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Effect of microwave pretreatment on some operating conditions for drying banana slices using infrared/convection dryer

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Abstract

The objective of this study is it investigates the effect of the microwave pretreatment on drying of banana slices by combined infrared / convection dryer under different power levels and different thickness of banana samples. Three levels of infrared power, namely: 150, 200 and 250 W and three thickness of sample are 2, 4 and 6 mm with air temperature 40^{o}C and air velocity 1.0 m/s were studied. Drying curves as affected by infrared power, thickness of samples and the microwave pretreatment, experimental data were fitted to some drying models. Specific energy consumption, dryer thermal efficiency, shrinkage of sample thickness and rehydration ratio were also studied. It is clear that the lower thickness sample and the higher infrared power the lower moisture ratio and total drying time at all experiments without microwave and with microwave and it was found that the least drying time was 30 min. at infrared power 250W and sample thickness 2mm with microwave pretreatment. The minimum value of specific energy consumption 1.24 (kw.h/kg$_{water\ removed}$) was recorded at infrared power 250 (W) and thickness of sample 2 (mm) for with assisted the microwave. The highest value of thermal efficiency 56.50 (%) was recorded at infrared power 250 (W) and thickness of sample 2 (mm) for with microwave assisted treatment.

Keywords: banana drying, infrared-convective dryer, drying models, shrinkage.

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1. Introduction

Banana (*Musa* spp.) is a major and important fruit crop, and it makes to the economies of many countries. Bananas make a useful contribution to the vitamins A, C and B6 content of the diet, and are an important and source of energy especially for sports people during training and competitions (Robinson and sauco, 2010). Banana is one of the most consumed fruits in many countries. However, ripe bananas are perishable quickly, so we must use drying technology to preserve it from damage and extend its the shelf life (Nguyen and Price, 2007). In Egypt, banana cultivated area is about 84205 feddans yearly producing about 1.5 million ton (feddan = 4200 m² = 0.420 hectares = 1.037 acres), with average productivity of 20 tons per Fadden. (Agricultural Statistical, 2020). The initial moisture content of Banana about 72 to 77 % (wb), bananas are a highly perishable fruit, it has short shelf life and marketing of fresh fruits is very difficult. Therefore, it is necessary to convert it into value added products which retain its colour, flavor and nutrients with longer shelf life. So, to increase the shelf life of banana, it converted into various processed products such as powder, to use in cake, bread, cookies dried slices, and juice, baby food, ice-cream, flavored milk, beverages, chocolates etc. (Chauhan and Jethva, 2016) However, there are normally much loss of thermal energy during drying by hot air making it an inefficient process. It is also well known that hot air-drying low quality of dried product, either in terms of the physical or nutritional quality. Microwave produces electromagnetic energy it works to increase of the heat in the body of the samples which will then lead to moisture removal, (See *et al*., 2013). On the other hand, infrared radiation is used to creates a high ambient temperature in drying environment. the energy of radiation penetrates through the material and is converted into heat Moisture is removed from the inner body (Swasdisevi *et al*., 2009). Infrared radiation has been applied in conjunction with several drying processes because it has advantages of increasing the drying efficiency , dried product quality is generally reported to be higher Several researchers have applied IR-assisted drying successfully to many food products, In addition the advantages of Infrared radiation, IR are energy savings, lower drying time, intermittent energy source, uniform temperature distribution, friend of the environment, and reduce the space (Eissa, 2021). The effect of microwave power air velocity and temperature on the final drying of bananas observed that increasing the drying rate by microwave power increased, thus making the drying time shorter (Omolola *et al*., 2015). drying of banana using three methods for drying namely convection (60°C at 1.45 m/s) under three thicks (4.3, 7.2 and 14 mm), microwave (350, 490 and 700 W power) and convection followed by microwave (at 350 W, 4.3 mm thick sample). It has been observed that longest drying period with convection and the highest drying rates were the higher power level for microwave in addition to dried banana was lighter in colour and had the highest rehydration value (Maskan, 2000). Two thermal heating units including a rotary dryer and an infrared drying unit were using to storage flax seeds for as long as possible. The heat-treated seeds were stored in different types of hermetic plastic bags for 8 months. Hermetic plastic bag gives a good control atmosphere when used for seed storage without deterioration. The principle of this type of bags depending upon full sealing of seeds without moisture absorption and increasing the level of CO_2 inside the bags due to seeds respiration. This condition decreases the level of fungal, microbial and insect growth. (Fouda *et al*., 2021). The objective of this study is to evaluate the microwave pretreatment on drying banana slices using develop infrared / convection dryer via study the effect of infrared power levels and thickness of samples.

2. Materials and methods

Experiments were carried out in Laboratory of Agricultural Product Processing Engineering Department, Faculty of Agricultural Engineering Al-Azhar University, Cairo, Egypt, during the period of January to March 2021.

2.1 Materials

2.1.1 Raw material

Fresh banana was purchased from a local market in Cairo, Egypt to use on drying process. Fresh peels were manually separated from the fruit. The banana was cut into slices 2 mm, 4mm and 6 mm by sharp knife made of stainless steel. The initial moisture content of banana was (77.40 % ± 0.5 w.b.).

2.1.2 Infrared / hot air dryer system

The infrared/hot air dryer consist of two components *i.e*., the chamber of drying and hot air supply unit. Elevation and plan of the infrared /convection dryer is shown in Figure (1). The first of components were the drying chamber of 400 × 300 × 300 mm were made from a plywood sheet of 8 mm thickness, The drying chamber was isolated and covered from inside with an aluminum foil, The drying chamber having infrared heater (tube type) of 400 W having length of 250 mm was fitted on the top inside surface of the drying chambers. The controlled in IR power levels using electronic circuit (Arduino uno) by changing the intensity of the electrical current. Inside the chamber a sample tray of woven wire mesh having dimension of 300 × 200 mm. connected from above with Electrical balance to measure mass changes during experimentation on intervals of 10 min. during drying process. 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. Drying air temperature was controlled using thermostat has been connected with the circuit of the air heater.

2.1.3 Microwave

A domestic microwave oven was used 700 W, 220 – 230 V, 2450 MHz, 5 levels of power, model N.SMB177KEB – POOC, made in Germany. The microwave oven having inside chamber dimensions of 300 × 180 × 260 mm.

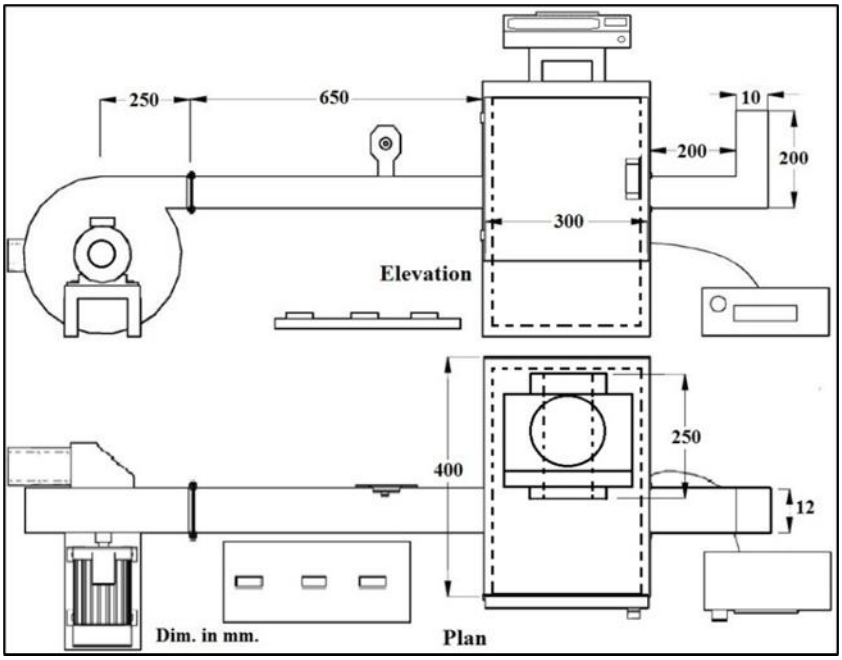

Figure (1): Elevation and plan of the infrared /convection dryer.

2.1.4 Arduino uno

The controlled in IR power levels using electronic circuit (Arduino uno) by changing the intensity of the electrical current. To achieve the required infrared power. Diagram of Arduino uno circuit is shown in Figure (2) and the circuit is composed of:

1. Variable resistance 10 K Ω to set the velocity and installed on the input a0.
2. Arduino UNO for processing inputs and outputs.
3. Infrared heater with a maximum power 400 watt and an alternating current of 220 volts.
4. lcd screen 2cell* 16 for data display>.
5. Another resistance 10 K Ω to adjust the contrast.
6. Diac number BD3 to turn off the frequency signal from the Arduino uno.
7. Thermistor number BTA24, it acts as a gateway to operate the heater lo.

2.2 Methods

2.2.1 The experimental procedure

In the present study the drying process experiments were divided in two groups, the first group involved infrared/convection drying and the second group involved microwave drying as pretreatment for five minutes at microwave power (85W) followed by infrared/convection drying. In order to evaluate the drying process for both previous groups, 54 experiments were carried out and the independent variables and their levels are shown in Table (1).

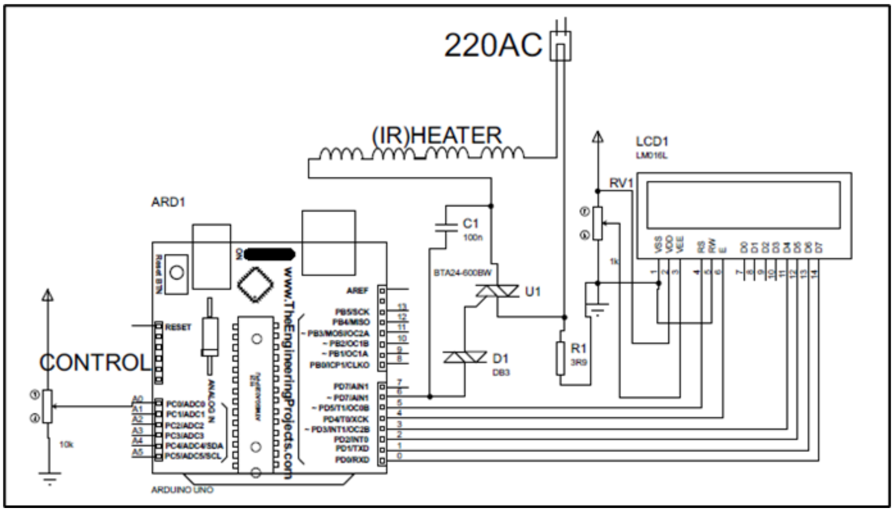

Figure (2): Diagram of Arduino uno circuit.

All experiments were carried out at constant air velocity of 1.0 m/s, air temperature of 40 °C and exposure distance (the distance between infrared heater and samples to be dried) of 200 mm. A sample of 100 g was taken from banana slices for proceeding with the drying experiments. Drying process is stopped when the sample weight is constant.

Table (1): The independent variables and their levels in this study.

Groups	The first group (without microwave treatment)	Independent variables	Infrared power levels (150, 200 and 250 W)	Replicates	3
	The second group (with microwave treatment)		Thickness of banana slices (2, 4 and 6 mm)		3
Total experiments= 2 group × 3 infrared power × 3 thickness of slices × 3 replicates =54 experiment.					

2.2.2 Calculations

2.2.2.1 Moisture ratio and mathematical modelling

The low quarter distribution uniformity the moisture content data derived from drying of banana slices were converted into the moisture ratio (*MR*) and fitted with four thin layer drying models listed in Table (2). the experimental Data were analyzed and discussed by SPSS 16 software program “Statistical Package for the Social Sciences”. Moisture ratio (*MR*) of banana slices during drying was calculated by:

$$MR = \frac{M_t - M_e}{M_i - M_e} \qquad (1)$$

Where, M_t, M_i and M_e are moisture content at any time, initial moisture content and equilibrium moisture content (d.b. %) respectively. The moisture content at any time (M_t) is calculated

(Badr, 2012) as follows:

$$M_t = \frac{B}{A}(1 + M_i) - 1 \quad (d.b\%) \qquad (2)$$

Where, *A* and *B* are initial mass of fresh sample (g) and mass of sample at any time (g) respectively. Table (2) showed that mathematical models fitted to experiment data. The following three statistical analysis criteria, namely, coefficient of determination (R^2), reduced chi-square or reduced mean square of the deviation (χ^2) and root mean square error (*RMSE*), have been used to evaluate the suitability of different models to fit experimental data:

$$R^2 = 1 - \frac{\sum_1^N (MR_{exp,i} - MR_{pre,i})^2}{\frac{1}{N}\sum_1^N (MR_{exp,i})^2} \quad \rightarrow (3)$$

$$\chi^2 = \frac{\sum_{i=1}^N (MR_{exp,i} - MR_{pre,i})^2}{N - z} \quad \rightarrow (4)$$

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2\right)^{0.5} \quad \rightarrow (5)$$

Where, $MR_{;exp;i}$ and $MR_{;pre;i}$ are experimental and predicted moisture ratios, respectively; *N* is observations number; and *z* is constants number. The best model of drying with the highest value of coefficient of determination (R^2), the lowest value of chi-square (χ^2) and root mean square error (RMSE).

2.2.3 Drying rate

The drying rate (g_{water} / min.) was calculated using the following equation:

$$Drying\ rate = \frac{D - D_f}{\theta} \quad \rightarrow (6)$$

Where, θ is drying time (min.); *D*and D_f are initial and final mass of sample (g) respectively.

Table (2): Mathematical models applied to the drying curves of banana slices.

Model name	Model	Reference
Lewis	*MR= exp (-kt)*	Roberts *et al*. (2008)
Logarithmic	*MR=a exp (-kt)+c*	Wand *et al*. (2007)
Modified Page	$MR = exp(-(kt)^n)$	Vega *et al*. (2007)
Handerson and Pabis	*MR = a exp (-kt)*	Erbay and Icier (2010)

2.2.4 Specific energy consumption (SEC)

The specific energy consumption (kW.h / kg $_{water\ removed}$) for evaporate water from the banana slices was calculated from the following equation:

$$SEC = \frac{\text{The energy consumption "}E_c\text{"}}{\text{The water removed "}W_w\text{"}} \quad \rightarrow (7)$$

The energy consumption was calculated as follows:

$$E_c = (P_{IR} \times \theta) + (P_{air} \times \theta) + (P_m \times \theta_m) \quad \text{"kW.h"} \quad \rightarrow (8)$$

Where, P_{IR}, P_{air} and P_m are infrared power, air power and microwave power (*kW*) respectively; θ and θ_m are total drying time and microwave processing time (*h*) respectively. ($P_m \times \theta_m$) = *0* without using microwave. The removed water (W_w) was calculated as follows:

$$W_w = \frac{A\,(m_i - m_f)}{(100 - m_i)} \quad \text{"kg"} \quad \rightarrow (9)$$

Where, m_i and m_f are initial and final moisture content, (w.b. %) respectively.

2.2.5 The dryer thermal efficiency (η)

$$\eta = \frac{E_u}{E_c} \times 100 \quad \text{"\%"} \quad \rightarrow (10)$$

Where, E_c is the energy consumption (kJ); and E_u is the useful drying energy (*kJ*) and was calculated as follows:

$$E_u = \left[\left(m.C_p.\Delta T\right) + \left(W_w.L\right)\right] \quad \rightarrow (11)$$

Where, *m* is mass of sample banana sample to be dried (kg); *ΔT* is the temperature difference of sample (^oK); W_w is the amount of water removed (kg); *L* is the latent heat of evaporation at sample temperature (kJ/kg); and C_p is specific heat of the banana sample (kJ/kg.^oK), its calculated by moisture content from following equation according to Toledo (1991):

$$C_p = 4.1868\, m_{w.b} + 0.83736 \times (1 - m_{w.b}) \quad \rightarrow (12)$$

2.2.6 Quality evaluation

2.2.6.1 Shrinkage of the thickness

The percentage thickness shrinkage of the dried sample was calculated by:

$$\text{Shrinkage} = \left(\frac{L_f - L_d}{L_f}\right) \times 100 \quad \text{"\%"} \quad \rightarrow (13)$$

Where, L_f and L_d are thickness (mm) of the fresh and dried samples respectively.

2.2.6.2 Ability of rehydration

The rehydration of dried slices was evaluated by immersing 5g of dried samples in distilled water at room temperature. Samples were removed at regular time intervals (each 5 min.) and until the weight is almost constant Rehydration ratio was calculated from the following equation (Badr, 2012):

$$\text{Rehydration ratio} = \frac{w_t - w_d}{w_d} \quad \rightarrow (15)$$

Where, w_t *and* w_d are the mass of rehydration sample at any time and mass of dried sample (g) respectively.

3. Results and discussion

3.1 Drying curves

Figures (3) and (4) show the relationships of moisture ratio and elapsed drying time as affected by sample thickness and infrared power both first group and second group during all experiments of drying. The lower thickness sample and the higher infrared power the lower the moisture ratio and reduced of the total drying time at all experiments without microwave and with microwave. The least drying times were 40 and 30 min. for without microwave and with microwave respectively at infrared power 250 W and sample thickness 2mm, while the highest drying times were 140 and 110 min. for without microwave and with microwave respectively at infrared power 150W and sample thickness 6 mm. In all experiments under the same conditions, drying times were lower in the group of experiments in which microwave was used as a primary treatment, this may be because exposing the banana samples to microwave radiation for five minutes reduced the moisture content of the samples from 77.40 to 65.86 w.b %.

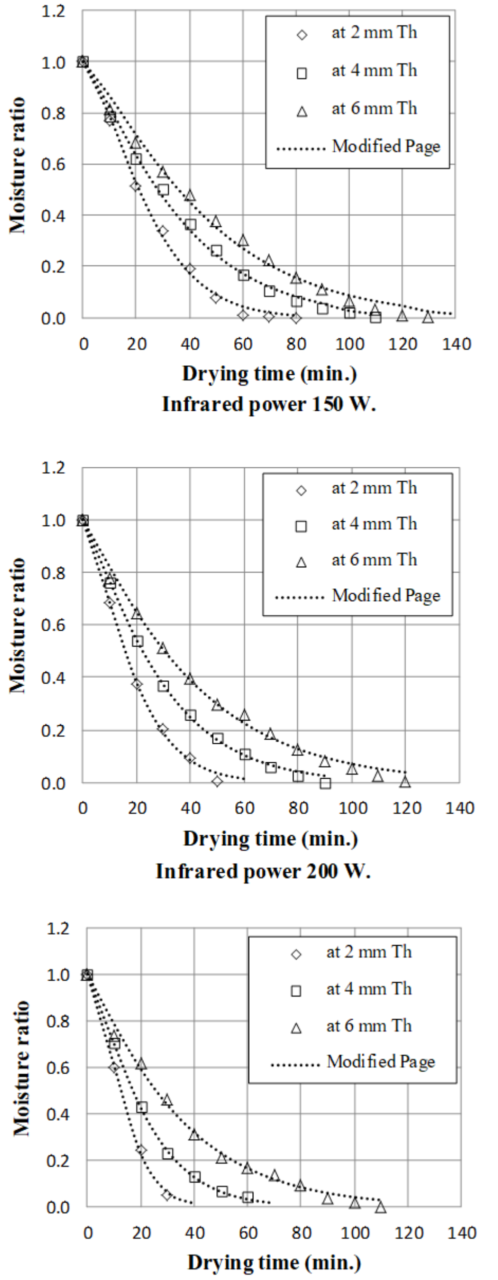

Figure (3): Moisture ratio during drying at different thickness of samples and different infrared powers without assisted microwave.

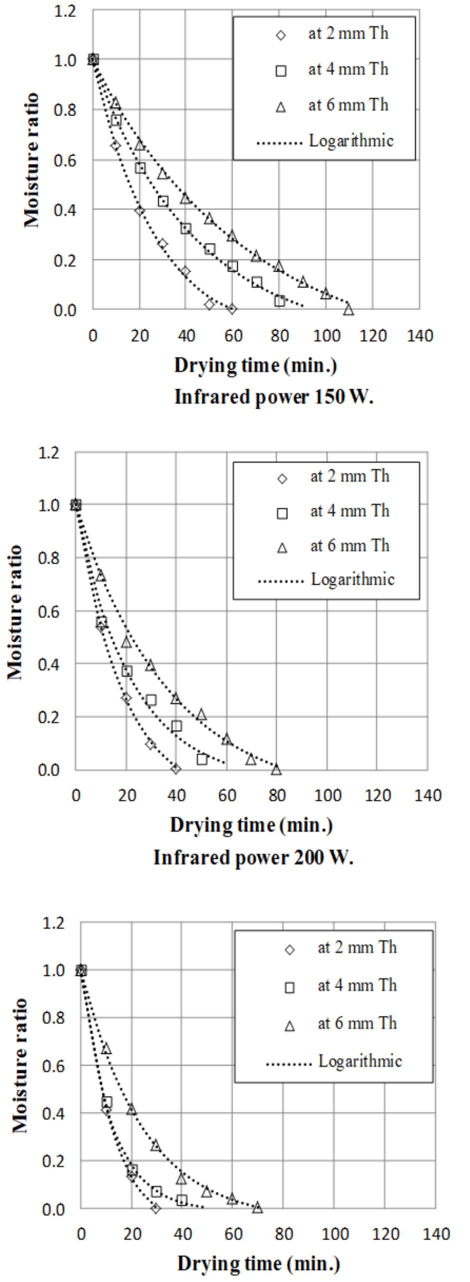

Figure (4): Moisture ratio during drying at different thickness of samples and different infrared powers with assisted microwave.

3.2 The drying curves fitting

The drying data of this study as moisture ratio and the drying time were fitted with some drying models in the previous Table (2). Table (3) shows the averages R^2, X^2 and RMSE for the selected drying models with the first experiments group (without microwave) and the second experiments group (with microwave).

Table (3): Averages of statistical analysis for different selected drying models.

Models	Experimental groups					
	Without assisted microwave			With assisted microwave		
	R²	*X²*	*RMSE*	*R²*	*X²*	*RMSE*
Liwis	0.9264	0.00220	0.04239	0.9675	0.00117	0.03085
Logarithmic	0.9801	0.00079	0.01968	0.9902	0.00051	0.01520
Modified Page	0.9827	0.00048	0.01803	0.9803	0.00078	0.02220
Handerson and Pabis	0.9340	0.00240	0.04028	0.9690	0.00138	0.03019

Without the microwave, the results showed that the highest average R^2 was 0.9827, while the lowest averages X^2 and RMSE were 0.00048 and 0.01803 respectively with the modified Page model, so modified Page model showed the best fitting and gave better predictions than others, and satisfactorily described the drying characteristics of banana sample in this experiments group as in Figure (3). With the microwave, the results showed that the highest average R^2 was 0.9902, while the lowest averages X^2 and RMSE were 0.00051 and 0.01520 respectively with the Logarithmic model, so Logarithmic model showed the best fitting and gave better predictions than others, and satisfactorily described the drying characteristics of banana sample in this experiments group as in Figure (4). Tables (4) and (5) show the constants of modified Page and Logarithmic and its statistical analysis. The statistical parameter estimations showed that R^2, X^2 and RMSE values were ranged from 0.9451, 0.00008 and 0.00796 to 0.9977, 0.00124 and 0.02972 respectively without microwave for modified Page model, while with the use of the microwave the statistical parameter estimations showed that R^2, X^2 and RMSE values were ranged from 0.9654, 0.00005 and 0.00426 to 0.9997, 0.00192 and 0.03314 respectively for Logarithmic model.

Table (4): The constants of modified Page model and its statistical analysis under all drying conditions in this study for without assisted microwave.

Samples thickness (mm)	Power levels (W)	Constants		*R²*	*X²*	*RMSE*
		k	*n*			
2	150	0.037	1.434	0.9862	0.00044	0.01850
	200	0.049	1.355	0.9933	0.00032	0.01504
	250	0.064	1.565	0.9975	0.00023	0.01185
4	150	0.026	1.223	0.9764	0.00049	0.02025
	200	0.033	1.192	0.9946	0.00014	0.01070
	250	0.044	1.268	0.9977	0.00008	0.00796
6	150	0.021	1.228	0.9451	0.00085	0.02714
	200	0.024	1.126	0.9716	0.00053	0.02112
	250	0.028	1.121	0.9815	0.00124	0.02972
Average				0.9827	0.00048	0.01803

Table (5): The constants of Logarithmic model and its statistical analysis under all drying conditions in this study for with assisted microwave.

Samples thickness (mm)	Power levels (W)	Constants			R^2	X^2	*RMSE*
		a	*k*	*c*			
2	150	1.135	0.036	-0.138	0.9914	0.00051	0.01713
	200	1.134	0.052	-0.134	0.9997	0.00005	0.00426
	250	1.116	0.074	-0.117	0.9985	0.00044	0.01046
4	150	1.125	0.023	-0.134	0.9934	0.00022	0.01233
	200	1.028	0.044	-0.051	0.9654	0.00192	0.03314
	250	1.016	0.081	-0.014	0.9960	0.00027	0.01172
6	150	1.198	0.015	-0.208	0.9921	0.00021	0.01269
	200	1.115	0.026	-0.124	0.9813	0.00071	0.02182
	250	1.065	0.040	-0.057	0.9935	0.00028	0.01326
Average					0.99015	0.00051	0.01520

3.3 Drying rate

The effect of changing the infrared powers and samples thickness for both without assisted microwave and with assisted microwave on drying rate (g_{water}/min.) is shown in Table (6). The results showed that with the increase in the infrared power levels and the decrease in the thickness of the samples, the average values of the drying rate increase. Without the assisted microwave, the highest value of the drying rate was 1.87 (g_{water}/min.) at infrared power 250 (W) and thickness of sample 2 (mm), while the lowest value was 0.53 (g_{water}/min.) at infrared power 150 (W) and thickness of sample (6mm). With the assisted microwave, the highest value of the drying rate was 2.12 (g_{water}/min.) at infrared power 250 (W) and thickness of sample 2 (mm), while the lowest value was 0.65 (g_{water}/min.) at infrared power 150 (W) and thickness of sample (6 mm). The results also showed that the initial microwave treatment increases the drying rate at different drying conditions in this study, this may be because volumetric distributions of energy within the sample with the microwave.

Table (6): Average values of drying rate at different drying conditions in this study.

Samples thickness (mm)	Power levels (W)	Drying rate (g_{water}/min.)	
		Without assisted microwave	With assisted microwave
2	150	0.93	1.14
	200	1.24	1.65
	250	1.87	2.12
4	150	0.68	0.78
	200	0.83	1.15
	250	1.06	1.35
6	150	0.53	0.65
	200	0.62	0.87
	250	0.68	0.99

3.4 Specific energy consumption (SEC)

Table (7) shows the specific energy consumption ($kW.h/kg_{water\ removed}$) influenced by infrared power levels and thickness of samples for without assisted microwave and with assisted microwave. It is clear that with the increase in the infrared power levels and decrease in the thickness of samples, the specific energy consumption decrease. The results also showed that microwave pretreatment reduces specific energy consumption by an average of 12.5% because using a microwave reduces drying times. The minimum value of "SEC" 1.24 ($kw.h/kg_{water\ removed}$) was recorded at infrared power 250 (W) and thickness of sample 2 (mm) for with assisted the microwave, while the maximum value of "SEC" 3.83 ($kw.h/kg_{water\ removed}$) was recorded at infrared power 150 (W) and thickness of sample 6 (mm) for without assisted the microwave.

Table (7): Specific energy consumption (SEC) at different drying conditions in this study.

Samples thickness (mm)	Power levels (W)	SEC ($kw.h/kg_{water\ removed}$)	
		Without assisted microwave	With assisted microwave
2	150	2.30	1.62
	200	1.91	1.43
	250	1.53	1.24
4	150	3.45	2.77
	200	3.06	2.39
	250	2.68	2.01
6	150	3.83	3.15
	200	3.45	2.77
	250	3.06	2.39

3.5 The dryer thermal efficiency (η)

Figures (5) and (6) show the relationship between the thermal efficiency of dryer and the sample thickness at infrared power levels (150, 200 and 250 W) for without assisted microwave and with assisted microwave respectively. It is clear that with the increase in the infrared power levels and decrease in the thickness of samples, the thermal efficiency increase. The results also showed that microwave pretreatment increases the thermal efficiency. The highest value of "η" 56.50 (%) was recorded at infrared power 250 (W) and thickness of sample 2 (mm) for with assisted the microwave, while the lower value of "η" 18.36 (%) was recorded at infrared power 150 (W) and thickness of sample 6 (mm) for without assisted the microwave. The relation between thermal efficiency "η" and sample thickness "x" was as the following equation:

$$\eta = b.x^{-d}$$

The relation between parameter "b" and infrared power "P_{IR}" was the following equations:

$$b = 0.2741\ P_{IR} \quad \rightarrow \text{without assisted the microwave}$$

$$b = (0.1994\ P_{IR}) + 34.312 \quad \rightarrow \text{with assisted the microwave}$$

It is clear that the parameter "d" doesn’t change significantly and take the average values 0.561 and 0.614 for without assisted the microwave and with assisted the microwave respectively. The general equations between the thermal efficiency "η", the sample thickness "x" and infrared power "P_{IR}" in this study were of the form:

$$\eta = (0.2741\, P_{IR}).\, x^{-0.561} \quad \rightarrow \text{without assisted the microwave}$$

$$\eta = [(0.1994\, P_{IR}) + 34.321].\, x^{-0.614} \quad \rightarrow \text{with assisted the microwave}$$

Figures (7) and (8) show the predicted and observed the thermal efficiency at different conditions in this study.

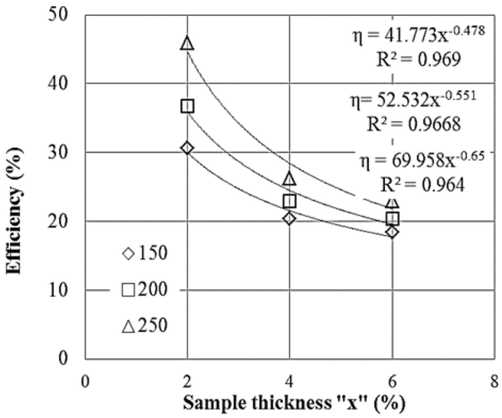

Figure (5): The relation between the thermal efficiency and sample thickness at different infrared powers without initial microwave treatment.

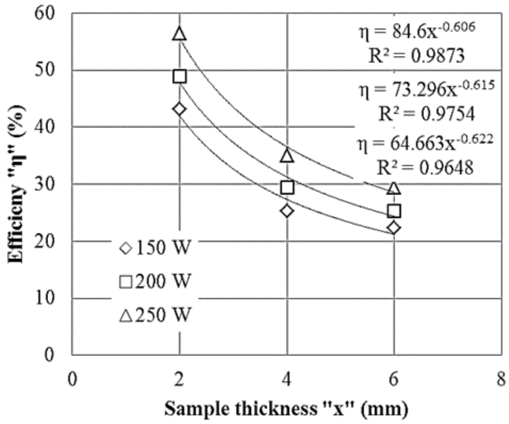

Figure (6): The relation between the thermal efficiency and sample thickness at different infrared powers with initial microwave treatment.

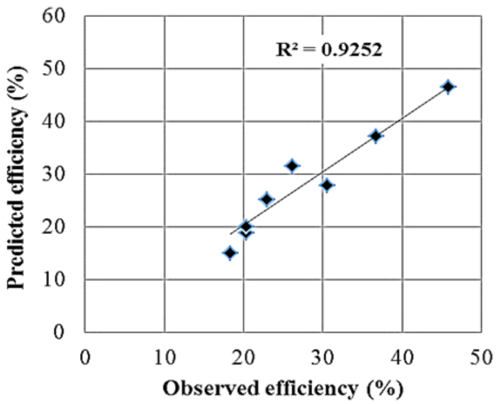

Figure (7): Predicted and observed thermal efficiency at different conditions without assisted microwave.

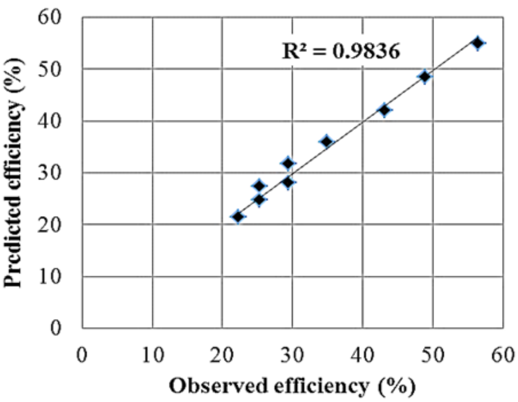

Figure (8): Predicted and observed thermal efficiency at different conditions with assisted microwave.

3.6 Rehydration ratio

The rehydration banana slices dried by infrared without assisted microwave and infrared with assisted microwave is affected by infrared power and sample thickness. Table (8) and (9) show the relation between rehydration ratio and rehydration time at different infrared power and different sample thickness for both experiments group. In all cases, the quantity of moisture absorbed increases with rehydration time and the rehydration stabilized in about 30 minutes. The results showed that the rehydration ratio under different infrared powers was in the range (1.20 – 2.01), (1.05 – 1.74) and (0.51 – 1.42) at the thickness of samples 2, 4 and 6 (mm) respectively for without assisted microwave, while with assisted microwave, the rehydration ratio was in the range (1.26 – 2.10), (1.08 – 1.81) and (0.86 – 1.48) at the thickness of samples 2, 4 and 6 (mm) respectively.

Table (8): Rehydration ratio versus rehydration time at different conditions in this study without assisted microwave.

Rehydration time (min.)	Rehydration ratio without assisted microwave								
	Sample thickness 2 (mm)			Sample thickness 4 (mm)			Sample thickness 6 (mm)		
	Infrared power levels (W).			Infrared power levels (W).			Infrared power levels (W).		
	150	200	250	150	200	250	150	200	250
5	1.26	1.22	1.20	1.12	1.11	1.05	0.83	0.71	0.51
10	1.62	1.61	1.60	1.36	1.36	1.34	0.98	0.92	0.71
15	1.85	1.74	1.66	1.48	1.45	1.43	1.22	1.07	0.85
20	1.96	1.85	1.73	1.65	1.61	1.52	1.26	1.18	0.88
25	2.00	1.95	1.87	1.74	1.66	1.56	1.38	1.22	1.13
30	2.01	1.96	1.88	1.74	1.68	1.57	1.42	1.30	1.14

Table (9): Rehydration ratio versus rehydration time at different conditions in this study with assisted microwave.

Rehydration time (min.)	Rehydration ratio with assisted microwave								
	Sample thickness 2 (mm)			Sample thickness 4 (mm)			Sample thickness 6 (mm)		
	Infrared power levels (W).			Infrared power levels (W).			Infrared power levels (W).		
	150	200	250	150	200	250	150	200	250
5	1.33	1.28	1.26	1.16	1.14	1.08	0.90	0.87	0.86
10	1.66	1.66	1.65	1.43	1.39	1.37	1.05	0.95	0.88
15	1.87	1.80	1.74	1.59	1.52	1.48	1.34	1.13	1.08
20	2.04	1.89	1.77	1.68	1.64	1.58	1.45	1.26	1.19
25	2.06	2.01	1.92	1.80	1.73	1.64	1.47	1.35	1.25
30	2.10	2.02	1.93	1.81	1.74	1.66	1.48	1.37	1.29

3.7 Shrinkage percentage

Figures (9) and (10) show the results of the thickness shrinkage of banana slices dried by different methods and different conditions. It is clear that with the increase in the infrared power levels and decrease in the thickness of samples, the shrinkage percentage increases, and the values of shrinkage percentage was lower when using the microwave as a pretreatment; this may indicate that the advantages of microwave volumetric energy distributions within the material improve quality and avoid surface limitations. The results showed that the shrinkage at different drying conditions in this study was in the range (35.50 – 56.50 %) for without assisted microwave, while the shrinkage was in the range (25.17 – 47.50 %) for with assisted microwave.

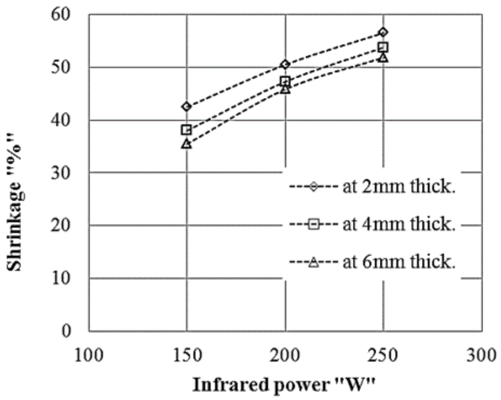

Figure (9): Effect of infrared power levels and sample thickness on shrinkage without assisted microwave.

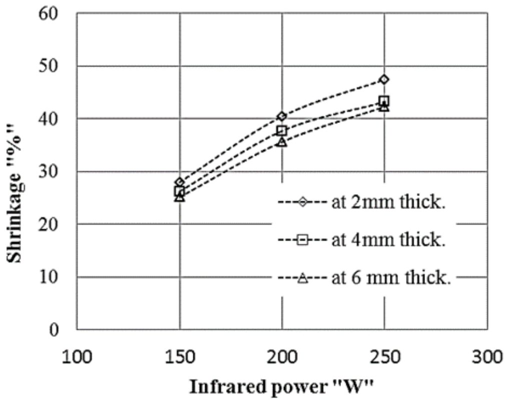

Figure (10): Effect of infrared power levels and sample thickness on shrinkage with assisted microwave.

4. Conclusion

The research Results indicate the following:

- The lower thickness sample and the higher infrared power the lower the moisture ratio and reduced of the total drying time at all experiments without microwave and with microwave, and it was found that the least drying time was 30 min. at infrared power 250W and sample thickness 2 mm with microwave pretreatment.
- The modified page model was the best fit for the experimental data without microwave treatment, which gave the highest value for average of coefficient of determination (R^2 = 0.9827), while the Logarithmic model was the best fit for the experimental data with microwave pretreatment which gave the highest value for average of coefficient of determination (R= 0.9902).
- The highest value of the drying rate was 2.12 (g_{water}/min.) at infrared power 250 (W) and thickness of sample 2 (mm) with microwave pretreatment.
- The minimum value of "SEC" 1.24 (kw.h/$kg_{water\ removed}$) was recorded at infrared power 250 (W) and thickness of sample 2 (mm) for with microwave pretreatment.
- The highest value of thermal efficiency *"η"* 56.50 (%) was recorded at infrared power 250(W) and thickness of sample 2 (mm) for

with assisted the microwave. a complete prediction equation for the thermal efficiency as the form:

$\eta = (0.2741\ P_{IR}).\,x^{-0.561}$
$\rightarrow$ without assisted the microwave

$\eta = [(0.1994\ P_{IR}) + 34.321].\,x^{-0.614}$
$\rightarrow$ with assisted the microwave

- The rehydration ratios ranged of 0.51 to 2.10 under various the drying conditions in this study.
- The shrinkage at different drying conditions in this study was in the range (25.17 – 56.50 %).

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