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DEVELOPMENT AND EVALUATION OF POMEGRANATE SEEDS DRYING UNIT USING INFRARED / HOT AIR DRYER

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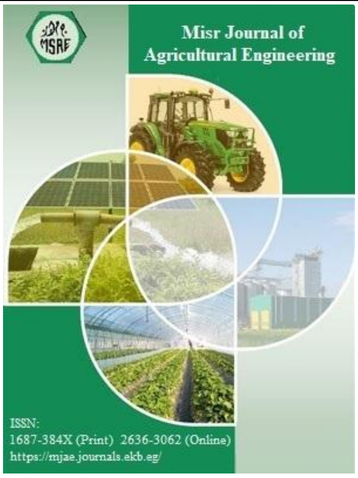

Keywords:
Infrared (IR) drying, pomegranate seed drying, hot-air drying, dehydration, mathematical modeling.

ABSTRACT

In the present study combined infrared and hot air dryer to dry a thin layer of pomegranate seeds. Three different levels of infrared power, namely: 200, 250 and 300 W and three different exposure distance "the distance between infrared heater and samples" of dying are 20, 15 and 10 cm with air temperature 40 °C and air velocity 1.5 m/s were studied. Drying time as affected by infrared power and exposure distance, compatibility of experimental data to some drying models, effective diffusivity "D_{eff}", rehydration and cost analysis were also studied. The results show that the drying time decreased with increasing infrared power and decreasing exposure distance. Midilli et al model showed the best fitness to experimental data with average R^2 0.9972. The maximum values of D_{eff} were recorded at highest infrared power 300 W. The rehydration ratios ranged between 0.55 to 1.16 under various drying conditions.

1. INTRODUCTION

The pomegranate (***Punica granatum L.)*** follows a Punicaceae family. Edible seeds (about 50% of total fruit mass) substantially include various bioactive compounds such as polysaccharides (pectin, sugars), various vitamins (ascorbic acid, vitamin E and K) and minerals such as potassium, calcium, magnesium, and sodium. **(sufer and Palazoglu, 2019).** The bioactive compounds like phenolic acids, anthocyanins and tannins have the ability of reducing cancer, obesity, diabetes risks. Threatening headache, dysentery and leucorrhea (**Dhinesh and Ramasamy, 2016).**The pomegranate juice is considered better for patient suffering from leprosy, high cholesterol levels and heart disorders. In addition, the harmful molecules that cause premature aging **(More et.al., 2017).** Due to these potential therapeutic benefits, pomegranate could be accepted as a functional food **(Viuda et.al., 2010)**. In Egypt, pomegranate cultivated area is about 79045 feddans yearly producing about 8 ton per Fadden **(Agricultural Statistics, 2018).** Dehydration is the process of removing water from food by mingling hot air through it, which prevents the growth of enzymes and bacteria. Dried foods are tasty, nutritious, lightweight, easy-to prepare, and easy-to-store and use. The energy input is less than what is needed to freeze or can, and the storage space is minimal compared with that needed for canning jars and freeze, . the drying reduce in weight and volume, minimizing packing, storage and transportation costs**, (Ahmed, et.al., 2013)** In recent years, infrared (IR) drying has become a significant technique in the drying processing because of its advantages, such as the energy savings, lower drying time, high-quality dried products, intermittent energy source, easy control of the process parameters, uniform temperature distribution, and clean operational environment, as well as space savings **(Riadh et.al., 2015).**One of the main parameters that can reduce the drying time is the ability of infrared radiation directly transfer heat to a certain depth of the food materials **(Bae et.al., 2010).** Infrared (IR) drying either alone or combined with others offers many advantages over convective air drying under similar drying conditions. Treatment in the food industry because of advantages such as equipment compactness, fast transient response, significant energy saving, and easy accommodation with convective, conductive . Because of its performance, IR energy transfer from the heating source to the material surface is performed without heating the surrounding air. The material absorbs all the heat coming from the source, resulting in less drying time. IR heating is considered as a potential method for obtaining the high quality of dried foodstuffs such as fruits, vegetables and grains. **(Pawar, and Pratape, 2017).** The pomegranate seeds were dried at 83, 104, 125, and 146 W IR power levels. It was reported that the power levels affected the drying rate and time. **(Doymaz, 2012)**.The aim of this study is to utilize infrared / hot air dryer for drying pomegranate seeds and study the effect of infrared power "IR" levels and a distance between infrared heater and the samples "exposure distance" on the pomegranate seeds moisture content, elapsed drying time, drying rate, effective moisture diffusivity. This study also aims to evaluating the compatibility of the thin layer data to some drying models, evaluating the production cost and calculate the rehydration as quality indicator.

2. MATERIALS AND METHODS

Experiments were carried out in Laboratory of Agricultural Product processing Engineering Department, Faculty of Agricultural Engineering Al-Azhar Univ., Cairo, Egypt, during the period of January to March 2020

MATERIALS:

Raw material:

Fresh pomegranate were purchased from a local market in Cairo, Egypt and kept in a refrigerator at 4°C prior to use before drying process. The pomegranate was cut into four pieces to facilitate seeds extract. The initial moisture content of seeds was (84.10 % ± 0.5 w.b.).

Infrared / hot air dryer construction:

The infrared-convective dryer comprised of two components i.e. the chamber of drying having infrared heater (tube type) and hot air supply unit. A schematic view of the experimental drier is shown in **Fig. 1.**The drying chamber of 400×300×300 mm were made from a plywood sheet of 8 mm thickness having a single door opening at the front. The drying chamber was isolated and covered from inside with an aluminum foil., Two slots the first is circular with diameter of 150 mm and the second is square with dimensions of 150×150 mm" were made in the two opposite short walls for entering and exiting of hot air. An infrared heater (tube type) of 400 W having length of 250 mm was fitted on the top inside surface of the drying chambers. It is controlled in IR power levels using electronic circuit (Arduino uno) by changing the intensity of the electrical current. A sample tray of woven wire mesh having dimension of 300×200 mm was placed beneath the infrared heater in a way that a distance of 100,150, and 200 mm was maintained between infrared heater and pomegranate samples in the tray. The hot air supply unit was a small air blower of 0.3 kW, 220 V, made in China, was used to supply the hot air flow rate. This blower was connected to the infrared drying chamber by means of housing with dimensions of 600 mm length, 100 mm width, 100 mm high made of galvanized iron sheet of 0.6 mm thickness and insulated from the outside by glass wool with thickness of 30 mm to prevent heat loss. The electrical heater of 2 kW was fixed inside the housing to heat the drying air. Controlling the inlet air temperature of the infrared drying chamber was justified by a gas type thermostat. the following specifications: Made in: Italy. Model: TUF – DF 09 The housing is connected to PVC tube diameter of 50 mm, insulated also by glass wool of thickness 30 mm. This tube passes the hot air through the infrared drying chamber cavity. The dryer was run idle for about 0.5 h to achieve a steady state in respect of pre-set experimental drying conditions before each drying run.

Measuring instruments

Electrical balance:

Initial and final masses and mass changes during drying process of each sample were measured by a digital electric balance throughout. The measurements were carried out during experimentation on intervals of 10 min.

Thermocouple:

Temperatures were measured using type K thermocouples, the output of the display are 4-digits. Their specifications are: Manufacture: U.S.A Model: 8528-40 Full Useful range: 4-45 ^{o}C.

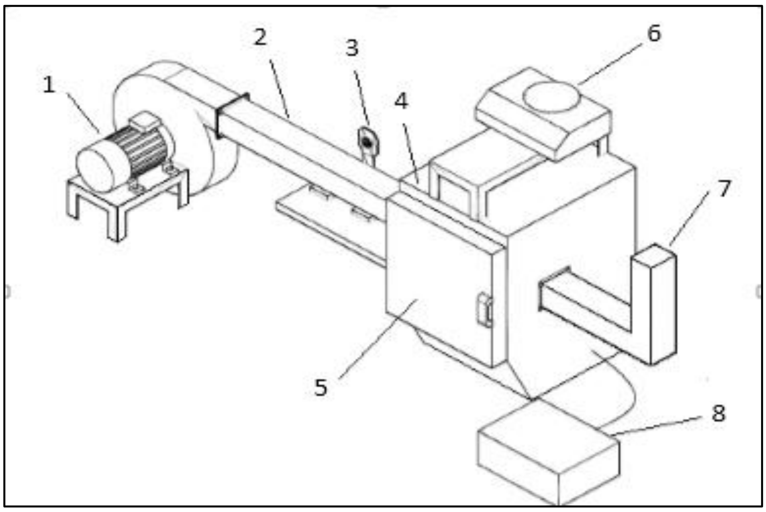

Fig. (1) Isometric of infrared-convective dryer setup.

1 Motor	**2 Air heater**
3 Thermostat	**4 Drying chamber**
5 Door of drying chamber	**6 A digital electric balance**
7 Chimney	**8 Electronic circuit (Arduino uno)**

Thermostat:

Drying air temperature was controlled using thermostat made in Germany, accuracy 1^{o}C. This thermostat has been connected with the circuit of the air heater.

Turbo meter:

A turbo meter was used for measuring of the drying air speed. It is manufactured in U.S.A. by Davis instruments, measuring range of (0 – 44.8) m/s.

METHODS:

In the present study was to study the effect of three IR power levels 200, 250, and 300 W and three a distance between infrared heater and samples in the tray (exposure distance) 100, 150, and 200 mm.

The initial moisture content of samples:

The initial moisture contents of the pomegranate are evaluated by oven dried at 105 ºC (±1) for 24 hours. It is determined a**ccording to the ASAE standards (2002).**

$$\boldsymbol{m = \frac{W_m}{W_m + W_d} \times 100 \quad (w.b)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(\mathbf{1})$$

Where:

$\mathbf{W_m}$ = mass of moisture in sample (g),

$\mathbf{W_d}$ = mass of bone-dry material (g).

Moisture content of sample during drying:

Moisture content (m), (wet basis %):

The moisture content, wet basis % is determined as follows: **(Tayel et. al., 2012).**

$$\boldsymbol{m = \frac{B - A\,(1 - M_i\,)}{B}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots..(\mathbf{2})$$

Where

$\boldsymbol{A}$ is the mass of fresh sample (g), $\boldsymbol{B}$ mass of sample at any time (g) and $\boldsymbol{M_i}$ initial moisture content, w.b. %.

Moisture content ($\mathbf{M_t}$), (dry basis %):

The moisture content, dry basis % is determined as follows:

$$\boldsymbol{M_t = \frac{B}{A}\,(1 + M_i) - 1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{3})$$

Where $\mathbf{M_i}$: initial moisture content, d.b. %. **(Tayel et. al., 2012)**.

Moisture ratio calculation (*MR*):

$$\boldsymbol{MR = \frac{M_t - M_e}{M_i - M_e}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{4})$$

Where $\mathbf{M_e}$ is the equilibrium moisture content, can be assumed $M_e = M_f$ (M_f is final moisture content).

Drying rate. (DR)

The drying rate is determined as follows:

$$\boldsymbol{DR = \frac{M_i - M_f}{t}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{5})$$

Where:

$\boldsymbol{M_i}$: Initial moisture content of the product %; $\boldsymbol{M_f}$: Final moisture content of the product %; and $\boldsymbol{t}$: Elapsed time of drying hr .

Compatibility of drying data to some drying models of thin layer:

The moisture content data observed at the drying experiments were converted into the MR (moisture ratio) and fitted to the 8 models listed in table (1). Data were analyzed using **SPSS 6** “Statistical Package for the Social Sciences” for selecting the best model to describe drying curves. The fitting quality of the experimental data to all models was evaluated using the coefficient of determination **($\mathbf{R^2}$),** reduced chi-square **($\mathbf{X^2}$),** root mean square error **(RMSE).).** and modeling efficiency **(EF).**

Table (1): Some mathematical models of drying applied to the drying curves of pomegranate seeds.

NO	*Name of model*	*Model*	*Reference*
1	*Lewis*	*MR= exp (-kt)*	***Roberts et al. (2008)***
2	*Weibull*	$MR = exp\left[-\left(\frac{t}{b}\right)^{a}\right]$	***Corzo et al. (2008)***
3	*Logarithmic*	*MR=a exp (-kt)+c*	***Wang et al. (2007)***
4	*Midilli et al*	$MR = a\ exp\ (-kt^{n}) + bt$	***Al – Muhtasab et al. (2010)***
5	*Page*	$MR = exp\ (-kt^{n})$	***Ojediran and Raji (2010)***
6	*Modified Page*	$MR = exp\ (-(kt)^{n})$	***Vega et al (2007)***
7	*Handerson and Pabis*	*MR = a exp (-kt)*	***Erbay and Icier (2010)***
8	*Wang and Singh*	$MR = 1 + at + bt^{2}$	***Akpinar (2010)***

The best model describing the drying characteristics of samples was chosen as the one with the highest $\mathbf{R^2}$, the least $\mathbf{X^2}$ and **RMSE (Inyang, et. al.,2018)**

Determination of the effective moisture diffusivity:

Fick's law used to determine the moisture diffusivity of various fruits and other biological materials, which is a function of temperature and moisture content in material. It was assumed that pomegranate seed had spherical geometry and uniform initial moisture distribution, symmetric mass transfer happened in accordance with the center of pomegranate, there was negligible surface resistant to mass transfer, no chemical reactions occurred, and diffusion coefficient was constant throughout the process. The solution of Fick's equation for an infinite slab is as follows:

$$\boldsymbol{MR = \frac{M_t - M_e}{M_i - M_e} = \frac{6}{\pi^2}\ exp\ \left(-\pi^2 . \frac{D_{eff}\ . t}{r^2}\right)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (\mathbf{6})$$

where, $\boldsymbol{D_{eff}}$ is the effective diffusivity (m^2/s), $\boldsymbol{r}$ is the radius of samples (m),.The previous equation (11) can be rewritten as:

$$\boldsymbol{Ln\ MR = Ln\left(\frac{6}{\pi^2}\right) - \left(\pi^2 . \frac{D_{eff}\ . t}{r^2}\right)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (\mathbf{7})$$

Then the effective moisture diffusivity $\boldsymbol{D_{eff}}$ can be calculated using the equation:

$$\boldsymbol{D_{eff} = \frac{-0.101\ ln(MR) - 0.0504}{(\frac{t}{r^2})}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (\mathbf{8})$$

Rehydration ratio:

Rehydration capacity is useful to determine how the dried product reacts with the moisture. The rehydration capacities of dried slices were evaluated by immersing 5g of dried samples in boiled distilled water at room temperature Samples were removed at regular time intervals (each 5 min.) and weighed until difference in successive weighing was insignificant. Rehydration ratio was calculated from the following equation **(Tayel et al., 2012).**

$$\mathbf{Re}\boldsymbol{hydration\ ratio = \frac{W_t - W_d}{W_d}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (\mathbf{9})$$

Where $\boldsymbol{W_t}$ is the mass of rehydration sample at any time **(g)** and w_d mass of dried sample **(g).**

Cost:

The dryer hourly costs were calculated based on the fixed and variable costs of the infrared-convective dryer by using the **Awady equation** (**Awady et. al., 2003)**

3. RESULTS AND DISCUSSION

Effect of infrared power levels and exposure distances for infrared rays on Pomegranate seeds drying curves:

Fig (2) shows the relationships of moisture ratio and elapsed time as affected by infrared power and exposure distance for infrared rays during all drying experiments. It is clear that the higher the infrared power and the lower exposure distance the reduced moisture ratio and total drying time. In addition, it was found that the least drying time was 40 min. with infrared power 300 W and exposure distance 10cm, while the highest drying time was 150 min. with infrared power 200 W and exposure distance 200 cm.

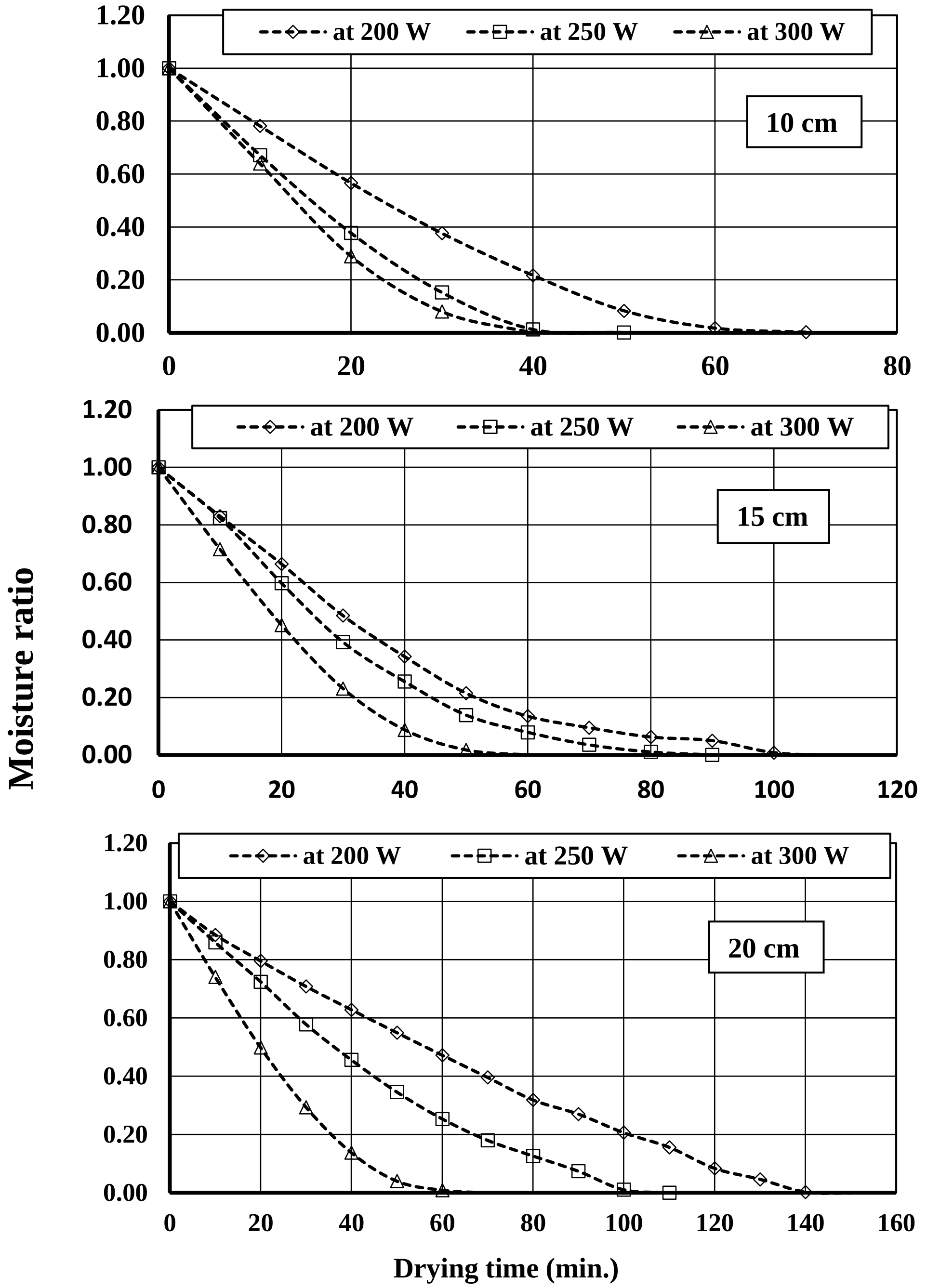

Fig. (2): Moisture ratio during drying at different Infrared radiation power levels, exposure distances 10,15 and 20cm at air velocity 1.5 m/s.

Fig (3) shows the relation between total drying time and infrared power levels at exposure distance (10, 15 and 20 cm). Generally, it can be observed that the drying time decreased with increasing infrared power and decreased exposure distance. The relation between total drying time (***t***) and infrared power levels (***P***) was as the following equation:

$$\boldsymbol{t = -\,aP + c}$$

The relation between parameter (***a***) and exposure distance (***d***) was as the following equation: $\boldsymbol{a = 0.0116\, d^{\,1.405}}$

The relation between parameter (**C**) and exposure distance (***d***) was as the following equation: $\boldsymbol{c = 6.8641 d^{1.2699}}$

The general equation between total drying times (***t***), infrared power levels (***P***) and exposure distance (***d***) for Pomegranate seeds was of the form:

$$\boldsymbol{t} = \left[\left(-\mathbf{0.0116}\, \boldsymbol{d}^{\mathbf{1.405}}\right) \times (\boldsymbol{P})\right] + [\mathbf{6.8641}\boldsymbol{d}^{\mathbf{1.2699}}]$$

Fig. (4) shows the predicted and observed total drying time (min.).

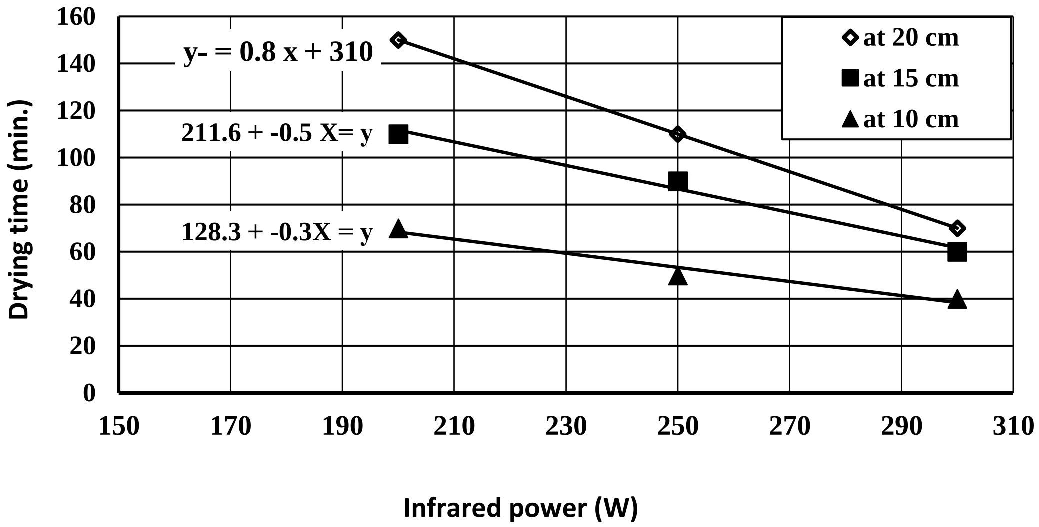

Fig. (3): Relation between the drying time and the Infrared power at different exposure distances

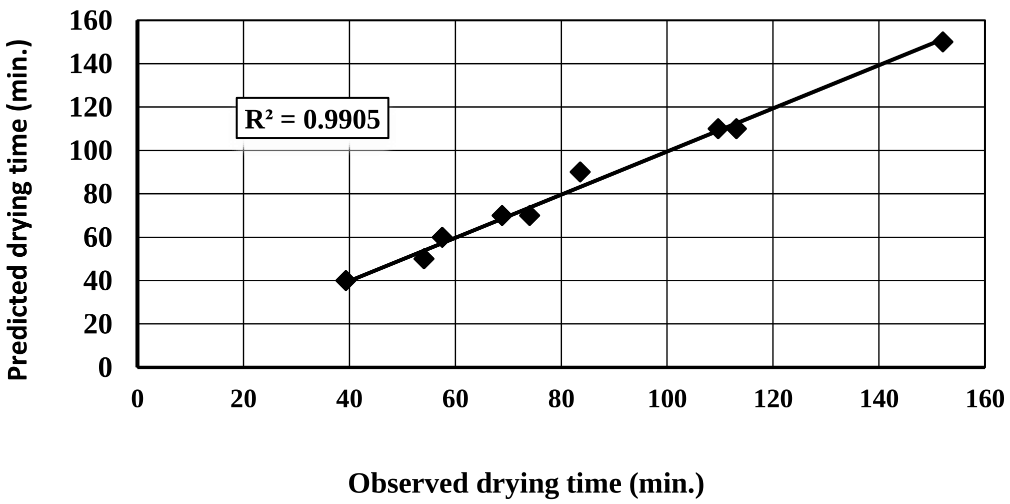

Fig. (4): Predicted and observed drying time at different infrared power and exposure distance.

Fig (5) shows the relationships between the drying rate (g_{water}/min.) and moisture content (% d.b) at the infrared power levels and different exposure distances. It is clear that increasing the infrared power level and reducing the exposure distance increases the drying rate.

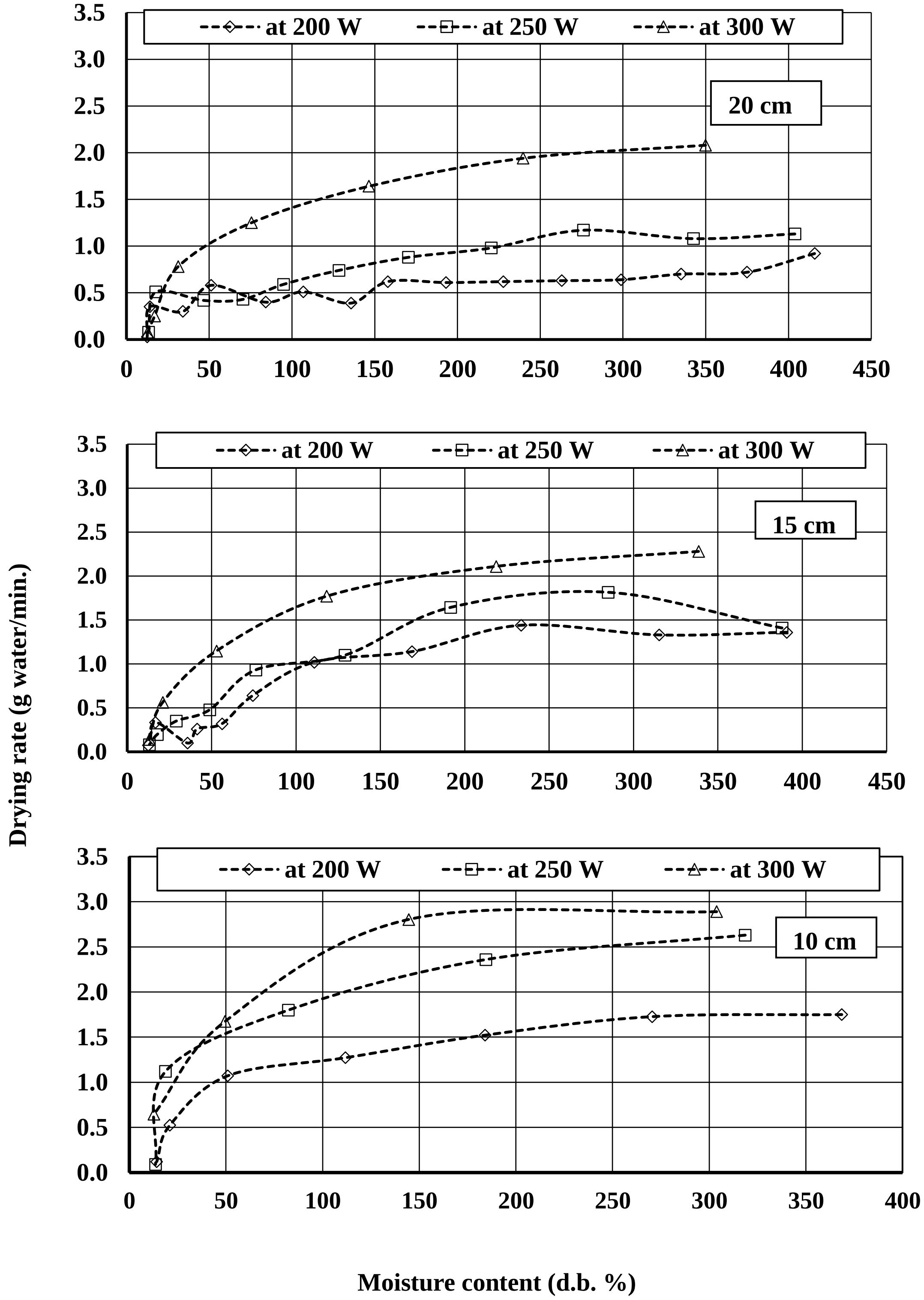

Fig. (5): Variation of drying rate as related to moisture content at different Infrared radiation power levels, exposure distances 10, 15 and 20 cm and air velocity of 1.5 m/s.

Compatibility of the drying curves with some drying models:

The selected models are identified in previous table (1). Table (2) shows the constants of different models for drying and its statistical analysis. The results showed that all models had good suitability to the experimental data under all drying conditions in this study. For all models, the R^2 and EF were higher than 0.8807 and 0.9688 respectively, while the X^2 and RMSE were lower than 0.007666 and 0.066016 respectively. Midilli et al model showed the best fitness to experimental data where the highest values for average R^2 and EF were 0.9961 and 0.9993 respectively, while the lowest values for average X^2 and RMSE were 0.0002 and 0.0084 respectively.

Table (2): The constants of different models for drying and its statistical analysis.

Models	Exposure dist.(cm)	Power levels (W)	Constant					R^2	EF	X^2	RMSE
			a	b	c	k	n				
Lewis	20	200				0.015		0.9089	0.9875	0.001610	0.038852
		250				0.022		0.9206	0.9859	0.001829	0.040945
		300				0.043		0.8910	0.9739	0.003703	0.056920
	15	200				0.028		0.8807	0.9808	0.002315	0.046065
		250				0.033		0.8890	0.9789	0.002814	0.050329
		300				0.047		0.9117	0.9755	0.003735	0.056580
	10	200				0.036		0.8815	0.9705	0.004499	0.062741
		250				0.055		0.9029	0.9688	0.005230	0.066016
		300				0.063		0.9565	0.9766	0.005432	0.063831
Aevrage								**0.9048**	**0.9776**	**0.0035**	**0.0536**
Weibull	20	200	1.419	69.771				0.9635	0.9950	0.000692	0.024601
		250	1.393	46.552				0.9935	0.9988	0.000165	0.011722
		300	1.450	24.985				0.9899	0.9976	0.000400	0.017313
	15	200	1.380	37.049				0.9956	0.9993	0.000093	0.008801
		250	1.450	31.470				0.9992	0.9999	0.000022	0.004160
		300	1.473	22.583				0.9933	0.9981	0.000342	0.015628
	10	200	1.501	29.079				0.9854	0.9964	0.000647	0.022022
		250	1.519	19.381				0.9895	0.9966	0.000708	0.021732
		300	1.579	17.000				0.9991	0.9995	0.000170	0.009214
Aevrage								**0.9899**	**0.9979**	**0.0004**	**0.0150**
Logarithmic	20	200	1.653		-0.652	0.007		0.9983	0.9998	0.000034	0.005247
		250	1.343		-0.322	0.014		0.9930	0.9988	0.000197	0.012165
		300	1.206		-0.181	0.031		0.9779	0.9947	0.001050	0.025617
	15	200	1.154		-0.114	0.023		0.9594	0.9935	0.000962	0.026867
		250	1.190		-0.150	0.026		0.9630	0.9930	0.001207	0.029064
		300	1.234		-0.212	0.032		0.9833	0.9954	0.001060	0.024610
	10	200	1.367		-0.346	0.021		0.9864	0.9966	0.000724	0.021268
		250	1.273		-0.257	0.036		0.9786	0.9931	0.001918	0.030969
		300	1.349		-0.335	0.037		0.9910	0.9952	0.003359	0.028980
Aevrage								**0.9812**	**0.9956**	**0.0012**	**0.0228**
Midilli et al	20	200	0.992	-0.002		0.006	1.102	0.9977	0.9997	0.000051	0.006192
		250	0.997	0.000		0.008	1.222	0.9993	0.9999	0.000022	0.003861
		300	0.995	0.000		0.011	1.381	0.9954	0.9989	0.000275	0.011719
	15	200	0.994	0.000		0.007	1.378	0.9960	0.9994	0.000107	0.008453
		250	0.999	0.000		0.007	1.418	0.9995	0.9999	0.000021	0.003532
		300	0.997	0.000		0.012	1.395	0.9972	0.9992	0.000237	0.010087
	10	200	0.993	-0.001		0.009	1.361	0.9957	0.9989	0.000287	0.011979
		250	0.997	0.000		0.014	1.410	0.9946	0.9982	0.000734	0.015639
		300	1.000	0.000		0.014	1.473	0.9998	0.9999	0.000058	0.003794
Aevrage								**0.9972**	**0.9993**	**0.0002**	**0.0084**

Continued.

Models	Exposure dist.(cm)	Power levels (W)	Constant a	b	c	k	n	R^2	EF	X^2	RMSE
Page	20	200				0.002	1.419	0.9635	0.9950	0.000692	0.024601
		250				0.005	1.393	0.9935	0.9988	0.000165	0.011722
		300				0.009	1.450	0.9899	0.9976	0.000400	0.017313
	15	200				0.007	1.380	0.9956	0.9993	0.000093	0.008801
		250				0.007	1.450	0.9992	0.9999	0.000022	0.004160
		300				0.010	1.473	0.9933	0.9981	0.000342	0.015628
	10	200				0.006	1.501	0.9854	0.9964	0.000647	0.022022
		250				0.110	1.519	0.9895	0.9966	0.000708	0.021732
		300				0.110	1.579	0.9991	0.9995	0.000170	0.009214
Aevrage								**0.9899**	**0.9979**	**0.0004**	**0.0150**
Modified Page	20	200				0.014	1.419	0.9635	0.9950	0.000692	0.024601
		250				0.021	1.393	0.9935	0.9988	0.000165	0.011722
		300				0.040	1.450	0.9899	0.9976	0.000400	0.017313
	15	200				0.027	1.380	0.9956	0.9993	0.000093	0.008801
		250				0.032	1.450	0.9992	0.9999	0.000022	0.004160
		300				0.050	1.473	0.9933	0.9981	0.000342	0.015628
	10	200				0.034	1.501	0.9854	0.9964	0.000647	0.022022
		250				0.052	1.519	0.9895	0.9966	0.000708	0.021732
		300				0.059	1.579	0.9991	0.9995	0.000170	0.009214
Aevrage								**0.9899**	**0.9979**	**0.0004**	**0.0150**
Handerson and Pabis	20	200	1.074			0.016		0.9184	0.9888	0.001546	0.036776
		250	1.070			0.024		0.9387	0.9891	0.001554	0.035982
		300	1.052			0.044		0.9038	0.9769	0.003815	0.053489
	15	200	1.067			0.026		0.9064	0.9850	0.001998	0.040801
		250	1.070			0.036		0.9113	0.9831	0.002531	0.044996
		300	1.048			0.055		0.9207	0.9780	0.004027	0.053630
	10	200	1.061			0.038		0.8970	0.9743	0.004564	0.058507
		250	1.041			0.057		0.9103	0.9711	0.006042	0.063465
		300	1.036			0.065		0.9591	0.9780	0.007666	0.061909
Aevrage								**0.9184**	**0.9805**	**0.0037**	**0.0500**
Wang and Singh	20	200	-0.010	0.000023				0.9982	0.9998	0.000034	0.005452
		250	-0.016	0.000062				0.9966	0.9994	0.000085	0.008419
		300	-0.030	0.000000				0.9954	0.9989	0.000181	0.011652
	15	200	-0.030	0.000000				0.9845	0.9975	0.000330	0.016584
		250	-0.020	0.000000				0.9833	0.9968	0.000477	0.019535
		300	-0.034	0.000000				0.9955	0.9988	0.000228	0.012770
	10	200	-0.026	0.000000				0.9931	0.9983	0.000307	0.015172
		250	-0.039	0.000000				0.9935	0.9979	0.000441	0.017140
		300	-0.044	0.000000				0.9953	0.9975	0.000889	0.021083
Aevrage								**0.9928**	**0.9983**	**0.0003**	**0.0142**

Fig. (6) shows the comparison between the experimental moisture ratio of pomegranate seeds and those predicted by Midilli et al. model at infrared power levels of 200, 250 and 300 W and exposure distances of 10, 15 and 20 cm. Midilli et al. model gave better predictions than others, and satisfactorily described the drying characteristics of pomegranate seeds.

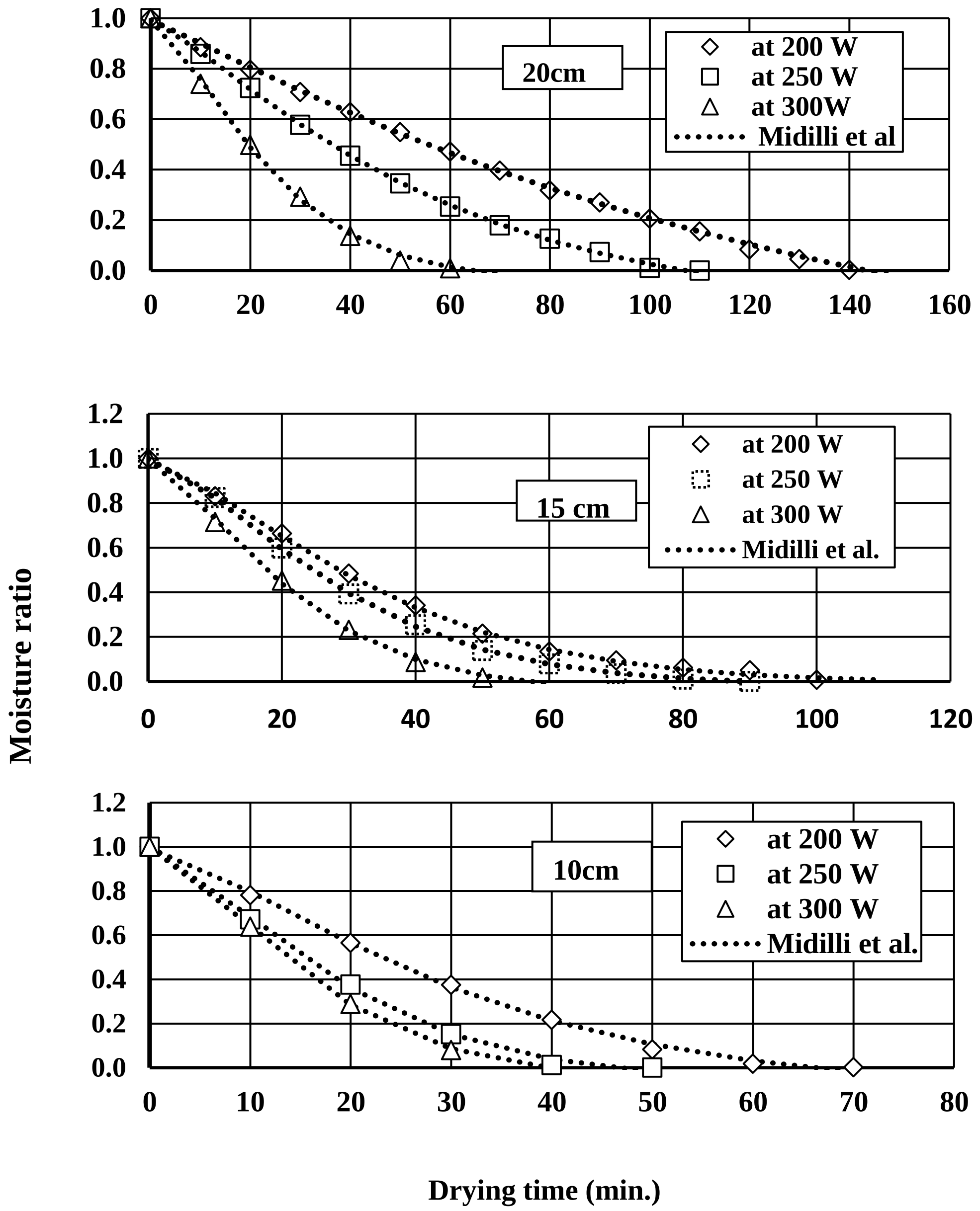

Fig. (6): Comparison between the experimental moisture ratios and those predicted by Midilli et al. model at different power levels and exposure distance10,15, and 20 cm.

Effective moisture diffusivity:

The effective moisture diffusivity of food material characterizes its intrinsic mass transport property of moisture, which includes molecular diffusion, liquid diffusion, hydrodynamic flow and other possible mass transport mechanisms. Table (3) shows the average effective moisture diffusivity at different infrared power and different exposure distance. The minimum values of the average effective moisture diffusivity (D_{eff}) 0.15×10^{-7}, 0.47×10^{-7} and 0.85×10^{-7} m^2/s were recorded at exposure distance 20, 15 and 10 cm with the lower infrared power 200 W, while the maximum values of the average D_{eff} $0.0.88\times10^{-7}$, 0.90×10^{-7} and 1.57×10^{-7} m^2/s were recorded at exposure distance 20, 15 and 10 cm with the highest infrared power 300 W.

Table (3): Effective average moisture diffusivity at different infrared powers and different exposure distance

Effective average moisture diffusivity ($D_{eff}\times10^{-7}$ m^2/s)				
Infrared power		200W	250W	300W
exposure distance	20 cm	0.15	0.43	0.88
	15 cm	0.47	0.86	0.90
	10 cm	0.85	1.18	1.57

Rehydration ratio:

The rehydration of pomegranate seeds dried by infrared dryer is affected by infrared power and exposure distance. Fig. (7) shows the relation between rehydration ratio and rehydration time at different infrared powers and different exposure distance.

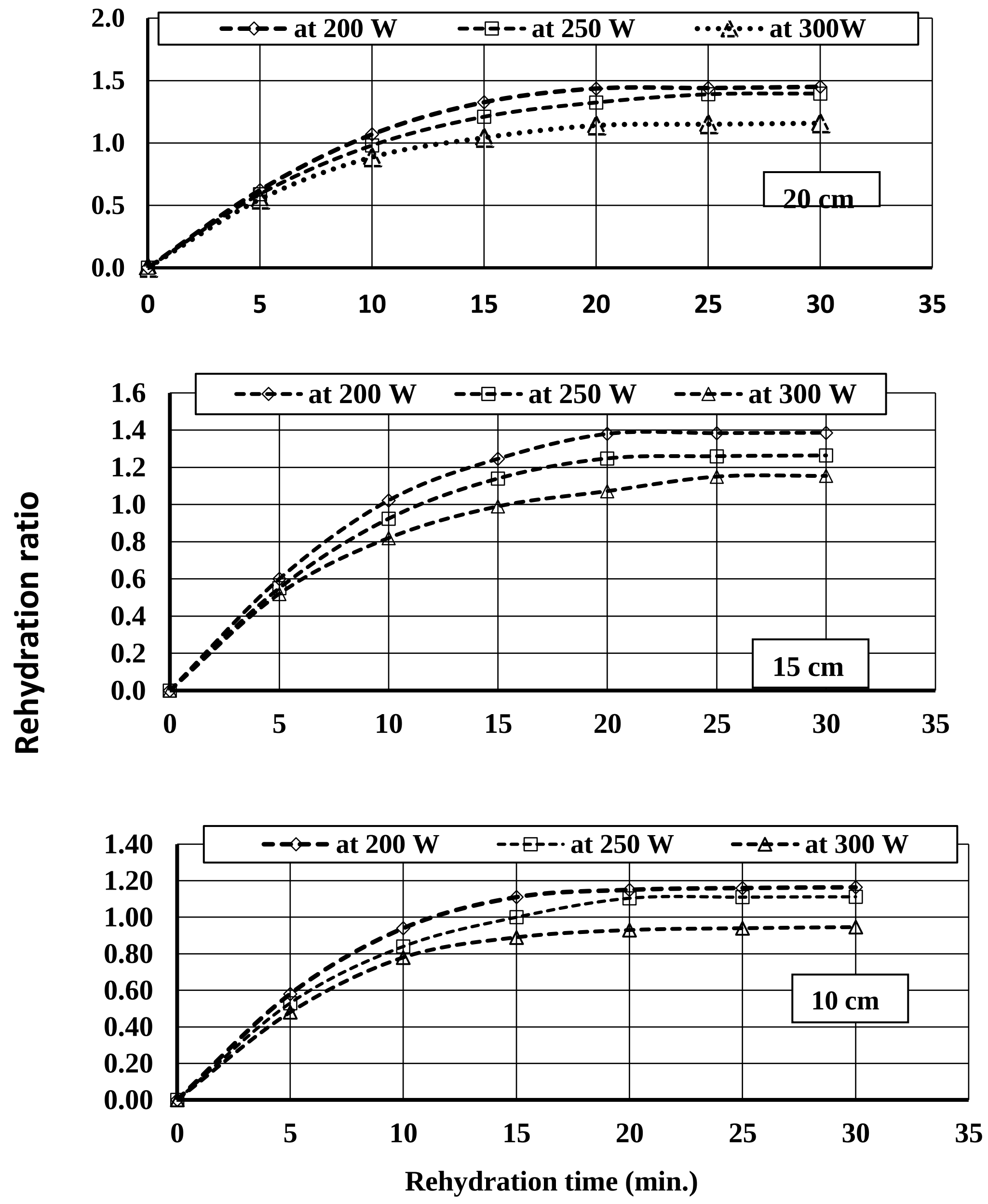

Fig. (7): Rehydration ratio versus rehydration time at different infrared power and exposure distance distances 10,15, and 20 cm

In all the cases, the amount of moisture absorbed increases with rehydration time and the rehydration stabilized in about 20 minutes. The rehydration ratio under various infrared powers was in the range (0.55 – 1.45), (0.52 – 1.39) and (0.48 – 1.16) at exposure distances of 20, 15 and 10 cm respectively.

Cost analysis:

Table (4) shows the costs for dried Pomegranate seeds at the different drying conditions. The minimum values of dried cost (6.29 L.E/kg $_{\text{dried seeds}}$) was recorded at infrared power of 300 W and exposure distance of 10 cm, while the maximum values was 23.00 L.E/kg $_{\text{dried seeds}}$ at infrared power of 200 W and exposure distance of 20 cm.

Table (4): cost analysis of dried pomegranate seeds at different infrared powers and different exposure distances.

costs (L.E/kg $_{\text{dried seeds}}$)				
Infrared power		**200W**	**250W**	**300W**
exposure distance	**20 cm**	23.00	16.72	10.99
	15 cm	16.54	13.96	9.40
	10 cm	10.77	7.72	6.29

4. CONCLUSION

The research results mentioned above could be concluded in the following points:

- The drying time decreased with increasing infrared power and decreased exposure distance. The general equation between total drying time (***t***), infrared power levels (***P***) of 200, 250 and 300 W and three different exposure distance of dying are 20, 15 and 10 cm with air temperature 40 ^{o}C and air velocity 1.5 m/s were studied. for Pomegranate seeds was of the form:

$$\boldsymbol{t} = \left[\left(-\mathbf{0.0116}\ \boldsymbol{d}^{\mathbf{1.405}}\right) \times (\boldsymbol{P})\right] + \left[\mathbf{6.8641}\boldsymbol{d}^{\mathbf{1.2699}}\right] \qquad \mathbf{R^2 = 0.9905}$$

- Increasing the infrared power level and reducing the exposure distance increases the drying rate.
- Midilli et al model showed the best fitness to experimental data where the highest values for average R^2 was 0.9961.
- The maximum values of the effective moisture diffusivity "D_{eff}" were recorded at highest infrared power of 300 W.
- The minimum values of dried cost (6.29 L.E/kg $_{\text{dried seeds}}$) were recorded at infrared power of 300 W and exposure distance of 10 cm.
- The rehydration ratios ranged between0.55 to1.16 under various drying conditions.

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تطوير وتقييم وحدة تجفيف بذور الرمان باستخدام مجفف الأشعة تحت الحمراء/الهواء الساخن

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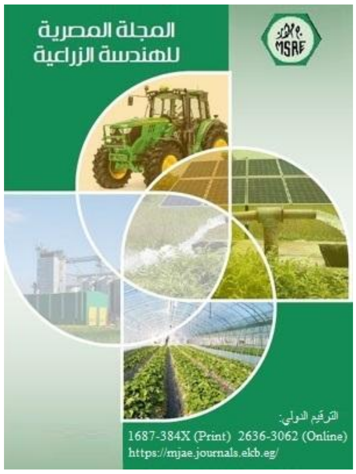

الملخص العربي

تهدف هذه الدراسة إلى تطوير مجفف يعمل بالأشعة تحت الحمراء والهواء الساخن معاً يناسب تجفيف بذور الرمان فى طبقات رقيقة. ودراسة بعض العوامل المؤثرة على التجفيف ومدى توافق النتائج التجريبية مع بعض صيغ التجفيف المعروفة وإيجاد ثوابت التجفيف لهذه الصيغ. كما تم تقييم جودة المنتج من خلال اختبار التشرب للعينات المجففة.

- وتم دراسة ثلاث قدرات من الأشعة تحت الحمراء (٢٠٠، ٢٥٠ و ٣٠٠ وات) وثلاث مسافات بين العينات المراد تجفيفها ومصدر الأشعة (١٠، ١٥ و ٢٠ سم).

ويمكن تلخيص أهم النتائج كما يلي:

- انخفض زمن التجفيف بزيادة القدرة من الأشعة تحت الحمراء وانخفاض المسافة بين العينات ومصدر الأشعة، وتم التوصل إلى نموذج رياضي للتنبؤ بزمن التجفيف عند ظروف التجفيف المختلفة حيث حقق الصورة: -

$$t = \left[\left(-0.0116\, d^{1.405}\right) \times (P)\right] + \left[6.8641 d^{1.2699}\right] \quad R^2 = 0.9905$$

- ازداد معدل التجفيف بزيادة قدرة الأشعة تحت الحمراء وانخفاض المسافة بين العينات ومصدر الأشعة.
- أظهر نموذج Midilli et al. أفضل ملائمة للبينات التجريبية حيث سجلت معها أعلى قيمة لمتوسط R^2 وهي ٠,٩٩٧٢.
- أعلى قيم للانتشار الرطوبى تم الحصول عليها عند أعلى قدرة للأشعة ٣٠٠ وات.
- سجلت أقل قيمه لتكاليف التجفيف ٦,٢٩(جنيه/كجم بذور مجففة) مع قدرة ٣٠٠ وات من الأشعة تحت الحمراء عندما تكون مسافة بين العينات ومصدر الأشعة ١٠ سم.
- تراوحت قيم التشرب للعينات المجففة عند مختلف ظروف التجفيف فى هذه الدراسة بين ٠,٥٥ و١,١٦.

الكلمات المفتاحية:
التجفيف بالأشعة الحمراء، تجفيف بذور الرمان، التجفيف بالهواء الساخن، النماذج الرياضية للتجفيف