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# Drying kinetics and rehydration characteristics of microwave-vacuum and convective hot-air dried mushrooms

S.K. Giri, Suresh Prasad *

*Department of Agricultural and Food Engineering, Post Harvest Technology Centre, Indian Institute of Technology, Kharagpur 721 302, India*

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**Abstract**

Microwave-vacuum dehydration characteristics of button mushroom (*Agaricus bisporus*) were evaluated in a commercially available microwave oven (0–600 W) modified to a drying system by incorporating a vacuum chamber in the cavity. The effect of drying parameters, namely microwave power, system pressure and product thickness on the drying kinetics and rehydration characteristics were investigated. The drying system was operated in the microwave power range of 115–285 W, pressure range of 6.5–23.5 kPa having mushroom slices of 6–14 mm thickness. Convective air drying at different air temperatures (50, 60 and 70 °C) was performed to compare the drying rate and rehydration properties of microwave-vacuum drying with conventional method. Microwave-vacuum drying resulted in 70–90% decrease in the drying time and the dried products had better rehydration characteristics as compared to convective air drying. The rate constants of the exponential and Page's model for thin layer drying were established by regression analysis of the experimental data which were found to be affected mainly by the microwave power level followed by sample thickness while system pressure had a little effect on the drying rate. Rehydration ratio was significantly affected by the system pressure. Empirical models are also developed for estimating the drying rate constant and rehydration ratio as a function of the microwave-vacuum drying process parameters.


*Keywords:* Microwave-vacuum drying; Button mushroom; Drying rate; Scanning electron microscopy; Rehydration ratio

## 1. Introduction

Mushrooms are edible fungi of commercial importance and their cultivation and consumption has increased substantially due to their nutritional value, delicacy and flavor. The button mushroom (*Agaricus bisporus*) is the most widely cultivated and consumed mushroom throughout the world and it contributes about 40% of the total world production of mushroom. Mushrooms are extremely perishable and the shelf life of fresh mushroom is only about 24 h at ambient conditions. Various physiological and morphological changes occur after harvest, which make these mushrooms unacceptable for consumption. Hence, they should be consumed or processed promptly after harvest and for this reason the mushrooms are traded mostly in processed form in the world market.

Dehydration is one of the important preservation methods employed for storage of mushroom and dehydrated mushrooms are valuable ingredients in a variety of sauces and soups. As mushrooms are very sensitive to temperature, choosing the right drying method can be the key for a successful operation. Mushroom growers continue to dry mushroom under sun, which yields unhygienic and poor quality product. The conventional hot-air drying of mushrooms normally involves thermal and/or chemical pretreatment and drying at temperature maintained between 50 and 70 °C. Due to long drying time and overheating of surface during hot-air drying, the problems of darkening in colour, loss in flavour and decrease in rehydration ability occur. Freeze drying produces a high quality product, but being an expensive process, its application for mushroom drying is limited. Vacuum drying is another

* Corresponding author. Fax: +91 3222 282288.
*E-mail addresses:* skgiri@agfe.itkgp.ernet.in (S.K. Giri), sp@agfe.iitkgp.ernet.in (S. Prasad).

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alternative method and is especially suitable for products that are prone to heat damage such as fruits and vegetables. However, in vacuum process requiring heat, transfer of heat energy to the workload becomes difficult, as convection is ineffective at low pressure. Most conventional vacuum dryers rely on conduction heat transfer from hot plates, which is slow, difficult to control and requires a large surface area and therefore, conventional vacuum drying has high operating and installation cost (Woodroof & Luh, 1986). The desire to prevent significant quality loss and to achieve fast and effective dehydration has resulted in increasing use of microwave heating for food drying.

Microwave drying is rapid, more uniform and energy efficient compared to conventional hot-air drying. In recent years, Microwave-vacuum drying (MVD) has been investigated as a potential method for obtaining high quality dried food products, including fruits, vegetables and grains. Microwave-vacuum drying combines the advantages of both microwave heating and vacuum drying. The low temperature and fast mass transfer conferred by vacuum combined with rapid energy transfer by microwave heating generates very rapid, low temperature drying and thus it has the potential to improve energy efficiency and product quality. Some fruits and grains have been successfully dried by microwave-vacuum drying techniques (Cui, Xu, & Sun, 2003; Drouzas & Schubert, 1996; Durance & Wang, 2002; Lin, Durance, & Scaman, 1998; Wardsworth, Velupillai, & Verma, 1990; Yongsawatdigul & Gunasekaran, 1996a, 1996b). Despite those investigations, there is scanty information available either in terms of the drying kinetics or quality of button mushroom undergoing microwave-vacuum drying technique.

The drying kinetics is often used to describe the combined macroscopic and microscopic mechanisms of heat and mass transfer during drying, and it is affected by drying conditions, types of dryer and characteristics of materials to be dried. Since on-line measurement of temperature and moisture is difficult and time-consuming for microwave assisted heating and drying, the drying kinetics models are essential for equipment design, process optimization and product quality improvement. The effect of vacuum in microwave drying operation is system specific, and for successful design and operation of an industrial microwave-vacuum drying system, knowledge of the drying characteristics of the material to be dried under a range of condition is vital (McLoughlin, McMinn, & Magee, 2003). The aim of the present work was to investigate microwave-vacuum drying characteristics of button mushroom slices and to compare with convective hot-air drying in respect to drying kinetics, rehydration qualities and micro structural changes of the dried products.

## 2. Material and methods

### 2.1. Materials

Fresh button mushrooms (*A. bisporus*) were obtained from market and kept in cold storage at 4–5 °C. Prior to dehydration, mushrooms were thoroughly washed to remove the dirt and graded by size to eliminate the variations in respect to exposed surface area. Slices of desired thickness were obtained by carefully cutting mushrooms vertically with a vegetable slicer and the slices from middle portions with characteristics mushroom shape were used for drying experiments without any pretreatments. They were immediately weighed and placed into the dryer. Moisture content of the samples was determined in a vacuum oven at 70 °C for 14–16 h (AOAC, 1984). The initial moisture content of the slices was ranged from 92% to 93% (w.b.).

### 2.2. Drying

#### 2.2.1. Hot-air drying

The mushroom slices were hot-air dried at air temperature of 50, 60 and 70 °C in a cross-flow type dryer with air flow rates of 1.5 m/s. Air was heated electrically before entering the heater. Slices were spread in a single layer on the tray. During air drying, weight and temperature of the sample were recorded at regular interval of times.

#### 2.2.2. Microwave-vacuum drying

The experimental setup used for the microwave-vacuum drying of the samples is depicted in Fig. 1, which consists of a microwave oven (IFB, model electron) of rated capacity of 600 W at 2.45 GHz. The oven is modified to give variable power output (from 0 to 600 W) by incorporating a 230 V AC variac in the circuit (Sharma & Prasad, 2001). A glass container containing the material to be dried was placed inside the microwave cavity and a vacuum pump was connected to the container for maintaining the desired levels of vacuum inside it. Vacuum in the container was monitored by using a vacuum gauge and a pressure regulating valve to maintain the pressure at desirable levels. An air tight condenser was also used in the vacuum line for condensing the water vapour released from the samples. About 100 g of sliced mushrooms were taken for each drying experiments in the microwave-vacuum dryer at different microwave power and pressure levels. The sample remained in the container for a specified time interval while drying took place. The weight of the sample was recorded at every 5 min intervals by switching off the microwave oven and after releasing the vacuum, which took about 40 s for each observation. The samples were dried till the moisture content was reduced to 6–6.5% (w.b.).

The variables chosen for microwave-vacuum drying experiments were microwave power ($Q$), system pressure ($P$) and thickness of the slices ($T$). Response surface methodology was used to determine the relative contributions of the above three variables to the drying characteristics and rehydration ratio. Twenty experiments were performed according to a central composite rotatable design with the three variables and with five levels of each variable. The maximum and minimum variable levels