiation intensity.
6- The average value of activation energy also be calculated, and its value was 4.2515 kW/kg.
7- Crimson grapes 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, TSS, total sugar, reducing sugars and remained SO_2.

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تجفيف طبقة رقيقة من العنب صنف كريمسون باستخدام الأشعة تحت الحمراء

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الملخص

تم اجراء الدراسة لتحديد خصائص تجفيف العنب صنف كريمسون باستخدام مجفف معملي يعمل بالأشعة تحت الحمراء كمصدر للطاقة الحرارية عند أربعة مستويات لشدة الإشعاع (0.861 -0.973 -1.093 – 1.161 كيلو وات\م^{2}) 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 (40-50-60) درجة مئوية، مع تثبيت سرعة الهواء المستخدم عند مستوي 2 م/ث. وأثناء التجارب تم خفض المحتوى الرطوبي للعنب من 292.46 ±1% الى محتوى رطوبي نهائي تراوح بين (13.87 – 19.96)% 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 (10x6.4057^{-10} – 6.8632 x 10^{-11} م^{2}/ث) وحساب القيمة المتوسطة لطاقة التنشيط والتي كانت (4.2515 كيلووات/كجم) . من ناحية أخري أظهرت نتائج اختبارات الجودة للعنب المجفف أن شدة الإشعاع 0.973 كيلووات\م^{2} عند درجة حرارة الهواء 60 درجة مئوية قد أعطت أفضل النتائج من حيث المحتوى الرطوبي النهائي ونسبة المواد الصلبة الكلية ونسبة السكريات والكبريت المتبقي.

الكلمات الدالة : التجفيف فى طبقات رقيقة، التجفيف بالاشعة تحت الحمراء، تجفيف العنب، الانتشار الفعال، طاقة التنشيط