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Evaluation of processing parameters for hot-air drying to obtain high quality dried mushrooms in the Mediterranean region

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Introduction

Edible mushrooms are appreciated for their delicacy, flavour, nutritional and medicinal characteristics. More than 2000 described species exist in nature but only 35 species are cultivated commercially, and of those, about 20 species are intensively cultivated on an industrial scale (Chang, 1999b). In Greece, approximately 1150 species of fungi have been identified as mushrooms and at least 400 species have shown various degrees of edibility (Konstantinidis, 2002). The well-established market acceptance of cultivated fruit bodies has been followed by a spectacular increase in the popularity of wild-growing mushrooms. However, fresh mushrooms are highly perishable commodities with short shelf life under ambient conditions of temperature and humidity and their commercialisation becomes difficult. Among the various techniques employed for preservation of mushrooms, drying seems to be an effective approach to extend shelf life and ensure distribution.

Conventional hot-air drying is considered as a comparatively simple, economical and efficient method to extend the shelf life of mushrooms. It involves thermal or chemical treatment prior to drying and an operational temperature range between 50 and 80 ºC. In practice, to avoid darkening of the mushroom surface during hot-air drying, a two phase-drying process is employed starting with 30 ºC or 40 °C followed by a final temperature of 60 ºC. Freeze drying is frequently applied to materials that are prone to heat damage and produces products with excellent structural characteristics, nevertheless, being a costly process (Lin *et al.*, 1998). Microwave-vacuum drying offers an alternative way for obtaining high-quality dried products. This method generates very rapid heat and mass transfer resulting in quick drying at low temperature. Recently microwave-vacuum drying was combined with conventional hot-air drying to sharply reduce drying time, optimize energy efficiency and improve product quality (Zhang *et al.*, 2006). When dealing with very sensitive materials in temperature such as mushrooms, the choice of the right drying method can be the key for developing dried products of superior quality (Giri & Prasad, 2006).

The quality of dried mushrooms is determined by combination of factors, but most properties or characteristics depend on consumer preference. Colour and texture are two of the most important quality parameters that influence consumer acceptance. Furthermore, the rehydration ability of the dried product is considered to be a critical parameter indicating the degree of the damage to the material caused by physico-chemical treatments (Okos *et al.*, 1992; McMinn & Magee, 1997; Krokida & Marinos-Kouris, 2003). In industry, the proper quality of mushrooms can be maintained by inhibiting adverse changes in colour or structure of the fruit bodies.

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Solutions with potassium metabisulfite and/or citric acid prior to drying are frequently used for mushrooms to prevent enzymatic or non enzymatic browning (Singh *et al.*, 1995; Walde *et al.*, 2006; Bernaś *et al.*, 2006).

The aim of this work is to investigate the effect of drying parameters and material size in order to analyse the optimum conditions for mushroom drying taking into consideration not only the drying behaviour but also the quality of the dried product. Additionally, it is intended to compare quality attributes of conventional hot-air dried mushrooms with samples obtained by freeze drying and combined microwave-vacuum with hot-air drying.

Material and Methods

Raw Material

Fresh button mushrooms (*Agaricus bisporus*) were purchased from the local market in Stuttgart, Germany and stored at 2 ºC and 90% relative humidity in a refrigerator for about three days. The mushrooms were selected according to their size and characteristic shape and cleaned thoroughly to remove adhering soil. Slices of the desired thickness were obtained by cutting mushrooms vertically with an electrical vegetable slicer. Prior to drying, about 500 g of mushroom slices were immersed in a solution of 0.25% potassium metabisulfite and 0.1% citric acid for 5 min at room temperature. Then they were immediately weighed and distributed on a perforated stainless tray and placed in the drying chamber. For freeze drying, treated mushroom slices of 5 mm thickness were frozen at -25 ºC for 24 hours. The initial and final moisture content of the mushrooms was determined by drying a constant weight in an atmospheric oven at 103 ± 2 ºC for 24 hours and replicated three times.

Drying Equipment

Thin layer laboratory hot-air dryer
The hot-air drying experiments were carried out using a laboratory through flow dryer designed in the Institute of Agricultural Engineering at Hohenheim University, Stuttgart, Germany (Guarte *et al.*, 1996), which ensured the control of the desired drying conditions over a wide range of operating parameters.

Freeze dryer
For freeze drying, a laboratory freeze dryer at the Institute of Food science and Biotechnology at Hohenheim University was used. The operation pressure was set at 1 mbar (100 Pa) with chamber temperature of 20 ºC and condenser temperature of -50 ºC.

Microwave-vacuum dryer
The 2.45 GHz microwave-vacuum dryer with a maximum power of 4 kW was designed by Heindl GmbH, Mainburg and used in the experiments. Apart from microwave heating an alternative heating source (plates) was included in the installation and controlled at a maximum temperature of 80 °C.

Drying Procedure

Mushroom samples of slice thicknesses 2, 5 and 10 mm were dried under actual industrial air drying temperatures by employing single and two-phase drying at 60, 80, 80/60 and 30/60 °C maintaining the absolute humidity at 10 $g \cdot kg^{-1}$ (T_{DP} = 13 °C). Also, trials were carried out at 15 and 20 $g \cdot kg^{-1}$ absolute humidity maintaining a temperature of 60 ºC to examine the effect of relative humidity. The level of air velocity was kept constant at 0.9 $m \cdot s^{-1}$. The system was warmed up for 60 min to achieve constant drying conditions for the desired set points. During the drying process, the weight loss was recorded at 10 min intervals for determination of drying curves. The initial moisture content of treated samples was about 94% ± 0.5 wet basis. Drying was terminated when 6% ± 0.5 wet basis of moisture content was reached. The dried mushroom slices were cooled, packed in aluminium coated polyethylene bags and stored in ambient conditions for further analysis.

Sliced mushrooms of 5 mm thickness were also subjected to freeze drying and combined drying of hot-air (temperature of 60 ºC, relative humidity 7.7%, air velocity 0.9 $m \cdot s^{-1}$) until the moisture content reached 45% wet basis followed by microwave-vacuum drying to the final moisture content of 6% wet basis (65 g sample: the microwave power level was 100% for 1.5 min, followed by 50% power level for 1.5 min, followed by 20% power level for 3 min, and finally 8% power level for 4 min at a constant vacuum of 60 mbar with temperatures above 50 °C). During the last drying stage on plates at 75 °C for 170 min, followed by drying at 60 °C for 10 min, and finally cooling at 24 °C for 30 min, the vacuum was maintained at 25 mbar. The alternative drying applications were used as a reference for quality evaluation.

Quality Evaluation of Dried Mushrooms

Colour Measurement
The colour of dried samples was evaluated by a Minolta Colorimeter (CR-300 Minolta Co., Japan) and expressed as L^* (whiteness/darkness), a^* (red/green) and b^* (yellow/blue). The instrument was calibrated with a standard white tile using D_{65} illumination before the measurements (Y=85.8, X=314, Y=331). One reading was made per mushroom slice by placing the colorimeter head directly above the cap. The mean of 10 replicates was taken for each experiment.

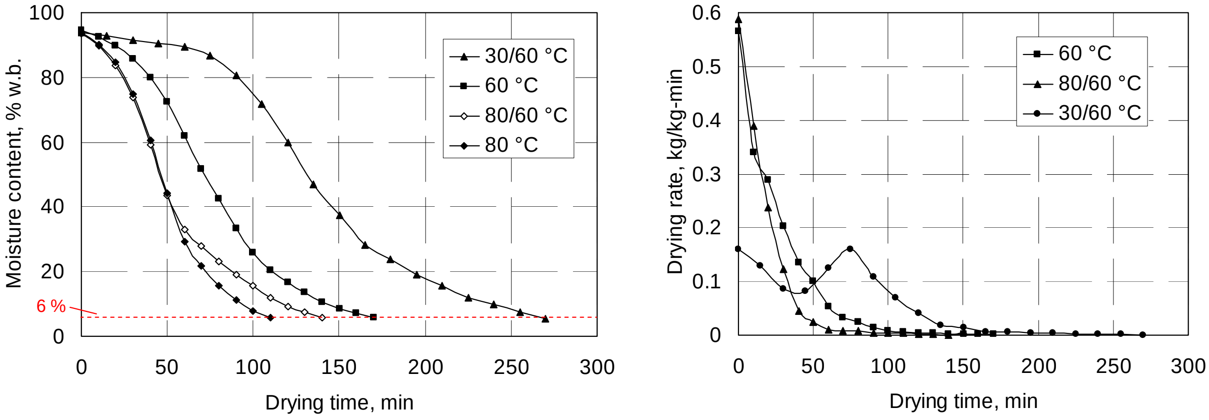
Texture Measurement
The texture was measured using a texture analyzer Instron universal testing machine (Model 4301). The analyzer was connected to a computer that records and analyses the data via the software program series 9. An 85 mm diameter compression plate was used to compress the rehydrated mushroom slices. The pre-speed of the probe and the post-speed was fixed at 100 mm/min and 0 mm/min respectively. The test speed was maintained at 300 mm/min during compression. The maximum shear-force required for cutting an individual mushroom slice was considered as the texture indicator of the rehydrated product. The mean value of 5 replicates was taken.

Rehydration ratio
The rehydration ratio of dried mushroom slices was determined by soaking samples with a defined weight (approx. 5 g) in boiling distilled water (1000 cm^3) for 15 min. The samples were removed, dried off with tissue paper and weighed. The water absorbed (g) divided by the dry sample weight (g) is expressed as the rehydration ratio.

Results and Discussion

Effect of air temperature on drying behaviour

Figure 1 (a) shows that the drying time decreases substantially with the increase in temperature of the drying air. This can be explained by the increased heat transfer potential between the air and the mushroom slice enhancing the mass transfer within the sample and the evaporation of the water from its surface. Figures 1 (b) shows the changes in drying rate as a function of drying time. The highest drying rate was obtained at 80/60 °C indicating faster removal of water at the beginning of the drying process. As the mushroom drying progressed the drying rate of this was then lower than the others.

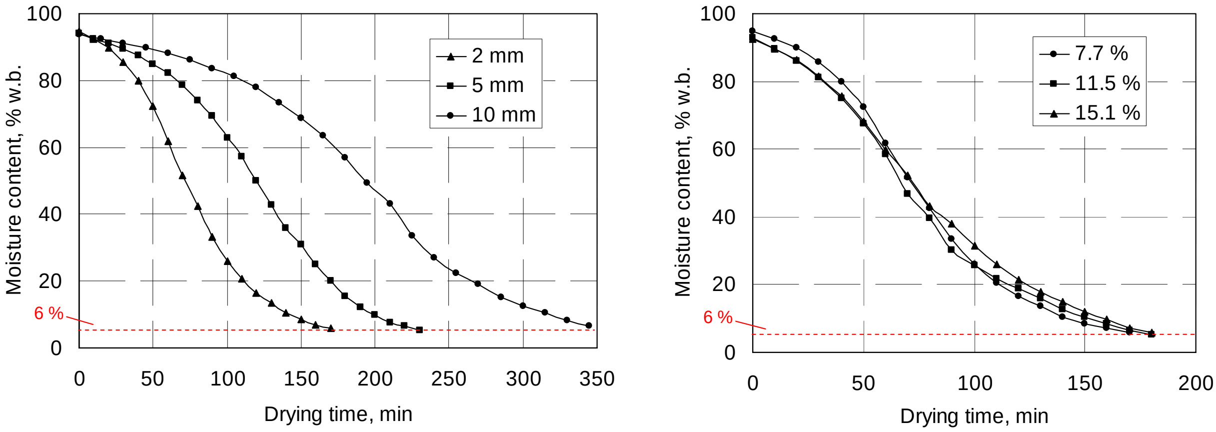


(a) (b)

Figure 1 (a) Drying curves for mushrooms at different air temperatures
(b) Drying rate curves for mushrooms at different air temperatures
(d=2mm, T_{DP}=13°C, v=0.9ms^{-1})

Effect of slice thickness and relative humidity on drying behaviour

The effect of slice thickness is depicted in figure 2 (a). Obviously, the drying time increases significantly as the slice thickness of mushroom increases. At the same drying time the thinner samples represented a more rapid moisture removal and steeper curves. The thinly sliced mushrooms dried faster compared to thick slices at all selected temperatures due to the decreased diffusion path for moisture migration within the sample.



(a) (b)

Figure 2 (a) Effect of sample thickness on air drying of mushroom (T=60°C, T_{DP}=13°C, v=0.9ms^{-1})
(b) Effect of relative humidity on air drying of mushroom (T=60°C, v=0.9ms^{-1}, d=2mm)

Figure 2 (b) shows that the total drying time was not affected by the examined range of relative humidity. Similar results were also obtained by Krokida *et al.*, (2003). It was found that the drying process of different vegetables including mushrooms was accelerated when the relative humidity is reduced from 40 to 20 %.

Colour

The highest possible value of L* is considered as the benchmark in industry for the colour quality of dried mushrooms (Mau *et al.*, 1991; Martinez-Soto *et al.*, 2001). Samples subjected to hot-air drying indicated that discolouration was greater in the samples dried at higher temperatures. The main factor causing colour changes during hot-air drying is enzymatic and non-enzymatic browning reactions. Lowering the drying air temperature in the first phase of drying resulted in lower thermal stress on the surface and a higher whiteness index (figure 3).

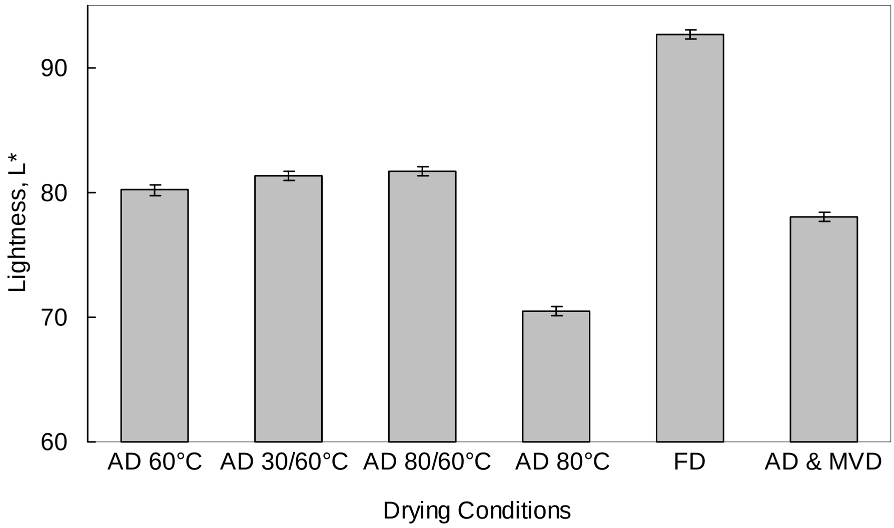


Figure 3 Mean value of lightness (± standard error) of mushrooms dried by three methods

Samples dried by conventional hot-air and combined drying of microwave-vacuum and hot-air were significantly darker than the freeze dried ones because of exposure to heat during drying. Freeze dried mushrooms had the brightest whiteness. The highest degree of lightness can be attributed to the absence of Maillard reactions due to the combined action of freezing and reduced oxygen quantities present during the process.

Texture

The mean cutting force of the samples subjected to three different drying methods is shown in figure 4. The air temperature had significant effect on texture and samples dried by two phase drying at lower initial temperatures were softer.

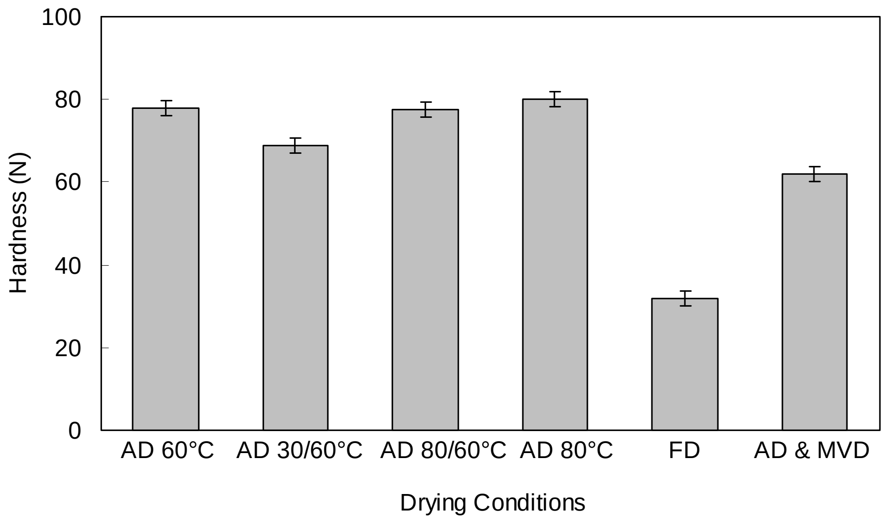


Figure 4 Mean cutting forces (± standard error) of rehydrated mushrooms dried by three methods

It is apparent that freeze dried mushroom slices were the softest while the samples dried by hot-air were the hardest. Hot-air drying probably caused heat damage and collapse of the internal mushroom structure throughout the drying process affecting adverse quality characteristics like texture. Combined microwave-vacuum and hot-air drying creates a more porous structure of the samples due to quick microwave heating that causes rapid evaporation of water and diffusion out of the tissue, while the vacuum facilitates water evaporation at a lower temperature. In freeze drying the ice is sublimed producing materials with fragile structure and tender texture.

Rehydration ratio

The results for the rehydration ratio are shown in figure 5. Mushrooms dried by hot-air at lower initial drying air temperatures were found to have greater rehydration ratio as compared with the sample dried at higher initial temperatures. At lower temperatures, less cellular destruction and dislocation occur thus, the material is capable of absorbing more water.

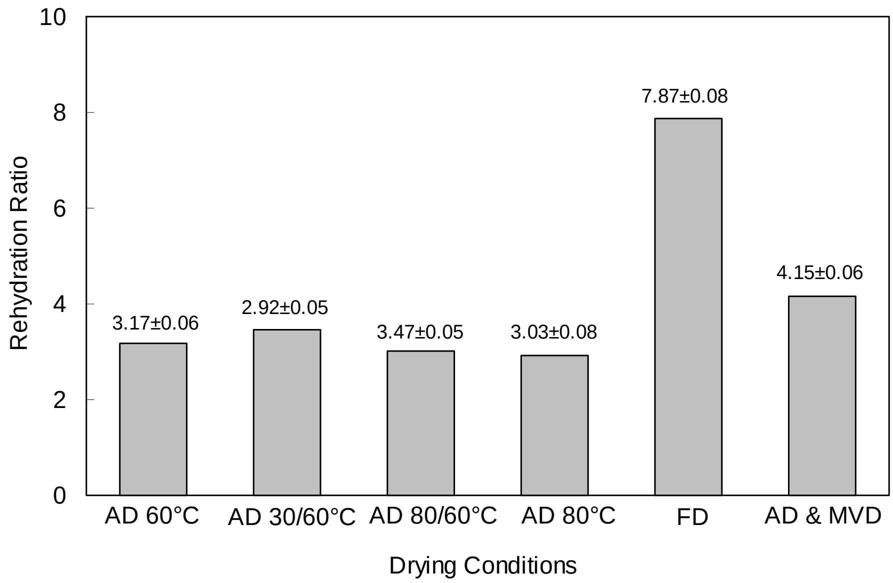


Figure 5 Mean rehydration ratio (± standard error) of mushroom slices dried by three methods

The most favourable rehydration ability was observed in freeze dried samples. This is because of the porous structure and non-shrunken cells that the solid state of water creates when it sublimes during freeze drying, protecting the primary structure and the shape of the products with minimal reduction of volume (Ratti, 2001). Furthermore, the mushroom slices dried by combination of hot-air and microwave vacuum exhibited a higher rehydration ratio than that dried completely by hot-air. This can be ascribed to the fact that the tissue cells were partially expanded and puffed due to high internal vapour pressure produced by microwave heating under vacuum.

Conclusions

The air temperature and slice thickness were significant factors affecting the hot-air drying characteristics of mushrooms. The effect of the observed range of relative humidity was insignificant. Two-phase drying at lower initial temperature resulted in a lighter slice colour, softer in texture with good reconstitution. Freeze drying produced dried mushroom slices of superior quality exhibiting the highest lightness, lowest hardness and maximum rehydration ratio. Samples dried by combination of hot-air and microwave-vacuum indicated improved quality parameters as compared to samples dried exclusively by hot air. In particular, the combined technique developed a dried product of puffed texture which could be considered as an important characteristic for manufacturing a snack type product.

Acknowledgment

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