Convective drying and desorption isotherms of Shiitake (*Lentinula edodes*) mushroom

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Abstract: The drying behaviour of the Shiitake mushrooms was investigated in a through-flow laboratory dryer at temperatures of 30, 40, 50, 60 and 70 °C, corresponding relative humidity and constant air velocity of 1.0 m/s. The moisture desorption isotherms were also established at temperatures ranging between 20 and 70 °C by a hygrometric method. The Midilli model was described adequately the drying kinetics while the modified Halsey equation gave the most accurate fit to the experimental sorption data. The results indicated the significant influence of drying temperature on colour ($p<0.05$) and the insignificant effect on rehydration capacity ($p>0.05$).

Keywords: Desorption isotherm, Hot-air drying, Shiitake mushroom

1. INTRODUCTION

Shiitake, *Lentinula edodes* (Berk.) Pegl. is one of the major edible cultivated mushroom species in both eastern and western countries. Shiitake mushrooms can be grown either on natural logs using various hard-woods (oak, beech, chestnut) or on synthetic logs containing mainly sawdust supplemented with wheat, rice, millet, rye or maize bran (Royse 2001). The fruiting bodies of Shiitake are marketed worldwide as fresh and processed products. Among the various methods for the preservation of mushrooms such as canning, pickling and freezing, dehydration is not only applied to extend their shelf life but also to develop new range of products. Dried Shiitake mushrooms are often preferred to fresh because of their characteristic umami flavour which is intensified by the drying process. Moreover, they are recommended as a supplement to one's daily diet due to their relatively high nutritive value and therapeutic properties (Regula and Siwulski 2007). They contain a natural chemical compound called ergosterol which, when exposed to ultraviolet light is converted to vitamin D_2 (Mau ***et al.*** 1998). Different drying systems i.e. solar tunnel dryers or hot-air cabinet dryers are commonly employed for the processing of Shiitake mushrooms. Most of the research in the literature has been focused on the drying behaviour of *Agaricus bisporus* (Giri and Prasad 2007; Xanthopoulos ***et al.*** 2007) and *Pleurotus spp*. (Pal and Chakraverty 1997; Arora ***et al.*** 2003). The impact of several dryers under various pre-treatments on the dehydration of button and oyster mushrooms was also examined (Walde ***et al.*** 2006). Furthermore, changes in colour and texture during convective drying of *Pleurotus spp.* (Kotwaliwale ***et al.*** 2007) and *Boletus edulis* (Argyropoulos ***et al.*** 2010) were assessed. Cao ***et al.*** 2003 analysed the thin-layer drying of another medicinal mushroom species (*Grifola frondosa*). A recent work published by Artnaseaw ***et al.*** 2010 investigated the effect of temperature and vacuum pressure on the drying characteristics of Shiitake mushrooms dried in a vacuum heat pump dryer. However, limited studies on conventional hot-air drying of Shiitake have been reported in the literature. Therefore, in order to optimize the convective drying of Shiitake mushrooms, the desorption isotherms were established at different temperatures and the quality in terms of colour and rehydration capacity of the dried product was evaluated.

2. MATERIALS AND METHODS

Raw material

Fresh raw Shiitake mushrooms *Lentinula edodes* (Berk.) Pegl. were purchased from the local market in Stuttgart (Germany) and stored at 4 °C and 90%

relative humidity in a refrigerator for a maximum of three days. The mushrooms were selected according to the diameter of the cap (60±5 mm) and cleaned thoroughly to remove extraneous matter. The caps were manually separated from the stalks and used for the sorption and drying experiments.

Convective drying

The thin layer drying experiments were carried out using an hot-air laboratory dryer developed at the Institute of Agricultural Engineering, University of Hohenheim in Stuttgart, Germany. A detailed description of the dryer has been given by Argyropoulos ***et al***. (2011). It essentially consists of four units: (i) an air flow control unit, (ii) an air conditioning unit with a thermostat-controlled water bath and sprayed Raschig-ring bed, (iii) a heating control unit with primary and secondary heating elements and (iv) two drying compartments to provide either through-flow or over-flow air stream for convective drying of products. Each unit is electronically controlled by PID control. A schematic diagram of the experimental dryer is shown in figure 1.

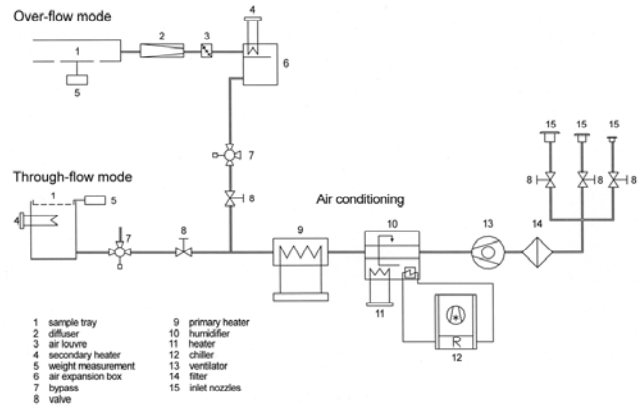

Fig. 1. Schematic diagram of the laboratory dryer and its components

The weight measuring system comprised different load cells (type PC6, Flintec Ltd, Vasteras, Sweden) for each drying chamber. The dryer is connected to an industrial computer using PLC software allowing pre-programming of the set drying conditions and monitoring of temperature, humidity, velocity and mass data during drying. Samples with a mass of approximately 300 g of mushroom caps were used for each drying trial. The dryer was warmed up for 30 min to reach the defined set points. Then, the material was evenly distributed on a round perforated tray (diameter: 340mm) by placing the caps with the gills face downwards and positioned in the through-flow mode of the dryer. The experiments were conducted at air temperatures of 30, 40, 50, 60 and 70 °C, the corresponding relative humidity for each temperature by maintaining 10 g water per kg of dry air and constant air velocity of 1.0 m/s. The experiments were replicated three times for each drying condition. During the drying process the weight change was recorded in ten minute time intervals for the determination of the drying curves and estimation of total drying time. The Midilli model (Midilli ***et al.*** 2002) was used to describe the drying kinetics of Shiitake mushrooms. The mathematical form of the equation is given as follows:

$$MR = \frac{M_t - M_e}{M_0 - M_e} = a\exp\left(-kt^n\right) + bt \qquad (1)$$

where, MR is the moisture ratio (-), M_t is the moisture content during drying (g water/g dry matter), M_e is the equilibrium moisture content (g water/g dry matter), M_0 is the initial moisture content (g water/g dry matter), k is the drying constant (min^{-1}), t is the drying time (min), a, b and n are constants.

Determination of desorption isotherms

The moisture sorption isotherms were established using a digital hygrometer Rotronic-Hygrometer (Rotronic AG, Bassersdorf, Switzerland). The apparatus consists of a temperature and humidity sensor with two thermostatic chambers where the samples are placed. The temperature is regulated through a water circulation tank which is attached to the instrument. Prior to measurements the relative humidity of the system was calibrated using the salts indicated by the manufacturer. The mushroom caps were dried by convection to establish different moisture contents and kept in glass containers for a certain time to allow for moisture uniformity. Then, material was finely ground in a laboratory water-cooled mill and the water activity was determined at temperatures of 20, 30, 40, 50, 60 and 70 °C. For all samples tested, equilibrium was reached in approximately 40 min. Readings were obtained in the form of % equilibrium relative humidity (ERH) and expressed as a_w (ERH/100). The mean value of three determinations was recorded. The moisture content at each value of water activity was measured in triplicate using a vacuum oven (70 °C for 7 h). The modified Halsey model was selected to fit the experimental sorption data.

$$M_e = \left[\frac{-\exp\left(a + b\cdot T\right)}{\ln\left(a_w\right)}\right]^{1/c} \qquad (2)$$

where, M_e is the equilibrium moisture content (g water/g dry matter), a_w is the water activity (-), T is the temperature (°C), a, b and c are constants.

Fitting accuracy

The accuracy of fit for both drying and sorption models was evaluated by R-squared (R^2), sum of squares due to error (SSE) and mean relative squared error (RMSE) using the non-linear squares procedure (Matlab v. R2010b, Mathworks, Inc.).

Colour measurement

The colour of mushrooms was measured by a Minolta Colorimeter (model CR-400 Minolta Co, Ltd., Japan). The instrument was calibrated with a standard white plate at D_{65} illumination before taking measurements (Y=93.7, x=0.3158, y=0.3324). Two readings were made per mushroom surface by placing the colorimeter head directly above the cap. The mean value of ten measurements was taken for each experiment. Colour parameters were expressed as L* describing lightness (L*=0 for black, L*=100 for white), a* describing intensity in green-red (a*<0 for green, a*>0 for red), b* describing intensity in blue-yellow (b*<0 for blue, b*>0 for yellow). Furthermore, other colour parameters such as C*, h* and ΔE* were also calculated. Chroma (C*) indicates colour saturation which is proportional to its intensity:

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (3)$$

For the hue value, an angle of 0° or 360° indicates red hue, while angles of 270°, 180° and 90° indicate blue, green and yellow hue respectively.

$$h^* = \arctan \frac{b^*}{a^*} \quad (4)$$

Total colour difference (ΔE*) was calculated as

$$\Delta E^* = \sqrt{(L^*_t - L^*_0)^2 + (a^*_t - a^*_0)^2 + (b^*_t - b^*_0)^2} \quad (5)$$

Rehydration capacity

The rehydration ratio of the dried caps was determined by soaking the samples in distilled water at 100°C. The water absorbed (g) divided by the dry sample weight (g) was defined as the rehydration ratio.

Statistical analysis

One-way analysis of variance (ANOVA) was performed using the OriginLab (ORIGINPRO v. 8.0 SR2) software. Differences among mean values of the quality attributes and the drying temperatures were examined by the Tukey's test at P<0.05 significance level.

3. RESULTS AND DISCUSSION

Desorption isotherms

The desorption isotherms of Shiitake caps were determined for a range of air temperatures between 20 and 70 °C. Among the various three-parameter models tested (Modified forms of Oswin, Chung-Pfost, Henderson and Halsey), the Halsey equation gave the most accurate fit to the experimental desorption data. Figure 2 shows the mean values of the results (points) and curves (solid lines) predicted by the Halsey model. As expected, the equilibrium moisture content of the mushroom caps increased with water activity at constant temperature. At constant equilibrium moisture content the water activity slightly increased with an increase of temperature. Similar sorption behaviour was observed by Shivhare ***et al.*** 2004 for both button (*Agaricus bisporus*) and oyster (*Pleurotus florida*) mushrooms. Nevertheless, the adsorption isotherms of the mushrooms were measured by the static gravimetric method and concluded that the Chung-Pfost was the best model to describe the adsorption isotherms. The values of the parameters of the Halsey model were used to calculate the equilibrium moisture content (M_e) of mushrooms for drying at different values of relative humidity and air temperature.

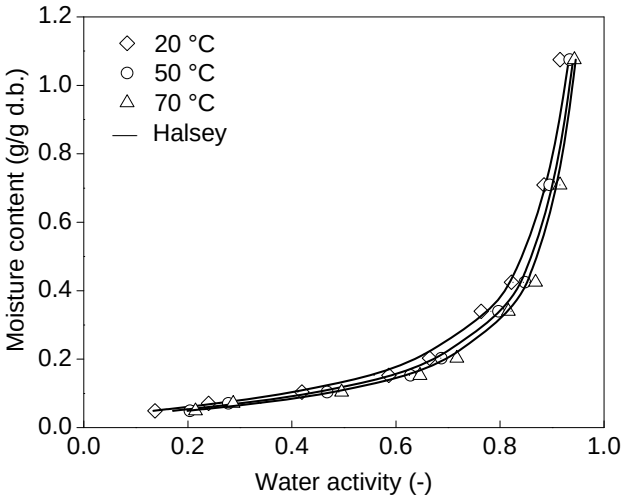

Fig. 2. Desorption isotherms of Shiitake mushrooms at different temperatures

Drying kinetics

Shiitake mushrooms with an initial moisture content of 92.05±0.7% in wet basis dried to equilibrium moisture content. Figure 3 shows changes in dimensionless moisture ratio as a function of drying time at temperatures of 30, 40, 50, 60 and 70 °C. The drying time decreased with an increase in drying temperature. The time required to reduce the moisture content to any given level was significantly shorter for the mushrooms dried at 70°C whereas it was extremely longer for the samples dried at 30 °C. The Midilli model was compared with six common thin layer drying equations retrieved from the literature (Newton, Page, Henderson & Pabis, Logarithmic, Two-term and Two-term exponential)

and found to be the best to describe the drying characteristics of Shiitake mushroom caps.

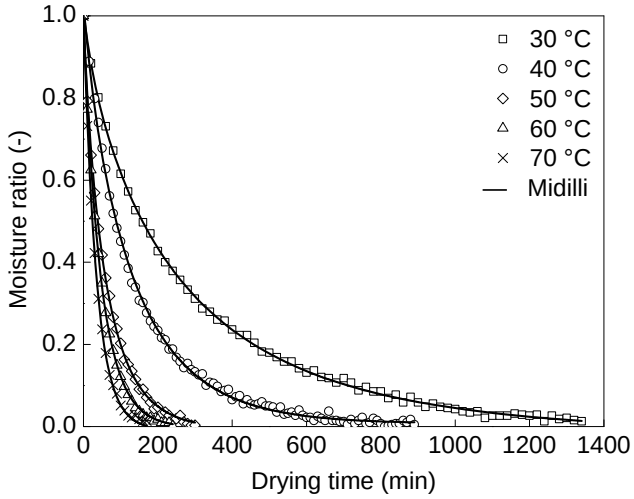

Fig. 3. Influence of air temperature on drying kinetics of Shiitake mushrooms

Colour

The colour of Shiitake mushrooms was affected by higher drying temperatures. The average moisture content of the samples obtained to measure colour was 6.3±0.3% in wet basis. The results of the colour parameters (L*, a*, b* and ΔE*) for the mushrooms dried at five different temperatures are shown in Figure 4. The colour components of the fresh caps were used as a reference (L*=44.07±4.23, a*=15.42±1.12, b*=24.26±3.52). The lightness, redness and yellowness of the samples decreased with an increase in drying temperature. This effect was moderate at temperatures up to 50 °C and more intensive at 60 and 70 °C. Previous studies on convective drying of other mushroom species such as *Pleurotus spp*. (Kotwaliwale et al. 2007), *Boletus edulis* (Argyropoulos et al. 2010) and *Agaricus bisporus* (Argyropoulos et al. 2011) indicated an increase of the a* and b* values, however, in the present work a reduction of both parameters was recorded. This can be attributed to the differences in colour among mushroom species. The C* value followed the behaviour of yellowness while a relatively constant value was observed for the hue angle. As far as the total colour difference is concerned, samples dried at 30 °C followed by 40 °C showed the least colour change whereas hot-air drying at 60 °C caused the greatest colour variation from the reference material. Nevertheless, the mean ΔE* value of the mushrooms dried at 60 °C was not significantly different from the value of the samples dried at 70 °C (p>0.05).

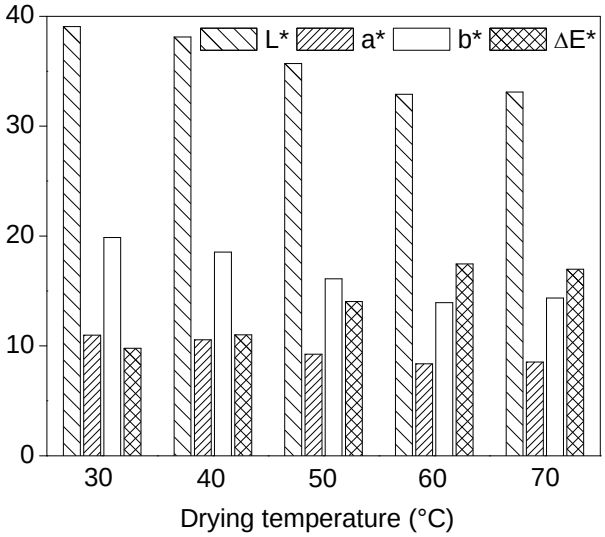

Fig. 4. Influence of drying temperature on colour parameters of Shiitake mushrooms

Rehydration ratio

The effect of drying temperature on rehydration ratio of shiitake mushrooms is shown in Figure 5. All the caps could not absorb the same amount of water as possessed when fresh. Samples dried at 30 °C indicated a slightly higher rehydration capacity as compared to the material dried at higher air temperatures. The statistical analysis revealed the insignificance influence of drying temperature on rehydration of shiitake mushrooms (p>0.05). The rehydration behaviour/capacity of the air-dried shiitake mushroom caps was examined extensively using conventional and vacuum techniques (Garcia-Segovia ***et al.*** 2011).

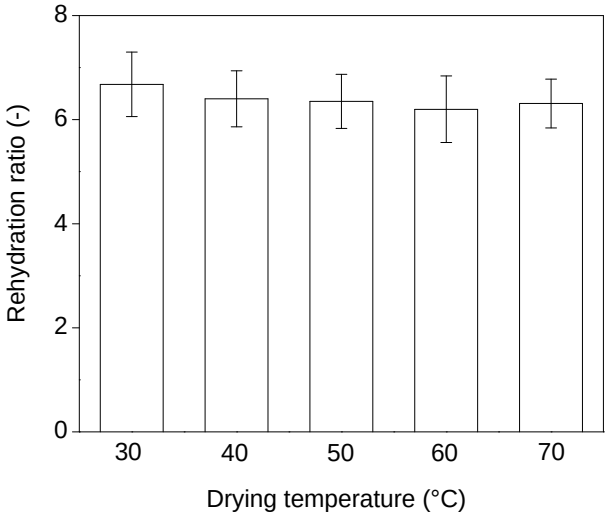

Fig. 5. Influence of drying temperature on rehydration ratio of Shiitake mushroom caps

4. CONCLUSIONS

The thin layer drying behaviour of Shiitake mushroom caps was investigated at different temperatures ranging between 30 and 70 °C. The equilibrium moisture content for the termination of convective drying was computed by the modified Halsey model. The Midilli model found to be the best model to describe the drying kinetics of Shiitake mushrooms. The results indicated the significant influence of drying temperature on colour and the insignificant effect on rehydration capacity. A temperature limit of 50 °C is recommended for the convective drying of Shiitake mushrooms.

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