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Drying Kinetics of White Button Mushroom (*Agaricus bisporus*) Using Different Equipment of Drying Considering of Power Density

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ABSTRACT

Drying process compared to others remains a promising method of food preserving technology. So, this work aimed to investigate drying kinetics of button mushroom (*Agaricus bisporus*) treated by microwave, convective dryer and electric oven within consideration of different power density levels of 3.5, 5 and 7.5 W.g^{-1}. Furthermore, five mathematical drying models were statistically analysed to simulate drying kinetics fitted to the obtained experimental moisture ratio results. The obtained results indicated that, increasing of power densities led to rapidly drying consuming low time. The shortest drying time of mushrooms having initial moisture content (d.b.) of 809% was provided with microwave treatment, whereas drying time decreased (at the above mentioned power density levels, respectively) by 77.7, 85.7 and 84%, comparing to convective dryer, whilst 91.6, 94.4 and 94%, comparing to oven. Page, Modified Page (I) and Modified Page (II) models appeared most expressed best description of the experimental drying results.

Keywords: drying kinetics; button mushroom; microwave; convective dryer; power density

INTRODUCTION

Mushroom is one of the most widely important fungi used in food, medicine and investment. This is because of its rich nutritional and healthy benefits (Cheung, 2010; Wasser, 2010). It is considered highly nutritious with low calories, richly good quality protein and having essential vitamins and minerals (Mattila *et al*., 2002; Heleno *et al*., 2010). From this point and recently, in Egypt, attention has been focused on commercially spreading of cultivation and production of mushrooms after it achieved great success whereas it opens up new horizons for work, production and profit for producers and farmers from youth. According to the available statistics, the local production of mushroom in Egypt was estimated at 650 to 750 ton/year (Steele, 2009). All commercial production is based on the white button mushroom (*Agaricus bisporus*) called 'champignon' due to its favorable nutritional value, where each 100 g represents 92 kJ of energy and includes 3.09 g of proteins, 0.34 g of fats, 1 g of dietary fibers, 1.65 g of sugars, 3.28 g of carbohydrates and about 85-90 g of water (Dhamodharan and Mirunalini, 2010). Moreover, it contains amino acid, iron and B5, B2, B3 and C vitamins. In this context, several investments are planned or underway because the quantity of mushroom production in Egypt is not enough due to the increasing demand for this commodity in the Egyptian market to meet the increased demand and consumption day after day. On the other hand, the increasing of mushrooms production contributes to solve the environmental problems of agricultural wastes accumulation estimated by more than 35 million tons per year (Hassan *et al*., 2014), as well as providing high nutritional food. So, there is a great interest and a wide trend towards the utilization of those wastes such as; rice straws, corn stalks, bagasse and the residues of food processing in development of mushrooms production contributing significantly to achieve social and environmental development in rural communities in Egypt.

From a point of view, the mushrooms are generally one of the quickest damaged types of vegetables due to the high rates of respiration of the harvested mushrooms compared to the other horticultural crops caused shorter postharvest life. Moreover, most of the mushrooms having high moisture and delicate in texture thus, it cannot be stored for more than 24 hours at the ambient conditions prevailing in the surroundings (Wakchaure, 2011). So, the preservation process is considered very important and essential for successfully investments of mushrooms thus encouragement of producers whereas the major problems facing those producers and farmers are dependability on the proper practices of post-harvest handling and storage of mushrooms. Therefore, the most two common preservation methods for enhancing shelf life of mushrooms used in Egypt are refrigeration and drying. Otherwise drying compared to other preservation methods remains a promising and low cost technique of food preservation engineering methods. The low cost of drying depends on low energy consumption during the drying process and the high capacity of the equipment which depends on drying rates (Kulshreshtha *et al*., 2009). Taking into consideration of moisture content at harvesting time of fresh mushroom often is about 85-95% thus it should to be 5-12 % in order to be packed and stored with longer shelf life with long storage retention duration of dried mushrooms in their natural qualities without spoilage when it is processed and well stored (Mattila *et al*., 2002; Rai and Arumuganathan, 2008; and Kumar *et al*., 2013). Thence, dried mushrooms can be used as an important ingredient in several food formulations including soups, pasta, casseroles, and meat and rice dishes or can be easily powdered and used in soups, bakery products, etc (Siddiqui and Ali, 2017).

Lidhoo and Agrawal (2006) dried button mushroom (*Agaricus bisporus*) in hot air oven and observed that, the minimum browning index was obtained at 65 °C and rehydration ratio of 2.9. Also, Xanthopoulos *et al*., (2007) simulated the convective drying of thin layer white button mushrooms using the logarithmic model in 65 °C hot air cabinet dryer. Giri and Prasad (2007) investigated dehydration kinetics of white button mushrooms (*A. bisporus*) in

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microwave oven (0-600 W) and compared the drying rate with conventional methods and resulted about of 70–90% decrease in the drying time occurred in microwave drying as compared to convective air drying. Recently, few investigations had been done to study drying kinetics of several types of mushrooms (Pasban *et al*., 2015; Xu *et al*., 2015; Salehi *et al*., 2017; Carrión *et al*., 2018; Liu *et al*., 2019; Mutukwa *et al*., 2019). Despite those investigations used drying techniques of freeze drying, infrared-vacuum, ultrasound-assisted and hot air, there is no available obvious results either in terms of the drying kinetics of button mushroom type undergoing microwave, convective dryer and oven drying apparatus. In this paper the different working principles and techniques had been clarified for the three apparatus. In view of various dryers and drying techniques thus, drying methods were proposed based on keeping power density or temperature under control (Li *et al*., 2006; Cuccurullo *et al*., 2017). Furthermore, the necessity of applying mathematical and empirical models in drying simulations in order to simulate the drying behavior of food products therefore are useful to control variable engineering factors and predict the moisture ratio during drying process duration as confirmed by (Celen *et al*., 2010).

In light of the above context, fresh harvested mushrooms need to be preserved within investigation under drying treatment. For this target, this work presents a comprehensive practical investigations focusing drying kientics and modeling of white button mushroom (*Agaricus bisporus*) treated by microwave, convective dryer and electric oven within consideration of different power density levels to meet essential requirement for successfully mushrooms investments hence encourage the producers, find solution of major problems facing those producers and farmers are dependability on the proper practices of post-harvest handling and preservation storage of mushrooms. Furthermore, mathematical drying models were fitted to suitable simulation of the drying behavior of white button mushrooms by statistical analysis.

MATERIALS AND METHODS

Main experiments were investigated at Faculty of Agriculture, Zagazig University, Egypt in order to study the drying kinetics of mushroom (*Agaricus bisporus*) using three different dryers within different drying techniques.

1. Samples preparation:

Fresh button mushrooms fruits (*Agaricus bisporus*) with a uniform size of stem diameter of 1-2.5 cm and cap diameter of 3-4 cm were obtained without any mechanical damages from a local market in Zagazig and kept in a refrigerator (4ºC) prior to the experiments. The samples were treated as a full fruit bodies without separating or cutting stems. The initial moisture content (M.C.) of mushrooms was determined using the oven method at 110ºC for 24h. Triplicate samples were used for the determination of M.C. and the average values were reported as 10.3122 kg water/kg dry matter (d.b.). The samples divided into three equaled groups to be prepared for drying within the proposed dryers.

2. Drying equipment:

The drying treatments were conducted using three drying equipment with different drying techniques are:

A domestic microwave oven, a microwave model of KOC-185V-Daewoo type, 50MHz, power output of 1000W was used. Microwave drying technique depends on heating the water molecules in the product by microwave radiation as electromagnetic waves as shown in Fig. (1-a). Then, the heat is transferred inside product carrying outside moisture by the hot air thus, drying is occurs. So, microwave drying is very suitable for wet products.

A convective dryer, a convective hot air dryer model HD 9920-Philips type, frequency of 50/60 Hz, power of 1425 W, voltage of 110 V was used. It consists of a centrifugal fan to supply the air flow above an electric heater, alterable temperature control drying chamber dimensions were H31.5 × W28.7 × D38.4cm. Convective dryer work on rapid air technology theory based on very high speed air circulation using top fan over the product as shown in Fig. (1-b). The heating grill is placed very close to the product for effective heating. Due to the high air speed circulation, the moisture is quickly removed from the product. Therefore, convective dryer is similar to oven, but the difference is its concentrated heat source and the size and placement of the fan, resulting quickly drying product.

An electric oven, an electric oven model SM40-TRC type, frequency of 50/60 Hz, power of 1500 W, voltage of 220 V is similar almost exactly alike to convective hot air dryer but the heating element is located down vice versa in convective dryer is located top and accompanied by powerful fan. Both use convective hot air circulation principle to dry product based on highly spreading the hot air within the area, see components in Fig. (1-c).

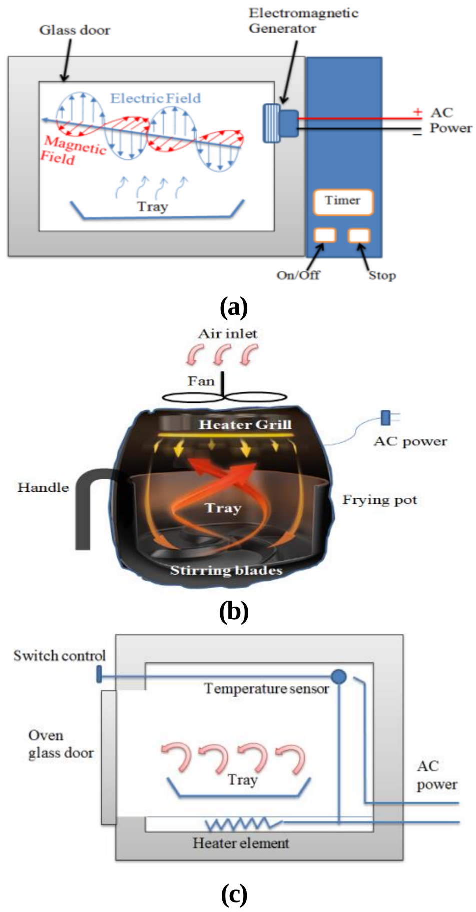

Fig. 1. The experimental drying apparatus based on techniques of: (a) microwave; (b) convective dryer; (c) electric oven.

3. Experimental conditions:

The kinetics of the drying process of white button mushroom (*Agaricus bisporus*) was experimentally studied under three different drying techniques using apparatus of microwave, convective dryer and electric oven considering of three different levels of power density (Equipment Power /

Mass) of 3.5, 5 and 7.5 W.g^{-1}. The experimental conditions used in this investigation are shown in Fig. (2).

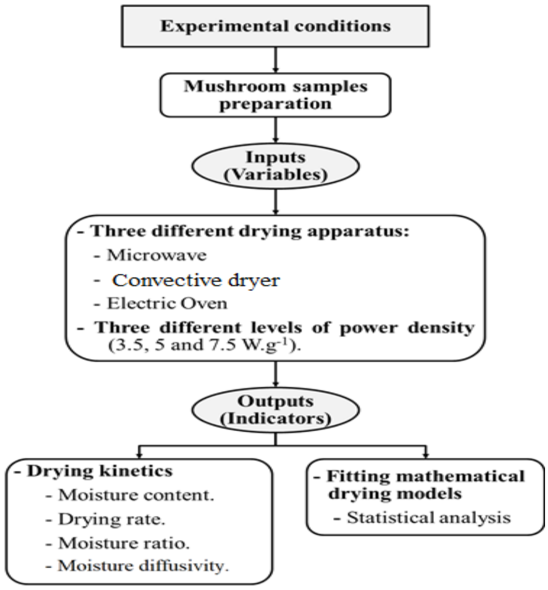

Fig. 2. Flowchart of the experimental conditions.

4. Analytical methods:

Studying the drying kinetics of mushroom was investigated based on the following indicators:

Moisture content: The average moisture content of fresh samples of mushrooms was determined by drying samples in a vacuum oven at 105ºC until reaching a constant weight according to (AOAC, 2002). Moisture content of mushrooms was 89% w.b. (809 % d.b.). The moisture losses of samples with time passing were recorded by a digital balance (Model-Ming Heng K1) with accuracy of ± 0.01 g. Drying process was carried out until the equilibrium moisture content reaches to a level about 10% (wb) according to (Gölükcü, 2015).

Drying rate: Drying rate (g.water.g^{-1}dry matter.min^{-1}) was calculated as Eq. (1):

$$\text{Drying rate} = \frac{(M_{t+dt} - M_t)}{(dt)} \qquad (1)$$

Where, ***M_t* is moisture content (g water/g dry matter) at time t; *M_{t+dt}* is moisture content (g water/g dry matter) at time *t+dt*; *dt* is the time difference (Doymaz, 2012).**

Moisture ratio and mathematical modeling: The moisture ratio (MR) was estimated as Eq. (2):

$$MR = \frac{M_t - M_e}{M_o - M_e} \qquad (2)$$

Where, *M_e* is the equilibrium moisture content (d.b.); *M_o* is the initial moisture content (d.b.). The value of *M_e* is relatively small compared with *M_t* or *M_o*. Therefore, the *MR* was simplified to *(M_t/M_o)* (El-Sebaii and Shalaby 2013).

Five semi-empirical models were applied to fit the experimental moisture data because they are widely used in drying agriculture products and they are equalities that explain the kinetics of the drying method in a safe way, as listed in Table (1).

Table 1 . Mathematical models given by various authors for the drying curves:

No	Model Name	Model	References
1	Newton	*MR = exp(-kt)*	O'Callaghan *et al*., 1971; Liu and Bakker, 1997
2	Page	*MR = exp(-kt^n)*	Agrawal and Singh, 1977; Zhang and Litchfield, 1991
3	Modified Page (I)	*MR = exp[-(kt)^n]*	Agrawal and Singh, 1977; Zhang and Litchfield, 1991
4	Modified Page (II)	*MR = exp[(-k(t/L2)n)]*	Diamante and Munro, 1991
5	Henderson and Pabis	*MR = a exp(-kt)*	Westerman *et al*., 1973; Chhninman, 1984

Statistical analysis: The Microsoft Office Excel software was used for analysis and interpretation the results. To evaluate the righteousness of the fit of the models, some several statistical parameters were used like; coefficient of determination (R^2), reduced chi square (x^2), mean bias error (*MBE*) and root mean square error (*RMSE*). Higher R^2 value and lower *RMSE* and *MBE* values were chosen as the best fit (Shahhoseini *et al*., 2013). These parameters can be calculated as Eq$_s$. (3, 4 and 5) (Liu *et al*., 2011):

$$x^2 = \frac{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})^2}{N-n} \qquad (3)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i}) \qquad (4)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{n}(MR_{pre,i} - MR_{exp,i})^2\right]^{\frac{1}{2}} \qquad (5)$$

Where, *$MR_{exp,i}$* is the stands for the experimental moisture ratio found in any measurement; *$MR_{pre,i}$* is the predicted moisture ratio for this measurement; *N* is the number of observations; n is the number constants.

Effective moisture diffusivity: the experimental drying data for the determination of diffusivity coefficients were interpreted using Fick's second diffusion model to describe the interior moisture transfer through drying process as Eq. (6) (Ghazanfari *et al*. 2006).

$$\frac{\partial M}{\partial t} = D_{eff}\nabla^2 M \qquad (6)$$

The settling of diffusion equation for slab geometry is settled by Eq. (7) (Crank, 1975) and assumed uniform initial moisture distribution, small external resistance, constant diffusivity and small shrinkage:

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}t}{4L^2}\right) \qquad (7)$$

Where: *D_{eff}* is the effective moisture diffusivity (m^2.s^{-1}), t is the time (s), *L* is the half thickness of samples (m), *n* is a positive integer. For long drying times, a limiting of this equation is obtained and expressed in a logarithmic form as Eq. (8) (Madamb, 2003):

$$lnMR = ln\frac{8}{\pi^2} - \frac{\pi^2 D_{eff}t}{4L^2} \qquad (8)$$

So, the effective diffusivity is calculated by putting data in terms of *ln(MR)* against time.

RESULTS AND DISCUSSION

The discussion of the obtained results was under the following heads:

1. Drying kinetics of moisture content versus drying time at different power density levels for different drying apparatus:

The data of variations of moisture contents for the experimented mushrooms samples versus drying time at levels of 3.5, 5 and 7.5 W.g^{-1} of power densities for drying apparatus of microwave, convective dryer and electric oven are showed in Fig. 3 (a, b and c). As a completely clarification, continuously increase of drying time caused a significant decrease in moisture content. Also it is cleared that, with increase of power density levels from 3.5 to 7.5 $W.g^{-1}$, the drying process is fast occurs and the samples consume low time to achieve significant and low levels of moisture contents and therefore the required drying time reduced. The obtained results indicated that, under microwave drying, the button mushroom having initial moisture content (d.b.) of 809% was dried to a final moisture contents on dry basis of 13.9% within 20 min, 10.7% within 10 min and 8.3% within 8 min at power density levels of 3.5, 5 and 7.5 $W.g^{-1}$, respectively. By a simple comparison, similar mushroom samples lost moisture and its levels (d.b.) became 13.2% within 90 min, 10.4% within 70 min and 39.4% within 50 min at the same power density levels, respectively, under convective dryer drying, and 12.1% within 240 min, 10.7% within 180 min and 8.9% within 135 min at the same power density levels, respectively, under oven drying. Thus, from the obtained results it can be concluded that, button mushroom (*Agaricus bisporus*) drying using microwave led to shorting drying times about 77.7, 85.7 and 84% at power density levels of 3.5, 5 and 7.5 $W.g^{-1}$, respectively, comparing to convective dryer for reaching the same values of low moisture content levels, whilst 91.6, 94.4 and 94% at the same power density levels, respectively, comparing to electric oven. Similar results of reducing drying times were obtained by (Giri and Prasad, 2007) whose reported that microwave vacuum drying of mushroom resulted in 70–90% decrease in the drying time as compared to convective air drying.

2. Drying kinetics of drying rate versus drying time at different power density levels for different drying apparatus:

On the same drying behavior of moisture content, the variations of drying rates (in g.water.g^{-1}dry matter.min^{-1}) of mushroom versus drying time for drying apparatus of microwave, convective dryer and electric oven are shown in Fig. 4 (a, b and c). The obtained results indicated the relation of drying rate versus drying time attributed to the experimental power densiy levels. It was noticed that drying rate decreased with increase of drying time whereas the drying rates were higher at the beginning of mushroom drying process then significantly decreased within drying time. Meanwhile with increase of power density levels from 3.5 to 7.5 $W.g^{-1}$, the drying process is fast occur achieving high drying rates and therefore the required drying time reduced. However, in case of oven drying, the drying rate, as function of moisture content reduction per 15 minutes, increased at the beginning especially at 3.5 $W.g^{-1}$ of power density level but soon decreased and took the normal curve pattern of drying rate again. This is may be, at this level, the latent heat was greater than sensible heat for mushrooms in the oven causing more time of drying which reached about 240 minutes. Finally, it can be concluded that the button mushroom begun with high initial drying rates as a function of moisture content attributed to power density to final low drying rates. Accordingly the power density often has a considerable effect on drying rates at the beginning of drying process but with increasing time, the effect of power density levels not eligible. Also, by the obtained results it can be confirmed that microwave drying has drying rates higher than either convective dryer or oven. This is due to rapidly heat and mass transfer within mushroom samples resulting of generated electromagnetic waves therefore, leading to heating the water molecules and carrying outside moisture by the hot air with high rates.

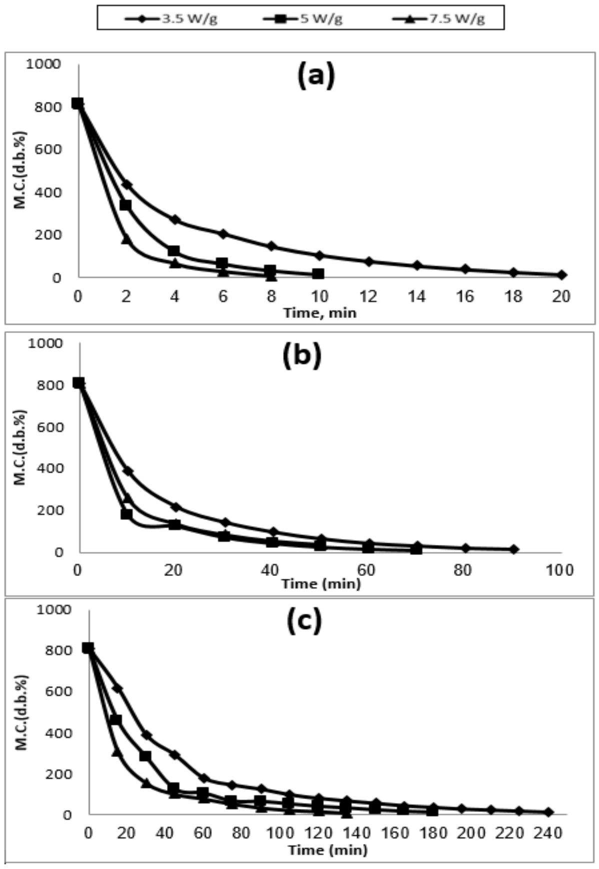

Fig. 3. Variations of mushroom's moisture content versus drying time at different power density levels for; (a) microwave, (b) convective dryer, (c) oven.

Table 2. Statistical parameters of the fitted mathematical models to microwave drying for different power densities of mushrooms

Model	Power density levels ($W.g^{-1}$)	Constants *k*	*n*	*a*	R^2	x^2	*MBE*	*RMSE*
Newton	3.5	0.1862			0.991	0.005792	0.047804	0.072201
	5	0.4226			0.995	0.000468	0.011989	0.019342
	7.5	0.4572			0.948	0.010512	0.065906	0.088793
Page	3.5	0.352	0.7843		0.993	0.000141	-0.002071	0.000141
	5	0.474	0.9554		0.994	0.000238	0.000624	0.0119452
	7.5	0.852	0.7865		0.993	0.000038	-0.000005	0.0043697
Modified Page (I)	3.5	0.2636	0.7843		0.992	0.000140	-0.001334	0.010585
	5	0.4576	0.9554		0.994	0.000238	-0.336221	0.489355
	7.5	0.8161	0.7865		0.993	0.000038	-0.000070	0.004350
Modified Page (II)	3.5	0.0768	0.7843		0.993	0.000140	-0.001353	0.010587
	5	0.0259	0.9554		0.994	0.000238	0.000671	0.011950
	7.5	0.0313	0.7865		0.993	0.000038	-0.000040	0.004359
Henderson and Pabis	3.5	0.1860		0.8283	0.992	0.004360	-0.006288	0.059061
	5	0.4230		0.9408	0.999	0.001454	-0.008821	0.029534
	7.5	0.5490		0.8328	0.990	0.015482	-0.027024	0.087983

3. Fitting of microwave, convective dryer and oven drying kinetics of button mushroom at different power density levels:

The results of computational statistical analysis of five different mathematical models based on comparing criteria of models coefficients of R^2, X^2, MBE and RMSE to assess the fitting ability of microwave, convective dryer and oven drying of button mushroom at different power density levels expressing the changes in the moisture ratio versus drying time are depicted in Tables (2, 3 and 4). The R^2 values for all mathematical models obtained 0.948 to 0.999, 0.9155 to 0.9993 and 0.7925 to 0.996 for microwave, convective dryer and oven, respectively. Furthermore, based on the obtained statistical coefficients, it was noticed that the microwave drying kinetics of button mushroom were best described by: models of Page and Modified Page (II) for power densities of 3.5 and 7.5 $W.g^{-1}$ meanwhile model of Henderson and Pabis was the best fitting for power density of 5 $W.g^{-1}$. On the other hand the best fit to experimented mushroom convective dryer drying was found by models of: Modified Page (I) for power density of 3.5 and 5 $W.g^{-1}$; and Modified Page (II) for power density of 7.5 $W.g^{-1}$. While the best describable fit of oven drying behavior of button mushroom was found by models of: Modified Page (I) for power density of 3.5 $W.g^{-1}$; models of Page and Modified Page (I) for 5 $W.g^{-1}$; and Page model for power density of 7.5 $W.g^{-1}$.

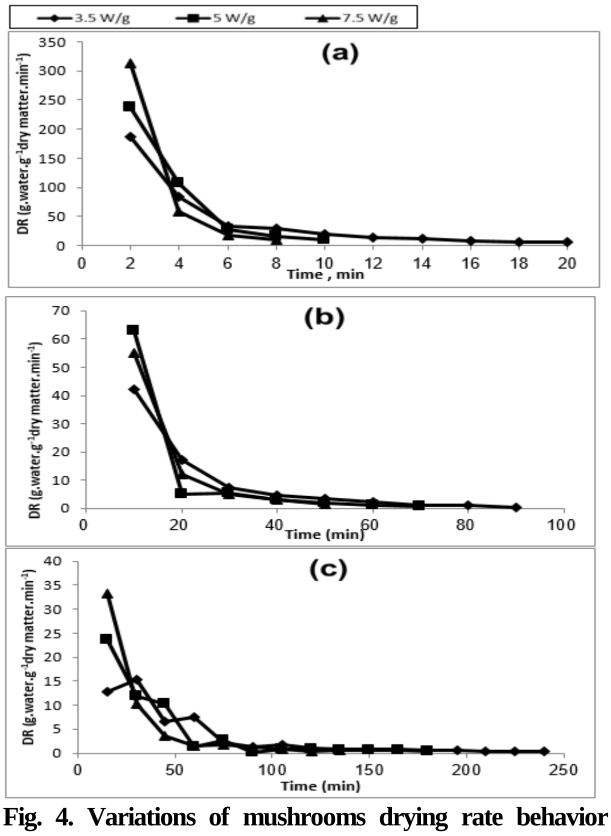

Fig. 4. Variations of mushrooms drying rate behavior versus drying time at different power density levels for; (a) microwave, (b) convective dryer, (c) oven.

4. Effective moisture diffusivity at different power densities for different drying apparatus:

The effective moisture diffusivity of mushrooms for microwave, convective dryer and oven dryers were evaluated from the obtained experimental drying data. Thence, the slope of ln(MR) versus drying time within predestined linear relations at power densities levels of 3.5, 5 and 7.5 $W.g^{-1}$ for the three dryers as depicted in Fig. 5 (a, b and c) were used in order to determine values of diffusion coefficients ($D_{eff.}$) in $m^2.s^{-1}$. Moreover the effect of different power density levels on $D_{eff.}$ for three dryers is shown in Fig. 6. It was found that, by increasing power density levels from 3.5 to 7.5 $W.g^{-1}$, the moisture diffusivity increased. It was also observed that, the $D_{eff.}$ values were higher for microwave-pretreated mushrooms as compared to both convective dryer and oven. The obtained values of $D_{eff.}$ of mushrooms ranged from 45.3×10^{-5} to 111.3×10^{-5} $m^2.s^{-1}$; 5.84×10^{-5} to 20.7×10^{-5} $m^2.s^{-1}$ and 3.99×10^{-5} to 7.3×10^{-5} $m^2.s^{-1}$ for microwave, convective dryer and oven, respectively. Thus, the microwave drying had $D_{eff.}$ higher than either convective dryer or oven due to rapidly heat and mass transfer within mushrooms samples resulting of lowest drying time.

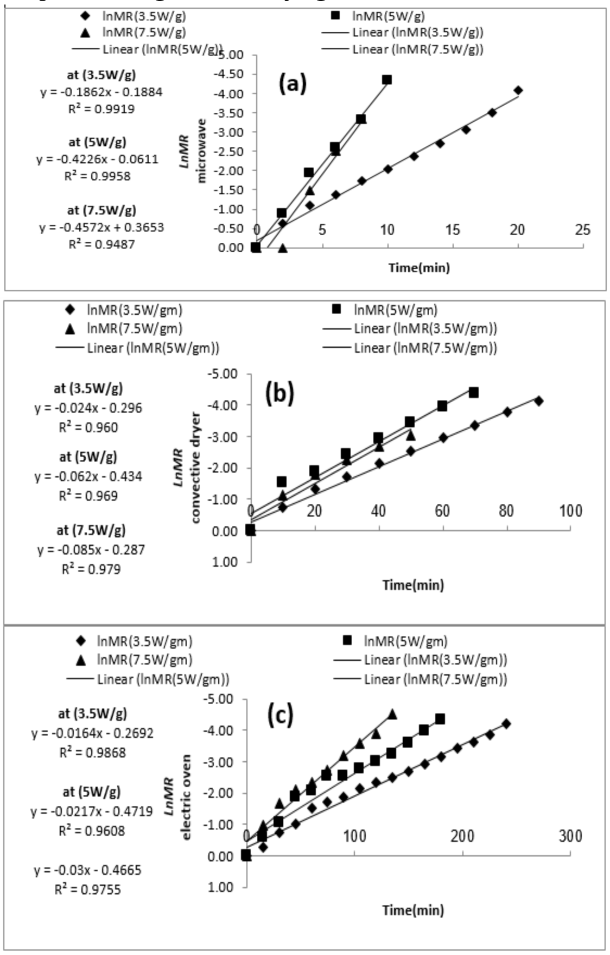

Fig. 5. The slope of *ln (MR)* of mushrooms versus drying time at different power densitt levels for; (a) microwave, (b) convective dryer, (c) oven.

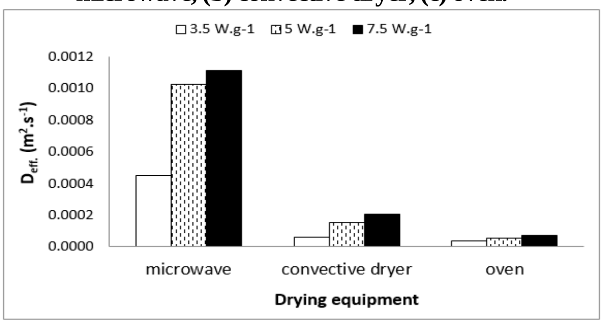

Fig. 6. Effect of different power density levels on effective moisture diffusivity of mushrooms for; (a) microwave, (b) convective dryer, (c) oven.

Table 3. Statistical parameters of the fitted mathematical models to convective dryer for different power densities of mushrooms

Model	Power density Levels ($W.g^{-1}$)	Constants			R^2	x^2	*MBE*	*RMSE*
		k	*n*	*a*				
Newton	3.5	0.0195			0.9155	0.101002	0.288002	0.299633
	5	-0.0569			0.9609	0.0263742	0.0993649	0.1503545
	7.5	0.0577			0.9489	0.0214769	0.0994116	0.1310783
Page	3.5	0.124	0.7767		0.999	0.000028	-0.000226	0.0046479
	5	0.377	0.5638		0.9715	0.000375	-0.000926	0.0163649
	7.5	0.285	0.6065		0.9993	0.000011	-0.000114	0.0025715
Modified Page (I)	3.5	0.067935	0.7767		0.9991	0.000028	0.000044	0.004668
	5	0.176931	0.5638		0.9715	0.000375	-0.226128	0.393662
	7.5	0.126052	0.6065		0.9993	0.000011	0.000094	0.002567
Modified Page (II)	3.5	0.225779	0.7767		0.9991	0.000028	0.000018	0.013996
	5	0.197899	0.5638		0.9715	0.000375	-0.000771	0.016374
	7.5	0.215047	0.6065		0.9993	0.000011	0.000101	0.092004
Henderson and Pabis	3.5	0.044		0.7519	0.9907	0.009159	-0.018112	0.084401
	5	0.057		0.5709	0.9609	0.037966	-0.038010	0.164678
	7.5	0.058		0.6919	0.9489	0.034044	-0.037723	0.142921

Table 4. Statistical parameters of the fitted mathematical models to oven drying for different power densities of mushrooms

Model	Power density Levels ($W.g^{-1}$)	Constants			R^2	x^2	*MBE*	*RMSE*
		k	*n*	*a*				
Newton	3.5	0.0089			0.7925	0.05754	0.2163826	0.2322672
	5	-0.0217			0.9608	467.825	14.4770222	20.7084543
	7.5	-0.0300			0.9755	692.41	17.1860945	24.8087815
Page	3.5	0.031	0.8988		0.9775	0.001003	0.007396	0.0296236
	5	0.084	0.7582		0.9722	0.000858	0.003217	0.0267318
	7.5	0.161	0.6661		0.9960	0.030593	-0.106596	0.1542549
Modified Page (I)	3.5	0.021098	0.8988		0.9775	0.000962	0.006190	0.029007
	5	0.038390	0.7582		0.9722	0.000845	-0.212587	0.352873
	7.5	0.064746	0.6661		0.9960	0.000104	-0.000004	0.008980
Modified Page (II)	3.5	0.511248	0.8988		0.9775	0.000963	0.006219	0.029022
	5	0.360667	0.7582		0.9722	0.000845	0.002203	0.026537
	7.5	0.288229	0.6661		0.9922	0.000251	0.000024	0.381930
Henderson and Pabis	3.5	0.016		0.7640	0.9868	0.006586	-0.012030	0.075913
	5	0.022		0.6238	0.9608	0.016484	-0.030881	0.117202
	7.5	0.030		0.6272	0.9790	0.020716	-0.027530	0.126936

CONCLUSION

The drying kinetics of button mushroom (*Agaricus bisporus*) dried by the microwave, convective dryer and electric oven driers under three different power density levels were investigated. Moreover, the changes in the moisture ratio versus drying time were fitted to five drying mathematical models. Microwave drying shorted drying times by 77.7, 85.7 and 84% at power density levels of 3.5, 5 and 7.5 $W.g^{-1}$, respectively, comparing to convective dryer to reach the same values of low moisture content levels, whilst 91.6, 94.4 and 94% at the same power density levels, respectively, comparing to electric oven. Furthermore, a considerable effect on drying rates at the beginning of drying process was appeared and decreased within increasing drying time. Additionally, the effective moisture diffusivity of drying mushrooms ranged from 45.3×10^{-5} to 111.3×10^{-5} $m^2.s^{-1}$ by using microwave treatment was obtained larger than convective dryer and oven treatments. Consequently, the microwave treatment had drying rates and moisture diffusivity higher than either convective dryer or oven hence, less drying time due to rapidly heat and mass transfer within mushrooms samples resulting of generated electromagnetic waves in microwave dryer. Finally, among the used models; Page, Modified Page (I) and Modified Page (II) most expressed the best description of the experimental button mushrooms drying results.

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سلوك التجفيف لفطر عيش الغراب الأبيض البتون (الأجاريكس *Agaricus bisporus*) باستخدام أنواع مختلفة للمجففات مع الأخذ فى الإعتبار كثافة القدرة

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تظل عملية التجفيف مقارنةً بطرق الحفظ الأخرى تقنية واعدة لهندسة حفظ الأغذية. لذا، يهدف هذا البحث إلى دراسة سلوك تجفيف فطر عيش الغراب النوع الأبيض البتون (الأجاريكس *Agaricus bisporus*) باستخدام الميكروويف، مجفف صناعي و الفرن الكهربائي تحت ثلاث مستويات مختلفة من كثافة القدرة (3.5 ، 5 و 7.5 وات. جم$^{-1}$). علاوة على ذلك ، تم إجراء التحليل الإحصائي لخمسة نماذج رياضية للتجفيف من أجل محاكاة سلوك وخصائص تجفيف المشروم للثلاث مجففات وذلك لوصف نتائج نسب الرطوبة المتحصل عليها. أظهرت النتائج المتحصل عليها أن زيادة كثافة القدرة أدت إلى تجفيف سريع وفي وقت أقل للوصول إلى مستويات منخفضة من محتوى الرطوبة. بالإضافة إلى ذلك ، تم التوصل لأقل زمن تجفيف للمشروم الذي يحتوي على رطوبة أولية (أساس جاف) بنسبة 809٪ تحت ظروف التجفيف باستخدام الميكروويف. وبالتالي، انخفض زمن التجفيف بنسبة 77.7 ، 85.7 و 84 ٪ عند مستويات كثافة القدرة المذكورة أعلاه، على التوالي، وذلك مقارنةً بالتجفيف باستخدام المقلاة الهوائية، في حين أن مستويات 91.6 , 94.4 و 94 ٪ عند نفس مستويات كثافة القدرة، على التوالي ، مقارنة بالتجفيف باستخدام الفرن الكهربائي . وأخيرا، من بين النماذج الرياضية المستخدمة؛ عبرت نماذج Page, Modified Page (I) وModified Page (II) عن أفضل وصف لنتائج تجارب تجفيف المشروم.