Mathematical Modelling of Dried Oyster Mushroom (*Pleurotus flabellatus*)

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Abstract: This work was conducted to assess the drying kinetics of oyster mushroom (*Pleurotus flabellatus*). Mushrooms were dried in sun drying, poly house drying, tray drying and vacuum drying. Oyster mushrooms were subjected to four pretreatments prior to drying. Drying took place in the falling rate period, and the drying behaviour was adequately described by the Lewis, Page, Peleg and Henderson & Pabis's equation. The experimental drying data were fitted to different theoretical models to predict the drying kinetics. Results indicated that the Pabis and Henderson model offered the best fit for experimental drying data for sun drying (average R^2 = 0.97) and Lewis model for tray drying (average R^2 = 0.9498).

Key words: **Drying, Mushroom, Page's model, Henderson and Pabis model, Pretreatment.**

I. INTRODUCTION

Mushrooms are highly perishable as they contain moisture in the range of 87% to 95% wet basis. Quality deterioration takes place if fresh mushrooms are not immediately processed. Drying is the most commonly used method of preservation of mushrooms. Dehydrated mushrooms are used as an important ingredient in several food formulations including instant soups, pasta salads, snack seasonings, stuffing, casseroles, and meat and rice dishes (Tuley, 1996). Furthermore, elevated temperatures during drying enhance enzymatic reaction that can result in improved flavour of dehydrated mushrooms (Tuley, 1996). Extending the shelf life of mushrooms is important to mushroom producers and consumers, and drying mushrooms is one method that would extend the shelf life (Tuley, 1996). The drying behavior of biological materials like food is a complex heat and mass transfer phenomenon, and requires simple presentation to predict the drying kinetics to optimize the drying parameters. The thin layer drying equations were used for prediction and generalization of drying curves (Karathanos and Belessisotis, 1999). The present study was undertaken on Pleurotus flagellates mushroom to study the drying kinetics in thin layer with to evaluate drying models during different drying methods. The most relevant aspects of drying technology are the mathematical modelling of the process and the equipment. The modelling is basically based on the design of a set of equations to describe the system as accurately as possible (Celma et al., 2007). McMinn (2006) outlines several thin layer drying models for explaining drying characteristics of agricultural products. Mathematical models of the drying processes are used for designing new or improving existing drying systems and even for the control of the drying process. Modeling the drying kinetics and determining the drying time of mushroom are two very important areas of drying. However, most production losses in the industry occur during drying. In order to minimize these losses, it is necessary to optimize the drying conditions, machine design, and product quality. There is a need to identify and evaluate the drying mechanisms, theories, applications, and comparison of thin-layer drying models of mushroom available in the literature.

I. MATERIALS AND METHODS

Experiments were conducted to study the effect of various pretreatment and drying methods viz. Sun drying, poly house drying, tray drying and vacuum drying on drying kinetics of oyster mushrooms (*Pleurotus flabellatus*). The mushrooms used for present study were produced in the Department of Post Harvest Engineering & Technology, Faculty of Agricultural Sciences, AMU Aligarh. All drying experiments were conducted on freshly harvested mushrooms.

Sample preparation: Freshly harvested oyster mushrooms (*P. flabellatus*) of uniform shape and size and free from blemishes were sorted out and thoroughly washed under the running tap water to remove adhering soil particles and other impurities. After removing surface moisture, they were trimmed and sliced into small pieces

Pretreatments: Sliced oyster mushrooms were subjected to four pretreatments prior to dehydration as mentioned below:

- **Control (P1)**: Freshly harvested mushrooms were thoroughly washed under the running tap water.
- **Blanching (P2)**: Samples were immersed in boiling water at 100^0C for 4 min, cooled immediately in cold water at room temperature and drained.
- **Steeping (P3):** Samples were soaked in the solution of KMS (0.50%) plus Citric acid (0.25%) for 30 min and drained.
- **Blanching and steeping (P4)**: Blanched samples as per process mentioned above were immersed in KMS (0.50%) plus Citric acid (0.25%) solution for 30 min and drained.

Initial moisture content: Initial moisture content of mushroom samples was determined by hot air oven drying method as recommended by Ranganna (1994).

Moisture ratio: Moisture ratio of mushroom samples during drying period was calculated using the following equation:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad \text{----- (1)}$$

where M_t, M_e, and M_0 are moisture content at any time, equilibrium moisture content, and initial moisture content, respectively. In this method, samples were placed in an environment maintaining relative humidity and temperature constant. When the change in the weight of samples was insignificant, the moisture of the samples was measured and adopted as the equilibrium moisture content (M_e). In order to low humidity in ambient (dry and hot weather), equilibrium moisture content is negligible and

$$MR = \frac{M_t}{M_0} \quad \text{--------- (2)}$$

... (1) Where, M.R =Moisture ratio, dimensionless, M =Moisture content at any time t, %, and Mo, Me =Initial and equilibrium moisture content on dry basis, respectively, %.

Mathematical Modelling of Drying Characteristics: The heated-air drying of biological materials in the falling rate period is a diffusion-controlled process and may be represented by Fick's second law of diffusion. Various types of mathematical models have been used to describe the drying of foodstuffs, ranging from theoretical models based on classical diffusion theory to purely empirical models (Pabis, 1999). Drying kinetics models does not take into account the effects of interactions by parameters other than the time of drying. Drying constant can be obtained from thin layer drying equation already developed and drying rate constant is a function of drying temperature (Bala, 2016). Henderson & Pabis model (Eq. 3), firstly used drying of corn is the first term of general series solution to Fick's law (Inyang et al., 2018). For simple case, it is used to calculate the drying constant for mushroom drying kinetics is as

$$\frac{M - M_e}{M_0 - M_e} = ae^{-kt} \quad \text{----------------- (3)}$$

Which can be written as

$$ln\left(\frac{M-M_e}{M_0-M_e}\right) = \ln a - kt \quad \text{---------- (4)}$$

Or

$$ln\left(\frac{M}{M_0}\right) = \ln a - kt \quad \text{----------- (5)}$$

This is compared with $y = mx + c$ ------------ (6)

$$y = ln\left(\frac{M - M_e}{M_0 - M_e}\right)\ or\ ln\left(\frac{M}{M_0}\right)$$

$x = t$

$m = -k$

$c = ln\ a$

when the equation (3) is plotted on a semi log paper, it will give a straight line. From fig k can be determined graphically by drawing straight line and determining slope of the straight line.

The concept of thin-layer drying models for characterizing the drying behaviour was suggested, initially, by Lewis (1921) who derived the semi-theoretical model (Eq. 7) for porous hygroscopic materials, which is analogous with Newton's law of cooling. The following model was developed and used for drying kinetics of mushroom.

$$\frac{M_t-M_e}{M_0-M_e} = \exp(-kt) \quad \text{------- (7)}$$

where MR is moisture ratio, k is drying constant (m^{-1}), t is drying time, M_t, M_e, M_o is moisture content at any time, equilibrium and initial, respectively. The semi-logarithmic plot of moisture ratio and drying time represent a straight line for Newton (Lewis) model. Page [11] modified the Lewis model by adding a dimensionless empirical constant (n) and used it for study the drying behaviour of shelled corns. For this model a log-log graph used to obtain a straight line with a positive slop in case of drying of mushroom. One equation that has been used successfully to describe drying behaviour of a variety of biological materials (Jayas and Sokhansanj, 1989; ASAE Standards, 1989; Tan et al., 2001; Arora et al., 2003; Addo et al., 2009) is Page's equation (Page, 1949):

$$\frac{M_t-M_e}{M_0-M_e} = \exp(-kt^n) \quad \text{------- (8)}$$

Since the values of the equilibrium moisture content, Me, are relatively small compared to M_t or M_o, equation (7) can be simplified to equation (8) (Thakor et al., 1999):

$$MR = \frac{M_t}{M_0} = \exp(-kt^n) \text{ ---------(9)}$$

To determine the constant k and n, from equation (9) can be expressed in the linear form as follows:

$$\ln[-\ln(MR)] = \ln(k) + n\ln(t) \quad \text{---------- (10)}$$

Peleg (1988) proposed a two parameters sorption equation and tested its prediction accuracy during water vapour absorption of milk powder and whole rice and soaking of whole rice. This equation has since been known as Peleg model (Eq. 11)

$$M = M_0 \pm \frac{t}{K_1+K_2t} \quad \text{-- (11)}$$

Where M is moisture content (db %) at time (t), M_0 is Initial moisture content (db %), K_1 is the Peleg rate constant (h db%$^{-}$), and K_2 is the Peleg capacity constant (db %$^{-1}$). In equation (11), "±" becomes "+" if the process is absorption or adsorption and "-" if the process is drying or desorption.
This equation is usually written in rather simple way for water absorption to test its ability to fit experimental curve (Eq. 12):

$$\frac{t}{M_0-M} = K_1 + K_2t \text{ ---------(12)}$$

According to Eq. (12), a plot of $\frac{t}{M_0-M}$ against drying time (h) gives a straight line, where K_1 is the intercept on the ordinate and K_2 is the slope of the line. The values of K_1 and K_2 were calculated by linear regression by using MS Excel software. The Peleg model has been used to describe the desorption processes in various foods.

II. Results and Discussion

Drying behaviour of oyster mushroom

Drying behaviour of oyster mushroom (*Pleurotus flabellatus*) samples under different drying methods with different pretreatments are reported in Table (1-4). Mushroom samples dried by sun, poly house, tray and vacuum drying methods. The initial moisture content of oyster mushroom (*P.*

flabellatus) was observed 91±1 percent (wb). As reported in literature, generally the values of dry weight basis moisture content are used for drying experiment purpose. Therefore, moisture content (wb) was converted into dry weight basis and found to be 1011 %. Drying behaviour of oyster mushroom in shown in Table 1-4. It is explicit that moisture content decreased rapidly with increase in drying time at the initial stage. This was, probably, due to the fact that during the initial stage of drying, there was fast removal of surface moisture from the product. Results revealed that the moisture content decreased sharply with increase of dehydration time and it is clearly state that moisture loss substantially depending up on the drying methods and pretreatments. Blanching attributed little bit lower moisture loss than those of other pretreatments during drying. Steeping pretreatment had higher moisture loss than other pretreatments except control sample.

Moisture content of mushroom samples decreased rapidly during the initial stage of drying as compared to latter parts. In case of all drying methods, untreated mushroom samples took minimum time when compared with pretreatments. However, it was noted that blanched plus steeped samples took maximum time to achieve the final moisture content. Maximum moisture loss was obtained in untreated (*control*) and minimum in blanched samples due to hard texture of mushroom by blanching pretreatment in hot water at 100^0C for 4 minutes. It was observed that the difference in moisture loss may be attributed to the various pretreatments. Moisture loss in vacuum drying was lower than those of other drying methods. Maximum moisture loss was obtained in untreated (*control*) samples and minimum in blanched samples. It may be because of hard texture of mushrooms due to blanching treatment. In general, it was observed that texture of mushroom samples became harder after blanching (Table 1-4).

Drying rate of oyster mushroom (*Pleurotus flabellatus*) samples under different drying methods with different pretreatments are reported in Table (1-4). Mushroom samples dried by sun, poly house, tray and vacuum drying methods did not follow constant rate period during drying. Tray dried mushroom samples exhibited higher drying rate until final stage of drying followed by poly house drying, sun drying and vacuum drying irrespective of pretreatments. Untreated mushroom samples had higher drying rate as compared to those of pretreated samples in case of all drying methods. The entire drying took place under falling rate period. Results revealed that initially drying rate increased and then decreased gradually with dehydration time irrespective of drying methods and pretreatments. Vacuum dried mushroom samples exhibited lowest drying rate irrespective of pretreatments. The results agree with the earlier observations of Apati (2010) and Tulek (2011) for oyster mushroom. The drying rate was observed lower in pretreated mushroom. It may be due to diffusion of water into mushroom during pretreatments and it increased amount free water into the mushroom. This shows that diffusion is the dominant physical mechanism for moisture movement in the mushroom (Gupta et al., 2022). It had taken more drying time as compared to untreated mushroom to accomplish the drying process. The study revealed that the pretreatments increased the water removal process from the mushroom during drying. As per this study, effect of the drying methods on drying rate of mushroom was more as compared pretreatments.

Mathematical models for predicting drying kinetics of oyster mushroom

Newton & Lewis's model, Page's model, Peleg's model and Henderson & Pabis's models were fitted to experimental data in their linearized forms using regression techniques as well as MS Excel to determine the constant of the models. In order to select the model which had better prediction and coefficient of determination (R^2) were considered.

Newton & Lewis's model: The drying constant 'k' of Newton & Lewis model / equation ($MR = e^{-kt}$) was obtained from the relationship of moisture ratio and drying time (Fig. 1 to Fig. 4) The semi-logarithmic plot between moisture ratio and drying time represented nearly by a straight line. The drying constants determined for all experiments conducted are shown in Table 5. The value of constant 'k' was ranged for SD (0.0628-0.0709), PD (0.0810-0.0846), TD (0.1620-0.1667) and VD (0.9303-0.9482). The value of coefficient of determination (R^2) were estimated graphically for SD (0.8496-0.8713), PD (0.8598-0.8880), TD (0.9193-0.9734) and VD (0.9303-0.9482). The range of R^2 were estimated for tray dried mushroom (Table 5). From Table 5, it revealed that Newton & Lewis model was found fit for tray drying of mushroom on basis of highest range of R^2. Among the pretreatments, Highest value of R^2 was found 0.9734 for blanched tray dried mushroom while lowest 0.8496 for untreated sun-dried mushroom samples. Although Newton & Lewis model is simple but the only drawback associated with this model is that it over predicts the early stages and under predicts the later stages of drying (Kashaninejad et al., 2007; Kumar et al., 2021).

Page's Model: Drying and statistical parameters obtained from page models (MR = e^{-kt}) is shown in Table 5. This model is two constant empirical modification of Newton's exponent model (Kumar et al., 2021). The range of drying constant 'k' was observed for SD (0.363-0.808), PD (0.395-0.473), TD (0.416-0.744) and VD (0.274-0.290) while value of constant 'n' varied for SD (0.4344-0.9112), PD (0.8244-0.8865), TD (1.0485-1.2216) and VD (0.8591-0.9227). The statistical parameter Coefficient of determination (R^2) were calculated for SD (0.8270-0.8535), PD (0.7870-0.8121), TD (0.8475-0.9047) and VD (0.7128-0.7553). The variation in experimental and prediction moisture ratio of mushroom with different drying methods under page's model is graphical presented in Fig. 5-8. The Page model was fitted with the experimental data in the form of changes in moisture content versus drying time, which were calculated using Excel software. The closeness of the plotted data to the straight-line representing equality between the experimental and predicted values illustrates the suitability of the model for describing the drying behavior of mushroom across different drying methods. The model provided a very good conformity between the experimental data and the predicted moisture ratios of mushrooms. It has been observed that the predicted data are banded around the ideal trend line indicating the suitability of the model in predicting the drying behaviour of mushrooms. Similar trends reported in red chillies (Najla and Bawatharani, 2019).

Peleg's Model: The drying constant i.e. Peleg's rate constant (K_1) and capacity constant (K_2) of mushroom determined by the equation [(t/ Mo-M) = K_1+K_2t] for different drying methods are presented in Table 1. The graphical plot is drawn between (t/M-Mo) and soaking time (t) showed in Fig. 9-12. It gives a straight line where K_1 is the intercept on the ordinate and K_2 is the slope of the line. The value of Peleg's rate constant (K_1) varied for SD (0.0024-0.0026), PD (0.0018-0.0024), TD (0.0017-0.0029) and VD (0.0042-0.0045) while capacity constant (K_2) varied from SD (0.0008), PD (0.0008-0.0009), TD (0.0005-0.0008) and VD (0.0007). The coefficient of determination (R^2) ranged between for SD (0.9340-0.9549), PD (0.8913-0.9343), TD (0.7344-0.9959) and VD (0.7879-0.8650) indicating fit of experimental data to Peleg's model at different drying methods. For the four drying methods tested, the constant K_1 shown tendency to invariable while K_2 near to constant with each pretreatment among the drying methods. In this study, it was found K_1 values were decreased with increasing drying time among the drying methods. It was also noticed that vacuum drying took more time to dry the mushroom as compared to other methods in the present study, it estimated higher value of K_1 while tray dried mushroom showed lower value of K_1 with lower drying time. Peleg's equation successfully represented the drying behavior of mushroom by different methods and could be used to estimate the moisture content at given drying time and pretreatments within the experimental condition considered. K_1 is a constant related to mass transfer rate and lowest average value K_1 is observed for tray dried mushroom while highest average for vacuum dried samples (Table 5). Pretreatments of mushroom had invariable effects on K_1. The constant K_2 indicated near to constant among pretreatments and drying methods. The constant K_2 is a constant related to drying rate i.e. the higher the K_2, the higher the drying rate. As per literature, Peleg model is applicably fit for hydration kinetics of grains.

Henderson & Pabis Model: The drying constant calculated by Henderson & Pabis's model (MR = a e^{-kt}) is depicted in Table 5 and graphical description in Fig. 13-16.

Table 1: Effect of pretreatments on moisture content and drying rate of sun-dried mushrooms

Time, h	Moisture content, % (db)				Drying rate (g H_2O removed/h/g bone dry wt.)			
	SDP1	SDP2	SDP3	SDP4	SDP1	SDP2	SDP3	SDP4
0	1011	1003	1015	1007	0.000	0.000	0.000	0.000
1	785	759	789	778	2.259	2.519	2.222	2.333
2	589	596	622	604	1.963	1.630	1.667	1.741
3	452	470	485	478	1.370	1.259	1.370	1.259
4	348	374	370	378	1.037	0.963	1.148	1.000
5	274	293	285	285	0.741	0.815	0.852	0.926
6	204	222	215	215	0.704	0.704	0.704	0.704
7	152	174	163	159	0.519	0.481	0.519	0.556
8	107	126	111	111	0.444	0.481	0.519	0.481
9	70	85	74	74	0.370	0.407	0.370	0.370
10	37	52	44	48	0.333	0.333	0.296	0.259
11	26	22	18	22	0.111	0.296	0.259	0.259
12	11	15	15	15	0.148	0.074	0.037	0.074
13		13	11	14		0.037	0.037	0.037

Table 2: Effect of pretreatments on moisture content & drying rate of Poly house dried mushrooms

Time, h	Moisture content, % (db)				Drying rate (g H_2O removed/h/g bone dry wt.)			
	PDP1	PDP2	PDP3	PDP4	PDP1	PDP2	PDP3	PDP4
0	1011	1003	1015	1007	0.000	0.000	0.000	0.000
1	715	752	781	737	2.963	2.593	2.296	2.741
2	533	567	600	567	1.815	1.852	1.815	1.704
3	404	433	456	433	1.296	1.333	1.444	1.333
4	296	330	341	330	1.074	1.037	1.148	1.037
5	218	252	244	241	0.778	0.778	0.963	0.889
6	156	193	174	178	0.630	0.593	0.704	0.630
7	100	141	122	122	0.556	0.519	0.519	0.556
8	55	96	78	78	0.444	0.444	0.444	0.444
9	11	63	40	41	0.444	0.333	0.370	0.370
10		33	11	11		0.296	0.296	0.296
11		11				0.222		

Table 3: Effect of pretreatments on moisture content and drying rate of Tray dried mushrooms

Time, h	Moisture content, % (db)				Drying rate (g H_2O removed/h/g bone dry wt.)			
	TDP1	TDP2	TDP3	TDP4	TDP1	TDP2	TDP3	TDP4
0	1011	1003	1015	1007	0.000	0.000	0.000	0.000
0.5	844	841	811	844	1.704	1.704	2.000	1.667
1.0	683	711	678	685	1.593	1.296	1.333	1.593
1.5	540	596	567	563	1.407	1.148	1.111	1.222
2.0	414	496	470	456	1.259	1.000	0.963	1.074
2.5	305	404	381	363	1.111	0.926	0.889	0.926
3.0	215	326	300	281	0.889	0.778	0.815	0.815
3.5	140	252	226	207	0.741	0.741	0.741	0.741
4.0	80	185	163	144	0.593	0.667	0.630	0.630
4.5	40	126	104	96	0.407	0.593	0.593	0.481
5.0	11	67	52	55	0.296	0.593	0.519	0.407
5.5		11	11	31		0.556	0.407	0.370
6.0				18				0.074

Table 4: Effect of pretreatments on moisture content and drying rate of vacuum dried mushrooms

Time, h	Moisture content, % (db)				Drying rate (g H_2O removed/h/g bone dry wt.)			
	VDP1	VDP2	VDP3	VDP4	VDP1	VDP2	VDP3	VDP4
0	1011	1003	1015	1007	0.000	0.000	0.000	0.000
1	852	841	856	863	1.593	1.704	1.556	1.481
2	722	715	722	733	1.296	1.259	1.333	1.296
3	604	607	604	615	1.185	1.074	1.185	1.185
4	500	518	507	511	1.037	0.889	0.963	1.037
5	404	433	418	422	0.963	0.852	0.889	0.889
6	330	359	344	344	0.741	0.741	0.741	0.778
7	263	296	281	274	0.667	0.630	0.630	0.704
8	200	233	222	215	0.630	0.630	0.593	0.593
9	144	181	178	163	0.556	0.519	0.444	0.519
10	96	130	137	118	0.481	0.519	0.407	0.444
11	52	85	100	81	0.444	0.444	0.370	0.370
12	11	44	67	52	0.407	0.407	0.333	0.296
13		11	37	26		0.333	0.296	0.259
14			11	11			0.259	0.148

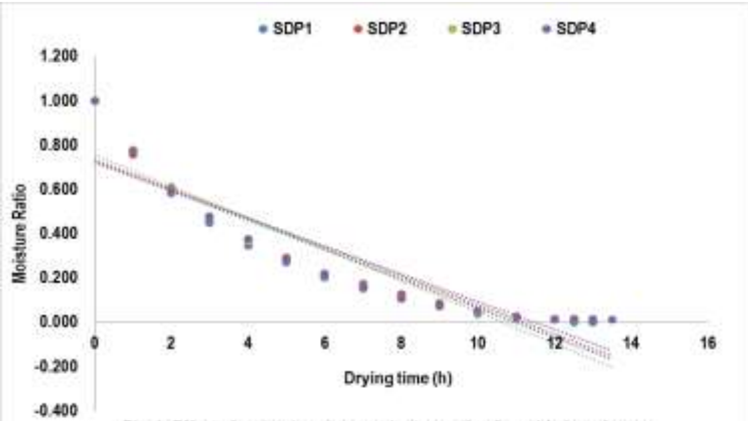

Fig. 1: Effect of pretreatments on moiusture ratio of sundried mushroom (Lewis Model)

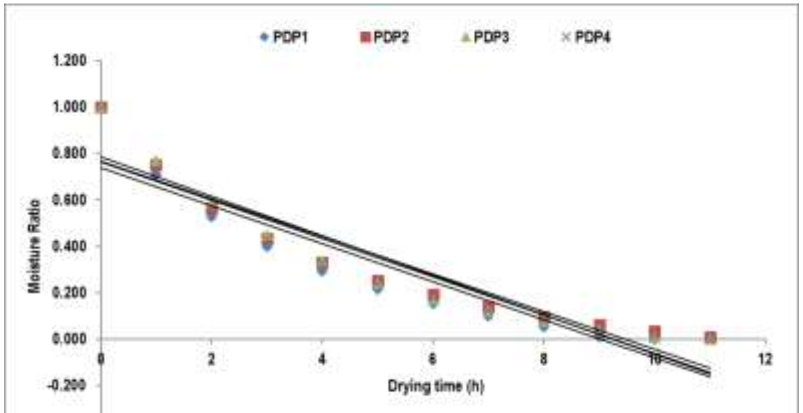

Fig. 2: Effect of pretreatments on moiusture ratio of Poly house dried mushroom (Lewis Model)

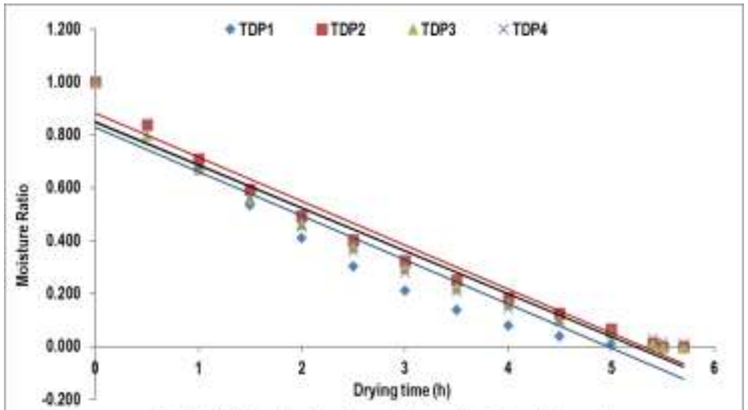

Fig. 3: Effect of pretreatments on moiusture ratio of Tray dried mushroom (Lewis Model)

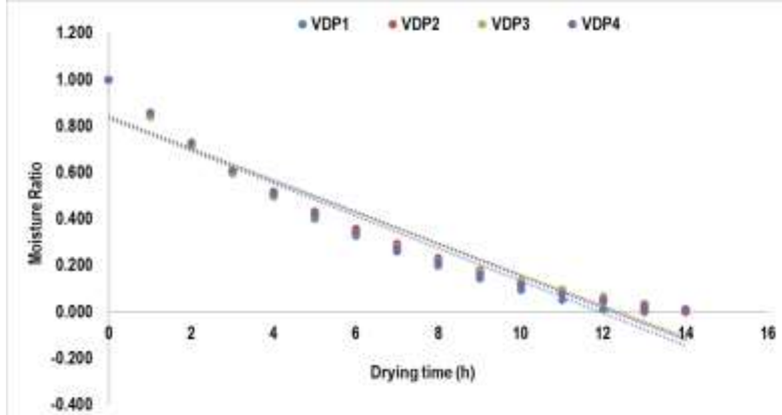

Fig. 4: Effect of pretreatments on moiusture ratio of Vacuum dried mushroom (Lewis Model)

Table 5: Model's constant of pretreated and dried mushroom with different drying methods

Drying methods	Treatments	Newton & Lewis's model [MR = exp (-kt)]		Page's model [MR = exp (-kt^n)]			Peleg's Model [(t/Mo-M) = K_1+K_2t]			Pabis' s model [MR = a exp (-kt)]		
		k	R^2	k	n	R^2	k_1	k_2	R^2	k	a	R^2
Sun drying (SD)	SDP1	0.0660	0.8496	0.808	0.4344	0.830	0.0024	0.0008	0.9340	-0.3504	1.3053	0.9667
	SDP2	0.0656	0.8667	0.377	0.8791	0.8368	0.0025	0.0008	0.9525	-0.3526	1.4028	0.9659
	SDP3	0.0709	0.8713	0.363	0.9015	0.8270	0.0026	0.0008	0.9352	-0.3610	1.4074	0.9671
	SDP4	0.0628	0.8497	0.363	0.9112	0.8535	0.0026	0.0008	0.9549	-0.3526	1.3732	0.9805
Poly house drying (PD)	PDP1	0.0816	0.8598	0.473	0.8244	0.7914	0.0018	0.0009	0.9216	-0.4253	1.3305	0.9051
	PDP2	0.0810	0.8780	0.420	0.8355	0.8121	0.0022	0.0008	0.9343	-0.3619	1.2887	0.9455
	PDP3	0.0846	0.8880	0.395	0.8865	0.7870	0.0024	0.0008	0.8913	-0.3995	1.3947	0.9317
	PDP4	0.0825	0.8817	0.434	0.8379	0.7958	0.0021	0.0008	0.9206	-0.3931	1.3407	0.9281
Tray Drying (TD)	TDP1	0.1667	0.9193	0.470	1.2216	0.9041	0.0017	0.0007	0.7344	-0.8107	1.6030	0.9115
	TDP2	0.1664	0.9734	0.416	1.0973	0.8475	0.0029	0.0005	0.9959	-0.6486	1.5420	0.8208
	TDP3	0.1620	0.9601	0.744	1.0485	0.8638	0.0017	0.0008	0.8261	-0.6749	1.5069	0.8536
	TDP4	0.1623	0.9465	0.439	1.1648	0.9047	0.0019	0.0007	0.8262	-0.7219	1.6251	0.9161
Vacuum Drying (VD)	VDP1	0.0700	0.9328	0.277	0.8868	0.7128	0.0042	0.0007	0.7879	-0.3063	1.5110	0.8698
	VDP2	0.0685	0.9482	0.275	0.8591	0.7171	0.0044	0.0007	0.8246	-0.2822	1.4906	0.8737
	VDP3	0.0667	0.9303	0.274	0.8705	0.7526	0.0042	0.0007	0.8650	-0.2703	1.4203	0.9114
	VDP4	0.0687	0.9333	0.290	0.9227	0.7553	0.0045	0.0007	0.8288	-0.2884	1.0572	0.9291

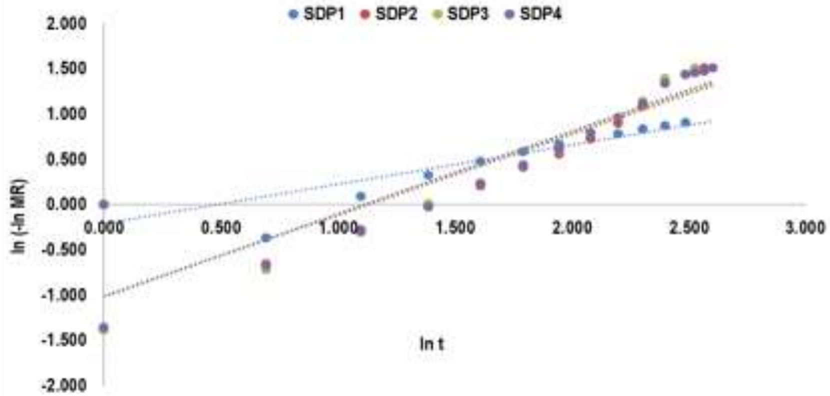

Fig. 5. Relationship between moisture ratio and drying time of sun dried oyster mushroom (Page's model)

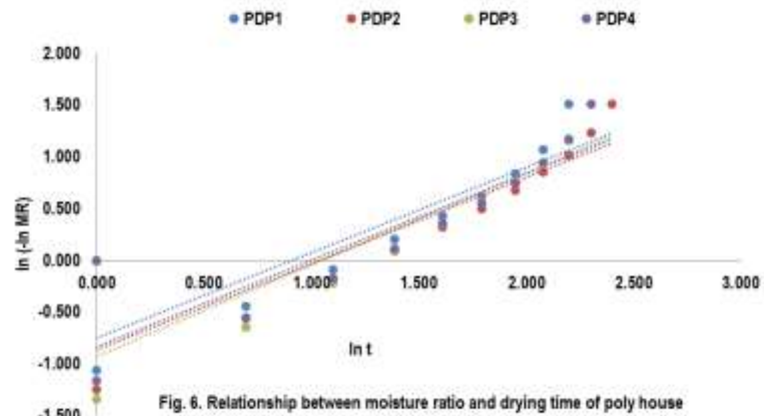

Fig. 6. Relationship between moisture ratio and drying time of poly house dried oyster mushroom (Page's model)

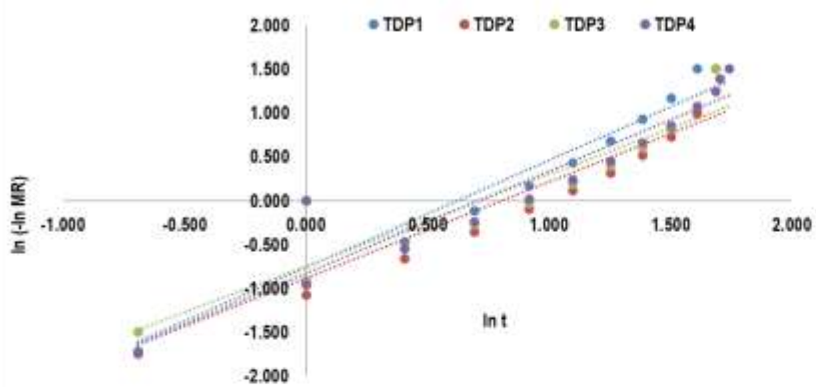

Fig. 7. Relationship between moisture ratio and drying time of tray dried oyster mushroom (Page's model)

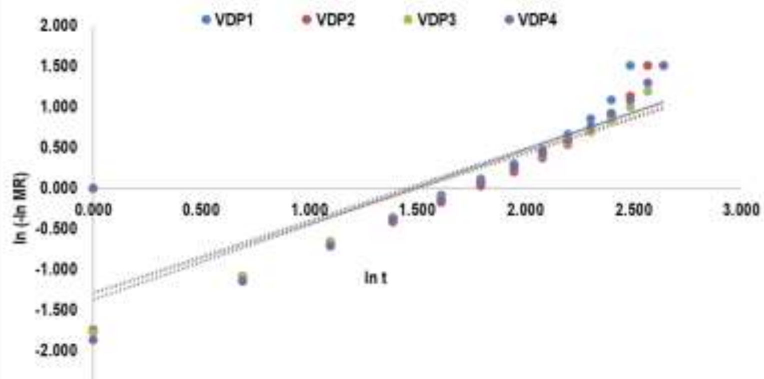

Fig. 8. Relationship between moisture ratio and drying time of vacuum dried oyster mushroom (Page's model)

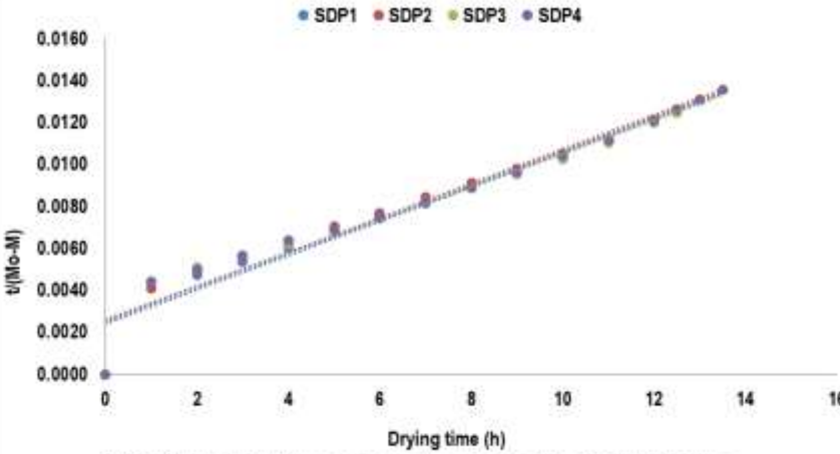

Fig. 9. Relationship between moisture ratio and drying time of sun dried oyster mushroom (Peleg's model)

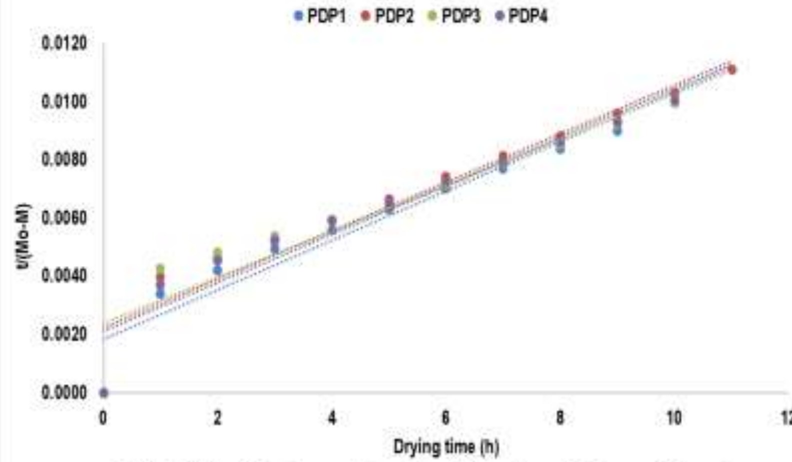

Fig. 10. Relationship between moisture ratio and drying time of poly house dried oyster mushroom (Peleg's model)

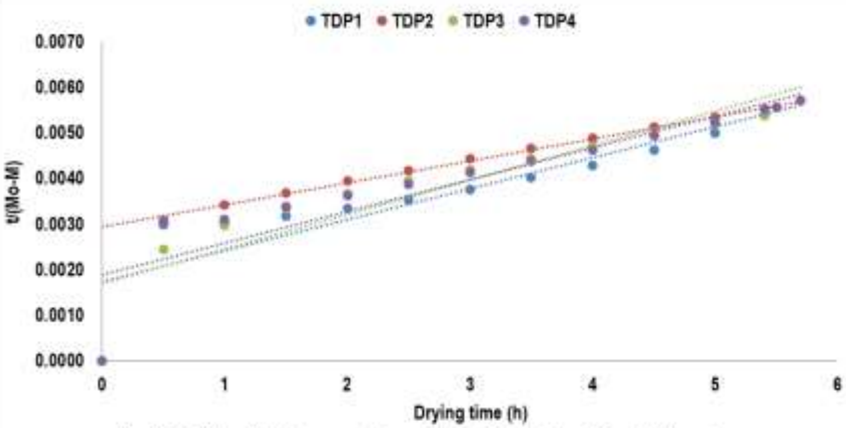

Fig. 11. Relationship between moisture ratio and drying time of tray dried oyster mushroom (Peleg's model)

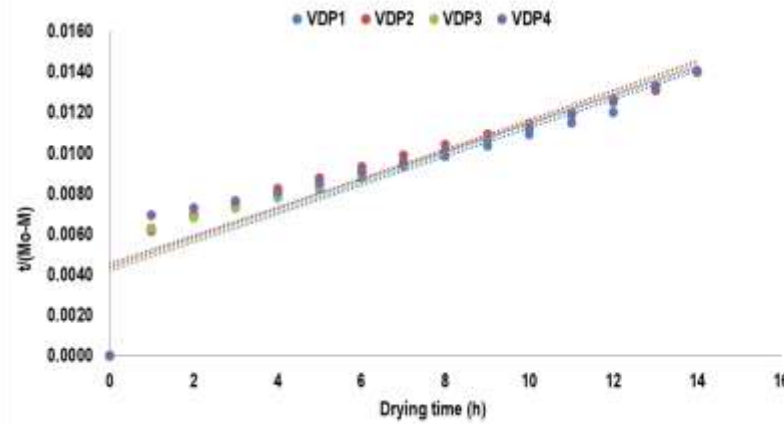

Fig. 12. Relationship between moisture ratio and drying time of vacuum dried oyster mushroom (Peleg's model)

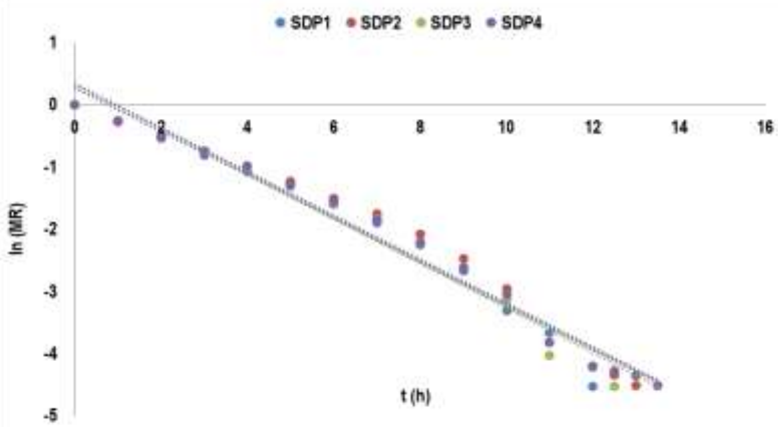

Fig. 13. Relationship between moisture ratio and drying time of sun dried oyster mushroom (Pabis's model)

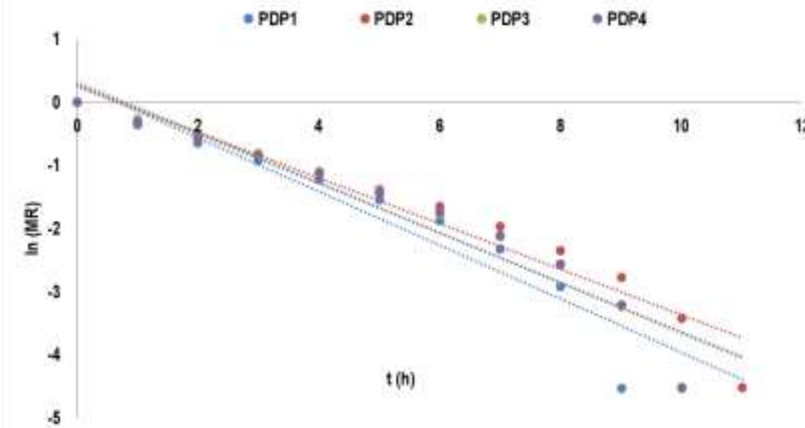

Fig. 14. Relationship between moisture ratio and drying time of poly house dried oyster mushroom (Pabis's model)

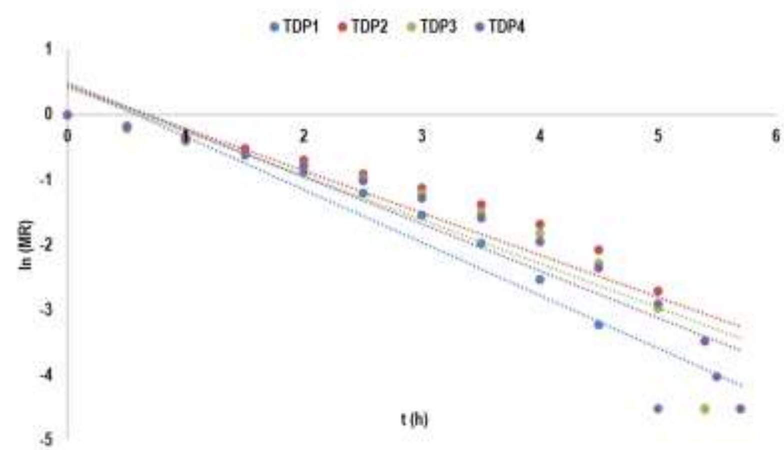

Fig. 15. Relationship between moisture ratio and drying time of tray dried oyster mushroom (Pabis's model)

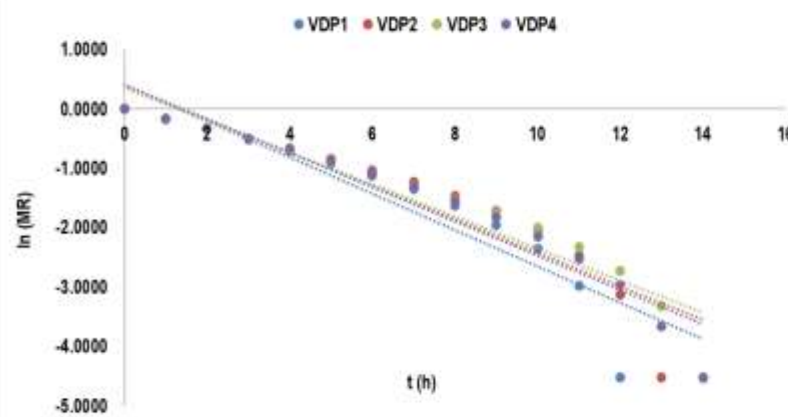

Fig. 16. Relationship between moisture ratio and drying time of vacuum dried oyster mushroom (Pabis's model)

The value of constant 'k' varied for SD (-0.3504 to -0.3610), PD (-0.3931 to -0.4253), TD (-0.6486 to -0.8107) and VD (-0.2703 to -0.3063) whereas range of constant 'a' varied for SD (1.3053-1.4074), PD (1.2887-1.3947), TD (1.5069-1.6251) and VD (1.0572-1.5110). The values of statistics parameter R^2 were found for SD (0.9659-0.9805), PD (0.9051-0.9455), TD (0.8208-0.9161) and VD (0.8698-0.9291). From table 5, it is explicit that the highest score of constants was found -0.2703 for blanched plus steeped vacuum dried mushroom and lowest -0.8107 for untreated tray dried mushrooms. The slope of this model (k) is related to effective diffusivity that controls the process (Kashaninejad et al., 2007). The graphical representation of Henderson & Pabis's model for drying of mushroom is shown in Fig. 13-16.

Model curve fitting

The moisture ratio of mushroom dried by different drying methods, were fitted with four drying models to identify their suitability to describe the drying behavior. The accuracy of the established model for the convective drying process was evaluated by comparing the predicted moisture ratio with observed moisture ratio. The coefficient of determination (R^2), and different model coefficients values are found from nonlinear regression modelling analysis are given in table 5. The best-fitted model to describe the drying kinetics of mushroom was identified in accordance with the highest value of R^2. From the model analysis results, it was found that that the Henderson and Pabis gave suitable fit for sun drying (average R^2 = 0.9700) and poly house drying (average R^2 = 0.9361) while Lewis model good fit for tray drying (average R^2 =0.9498) and vacuum drying (average R^2 =0.9361). It identified as best suitable model to expressed the drying behavior of mushroom. The actual and predicted graph of best fitted model has been shown in Fig.1-16.

III Conclusion

The oyster mushroom (Pleurotus flabellatus) was dried by sun, poly house, dtar and vacuum drying methods. The drying kinetics and moisture ratio affected by types of drying methods. The Henderson and Pabis model was identified as best suitable model with higher coefficient of determination (R2) to describe the drying kinetics of mushroom during drying progression in sun and poly house drying methods. Furthermost the result concluded that the mushroom can be dried effectively by sun and poly house to achieve bone dry in natural during condition for shorter period of time.

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