Mathematical Modelling Of Thin Layer Drying Kinetics Of Paddy Straw Mushroom (*Volvariella Volvacea*)

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ABSTRACT

This study was conducted to investigate the drying kinetics of paddy straw mushroom (*Volvariella volvacea*). Mushrooms were dried using different drying methods and parameters were studied for preparation of dried mushroom. Mushrooms were dried in a tray dryer (50, 60 and 70°C), microwave convective dryer (0.72, 1.44 and 2.16 W/g power levels and constant air temperature of 50°C). The experimental drying data were fitted to different theoretical models to predict the drying kinetics. Results indicated that the Page model offered the best fit for experimental drying data for hot air drying and Wang and Singh model for microwave convective drying. The value of effective diffusivity in Microwave convective drying was more than that of hot air drying. The calculated activation energy (Ea) was 0.269 W/g in Microwave convective drying and 44.97 kJ/mol in hot air convective drying.

Keywords Convective dying, Microwave convective drying, paddy straw mushroom, thin layer drying models, effective diffusivity and activation energy.

INTRODUCTION

Mushrooms are found all over the world and have been a time honoured food in many cultures. These are tropical and subtropical saprophytic fungus belonging to the family Pluteaceae of Basidiomycetes. These are liked for their delicious flavour, low calorific value and high protein, vitamins of B-groups and minerals. They contain proteins and have no cholesterol and are almost fat free (Walde *et al*., 2006).They have been used not only as a food but also for medicinal purpose (Bobek *et al*., 1997; Yang *et al*., 2001; Chocksaisawasdee *et al.*, 2010).

Medicinal mushrooms have become important due to their antitumor, antifungal and reducing hyper cholesterolemia activities (Chang and Buswell, 1996). According to research, *Agaricus bisporus*, *Hericium erinaceus*, *Flammulina velutipes*, *Lentinus edodes*, and *Pleurotus ostratus* may have anti-aging and possibly antioxidative benefits on food preservation (Kim *et al.* 2001; Lee *et al.* 2003). Studies also indicate that some of the edible mushrooms possess potential anti-carcinogenic, anti-cholesterolaemic and anti-viral properties (Emilia *et al.*, 2006; Roman *et al.*, 2006). Besides producing delicious, highly nutritious food and medication, mushroom farming can also be an effective way to get rid of debris, particularly agricultural wastes like hay and paddy straw. (Mandeel *et al.*, 2005). Literally, there are less than 25 species of edible mushrooms out of more than 2000 species that exist. Currently, three varieties of mushrooms, viz. white mushroom (*Agaricus bisporus*), paddy straw mushroom (*Volvariella volvacea*) and oyster mushroom (*Pleurotus sajor-caju*) are widely cultivated in India for commercial purpose (Barros *et al.* 2007). These mushrooms possess good quality of proteins, unsaturated fatty acids, fibres, minerals and vital vitamins that we need in our daily diet (Ouzouni *et al.* 2009; Hung and Nhi, 2012). The *Volvariella volvacea,* locally known as paddy straw mushroom or straw mushroom, or Chinese mushroom.

In the state of Odisha straw mushroom is grown commercially for 10 months a year (February-November) involving poor farmers and the production stands at 9550 tonnes/annum (AICRP, 2016). However, the straw mushroom growers often suffer from distress sell because of its short shelf life and unavailability of suitable storage technology. The farmers usually sell fresh mushroom to the market without any post-harvest treatment. However, the mushroom starts to spoil with undesirable smell, texture and odour very quickly even after 6-7 hours. This indirectly creates economic loss to the people who rely on it for livelihood. The commonly used food preservation techniques such as canning, freezing and drying can be employed for preservation of mushrooms. Although canning is widely used on a commercial scale, it is quite expensive. Cold chain is often beyond the reach of common mushroom growers. Drying seems to be more effective approach to extend shelf life than freezing as the process is cheap, convenient and if properly packaged can extend the shelf life for years.

There are many drying methods, such as solar drying, convection drying, freeze drying, fluidised bed drying and microwave drying. Drying under open sun results in unhygienic and poor quality products (Chua *et al*. 2001). Hot air drying is simple, economical and a more efficient method of drying, but there may be darkening of the product leading to poor acceptance by consumers. Freeze drying is frequently applied to materials that are prone to heat damage and it yields products with excellent structural characteristics. It may also overcome the problem of mushroom darkening. But the process is capital intensive and may not be recommended to small mushroom growers. Fluidized bed drying is also a newer method that is faster and produces better quality product than that obtained by conventional hot air drying; but it is also more expensive than cabinet dryers. Microwave drying is considered as the fourth generation drying technology. Waves can penetrate directly into the material and the heating is volumetric (from inside to outside). It also offers many advantages such as less start up time, faster heating, uniform heating throughout the entire product, better energy efficiency (most of the electromagnetic energy is converted to heat), saving in space, and precise process control. Besides the final product also has a better nutritional quality than conventional methods, but the commercial microwave dryers are yet to take up. For small and marginal farmers, these costly technologies may not be recommended and the use of hot air cabinet drying could be the most practicable solution. The aim of this work was to model the drying kinetics of the paddy straw mushroom in a hot air dryer and a microwave convective dryer over a wide range of temperature and power level. In addition, the effective diffusivities and activation energies of the mushroom samples were calculated and presented.

Material and Methods

Freshly harvested *Volvariella volvacea* mushroom was purchased from a local mushroom grower. The mushroom samples were then cleaned by hand to separate the undesirable portions. The mushrooms were sorted on the basis of size (6mm) and then the samples were cut longitudinally to four parts with the help of a sharp knife. The initial moisture content of fresh paddy straw mushroom was estimated by calculating the loss of water in a hot air oven (Uni-tech Model-UsTS 1.01c) at 105°C for 24 hours (AOAC, 1990) until it reached a fixed weight.

Experimental procedure

Hot air drying system

A laboratory hot air dryer (Make:Smita Scientific, Model: STRD-1) was used for this experiments. The samples were kept in the dryer after the dryer reached the desired air temperature for drying. Six hundred grams of sample was placed on trays and dried until the desired weight corresponding to the final moisture content was achieved. A digital balance (Mettler Toledo, Switzerland; Model number: ME54E) was used for taking the weight of the samples. The sample tray was removed from dryer and weighed regularly, initially at intervals of 15 minutes (up to 1 hour) and then onwards at 30 minutes intervals. Three replicates were taken for each experiment. The drying of samples in hot air dryer was continued till a final moisture content of 9% (d.b.) (Kim, 2004). The drying air temperature was maintained at 50, 60 and 70°C. At the end of each drying experiment, the final moisture content of the sample was determined. The drying rate were computed from the experimental data and corresponding drying characteristics curves were plotted.

Microwave convective dryer

A laboratory microwave convective dryer (LG, Model no. 3850W2G031A) was used for the study. The system has a maximum output 900W at 2450 MHz. The dimension of the microwave cavity was 215mm × 350mm × 330mm. The oven has a fan for hot air flow in drying chamber and cooling of magnetron. The blower and heater were connected to the oven. The moisture from drying chamber was removed with blower air by passing it through the openings on the top of the oven wall to the outer atmosphere. The dryer was fitted with a glass turntable (30 cm diameter) and had a digital control facility to adjust the microwave output power by the 20% decrements and the time of processing. The fresh cut mushrooms were uniformly spread on microwave plate and kept on turntable inside the microwave cavity, for an even absorption of microwave energy. Three replicates were taken for each experiment. Depending on the drying conditions, moisture loss was recorded at 5 min, 3 min or 2 min intervals by removing the plate from the microwave, and periodically placing the sample on the digital balance. The material loaded for each section of drying was 250 g and the drying was continued till the samples reached a moisture content of 9% (d.b.).

Theoretical consideration

Mathematical Modelling of Drying Curve

The moisture ratio (MR) of the samples during drying process was calculated at any time using the following equation.

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad \text{...(1}$$

where, Mt= moisture content (% d.b.) at the particular time, Me = Equilibrium moisture content (% d.b.) and Mo = Initial moisture content at time, t=0 s

Various exponential forms of empirical models have been developed and tested by many investigators. In this expression, the moisture ratio has been simplified to M_t/M_0 , instead of equation(1), because of the fact that air humidity in the hot air dryer was not constant (Rayaguru and Routray; 2012). The removal of water with time for each drying condition was observed regularly. The drying rate of each time interval for each drying temperature was calculated by considering the water removed per unit time for the interval.

$$\text{Drying rate} = \frac{\text{Amount of water removed (g/g)}}{\text{Time taken in min.} \times \text{amount of dry matter (g)}} \qquad \text{...(2}$$

The drying curves obtained were processed for drying rates to find the most convenient model among the nine different expressions proposed by earlier authors given in Table 1. The non-linear regression analysis was performed using the software DATAFIT 9.0 and the graphs were plotted using Microsoft Office 2007 Excel. Although the coefficient of determination (R^2) was one of the primary criterions for the selecting the best model to describe thin layer curves of mushroom samples, the statistical test methods such as root means square error (RMSE) and reduced chi-square (χ^2) were also used to evaluate the goodness of fit of the models. The lower RMSE value and the higher R^2 (Coefficient of determination) values were determined as the basis for goodness of fit. The reduced chi-square (χ^2) and the root mean square error (RMSE) can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N - z} \quad \text{...(3}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2} \quad \text{...(4}$$

Effective Moisture Diffusivity and Activation Energy

Drying of most food materials occurs in the falling rate period (Wang and Brennan, 1992), and moisture transfer during drying is controlled by internal diffusion (Saravacos and Charm,1962). For most biological materials, Fick's second law of diffusion has been widely used to describe the drying process during the falling rate period (Saravacos and Maroulis, 2001; Crank, 1975) as follows:

$$\frac{\partial M}{\partial t} = \nabla\left[D_{eff}(\nabla M)\right] \quad \text{...(5}$$

where, D_{eff} is the effective moisture diffusivity representing the conductive term of all moisture transfer mechanisms. This parameter is usually determined from experimental drying curves (Saravacos and Maroulis,2001). The solution of Fick's second law in slab geometry is given by Crank (1975) as shown in Eq. (6), assuming moisture migration being only by diffusion, constant temperature and effective moisture diffusivity, and negligible shrinkage:

$$\frac{\partial M}{\partial t} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}t}{4L^2}\right) \quad \text{...(6}$$

where, L is the half thickness of the slab in the samples (m) and n is a positive integer.
In practice, only the first term of Eq.(6) is used, yielding

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff}t}{4L^2}\right) \quad \text{...(7}$$

The effective moisture diffusivity can be determined from the slope of the normalized plot of the unaccomplished moisture ratio, ln (MR)-vs-time, using the following equation.(Lomaura *et al*. 1985).

$$D_{eff} = \frac{-slope\,4L^2}{\pi^2} \quad \text{...(8}$$

Temperature dependence of the effective diffusivity has been shown to follow an Arrhenius relationship.

$$D_{eff} = D_0 \exp(\frac{-E_a}{RT}) \quad \text{...(9}$$

where, D_0 is the pre-exponential factor of the Arrhenius equation (m^2s^{-1}), E_a is the activation energy (kJ mol^{-1}), R is the universal gas constant (kJ $mol^{-1}K^{-1}$), and T is the absolute air temperature (K). The activation energy is determined from the slope of the Arrhenius plot, ln (D_{eff}) vs. $1/T$.

For microwave convective drying it is assumed as related to effective moisture diffusion and the ratio of microwave output power to sample weight (m/p) instead of to air temperature. Then Eq. (10) can be effectively used as follows (Ozbek and Dadali, 2007):

$$D_{eff} = D_0 \ \mathrm{Exp}\left(-\frac{\mathrm{E_a} m}{P}\right) \quad \text{...(10}$$

where E_a is the activation energy (W/g), m is the mass of raw sample (g), D_0 is the pre-exponential factor (m^2/s) and P is the microwave power (W).

Table 1. Selected single layer drying models for describing paddy straw mushroom drying data.

S. No.	Model equation	Name	References
1	$MR = ae^{\left(-kt^n\right)} + bt$	Midilli	Midilli*et al.* (2002)
2	$MR = e^{\left(-kt^n\right)}$	Page	Page (1949)
3	$MR = e^{(-kt)^n\ n}$	Modified page	Modified page (1965)
4	$MR = ae^{\left(-kt\right)}$	Henderson and Pabis	Henderson and Pabis(1961)
5	$MR = e^{\left(-kt\right)}$	Newton	O' Callaghan *et al.*, (1971)
6	$MR= 1+at+bt^2$	Wang and Singh	Wang and Singh (1978)
7	$MR = ae^{\left(-kt\right)} + c$	Logarithmic	Dawn *et al.* (2015)
8	$MR = a * b^x$	Modified power	Tuncay *et al.* (2015)
9	$MR = ae^{\left(-k_0 t\right)} + be^{\left(-k_1 t\right)}$	Two -term	Dadali and ozbek (2008)

RESULTS AND DISCUSSION

The initial moisture content of sample was 837.20 % (d.b.) and the final moisture content of the samples were kept as 9% (d.b.). The air flow was kept as 1 $m.s^{-1}$. Fig.1 represents the variation of moisture content with drying time for hot air convective drying (HAD) of mushrooms at 50, 60 and 70°C. To attain the final moisture content of 9 % (d.b), it took approximately 420, 330 and 180 min. The moisture content rapidly reduced and then slowly decrease with increase in drying time. It was also obvious from figure 1 that drying temperature has an important effect on total drying time. The drying rate, defined as the quantity of water removed per unit mass per unit time-vs.- average moisture content were also calculated and are shown in Fig.2. The peak drying rate for paddy straw mushroom was found to be 7.82 g/100g min. at a moisture content 1091% db at 50°C during air temperature as compared to 14.28 g/100g min. at 70°C. Fig.3 shows the moisture ratio versus drying time. As expected, the moisture ratio decreased with increasing drying time. The drying rate decreased continuously with decreasing moisture content. There was no constant rate drying period and all drying operations were found to occur in the falling rate period. This shows that diffusion is the dominant physical mechanism for moisture movement in the mushroom. The results agree with the earlier observations of Apati (2010) and Tulek (2011) for oyster mushroom; and Giri and Prasad (2007) for button mushroom, Lee and Lee (2008) for chaga mushroom, Krokida *et al.* (2003) for various vegetables.

Fig. 4 represents the variation of moisture with drying time for microwave convective drying (MWCD) of mushroom at 0.72, 1.44 and 2.16 W/g. Time taken at different power level for drying were 30,28 and 27 min. The microwave power level affected the drying rates for all conditions and the drying rates increased with the increase in microwave power levels (Fig.5). The maximum drying rates were approximately 49.348, 51.818 and 66.60 g/100g min. at 0.72, 1.44 and 2.16 W/g respectively. Figs. 6 shows the moisture ratio versus drying time. The moisture content of the material was very high during the initial phase of drying which resulted in higher absorption of microwave power and higher drying rates due to the higher moisture diffusion. As the drying progressed, the loss of moisture in the product caused a decrease in the absorption of microwave power and resulted in a fall in the drying rate. These results are similar to those reported by Naik*et al.* (2006), Arumuganathan *et al.*(2009), Giri and Prasad (2007) for the microwave drying of mushroom, moradi *et al.*(2013) for potato and zarein *et al.*(2015)for apple slices.

It was observed that with every 10°C increase in drying temperature from 50 to 70°C in hot air dryer, the dring time decreased by 26.66 to 45.45% and for microwave convective dryer, drying time decreased by 6.66 to 3.57%.

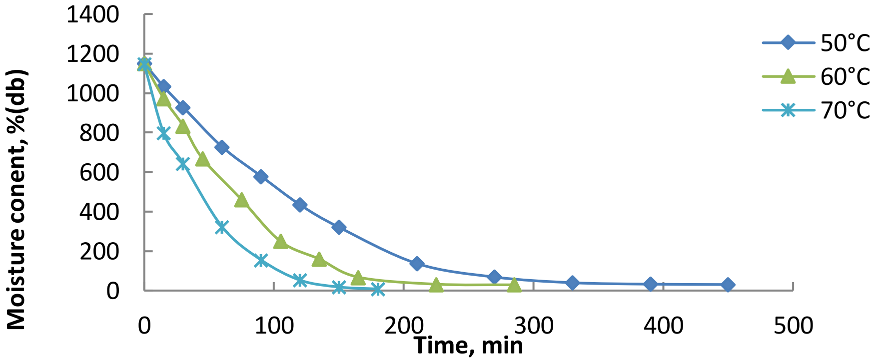

Fig. 1 Moisture loss of mushroom in hot air drying (HAD)

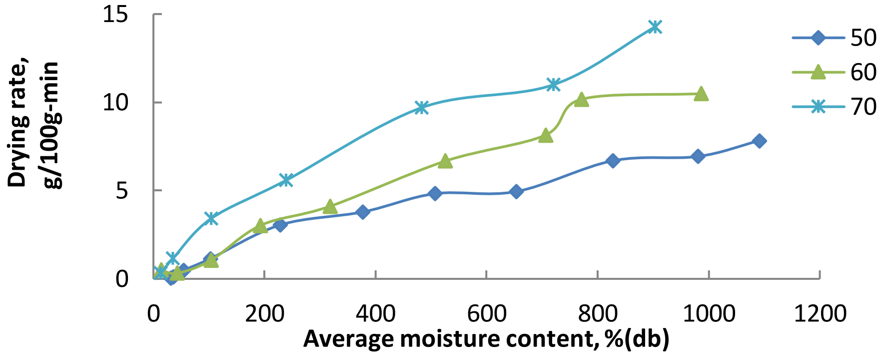

Fig. 2 Variation of drying rate with average moisture content in HAD

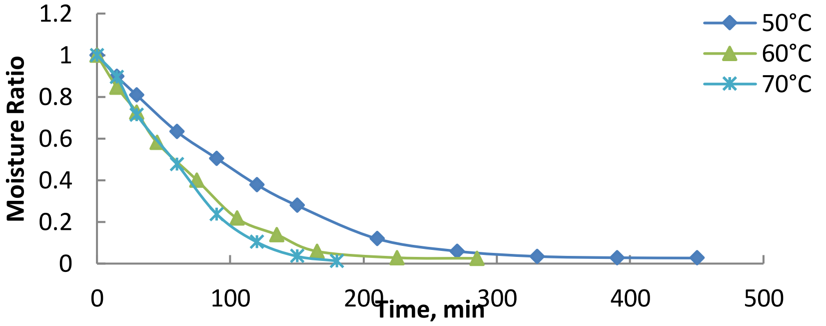

Fig. 3 Variation of moisture ratio with drying time in HAD

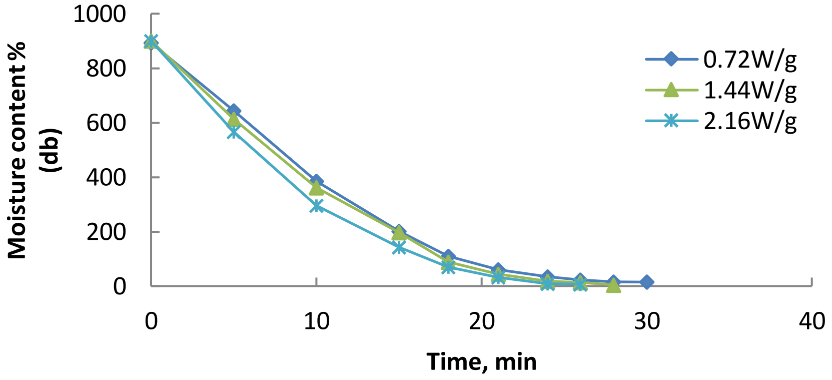

Fig. 4 Variation of moisture content (d.b) with time in MWCD

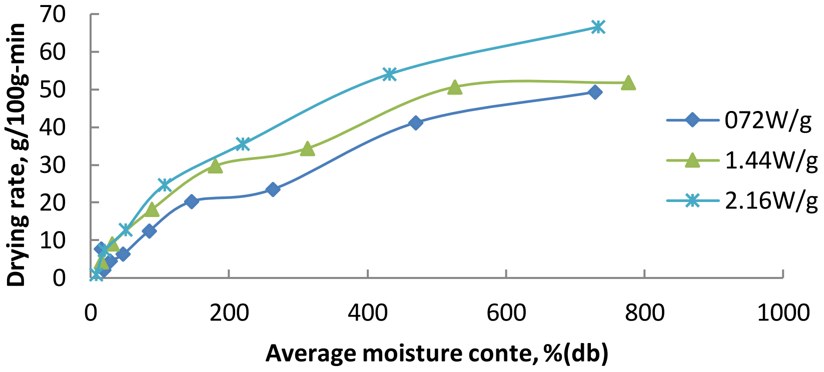

Fig.5 Variation of drying rate with average moisture content MWCD

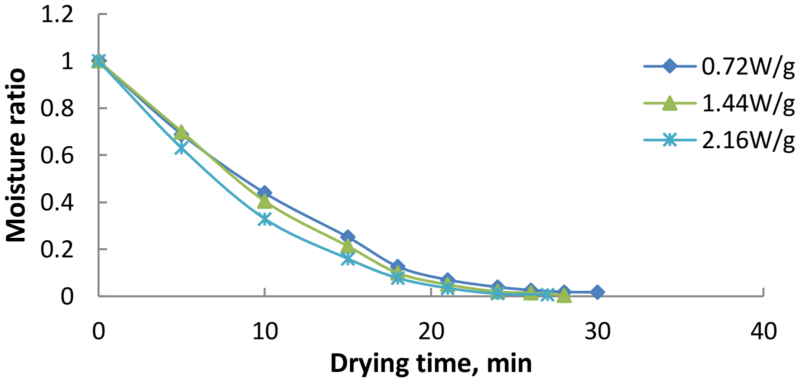

Fig. 6 Variation of moisture ratio with drying time in MWCD

Evaluation of the models

Data obtained from drying experiment, basically the moisture content was converted to moisture ratio (MR) and was fitted to the nine models listed in Table 1. It was observed that the R^2 value was highest with minimum chi- square and RMSE value for Page Model for all the three drying air temperatures and the Page Model (1949) could satisfactorily describe the drying characteristics of mushroom at all the three selected temperatures. The coefficient obtained for different models fitted at the different temperatures are reported in Table 2. The accuracy of the established model for the convective drying process was evaluated by comparing the predicted moisture ratio with observed moisture ratio. The performance of the model for all the drying conditions has been illustrated in Fig. 7. The predicted data generally banded around the straight line which showed the suitability of the Page Model in describing the drying behaviour of mushroom in convective drying.

Wang and Singh (1978) was observed to be the most appropriate one for microwave convective drying behaviour with the higher value for the coefficient of determination (R^2) and chi-square and RMSE compared with those obtained for the other models shown in Table

3. It was observed that the value of drying rate constant (k) increased with the increase in microwave output power. This implies that with the increase in microwave output power, drying curve becomes steeper indicating increase in drying rate. The reported results are in agreement with Izki and Iski (2014) for button mushroom.Ghaderi *et al*. (2012) and Artnaseaw *et al*. (2010) reported that drying characteristics of mushroom were best described by model proposed by Midilli*et al*.(2002). On the other hand, Xanthopoulos*et al*. (2007) found that the Logarithmic model (2002) showed the best fit to experimental drying data of mushrooms. Diffusion Approach(2001) and Wang and Singh (1978) models were also suggested by Sacilik*et al*. (2006) and Farhang *et al*.(2010) to describe drying behaviour of different food products. The fitness of the data is illustrated in Fig 8.

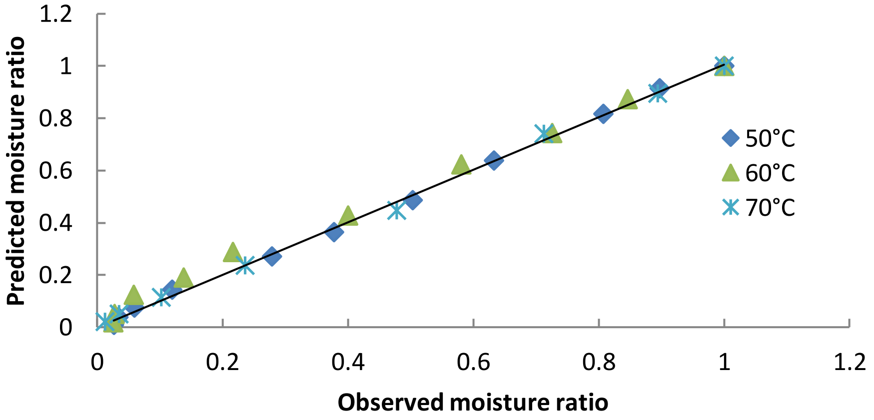

Fig. 7 Comparison of predicted moisture ratio (Page Model) with observed moisture ratio in HAD

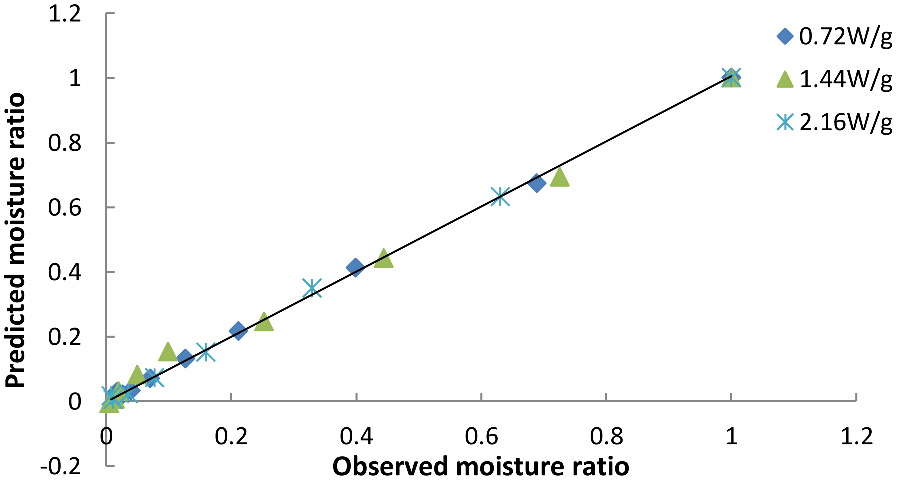

Fig. 8 Variation of predicted moisture ratio (Wang and Singh) with observed moisture ratio in MWCD

Table 2: Results of statistical analysis on the modelling of moisture ratios and drying time for the HAD

Temperature	Model name	Model equation	Coefficient	R^2	χ 2	RMSE
50°C	Page	$MR = e\left(-kt^n\right)$	k= 0.00383 n =1.16357	0.998468	0.0002237	0.013653
	Modified power	$MR = a * b^x$	a =1.028299 b = 0.99135	0.995049	0.0007227	0.024541
	Modified Page	$MR = e(-kt)^n$	K = -0.091 n = -0.091	0.993906	0.0008896	0.027227
	Wang and Singh	MR= 1+at+bt^2	a =-0.006 b =0.0000087	0.991287	0.0012721	0.032559
60°C	Page	$MR = e\left(-kt^n\right)$	K=0.00608 n =1.143655	0.996615	0.0005041	0.020082
	Modified power	$MR = a * b^x$	a =1.020432 b =0.988178	0.993642	0.000947	0.027525
	Modified Page	$MR = e(-kt)^n$	k = -0.10777 n = -0.10777	0.993022	0.0010394	0.028836
	Wang and Singh	MR= 1+at+bt^2	a = -0.00820 b =0.0000163	0.987919	0.0017995	0.037942
70°C	Page	$MR = e\left(-kt^n\right)$	k =0.00231 n = 1.429858	0.997954	0.000374	0.016748
	Modified power	$MR = a * b^x$	a = 1.070035 b = 0.984319	0.996043	0.000723	0.023289
	Modified Page	$MR = e(-kt)^n$	k = -0.12135	0.978101	0.004002	0.054788

			n =-0.12136			
	Wang and Singh	MR= 1+at+bt^2	a =-0.0108 b =0.0000294	0.97089	0.00532	0.063168

Table 3: Results of statistical analysis on the modelling of moisture ratios and drying time for the MWCD

Microwave power	Model name	Model equation	coefficient	R^2	χ 2	RMSE
0.72W/g	Wang and Singh	$MR= 1+at+bt^2$	a=-0.0720 b =0.00132	0.999506	0.0000625	0.007071
	Page	$MR = e\left(-kt^n\right)$	K=0.040285 n =1.3628	0.999248	0.0000875	0.008367
	Modified power	$MR = a * b^x$	a =1.036168 b =0.899093	0.982661	0.0021875	0.041833
	Two term	$MR = ae^{(-k_0 t)} + be^{(-k_1 t)}$	a =0.51808,k$_0$ =0.10636 b=0.518084,k$_1$=0.10636	0.982661	0.0029167	0.041833
	Modified page	$MR = e(-kt)^n$	K= -0.32184 n =-0.32194	0.981115	0.0023875	0.043704
	Wang and		a= -0.0668	0.997411	0.0003714	0.016997

1.44W/g	Singh	$MR= 1+at+bt^2$	b=0.0011			
	Page	$MR = e^{(-kt^n)}$	k=0.0253 n=1.513198	0.996014	0.0005857	0.021344
	Modified Power	$MR = a*b^x$	a= 1.050541 b= 0.90326	0.965467	0.0049857	0.062272
	Two term	$MR = ae^{(-k_0 t)} + be^{(-k_1 t)}$	a= 0.5252, k_0= 0.10174 b=0.525271,k_1=0.10174	0.965467	0.00698	0.062272
	Modified page	$MR = e(-kt)^n$	K=-0.31325 n=-0.31316	0.962384	0.0054429	0.065064
2.16W/g	Wang and Singh	$MR= 1+at+bt^2$	a= -0.0818 b=0.00168	0.999046	0.000133	0.01
	Page	$MR = e(-kt^n)$	k=0.0521 n=1.336811	0.998918	0.00015	0.010607
	Modified power	$MR = a*b^x$	a= 1.02416,b=0.8860	0.985062	0.002217	0.040774
	Two term	$MR = ae^{(-k_0 t)} + be^{(-k_1 t)}$	a=0.51208,k_0=0.12096 b=0.51208,k_1=0.12096	0.985062	0.003325	0.040774

	Modified page	$MR = e(-kt)^n$	k==-0.34468 n= -0.3447	0.984315	0.002317	0.041683

Effective diffusivities and activation energy

The value of effective diffusivities at 50°, 60° and 70°C were 5.471×10^{-10}, 7.295×10^{-10} and 14.591×10^{-10} m^2min^{-1}, respectively and at 0.72, 1.44 and 2.16 W/g were 8.937×10^{-9}, 11.0×10^{-9} and 11.368×10^{-9} m^2min^{-1}, respectively (Table 4). . These values are within the range reported for different food materials by Madamba *et al.*(1996).This is also consistent with the reports of Chong *et al.* (2008), Doymaz (2007) for pumpkin slices, Doymaz (2009) for spinach leaves, and Bhattacharya *et al.*(2015) for oyster mushroom. It was observed that in table 4 effective moisture diffusivity increased with increasing drying temperature and power level therefore, time taken for drying was also decreased with increasing both temperature and power level. The logarithm of effective diffusivity (D_{eff}) as a function of the reciprocal of the absolute temperature (T) is plotted in Fig.8, which is approximated as a linear relationship between (lnD_{eff}) and (1/T). The calculated activation energy (E_a) was 44.97 kJ mol^{-1}. The logarithm of effective diffusivity (D_{eff}) as a function of the mass per unit power levelis plotted in figures 9, which is approximated as a linear relationship between (lnD_{eff}) and (m/P). The calculated activation energy (E_a) was 0.269 W/g. It was observed that the value of effective diffusivity was higher than that of hot air drying. The effective moisture diffusivity increased with decrease in moisture content. Further, the moisture diffusivity was higher at any level of moisture content at a higher microwave power level. The temperature of the product rise rapidly in the initial stages of drying, due to more absorption of microwave heat, as the product had a high loss factor at higher moisture content. This increased the water vapour pressure inside the pores and resulted in pressure induced opening of pores. In the first stage of drying, liquid diffusion of moisture could be the main mechanism of moisture transport. As drying progressed further, vapour diffusion could have been the dominant mode of moisture diffusion in the latter part of drying. Sharma and Prasad (2004) and Sharma *et al.* (2005) also reported a similar trend in the variation in the moisture diffusivity with moisture content.

Table 4. Effective diffusivity and activation energy in HAD and MWCD

Temperature	Effective diffusivity(m^2/sec)	Activation energy
50°C	5.471×10^{-10}	44.97KJmol^{-1}
60°C	7.295×10^{-10}	
70°C	14.591×10^{-10}	
0.72 W/g	8.937×10^{-9}	0.269 W/g
1.44W/g	11.0×10^{-9}	
2.16W/g	11.368×10^{-9}	

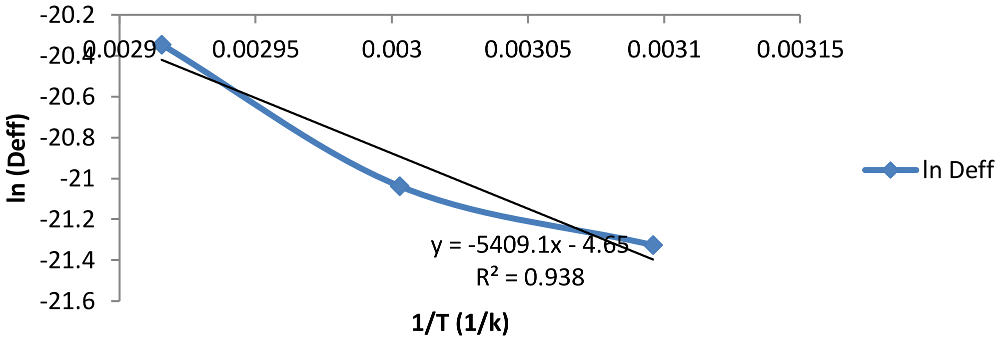

Fig.8 Arrhenius relationship between effective moisture diffusivity and reciprocal of the absolute temperature

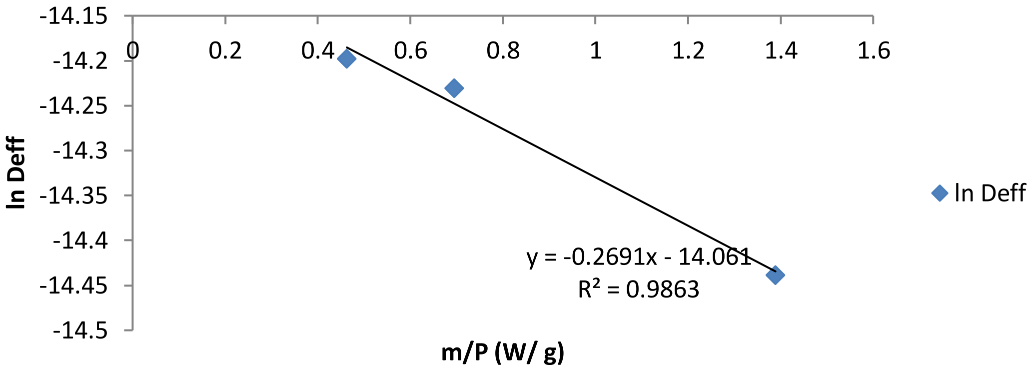

Fig. 9 Arrhenius type relationship between effective ln (Deff) and reciprocal of microwave power

CONCLUSION

The drying kinetics of paddy straw mushroom with 6mm of the thickness in hot air dryer at three air temperature (50,60 and 70°C) and microwave convective dryer at different power level (0.72,1.44 and 2.16 W/g) were studied. The whole drying process of paddy straw mushrooms took place in falling rate period. The most important aspect of drying technology is the mathematical modelling of drying proessess and puspose to allow design engineers to choose the most suitable operating conditions. This study indicated that based on non- linear regression analysis, the Page model gave best fitting to the drying experimental data for hot air dried sample and Wang and Singh model gave good fitting for MWCD of paddy straw mushroom. The drying time of paddy straw mushroom decreases and the effective diffusivity increases as the drying temperature and output power increases. The effective moisture diffusivity of mushrooms was found to range between 5.471×10^{-10} to 14.591×10^{-10} m^2sec^{-1}, respectively within the temperature range of 50, 60 and 70°C and activation energy was also found to be 44.97 $KJmol^{-1}$. In microwave convective drying effective moisture diffusivity found to be 8.937×10^{-9} to 11.368×10^{-9} m^2sec^{-1} at 0.72, 1.44 and 2.16 W/g and activation energy was 0.269 W/g.

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