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Alternate microwave and convective hot air application for rapid mushroom drying

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ABSTRACT

The objective of the study was to develop an integrated drying system for optimal drying of button mushroom. Microwave (MW) was decided to be applied alternatively with convective hot air. Judicious application of microwave was decided by analysing the slope of the drying curves at every 10, 20 and 40 min of convective drying. The optimal time of MW application was found to be 20 ± 3 min based on minimum drying time and better quality attributes. The experiments were then performed on slice thickness of 2.5, 5 and 10 mm under optimal conditions (MW at 21st, 42nd, 63rd and 84th min of drying) and compared with conventional hot air drying in terms of drying kinetics, colour, water activity and rehydration ratio. The optimum thickness was found to be 2.5 mm which met the quality standards of commercial dried mushroom in relatively shorter time (72 min).

1. Introduction

Mushroom, one of the most popular and a valuable edible fungus is highly appreciated in human diet because of its delicacy, texture and nutritional value. There has been a tremendous increase in production and consumption of mushrooms in last few years mainly due nutritional significance and awareness among farmers about the commercial value of this commodity (Singh et al., 2008). Analysis of fresh button mushroom shows that it contains 90–95% moisture, 1.8–2.1% crude protein, 1.5–3.3% crude fibre, 0.41–0.78% ash, 4.5–5.8% carbohydrates and 0.31–0.35% fat (wet basis) (Mattila et al., 2002). Button Mushroom (*Agaricus Bisporus*), the most popular mushroom variety grown and consumed are highly perishable with shelf life of about 24 h at ambient and 5–7 days under refrigerated conditions (Motevali et al., 2011). Among the various techniques employed to extend the shelf life, drying is the most frequently adopted preservation method in the commercial space. Dried mushrooms are used as an important ingredient in the broad range of food formulations, such as instant soup premix, snack seasoning, stuffing, pasta, pizza, salad, rice dishes, etc (Dehkordi, 2010). Application of drying techniques to enhance the shelf life and maintain the quality of the produce in a cost effective manner plays a significant role from commercialization viewpoint.

Several drying processes for mushrooms have been investigated (Riva et al., 1991; Loch-Bonazzi, 1994; Seyhan and Evranuz, 2000; Kar and Gupta, 2001; Giri and Prasad, 2007; Jambrak et al., 2007; Shukla and Singh, 2007; Argyropoulos et al., 2011). Drying using convection dryers (hot air) is the most adopted technique on a global scale. As pointed out by many researchers, exposure to higher temperatures for longer durations cause serious damage to the flavor, color, volatile concentration (from 4500 to 200μg/100 g) and nutrients of the dried mushroom (Kotwaliwale et al., 2007; Politowicz et al., 2017) and also a very energy intensive operation. To prevent significant quality loss, and achieve fast and effective thermal processing new technologies such as infrared, microwave, ultrasonic and radiofrequency have been evaluated by various researchers at a great length.

Application of microwave (MW) is becoming more popular in food drying, since it selectively heats the product and reduces drying time substantially (Soysal et al., 2006). However, it is known to result in a poor-quality product (e.g. charred edge, over-oxidation) if not properly applied (Drouzas and Schubert, 1996). Continuous exposure of MW during microwave assisted drying leads to creation of localized hot spots within the product especially when product geometry is not well defined. Hence, it is prudent to combine MW with other drying techniques such as hot-air, vacuum, etc to achieve more uniform, fast and effective drying without significant quality loss (Wang et al., 2004). Microwave along with hot air is usually employed either in series or combinations for drying of food (Shaheen et al., 2012). Using MW intermittently

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showed improvement in energy efficiency when compared with continuous microwave/convective drying operations. Intermittent drying is accomplished either by controlling the intensity of thermal energy or by varying the mode of energy input (e.g., convection, conduction, radiation, or microwave).

The most common type of intermittency investigated so far is on/off strategy, where heat source is periodically turned on and off (Kumar et al., 2014). Various researchers reported the intermittent microwave-convective drying (IMCD) of oregano, carrot, sage leaves etc (Soysal et al., 2009; Zhao et al., 2014; Esturk, 2012) and found that IMCD provided the best quality with best colour, highest rehydration rate, α- and β-carotene contents with lowest drying time and energy consumption when compared with continuous convective drying. Almost in all the cases, it has been proved that intermittent application of MW energy is promising because of the lowest drying time which translates into relatively low energy consumption. Crucial component of intermittent drying process is to choose microwave application time or else the arbitrary selection may result into a more expensive process. Such strategy has to be decided based on the product properties and drying characteristics. Otherwise, expected optimum energy efficiency and product quality improvement will not be attainable. To the best of our knowledge, there is no published report on strategically using microwave and hot air alternatively for mushroom drying. The objective of the study is to develop an integrated drying system i.e. application of microwave and hot air alternatively (AMCD) for optimal drying of button mushroom and to evaluate its quality attributes.

1.1. Theory behind the developed process

Initially when moisture content is high, drying is comparable to an open faced water body. Diffusion of moisture from within maintains saturated surface conditions and as long as these last, evaporation takes place at constant rate. As when surface water dries up, moisture gradient begins to develop. Thus, drying rate decreases with time (onset of falling rate period). Since convective drying is a surface phenomenon, drying rate decreases significantly during the later stages as samples do not contain sufficient surface moisture. Continuous exposure to hot air for prolonged period results in quality degradation and wastage of heat energy. Thus, it is logical and evident from literature that applying MW and hot air alternatively during drying process would help bring the internal moisture to the surface and subsequently convective drying would sweep away surface moisture. Such approach would allow redistribution of temperature and moisture within the product and in turn help improve the product quality by minimizing warping and case hardening effects on product. Constant and falling rates are not very well defined in real life situation due to heterogeneity of the material. In order to optimize the drying process, it is necessary to understand the fundamental mechanisms of water transport in the given system.

Our hypothesis was that microwave application as an intermittent drying method would be very effective if time of onset of falling rate period in a convective drying is known. Short exposure of microwave during this time, would be appropriate to bring core moisture to the surface, which would necessitate convective drying and remove surface moisture easily. This cycle should go on until desired moisture level of the product is reached. Experimental validation of the hypothesis has been presented in section 4.2.

2. Materials and methods

Fresh button mushrooms (*Agaricus Bisporus*) procured from the local market were used for the experimentations. Samples were subjected to successive steps of washing (to remove the dirt and dust), sorting (to eliminate the variations in exposed surface area) and then slicing. Cap (pileus) of the mushrooms with the approximate size of 150 mm width were selected and used in the drying experiments. Slices of desired thickness were obtained by carefully cutting mushrooms vertically with a knife and the slices from middle portions with characteristics mushroom shape were used for drying experiments.

2.1. Proximate composition analysis

Button mushroom was analyzed for the composition (moisture, proteins, fat, carbohydrates and ash) according to the Association of Official Analytical Chemists (AOAC, 1995). The moisture content was determined by drying in a hot air oven at 100±5 °C to a constant weight. In this study, the average initial moisture content of the slices ranged from 92% to 95% (wet basis). The crude protein content was estimated by the macro-Kjeldahl method using a conversion factor of 4.38 (Shin et al., 2007). The crude fat was determined by extracting a known weight of powdered sample with petroleum ether using a Soxhlet apparatus. After the crude fat analysis, the samples were used to investigate the crude fibre content by sequential extraction of the sample with 1.25% H_2SO_4 and then 1.25% NaOH. After the digestions, the samples were dried and used to determine the ash content by incineration at 550 ± 5 °C. The carbohydrate content was calculated from the sum of the percentages of moisture, crude protein, ash, fat and crude fibre subtracted from 100.

2.2. Drying experiments

Mushroom slices of 2.5, 5 and 10 mm thickness and uniform shapes were dried to a final moisture content of about 10% (wet basis) by applying MW and hot air alternately throughout the process. Prior to drying, samples of approximately 100 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 (Argyropoulos et al., 2008). After soaking for 5 min in 0.25% KMS and 0.1% citric acid, water was drained and mushroom was kept at room temperature for 1 h to establish equilibrium. Then moisture content was measured and increase in moisture was noted. Observed change was 1–2% which was used throughout the study. The experiments were conducted at MW power level of 120 W and drying air temperature of 60 °C. Microwave power level of 120 W was selected for the present study. Based on the results of our preliminary experiments i.e. when mushroom was subjected to MW heating at 120, 240 and 360 W, excessive browning and shrinkage of the product was observed at higher power levels. The temperature of hot air was kept at 60 °C during the process, as higher drying temperature (i.e.70 °C) resulted in poor product quality and heat damage to the surface. The lower drying air temperature i.e. 50 °C corresponds to longer drying time, there by which resulted in higher energy consumption (Das & Kumar, 2013). The velocity of the drying air was kept constant as 1.0 ± 0.2 m/s. The pre-treated mushrooms with a moisture content of 90–95% (wet basis) were dried by applying microwave for 60s and hot air for 20min alternatively till it reached 10% moisture content which is considered ideal for safe storage. The drying experiments were replicated three times for each drying method. The dried mushroom slices were cooled and kept in air tight polyethylene bags and stored at ambient conditions for further analysis i.e. rehydration ratio, colour, specific energy consumption and water activity.