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Research Note

Kinetics of Thin Layer Drying of Button Mushroom

G.C. Wakchaure[1], K. Manikandan[1], Indra Mani[2] and Mahantesh Shirur[1]

ABSTRACT

Drying kinetics of white button mushroom (*Agaricus bisporus*) slices in a fluidized bed dryer at three different drying air temperatures of 45, 55 and 65°C with constant drying air velocity of 2.5 $m.s^{-1}$ was studied. The drying of mushroom slices occurred in the falling rate period. Seven thin-layer drying models, commonly used for perishable fruits/vegetables, were tested for the drying behaviour of mushroom slices. The logarithmic model fitted best to moisture ratio data with higher R^2 and least c^2, *MBE, RMSE* values. The effective moisture diffusivity in white button mushroom increased from 9.21×10^{-8} to 1.49×10^{-7} $m^2.s^{-1}$ with increasing drying air temperatures in the fluidized bed dryer. The average activation energy of 36.39 $kJ.mol^{-1}$ was required for detaching the water molecules from mushroom slices during fluidized bed drying.

White button mushroom (*Agaricus bisporus*), oyster mushroom (*Pleurotus* spp.), milky mushroom (*Calocybe indica*) and paddy straw mushroom (*Volvariella volvacea*) are the major species of mushrooms grown in India. Of these, white button mushroom is more popular and contributes about 85% of the total mushroom production. Mushrooms are highly perishable in nature, with extremely short shelf life as they contain moisture in the range of about 87 to 93% (wb) (Arumuganathan *et al.,* 2004). Hence, their processing to get stable products is important. Long-term preservation methods like canning and drying are most commonly used in preservation of mushrooms to make the product available round the year.

Drying reduces the bulk volume and facilitates handling, transportation and storage. Drying of button mushroom can be done by different methods viz., sun, tray, cabinet, fluidized/spouted bed and freeze drying.

Mushrooms need to be dried to 4-8% moisture level for safe storage (Komanowasky *et al.,* 1970). Wide temperature range of 37.8-70°C with finishing temperature up to 82.2°C was reported for mushroom drying. However, mushrooms are dried for commercial purpose after blanching for 2-5 minutes to a moisture level of 5% at temperature less than 65.5°C (Luh and Woodroof, 1975). Dehydrated mushrooms are used as ingredient in several food formulations like soup powder, pasta salads, snack seasonings, stuffing, casseroles, meat and rice dishes (Tuley, 1996).

The drying kinetics of food is a complex heat and mass transfer phenomenon, and requires simple presentation to predict the drying behaviour to optimize the drying parameters. The thin layer drying equations were used for prediction and generalization of drying curves (Karathanos and Belessisotis, 1999).

Limited research is reported on different drying characteristics of mushrooms (Pruthi *et al.,* 1978; Deshpande and Tamhane, 1981; Nehru *et al.,* 1995; Suguna *et al.,* 1995). The present study was undertaken on white button mushroom to study the drying kinetics in thin layer, evaluate drying models, and determine effective moisture diffusivity and activation energy during drying.

MATERIALS AND METHODS

Freshly harvested white button mushroom (*Agaricus bisporus*) of uniform maturity were collected from the Directorate of Mushroom Research, Solan and washed with clean water at room temperature (27±1°C) to remove dirt (soil and compost). About 400 g of cleaned white button mushroom sample of cap diameter 35-40 mm without stipe was taken, cut into 10±1 mm thick slices by using a sharp stainless steel knife, and dried on the same day in a fluidized bed dryer (Model: Retsch, TG 100) at constant velocity of 2.5 $m.s^{-1}$ and three different drying temperatures of 45, 55 and 65±1°C separately by uniformly spreading the slices in thin layer of 4-6 cm over perforated stainless steel grit. The diameter and cross section area of sample holding surface in the dryer was 20 cm and 314.28 cm^2, respectively. The terminal velocity of fresh sliced mushroom of size 10±1mm was found to be 2.0 $m.s^{-1}$. Thus, slightly higher air velocity of 2.5 $m.s^{-1}$ was selected for thin layer drying

[1]Scientist, Directorate of Mushroom Research, Chambaghat, Solan-173 213 (H.P.), [2]Senior Scientist, Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi-110 012, Email: goraksha_wakchaure@yahoo.com, Fax: 01792 - 231207

of button mushroom. Moisture loss was recorded at 30 minutes intervals by digital balance of 0.01 g accuracy (D'Arts-DG 25, India). The drying of slices continued up to 7% moisture content for better quality and long-term (more than 1 year) storage. The relative humidity of drying air was not regulated and ranged from 16 to 50 per cent. The moisture content of button mushroom was measured by the AOAC Method No. 934.06 (AOAC, 2000). The physical parameters such as weight loss and bulk density of mushroom slices were measured by using standard methods. The experiment was replicated thrice, and data was analyzed using SATISTICA (Version 6) software package.

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

$$M.R. = \frac{M - Me}{Mo - Me} \qquad \ldots (1)$$

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, %.

The temperature and relative humidity of the moving air passing through the samples was not uniform and hence simple and modified equation of moisture ratio for thin bed fluidized drying given by Pala *et al.*, (1996) and Doymaz (2004) was used for the present study;

$$M.R. = \frac{M}{Mo} \qquad \ldots (2)$$

Different thin layer drying equations, commonly used for drying of highly perishable fruits/vegetables (Table 1), were used to identify suitable drying model to get drying curve, which described drying behaviour in thin layer drying of white button mushroom. The moisture ratio data was fitted in different drying models.

The coefficient of correlation, R^2 was used as one of the main criteria for selecting the best model. In addition, the goodness of fit was determined by various statistical parameters such as reduced Chi-Square (ψ^2), Mean Bias Error (*MBE*) and Root Mean Square Error (*RMSE*) values. For quality fit, R^2 value should be higher and *MBE* and *RMSE* values should be lower. These parameters were calculated by using the following equations;

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(MR_{\exp} - MR_{pre}) \qquad \ldots (3)$$

$$RMSE = [\frac{1}{N}\sum_{i=1}^{N}(MR_{\exp} - MR_{pre})^2]^{½} \qquad \ldots (4)$$

$$\Psi^2 = \frac{\sum_{i=1}^{N} MR_{\exp} - MR_{pre})^2}{N - z} \qquad \ldots (5)$$

Where,

ψ = Reduced chisquare,

MR_{exp} = Experimental moisture ratio,

MR_{pre} = Predicted moisture ratio,

N = Number of observations, and

z = Number of drying constants.

Fick's diffusion equation for particles with slab geometry was used for calculation of effective moisture diffusivity. Since the mushrooms were dried after slicing, the samples were considered to be of slab geometry. The equation is expressed as (Maskan *et al.,* 2002):

Table 1. Thin layer drying models for highly perishable commodities

Equation	Model	Reference
MR= a exp (-kt)	Handerson and Pabis	Henderson and Pabis (1961)
MR= exp (-kt)	Newton	O' Callaghan *et al.* (1971),
		Liu and Bakker-Arkema (1997)
MR= exp (-kt^n)	Page	Zhang and Litchfield (1991)
MR=1+at+bt^2	Wang and Singh	Wang and Singh (1978)
MR=a exp (-k_0t)+b exp (-k_1t)	Two Term	Henderson (1974)
MR= a exp (-kt)+(1-a) exp (-kat)	Two term exponential	Sharaf-Eldeen *et al*, (1980)
MR= a exp (-kt)+c	Logarithmic	Yaldiz *et al.* (2001)

Note: a, b, c, k, k_0, k_1, n are drying constants

$$MR = \frac{8}{\pi^2}\exp\left(\frac{-\pi^2 D_{eff}.t}{L^2}\right) \quad \ldots (6)$$

Where,

D_{eff} = Effective moisture diffusivity, $m^2.s^{-1}$,

T = Time of drying, s, and

L = Slab thickness, m.

The linear solution of the equation is obtained by taking the natural logarithm of both sides. This shows that the time to attain given moisture content will be directly proportional to the square of the thickness and inversely proportional to D_{eff}:

$$lnMR = ln\frac{8}{\pi^2} - ln\frac{\pi^2 D_{eff}.t}{L^2} \quad \ldots (7)$$

The diffusion coefficient was calculated by using the slope of equation, namely, when natural logarithm of MR versus time was plotted, a straight line with a slope k was obtained.

$$k = \frac{\pi^2 D_{eff}.t}{L^2} \quad \ldots (8)$$

The activation energy can be termed as the minimum energy that must be supplied to break water-solid and/or water-water interactions, and to move the water molecules from one point to another in solid. The activation energy required for drying was calculated by using the Arrehenius equation (Gaston *et al.,* 2004):

$$D_{eff} = Do\exp-\left(\frac{Ea}{RT}\right) \quad \ldots (9)$$

Where,

D_{eff} = Effective moisture diffusivity, $m^2. s^{-1}$,

Do = Constant (measured as intercept at y axis),

Ea = Activation energy, $kJ.mol^{-1}$,

R = Universal gas constant, 8.314, $kJ. mol^{-1} .K^{-1}$, and

T = *A*bsolute temperature, K.

The equation in linear form can be developed by taking natural logarithm on both sides:

$$ln(D_{eff}) = ln(Do) - \left(\frac{Ea}{R}\right)\left(\frac{1}{T}\right) \quad \ldots (10)$$

RESULTS AND DISCUSSION

Effect of Drying Time and Temperature on Moisture Content and Mushroom Quality

The final moisture content of white button mushroom slices dried at 45, 55, and 65°C were found to be 6.79, 6.97 and 6.52% (wb), respectively. The time taken for drying of mushroom slices varied with drying temperature (Table 2), showing an inverse relationship (reduction in drying time with increase in drying temperature). The results were similar to drying of milky mushroom slices (Armugnathan *et al.,* 2009).

Table 2. Time required for drying of button mushroom slice

Drying temperature, °C	Drying time, min	Moisture content, % w.b
45	510	6.79
55	390	6.97
65	360	6.52

Physical parameters of button mushroom slices especially colour change from white to yellowish creamy, bulk density from 780-790 $kg.m^{-1}$ to 487-510 $kg.m^{-1}$ and weight loss from 88.20 to 92.37 % without much change in mushroom flavour occurred during thin layer drying at all three air temperature of 45, 55 and 65°C. The best quality of dried mushroom slice was at temperature of 55°C in terms of colour, crispy texture, flavour and comparatively less shrinkage than the other two temperatures (Fig.1). Thus, drying temperature of 55°C was recommended as the optimum temperature for thin layer drying of white button mushroom.

Computation of Drying Rates

The continuous decrease in moisture content (w.b) and moisture ratio was seen with drying time and increase of drying rate with the increase in drying temperature (Fig. 2, 3). The drying took place in the falling rate period for the entire duration, indicating that internal mass transfer occurred by diffusion in mushroom slices and constant rate period was absent. Similar observations were reported for thin layer drying of lettuce and cauliflower leaves (Lopez *et al.,* 2000), apricots (Doymaz, 2004), peach (Kingsly *et al*., 2007) and plums (Goyal *et al.,* 2007).

Selection of Thin Layer Drying Model

It is observed (Table 3) that the values of R^2 were greater than 0.99, indicating good fit for almost all models used, except for Wang and Singh and Page model where the R^2 values reported were slightly lower. Logarithmic model gave comparatively higher R^2 values (0.9939 to 0.9973) for all the drying temperatures, whereas the values of ψ^2(0.0003 to 0.0006), *MBE* (-3E-12 to -5E-10) and *RMSE* (0.0154 to 0.0222) were found to be lowest.

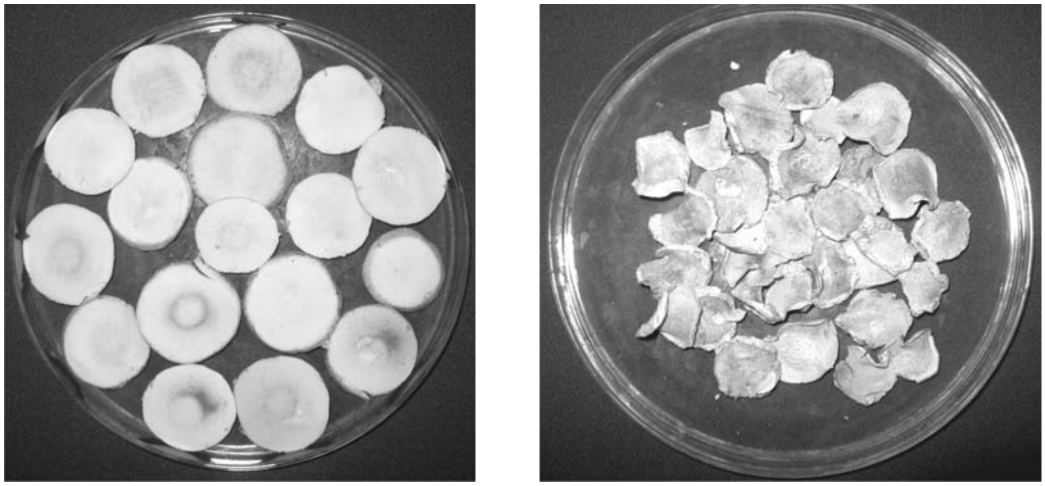

Fig. 1: Fresh slices of button mushroom before and after drying at 55°C air temperature in fluidized bed dryer

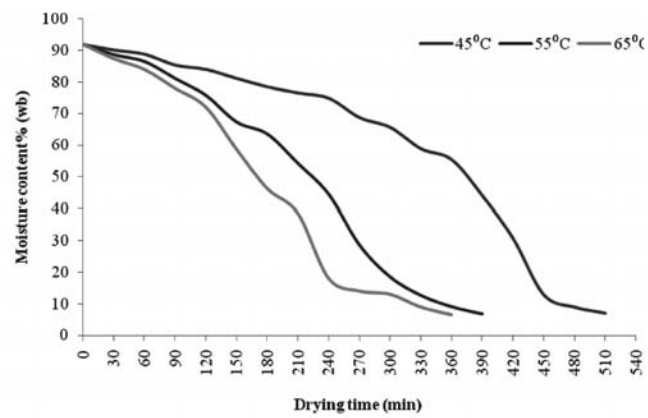

Fig.2: Variation in moisture content % (w.b) of white button mushroom with drying time during thin layer drying

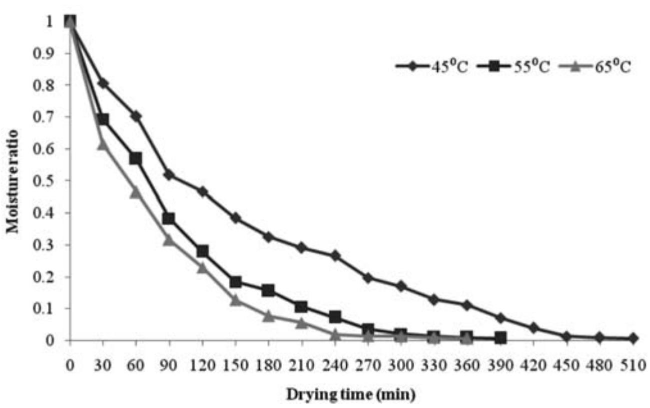

Fig.3: Variation in moisture ratio of white button mushroom with drying time during fluidized bed drying

Thus, the Logarithmic model best explained the thin bed drying process of white button mushroom slice, followed by Handerson and Pabis models. Two-term exponential and Two-term also performed best to represent the drying process. Thus, the logarithmic model was considered to be the best model to represent the thin layer drying of white button mushroom slice.

Effective Moisture Diffusivity and Activation Energy Determination

The effective moisture diffusivity, D_{eff}, was calculated using the method of slopes (Doymaz, 2004; Maskan *et al*., 2002). The moisture diffusivity values were calculated using the slope of the best-fit linear equations and equation (8). Effective moisture diffusivity values (Table 4) for white button mushroom slice ranged from 9.21×10^{-8} to 1.50×10^{-7} $m^2.s^{-1}$ for thin bed drying. These values were slightly higher than the general range of 10^{-9} to 10^{-11} $m^2.s^{-1}$ for drying of food materials (Maskan *et al*., 2002), mainly due to highly perishable nature (92% moisture) of white button mushroom. The moisture diffusivity increased with drying air temperature. Similar results were reported for apricot (Pala *et al.,* 1996; Doymaz, 2004), peach (Kingsly *et al.,* 2007) and plum (Goyal *et al*., 2007).

The activation energy was calculated using the Arrhenius expression giving correlation between the effective moisture diffusivity and absolute temperature as:

$$y = 0.243x - 16.44 \quad (R^2 = 0.999) \qquad \text{... (11)}$$

Where,

y = $\ln D_{eff}$, $m^2.s^{-1}$, and

x = Temperature T, K^{-1}.

Table 3. Statistical parameters for different thin layer drying models

Sr. No.	Name of model	Temp, °C	R^2	ψ^2	RMSE	MBE
1	Newton	45	0.9914	0.0007	0.0263	-0.0048
		55	0.9963	0.0003	0.0179	-0.0042
		65	0.9953	0.0004	0.0200	-0.0037
2	Wang and Singh	45	0.9688	0.0028	0.0503	-0.0120
		55	0.9633	0.0037	0.0565	-0.0138
		65	0.9388	0.0061	0.0721	-0.0186
3	Page	45	0.3492	0.0594	0.2297	0.0000
		55	0.9965	0.0004	0.0173	-0.0035
		65	0.9955	0.0004	0.0195	-0.0045
4	Henderson and Pabis	45	0.9915	0.0008	0.0262	-0.0043
		55	0.9963	0.0004	0.0179	-0.0042
		65	0.9955	0.0004	0.0195	-0.0028
5	Logarithmic	45	0.9939	0.0006	0.0222	-5E-10
		55	0.9973	0.0003	0.0154	-3E-12
		65	0.9959	0.0005	0.0187	-7E-10
6	Two-term	45	0.9916	0.0009	0.0261	-0.0046
		55	0.9963	0.0004	0.0179	-0.0042
		65	0.9955	0.0005	0.0195	-0.0028
7	Two-term exp	45	0.9916	0.0008	0.0261	-0.0046
		55	0.9963	0.0004	0.0180	-0.0043
		65	0.9964	0.0004	0.0174	-0.0046

Table 4. Moisture diffusivity equations and effective moisture diffusivity values for drying of white button mushroom at different temperatures

Drying temp, °C	Moisture Diffusivity equation	R^2	Effective Moisture Diffusivity, $m^2.s^{-1}$
45	y = -0.009x + 0.425	0.905	9.21E-08
55	y = -0.013x + 0.239	0.986	1.35E-07
65	y = -0.014x + 0.076	0.987	1.50E-07

y= *lnMR* ratio, x= drying time, min

The activation energy for white button mushroom was found to be 36.39 kJ.mol^{-1} (R^2=0.999), and was higher (19.8 kJ.mol^{-1}) than vegetable waste (Lopez *et al.,* 2000) and lower (54.9 kJ.mol^{-1}) than garlic slice (Madamba *et al.,* 1996).

CONCLUSIONS

1. The thin layer drying process of white button mushroom slice occurred in falling rate period, and increase in drying air temperature (45, 55 and 65°C) decreased the drying time (8.5, 6.5 and 6 h), respectively. The optimum temperature was 55°C, which gave the best quality of dried mushroom slices in terms of physical parameters viz., colour, crispy texture, flavour and comparatively less shrinkage.
2. Logarithmic drying model showed better fit with highest correlation coefficient and lower ψ^2, *MBE* and *RMSE* values during the drying of white button mushroom.
3. The effective moisture diffusivity ranged from 9.21x10^{-8} to 1.50x10^{-7} m^2. s^{-1}, with higher values at high drying temperature. The minimum average activation energy of 36.39 kJ.mol^{-1} was required for drying.

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