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EFFECT OF DRYING CONDITIONS ON MUSHROOM QUALITY

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Abstract

Fluidized bed drying of mushroom was undertaken to study the drying characteristics and quality of the dried mushrooms. Drying was done at drying air temperatures of 50, 70, and 90°C and air velocities of 1.71 and 2.13 m/s. Two batch sizes, namely, 0.5 kg and 1 kg of sliced milky mushrooms were dried. Drying characteristics and the quality of dried mushrooms were analyzed. The results indicated that the drying time decreased only marginally with increase in air velocity. Drying air temperature of 50°C was better as it resulted in a dried product having better rehydration characteristics, lesser shrinkage and lighter color. Highest energy efficiency (79.74%) was observed while drying a batch size of 1 kg at a drying air temperature of 50°C, using an air velocity of 1.7 m/s.

Keywords: Mushroom, Fluidized bed drying, Drying behaviour, Quality characteristics.

1. Introduction

Mushrooms are non-green, edible fungi. They are a large heterogeneous group having various shapes, sizes, appearance and edibility. Mushrooms are a good source of non-starchy carbohydrates, dietary fiber, protein, mineral and vitamins[1]. Mushrooms are a seasonal and highly perishable crop and contain about 90%(w.b.) moisture.

After harvesting, moisture loss, shrinkage and rapid spoilage in terms of color and texture takes place. The shelf life of mushroom is only about 2 to 5 days depending upon the variety. There are many methods for preservation and enhancement of shelf life of mushrooms. The most common processes include canning, freezing and drying. Although canning is widely used on a commercial scale, it is quite expensive. In case of large scale freezing and cold chain transportation, high

Nomenclatures

A	Constant, dimesionless
k	Drying rate constant, s^{-1}
M	Moisture content at any time, % d.b.
Me	Equilibrium moisture content, % d.b.
Mo	Initial moisture content, % d.b.
MR	Moisture Ratio= (*M*-*Me*)/ (*Mo*-*Me*), dimesionless
t	Time of drying, s
Abbreviations	
w.b.	Wet weight basis
d.b.	Dry weight basis

cost and intermittent/irregular electric power supply in many developing countries, become the main constraints.

Dehydration, therefore, remains a promising technique of preservation. Fluidized bed drying is an advanced drying method that is faster and produces better quality product than that obtained by conventional hot air drying [2,3]. This study was undertaken to examine the effect of the operating parameters of a fluidized bed dryer, namely, drying temperature, air velocity and batch size on the drying behavior, quality of dried mushrooms and energy consumption of the dryer.

2. Materials and Methods

Experiments were conducted to study the effect of three variables, namely, drying temperature, air velocity and batch size, on the drying of mushrooms. Experiments were conducted at three drying temperatures, (50°C, 70°C and 90°C), two air velocities (1.7 m/s and 2.1 m/s) and two batch sizes (1 kg and 0.5 kg).

Fully matured milky mushrooms of commercial grade variety were procured from the Mushroom Research Center of the University. The mushrooms were cut into 5-8 mm thick slices. No pre-treatment/blanching was done and the mushroom slices were dried from an initial moisture content of approximately 90%(w.b.) to the final moisture content of about 10%(d.b.) in a fluidized bed dryer.

The fluidized bed dryer developed by the Tamil Nadu Agriculture University (Department of Agricultural Engineering) was used in the study. The dryer is shown in Fig. 1 below.

Fig. 1. Fluidized Bed Dryer.

3. Results and Discussion

The drying behaviour and the product quality characteristics were studied in terms of product moisture content, rehydration ratio, rehydration fraction, bulk density, true density, porosity, bulk shrinkage, slice shrinkage and color.

3.1. Drying behaviour

The drying characteristic of the mushroom slices varied according to the drying conditions. The drying rates were analyzed as total drying time, drying kinetics and the influence of operating conditions upon them.

Total drying time

The total drying time to reduce the moisture content of mushroom from approximately 868%(d.b.) to about 10%(d.b.) is summarized in Table 1. Depending upon the operating conditions, the drying time varied from 1 h 11 min to 5 h 45 min.

Table 1. Total Drying Time (min.) to Dry Mushrooms to Approximately 10% (d.b.) under Different Drying Conditions.

Velocity (m/s)	Batch size (kg)	Temperature (^{o}C)		
		50	70	90
2.13	1	325	210	124
	0.5	213	112	71
1.71	1	345	230	154
	0.5	254	114	70

It was observed that the total drying time decreased upon increasing the temperature for a given drying air velocity and batch size. The drying time also decreased upon increasing the drying air velocity for a given temperature and batch size. For a given drying air velocity and temperature, the total drying time was more for larger batch size, which is expected.

Drying kinetics

The drying kinetics behavior of mushrooms was examined in terms of an exponential model having the form:

$$MR = Ae^{-kt} \quad (1)$$

Since, in all cases, the mushroom slices were dried to a final moisture content of about 10%(d.b.), the value of Me would be even less, and therefore very small compared to the initial moisture content of about 868%(d.b.). Therefore, Me was neglected and MR was represented as M/Mo. Further, since $M = Mo$ at $t = 0$, the value of A comes out to be unity. The drying kinetics is then represented as:

$$M / Mo = e^{-kt} \quad (2)$$

The values of drying rate constant, k, for temperatures 50, 70 and 90^{o}C were estimated using least square regression and are tabulated in Table 2. The model was then used to predict the drying behavior under the experimental conditions.

Typical observed and predicted drying behaviors of the 0.5 kg batch at different temperatures at an air velocity of 2.13 m/s are compared in Fig. 2.

Table 2. Drying Rate Constant (min^{-1}) at Different Drying Conditions.

Velocity (m/s)	Batch size (kg)	Temperature (°C)		
		50	70	90
2.13	1	0.0140	0.0211	0.0363
	0.5	0.0195	0.0402	0.0640
1.71	1	0.0135	0.0203	0.0302
	0.5	0.0180	0.0401	0.0642

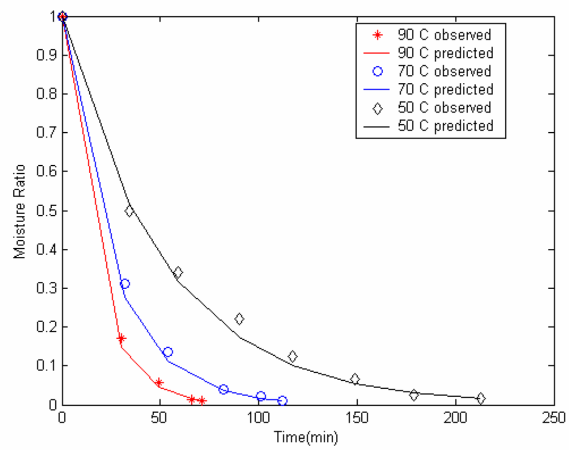

Fig. 2. Drying Behavior of 0.5kg Batch of Mushroom at an Air Velocity of 2.13 m/s.

It may be noted from Fig. 2 and the Table 1 that, other conditions being constant, the drying rate constant increased with drying temperature as well as with air velocity. The drying rate constant decreased for larger batch size.

Effect of temperature

The effect of temperature is also illustrated in the drying curves of Fig. 2. The drying rate increased with the temperature of the drying air as the curve of successively higher temperatures fall below the curve of lower temperature.

Effect of velocity

Only two levels of velocity were taken in this study. These were obtained by varying the flap at the angle of 45° and 90° at the inlet of the blower. The average velocities at these settings were 1.71 m/s and 2.13 m/s.

It was observed that even within a drying run, the air velocity increased with time, possibly due to shrinkage of material. For 1.71 m/s the value of velocities increased from 1.16 m/s to 1.91 m/s in case of 1 kg batch size and from 1.3 m/s to 2.07 m/s in case of 0.5 kg batch size. Similarly for 2.13 m/s the value of velocities varied from 1.16 m/s to 2.6 m/s in case of 1 kg batch size and from 1.56 m/s to 2.4 m/s in case of 0.5 kg batch size. However this rise of velocity is within an experimental run was ignored and the data was analyzed on the basis of mean velocities that are 1.71 m/s and 2.13 m/s. The effect of air velocity in a typical case (air temperature at 50°C and batch size of 1 kg) is shown in Fig. 3. It may be noted that although at higher air velocities, the drying rate is generally higher; the effect of the air velocity is not very significant.

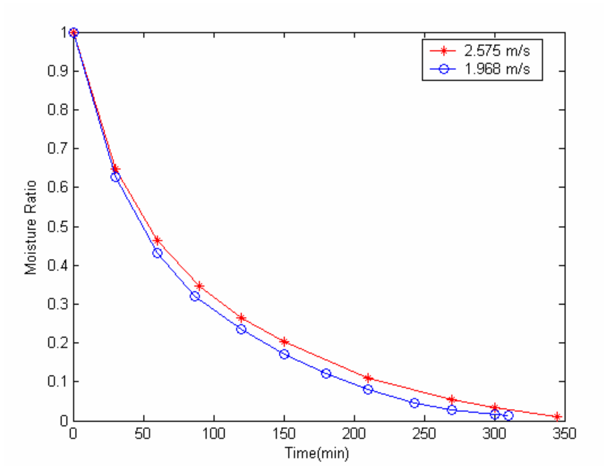

Fig. 3. Drying Behavior of 1 kg Batch of Mushroom at Drying Temperature of 50°C.

Effect of batch size

The typical effect of batch size (air velocity of 2.13 m/s and air temperature of 50ºC) is shown in Fig. 4. It is clearly evident from the figure that the drying rate increases very significantly with the decrease in batch size. It can be noticed that by reducing the batch size from 1 kg to 0.5 kg, the drying time is reduced by about 48%.

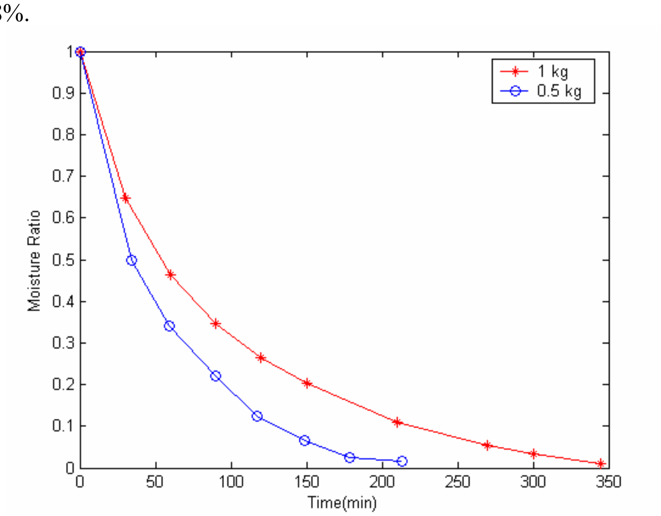

Fig. 4. Drying Behavior of Mushroom at an Air Velocity of 2.13 m/s and Drying Temperature of 50°C.

3.2. Product quality

The rehydration ratio, bulk shrinkage, shrinkage of individual mushroom slice and color were taken as quality parameters and their changes during drying are discussed in the following sections:

Rehydration Characteristics

The shape and size of the mushroom slices significantly differed from the fresh ones due to shrinkage resulting from the removal of large quantities of water. The rehydration behavior was analyzed in terms of the ability of the dried product to regain its original mass. This characteristic was expressed in terms of a rehydration ratio, calculated as the ratio of the rehydrated mass to the dehydrated mass, and a rehydration fraction, calculated as rehydrated mass per unit initial mass. The rehydration ratios obtained under different conditions are tabulated in Table 3. The rehydration fractions under different conditions are tabulated in Table 4.

Table 3. Rehydration Ratios of Dried Mushrooms under Different Drying Conditions.

Velocity (m/s)	Batch size (kg)	Temperature (°C)		
		50	70	90
2.13	1	3.184	2.93	2.563
	0.5	3.914	3.528	2.665
1.71	1	4.015	2.765	2.605
1.71	0.5	3.515	3.58	3.77

Table 4. Rehydration Fraction of Dried Mushrooms under Different Drying Conditions.

Velocity (m/s)	Batch size (kg)	Temperature (°C)		
		50	70	90
2.13	1	0.366	0.335	0.290
	0.5	0.460	0.400	0.305
1.71	1	0.449	0.309	0.289
	0.5	0.396	0.403	0.427

It may be noted that higher rehydration ratio indicates better product. The rehydration ratio ranged from 2.563 to 4.015 for different operating conditions. It was found that the rehydration ratio of dried samples was higher at the lower temperatures and was highest at 50°C. There was no significant effect of drying air velocities on the Rehydration ratio. With decrease in the batch size, in general, the rehydration ratio increased. Similar to rehydration ratio, a higher rehydration fraction indicates a better product. A rehydration fraction of 1 will indicate an ideal product. It was observed that as the temperature decreased, the rehydration fraction increased. The increase in drying air velocity decreased the rehydration fraction, while the decrease in batch size increased the rehydration fraction.

Bulk shrinkage

The bulk shrinkage was calculated for different conditions to find out the reduction in space required for storage purposes. Higher value of bulk shrinkage is favorable for storage purposes as higher the value of bulk shrinkage, lesser is the volume required for storage. However, with reference to the product quality, bulk shrinkage should be less. This is because for lower bulk shrinkage, mushroom slices will have greater tendency to regain their original shape. Bulk shrinkage for different conditions is tabulated in Table 5. There was no systematic trend of bulk shrinkage with the temperature and drying air velocity, but it generally increased with the batch size.

Table 5. Bulk Shrinkage (%) of Dried Mushrooms under Different Drying Conditions.

Velocity (m/s)	Batch size (kg)	Temperature (^oC)		
		50	70	90
2.13	1	75.59	73.57	82.11
	0.5	68.47	73.27	78.34
1.71	1	78.26	82.1	82.79
	0.5	78.7	71.46	71.29

Slice shrinkage

The slice shrinkage was analyzed to measure the reduction in the size of individual mushroom slice after losing the moisture content from 868%(d.b.) to approx. 10%(d.b.). The shrinkage of individual pieces of sliced mushrooms was calculated and is tabulated in Table 6. Like bulk shrinkage, in slice shrinkage also no systematic trend was observed. However the majority of the data indicate that shrinkage decreases with increase in drying air velocity and also shrinkage is lower at lower temperatures as compared to the higher temperatures.

Table 6. Slice Shrinkage (%) of Dried Mushrooms under Different Drying Conditions.

Velocity (m/s)	Batch size (kg)	Temperature (^oC)		
		50	70	90
2.13	1	73.84	73.9	82.75
	0.5	68.47	79.42	83.52
1.71	1	79.75	85.5	83.98
	0.5	80.27	74.8	75.08

Color

Color is an important quality parameter for the dried mushroom and was determined by comparison with a standard color chart. The color index of the dried mushrooms slices was noted in five replications. The average color index in different drying experiments is presented in the Table 7. Generally the browning of the dried product is more pronounced at higher temperatures. In this study on fluidized bed drying, the color of the dried mushroom slices was not significantly affected with the temperature and batch size, although generally, the color is better at lower velocity (1.71 m/s) and lower temperature (50°C).

Table 7. Color Index of Dried Mushrooms under Different Drying Conditions.

Velocity (m/s)	Batch size (kg)	Temperature (°C)		
		50	70	90
2.13	1	8	7.4	8.8
	0.5	7.8	8.2	9.6
1.71	1	7.4	7.8	7.8
	0.5	7.4	7.2	7

3.3. Energy analysis

The energy consumption varied with the operating conditions of the dryer. Total energy consumption, total power consumption, blower power consumption, thermal power consumption, specific energy consumption per unit mass of moisture evaporated and efficiency of the dryer were calculated. To calculate the efficiency of the dryer the reference point is taken as the latent heat of free water, which is 2257 kJ/kg (540 kcal/kg). The analysis is summarized in Table 8.

Table 8. Energy and Power Requirement under Different Drying Conditions.

Drying Temperature	Total energy consumption	Power consumption	Blower power	Thermal power consumed	Specific energy consumption	Efficiency
°C	kJ	kW	kW	kW	kJ/kg moisture evaporated	%
Air velocity = 1.71 m/s				Batch size = 0.5 kg		
50	2952	0.193	0.060	0.134	6626.26	34.11
70	2160	0.316	0.060	0.256	4967.80	45.50
90	2196	0.523	0.060	0.448	4875.67	46.36
Air velocity = 2.13 m/s				Batch size = 0.5 kg		
50	2232	0.174	0.075	0.099	5038.37	44.86
70	2404	0.358	0.075	0.283	5390.13	41.93
90	2340	0.550	0.075	0.475	5254.88	43.01
Air velocity = 1.71 m/s				Batch size = 1.0 kg		
50	2520	0.120	0.060	0.060	2834.65	79.74
70	3744	0.270	0.060	0.210	4206.74	53.73
90	3384	0.370	0.060	0.310	3768.37	59.98
Air velocity = 2.13 m/s				Batch size =1.0 kg		
50	3672	0.200	0.075	0.125	3903.70	57.90
70	5976	0.470	0.075	0.395	6744.92	33.51
90	3420	0.460	0.075	0.385	3834.08	58.95

The variation of the specific energy and average power consumption is shown in Fig. 5. On the basis of the energy consumption data, it is concluded that on increasing the drying air velocity, the specific energy consumption increased and on increasing the batch size, the specific energy consumption decreased. The power requirement increased with increase in drying air temperature and air velocity.

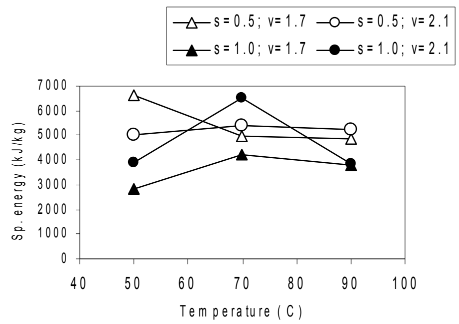

Fig. 5. Specific Energy Consumption at Different Operating Parameters.

4. Conclusions

On the basis of above results it can be concluded that drying rate constant is maximum (k = 0.064) for the batch size of 0.5 kg at drying air temperature 90^{o}C and air velocity of 2.13 m/s. The efficiency is best for the batch size of 1 kg with air velocity 1.7 m/s at drying air temperature of 50^{o}C. Drying air temperature of 50^{o}C is better as it gives dried product with higher rehydration ratio and higher rehydration fraction, lower shrinkage and better color.

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