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Research Article

Effects of Puffing and Dehydration of Maitake *(Grifola frondosa)* Slices by Pulsed-microwave Vacuum Puffing

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Abstract: In order to investigate the puffing and dehydration characteristics of maitake (Grifola frondosa) under Pulsed-Microwave Vacuum Puffing (PMVP) conditions, PMVP experiments were conducted. The effect of vacuum pressure (-60±1.5, -70±1.5, or -80±1.5 kPa), microwave power intensity (75, 150, or 225 w/g), the initial moisture content (50±1.0%, 45±1.0%, 40±1.0%, 35±1.0%, or 30±1.0%) and pulse ratio1.2 on dehydration rate, expansion ratio and sensory score were determined. Moreover, a mathematical model and correlation coefficients for the dehydration rate and expansion ratio of maitake mushrooms with moisture content was established for three microwave intensities. Puffing of samples showed that the microstructures of the maitake slices quickly formed a porous structure during the volume expansion stage and the hardness increased then suddenly decreased. These results are useful for the industrial scale production of high-quality maitake products.

Keywords: Characteristics, Maitake (*Grifola frondosa*), mathematical model, microstructures, pulsed-microwave vacuum puffing

INTRODUCTION

Maitake (*Grifola frondosa*), also known as Bayesian polypore, chestnut mushroom, mushroom cloud and lotus bacteria, is a polypore belonging to the fungi phylum basidiomycetes. This edible fungus can be used as medicine or food (Shin and Lee, 2014; Cao *et al*., 2003) and is widely used as a culinary material and dietary supplement in Asia because of its enticing taste and nutritional value (Tsao *et al*., 2013; Hong *et al*., 2013). Maitake is rich in vitamins C, D_2 and B_2, as well as, Mg, P, Ca, dietary fibers and amino acids (Cao *et al*., 2003). Maitake displays physiological activities including antitumor activity (Tsao *et al*., 2013), antioxidant activity (Shin and Lee, 2014), hypotensive effects (Talpur *et al*., 2002), hypoglycemic effects (Mau *et al*., 2004) and immune-stimulating effects (Chen *et al*., 2012). Fresh maitake mushrooms are easily deteriorated because of their high moisture content and rich nutrient content. Dehydration is a feasible method of preserving various perishable foods (Zheng *et al*., 2012); however, the properties of these mushrooms mean that long cooking times are required to soften maitake, which limits its culinary uses.

Consumers highly prize snack foods that are crispy, puffy and delicious (Liu *et al*., 2009). Microwave technology can provide thermal energy for drying and speed up the vacuum drying process (Krulis *et al*., 2005). Moreover, microwave-vacuum drying can be used to create a desirable, crispy texture for dried foods, such as snack foods, that can be consumed without the need for rehydration (Bai-Ngew *et al*., 2011). During the Microwave-Vacuum Puffing (MVP) process, microwave energy absorbed by the water molecules in the material generates thermal motion of the water molecules. Because of the thermal motion and the vacuum environment, water evaporates rapidly at a low temperature. With the increasing of the kinetic energy of the water molecules, water molecules generate discrete when the kinetic energy of water molecules power than the molecules mutual attraction. The phase change of the water molecules in the material to form water vapor has an impact on the internal structure of the material. When the effect exceed the power of material support of space structure of high polymer material, the water molecules can cause the internal spatial structures of the material to deform, which causes expansion and internal gaps and eventually results in porous puffed materials (Ressing *et al*., 2007; Huang *et al*., 2011). MVP has been found to be a suitable method to obtain high-quality snack food products from heat-sensitive foods, such as cereal grains, fruits and vegetables (Zheng *et al*., 2013; Qiao *et al*., 2012; Wojdylo *et al*., 2009).

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Moreover, Pulsed-Microwave Vacuum Puffing (PMVP) can be used to intermittently equilibration and redistribute moisture and temperature throughout materials, which improves the quality of dried materials while drying them faster and effectively controlling the temperature of heated materials (Gunasekaran, 1999). PMVP has previously been shown to be more energy efficient than continuous MVP (Gunasekaran, 1999; Liu *et al*., 2014).

However, the properties of puffed materials, the puffing and dehydration ratios, are different from those of the different materials (Qiao *et al*., 2012). It is important to determine the effects of microwave energy on the quality of the material following the PMVP process. There are few published reports on the effects of the parameters of the PMVP process on puffing mushrooms. Therefore, the objective of this study was to determine the puffing behavior and product quality of maitake (*G. frondosa*) with various moisture contents under different PMVP conditions. The puffing behavior examined included volume expansion, dehydration rate, hardness change and microstructure of the puffed material. A tentative mechanism for volume expansion and dehydration rate related to the removal of moisture has been proposed. The results of this study will be useful to obtain highly palatable maitake snack foods using the PMVP process.

MATERIALS AND METHODS

Material preparation: Fresh maitake mushrooms were obtained from the local market. The maitake were finely coloured, free of disease, pests and mechanical damage. The initial moisture content of the maitake was 89±1.5%. Prior to the experiments, the maitakes were taken from the refrigerator (stored at 4°C) and kept under ambient conditions for 2 h until they reached room temperature (Sham *et al*., 2001). The maitakes were then washed in tap water. The dendritic cap (length 5 cm and width 3 cm) and stipe were separated and the stipe was discarded. Millet was also procured to measure maitake expansion ratio.

After blanching, the maitake was placed in an electric thermal dryer (Type-101-2, Shanghai Boxun Experimental Apparatus Co., Ltd., Shanghai, China) and dried at a constant temperature (40°C) to obtain the required initial moisture content of the material.

Moisture content of mushrooms: The initial moisture content of the predehydrated and samples mushroom caps was measured and calculated using infrared moisture meter (KETT FD720, Japan).

Pulsed-microwave vacuum puffing equipment: A microwave-vacuum dryer (cNWB-3ZK, Guangzhou Wancheng Microwave Energy Co., Ltd., Guangzhou, China) was used to puff the maitake mushroom slices (Zheng *et al*., 2013). The equipment consisted of three 0.7 kW magnetrons installed on top of a drying chamber, three rotating baskets to hold polytetrafluoroethylene trays, a vacuum pump and a venting system. The vacuum in the chamber was set in the range 0-100 kPa.

Experimental design and procedure: The microwave power, vacuum pressure and initial moisture content were selected as independent variables. The expansion ratio, moisture content, sensory evaluation and hardness were assigned as response variables. Based on the results of preliminary experiments, the experimental design consisted of a pretreatment of boiling for 3 min, followed by placement of the maitake mushroom on a 12 cm glass plate for thin layer puffing. Experiments examining the effect of microwave intensity were carried out using the following conditions: initial moisture content: 40±1.0%; microwave intensity: 75, 150 and 225 W/g; vacuum pressure: -60±1.5 kPa; According to the results from preliminary experiments (pulsed ratio: 1.1, 1.2, 1.3, 1.4), the independent experimental variable of pulsed ratio and levels were determined: (Cycle power on time+Cycle power off time) /Cycle power on time), 1.2. Experiments examining initial moisture content were carried out using the following conditions: Initial moisture content: 50±1.0%, 45±1.0%, 40±1.0%, 35±1.0% and 30±1.0%; microwave intensity: 150 W/g; vacuum pressure: -70±1.5 kPa; pulse ratio1.2. Experiments on the effect of vacuum pressure were carried out using the following conditions: initial moisture content: 40±1.0%; microwave intensity: 150 W/g; vacuum pressure: -60±1.5, -70±1.5 and -80±1.5 kPa; pulse ratio 1.2. The expansion rate, dehydration rate and moisture content of the samples were measured over time. The final moisture content of the puffed mushroom samples was 7±1.0%. The puffed maitake samples were stored in an airtight plastic bag for the further analysis. All experiments were conducted three and all data was determined in triplicate.

Pretreatment for enzyme inactivation: Samples of maitake (each sample contained 200 g of maitake slices) were boiled in water for 0, 1, 2, 3, 4, or 5 min and then quickly cooled in water to below 5°C (Matilla *et al*., 2002). Polyphenol Oxidase (PPO) and Peroxidase (POD) were extracted from the cooled maitake samples after being ground and their activity curves were plotted. The methods used to extract these enzymes and measuring the PPO and POD activity were the pyrocatechol and guaiacol colorimetric methods, respectively (Long and Alben 1969; Vámos-Vigyázó, 1981).

Expansion ratio: A method of displacing millet (Zhang *et al*., 2007) was used to measure the volume of the maitake slices and their expansion ratio was calculated using Eq. (1):

$$ER\ (\%) = V_2/V_1 \times 100\% \tag{1}$$

where,
ER = The expansion ratio (%)
V_1 and V_2 = The volumes of the maitake before and after puffing, respectively.

Dehydration rate: Under the condition of PMVP, the dehydration rate of maitake is defined as the difference in the moisture content of the sample over the sampling time interval (Zheng *et al*., 2013) and is calculated using Eq. (2):

$$y = (X_{i+1}-X_i)/t \tag{2}$$

where,
y : Dehydration rate, (g (100 g/s))
X_{i+1} and X_i : The respective moisture contents of sample (g/100 g)
t : The sampling interval time (s)

Sensory evaluation: The samples with the highest expansion ratio in each batch were subjected to sensory evaluation by a semi-trained panel of 40 people (20 males and 20 females). The panel was selected from among the students in the graduating class and the staff members of the Food Engineering Department (Hebei Normal University of Science and Technology, Qinhuangdao, China), all of whom have experience in the sensory evaluation of puffed snack foods. The panelists used a 7-point hedonic scale (from 1 = dislike very much to 7 = like very much) to evaluate the color, flavor, appearance and texture of the puffed maitake. Samples of the maitake coded with three-digit numbers were given in a random order to the panelists after the training orientation (Altan *et al*., 2008).

Hardness measurement: The hardness of the puffed maitake was measured using a TA-XT2i texture analyzer (Texture Technologies Corp., Scarsdale, NY, USA). The mean peak compression forces expressed in Newton were used to measure hardness. The test parameters were as follows: pre-speed and post-speed of 3.0 mm/s, test speed of 0.5 mm/s, a distance of 30% strain (i.e., penetration depth) and a 0.1 N trigger. Force-time curves were recorded and analyzed using the Texture 32 software program (version 3.0, Texture Technologies Corp.). Five measurements were performed on each sample to obtain the average hardness for each sample.

Scanning electron microscopy: To evaluate the effect of puffing on the structure of the maitake samples, images of three samples were obtained using a scanning electron microscope (KYKY-2800, Zhongke, Beijing, China) operated at a 2.0 kV acceleration voltage. The samples were coated with gold in order to provide a reflective surface for the electron beam. The gold-coated samples were subsequently viewed under the microscope and were observed at 100 and 200×magnification (Sowbhagya *et al*., 2008; Nath and Chattopadhyay 2008). The conditions of maitake puffing for these samples were initial moisture content: 40±1.0%; microwave intensity: 150 W/g; vacuum pressure: -70±1.5 kPa, pulse ratio1.2.

Statistical analysis: All the analyses were performed in triplicate and are shown as mean±standard deviation (SD). Duncan's multiple range tests ($p<0.05$) were performed using SPSS (IBM SPSS Statistics, IBM Corp., USA, Version 17.0).

RESULTS AND DISCUSSION

Enzyme inactivation: Blanching in boiling water causes starch gelatinization and is not only beneficial for maitake mushroom expansion, but also can result in PPO and POD inactivity in the cells. The blanching process can thus prevent enzymatic browning in order to protect the colour of the maitake samples. In Fig. 1, blanching for 3 min decreased PPO and POD to 15.78 U/g and 5.33 U/g, respectively. After 3 min, there was no significant change in enzyme activity ($p<0.05$). Bottcher (1975) indicated that vegetables have better quality if a small amount of POD activity was present after hot processing and that no residual POD activity indicates excessive hot processing. Therefore, to retain more nutritional value, the maitake samples were processed by boiling for 3 min and the residual PPO activity was 4.9% and the POD activity was 6.6%.

Microwave power intensity effect on puffing process:

The effect of microwave power intensity on the dehydration rate of maitake: Changes in the dehydration rate, expansion ratio and sensory

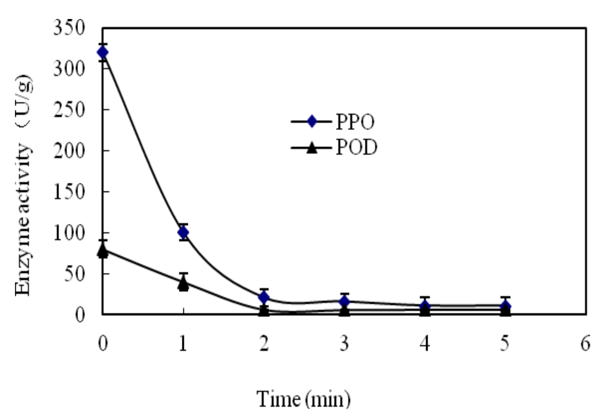
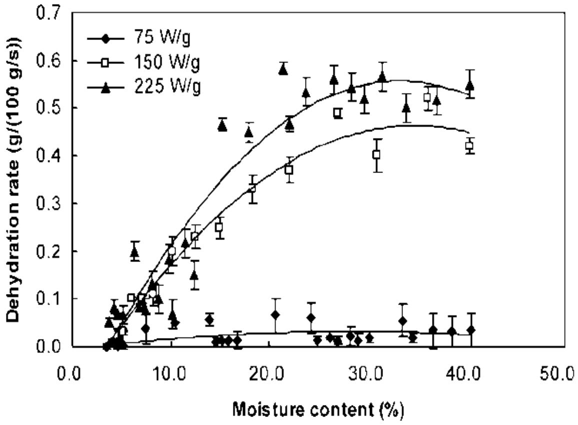
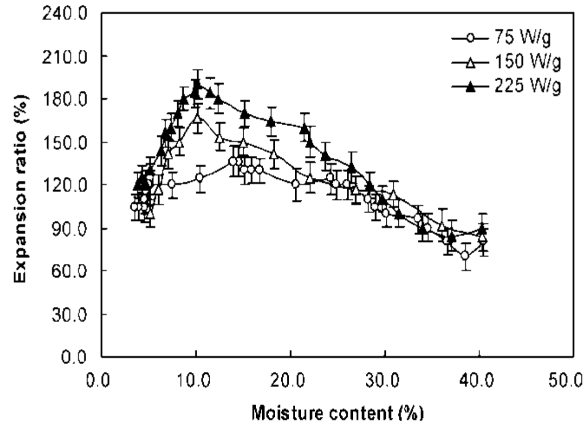


Fig. 1: Changes in PPO and POD enzyme activity with boiling time



(a)



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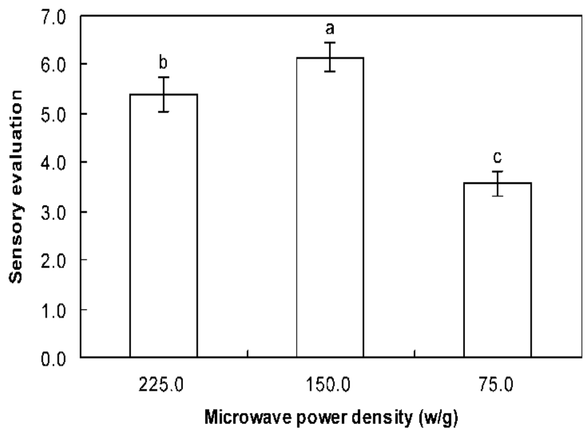


(c)

Fig. 2: Effect of microwave power intensity on puffing characteristics; (a): dehydration rate; (b): expansion ratio and; (c): sensory evaluation (initial moisture content: 40±1.0%; vacuum pressure: -60±1.5 kPa; pulse ratio 1.2. values bearing different lowercase letters (a–c) are significantly different (Duncan, $p<0.05$))

evaluation of the maitake slices during the PMVP process are presented in Fig. 2. In Fig. 2a, an increase in the microwave power intensity from 75 to 225 W/g enhanced the dehydration rate. This result is in agreement with those reported for berry slabs (Zheng *et al*., 2013). Increased microwave power and moisture content are usually accompanied by an increase in dielectric properties of the samples. An increase in the dielectric properties also improves the ability of a sample to absorb microwave energy, which can accelerate the dehydration rate of the sample (Zheng *et al*., 2013; Giri and Prasad, 2007). The drying kinetics of the maitake was similar at microwave power intensities between 150 and 225 W/g, which is a result of a non-significant difference in the loss tangent of the samples. Thus, the efficiency of converting the microwave energy into thermal energy was similar (Bai-Ngew *et al*., 2011). At a microwave power intensity of 225 W/g, a fluctuating trend was observed in the dehydration rate ($p<0.05$). The variation may be attributed to removal of surface water from the maitake as the dehydration rate increased, until a dry spot occurred (Zheng *et al*., 2012). At a microwave power of 75 W/g, the dehydration rate was significantly lower than that of the other two powers studied ($p<0.01$) and this power the dehydration rate is not significant ($p>0.05$). At the beginning of the puffing process, the dehydration rate of the maitake increased until the moisture content was about 30% and then decreased quickly. Therefore, initially when the sample has a moisture content of 40%, more microwave energy can be absorbed and converted into heat energy to make water vapor and cause tissue expansion; this accelerated dehydration process occurs until 30% moisture content. The dehydration rate curves, can be described by a parabolic regression equations with three factors ($R^2>96.6\%$ at $p<0.05$) (Table 1). It was found that the constant a_1 had negative correlation to the microwave power, but coefficient c_1 and b_1 had positive correlation.

Table 1: Regression model and coefficients for the dehydration rate (y) of puffed maitake (*G. frondosa*) as a function of moisture content (X) at three microwave power intensities

	$y = a_1+b_1X+c_1X^2$			
Microwave power (W/g)	a_1	b_1	c_1	R^2
75	-0.0044	0.0042	8.6105	0.9660
150	-0.1027	0.0373	0.0006	0.9848
225	-0.1023	0.0371	0.0005	0.9715

Table 2: Regression model and coefficients for the expansion ratio (y) of maitake (*G. frondosa*) as a function of moisture content (x) at three microwave intensities

	$y = (a+bx)/(1+cx+dx^2)$				
Microwave power (W/g)	a	b	c	d	R^2
75	10.3202	3.4368	-0.0214	0.0018	0.9522
150	19.6191	19.9245	-0.0094	0.0060	0.9782
225	48.6359	15.9333	-0.0475	0.0061	0.9662

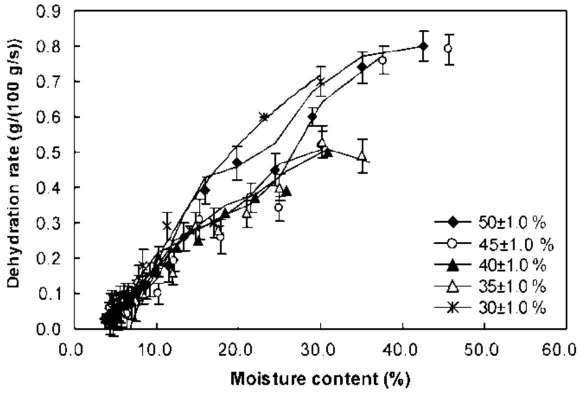
The effect of microwave power intensity on the expansion ratio of maitake: The water inside the maitake matrix absorbed microwave energy to generate water vapor, which resulted in the volume expansion of the samples (Zheng *et al*., 2012). When the microwave intensity was 225 W/g, the maitake mushroom expansion rate was significantly higher than that at 75 and 150 W/g ($p<0.05$, Fig. 2b). At a water content of 9.8%, a maximum expansion of 190% was observed. There was no significant difference ($p>0.05$) between the expansion ratios observed for microwave power intensities of 150 and 75 W/g. This similarity may occur because the reduction of moisture content and increased amount of air in the puffed materials decreases the absorption of microwave energy owing to the reduction of the dielectric properties of the material (Zheng *et al*., 2013). At the higher microwave intensity, a higher temperature in mushroom results in a faster rate of moisture removal therefore the expansion rate is higher. When the water content was more than 30%, the expansion rate was not significantly different ($p>0.05$) with the different microwave intensities and a relatively constant increase in the expansion ratio was observed until 10%, when the ratio decreased sharply. At moisture contents greater than 35%, only surface water is removed and the inflation of the sample remains stable. The expansion ratio of maitake could be described by three factors (Table 2) with high reliability (R^2>95.2% at $p<0.05$). From these models shown in Table 2, it can be seen that the highest expansion ratio of maitake in 225W/g based on the higher value of a. The results agree with Fig. 2b.

The effect of microwave power intensity on the sensory evaluation of maitake: Figure 2c shows the results obtained for the sensory evaluation of maitake samples prepared using three different microwave power intensities. The sensory evaluation changed with decreasing microwave power ($p<0.05$). The lower sensory evaluation for the maitake sample prepared at the highest microwave power corresponds to the sample prepared with the greatest dehydration rate; the higher microwave power used results in the sample having a scorched aroma. The mushroom sample puffed using 75 W/g showed a low expansion ratio and had a hard texture.

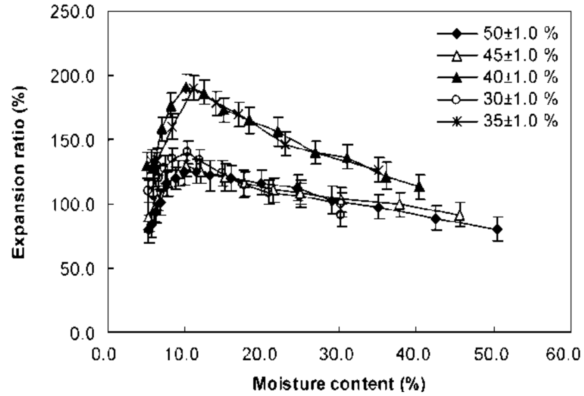
Initial moisture content effect on puffing process:

The effect of initial moisture content on the dehydration rate of maitake: The variations in the expansion ratio, dehydration rate and sensory evaluation for puffed maitake mushrooms with five different initial moisture contents are presented in Fig. 3. In Fig. 3a, the dehydration rate for the samples with initial moisture contents of 30±1.0%, 45±1.0% and 50±1.0% decreased quickly. However, the samples with an initial moisture content of 40±1.0% and 35±1.0% had lower initial dehydration rates and were not significantly different ($p>0.05$). These lower dehydration rates may be a result of the low initial moisture content; The pretreatment drying time is relatively long and the moisture content is lower, caused the water vapor does not remain in the center of the material and the dehydration rate drops quickly. Moreover, when the moisture content was relatively high (45±1.0% and 50±1.0%), increased dielectric properties of the materials accelerated the dehydration (Zheng *et al*., 2013).

The effect of initial moisture content on the expansion ratio of maitake: According to the trends observed in the volume expansion curves shown in Fig. 3b, as the puffing progressed the expansion ratio of the sample increased significantly until the moisture content was decreased to 10%. The initial moisture content of the samples had a significant effect ($p<0.05$) on the expansion ratio. The samples with initial moisture contents of 40±1.0% and 35±1.0% showed a higher level of puffing (190.33% and 191.67%, respectively). The microwave heating process is a key



(a)



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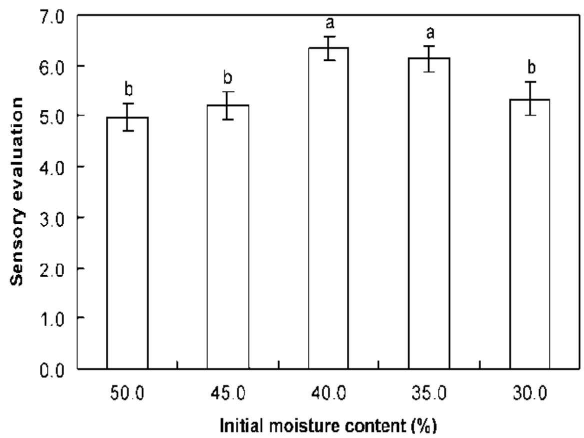

(c)

Fig. 3: Effect of initial moisture content on puffing characteristics by initial moisture content; (a): dehydration rate; (b): expansion ratio and; (c): sensory evaluation (microwave intensity: 150 W/g; vacuum pressure: -70±1.5kPa; pulse ratio 1.2. values bearing different lowercase letters (a–b) are significantly different (Duncan, p<0.05))

factor in producing puffed products as steam is quickly generated inside the sample. The generation of vapor depends on the microwave intensity and the mechanical properties depend on the moisture content of the material. The volume change in puffed materials are associated with mechanical properties, such as hardness, viscosity, which are significantly affected by the moisture diffusion (Rakesh and Datta, 2011). Volume expansion of a material is caused by two opposing trends: internal steam expansion and shrinkage cause be evaporation of surface water. Therefore, for samples with initial moisture contents of 40±1.0% and 35±1.0%, the higher amount expansion may be due to sufficient steam generation and a suitable moisture content inside the sample during the expansion (Zheng *et al*., 2013; Rakesh and Datta, 2011).

The effect of initial moister content on the sensory evaluation of maitake: As presented in Fig. 3c, the maitake samples with initial moisture contents of 40±1.0% and 35±1.0% had the highest sensory score and there was no significant difference between these two samples ($p>0.05$). However, compared with the sensory scores of the other values, there were significant differences ($p<0.05$). The sensory score and puffing rate of the samples was significantly correlated; the higher dehydration rates caused low expansion rates and increased the surface hardness of the samples and made them hard to chew.

Vacuum pressure effect on puffing process:

The effect of vacuum pressure on the dehydration rate of maitake: The effect of vacuum pressure on the dehydration rate of maitake during the PMVP process is shown in Fig. 4. The maitake dehydration rate during the maitake puffing process did not depend significantly on vacuum pressure ($p>0.05$, Fig. 4a). The maximum dehydration rate was observed when the water content of the sample was about 30%, after fell rapidly at lower moisture contents. This may occur

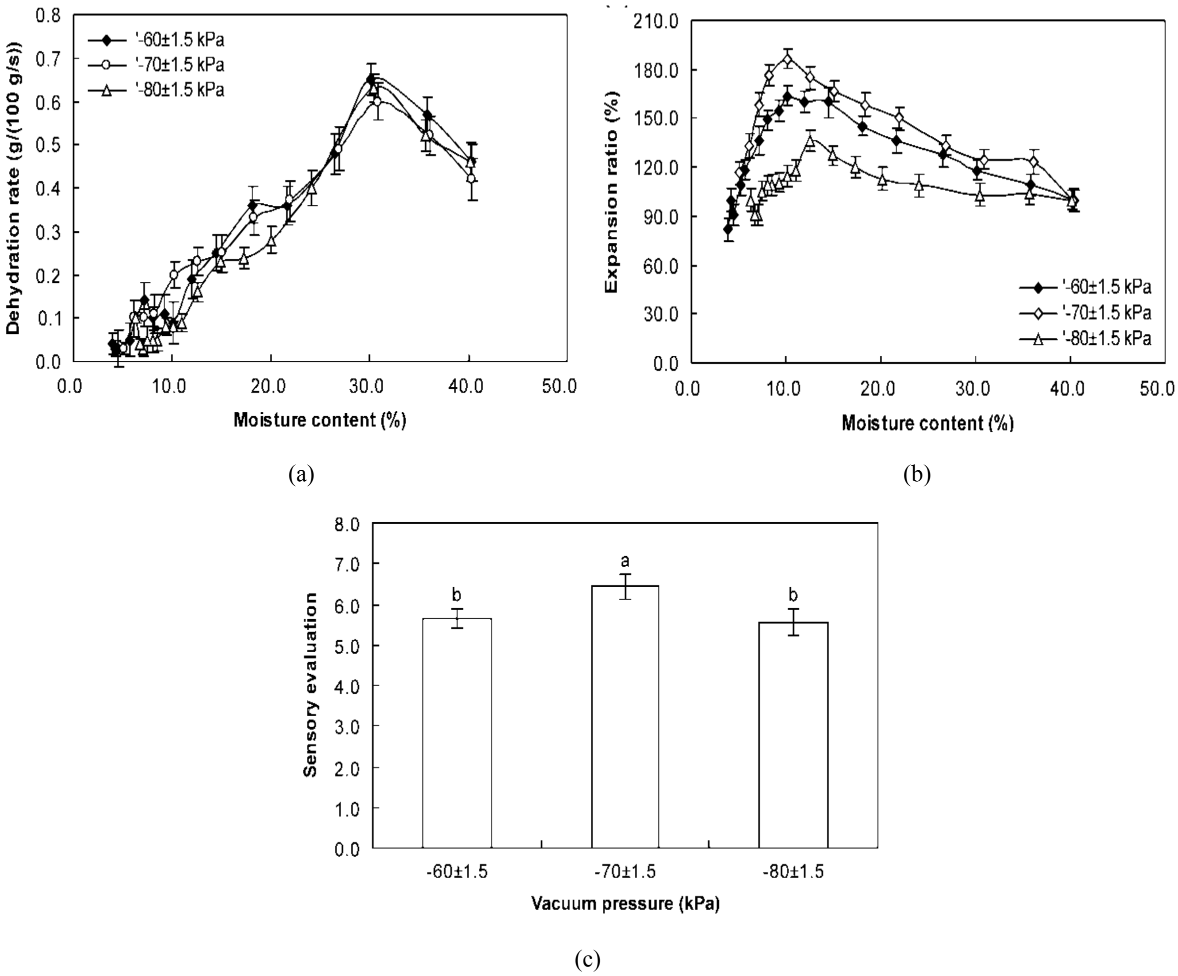

Fig. 4: Effect of vacuum pressure on puffing characteristics by initial moisture content; (a): dehydration rate; (b): expansion ratio and; (c): sensory evaluation (initial moisture content: 40±1.0%; microwave intensity: 150 W/g; pulse ratio 1.2. values bearing different lowercase letters (a–b) are significantly different (Duncan, $p<0.05$))

because the maitake mushrooms are simultaneously dried and puffed in the PMVP process. The vacuum pressure can significantly affect the puffing process but has less influence on the drying process.

The effect of vacuum pressure on the expansion ratio of maitake: In Fig. 4b, the volume change observed for all the maitake samples exhibited similar trends with all three vacuum levels. When the volume was stable, no significant differences were observed at the different vacuum pressures used in the present study ($p>0.05$). When the moisture content was greater than 30%, the effect of the vacuum pressure on mushroom expansion was not significant ($p>0.05$). At lower moisture contents, the expansion ratio increased gradually until a critical moisture value of about 10% (Fig. 4b). The vacuum pressure of -70±1.5 kPa resulted in a relatively high ratio of maitake mushroom puffing, greater than that for -60±1.5 kPa. The expansion ratio for these samples decreased sharply at the same moisture content. However, for the sample prepared with a vacuum pressure of -80±1.5 kPa, the expansion ratio decreased slowly. This difference may be caused by an interruption of the volume expansion in the low vacuum pressure sample (-60±1.5 kPa). Moreover, the high vacuum pressure of -80±1.5 kPa (low pressure) promoted the dehydration process and tissue shrinkage, which could weaken the sample toward volume expansion. The use of a vacuum pressure of -70±1.5 kPa improved the expansion ratio of maitake mushroom snacks.

The effect of vacuum pressure on the sensory evaluation of maitake: As presented in Fig. 4c, the sensory score of maitake mushroom in the process of PMVP changed significantly ($p<0.05$) with vacuum pressure. The samples prepared using a vacuum pressure of -70±1.5 kPa had the highest sensory evaluation (6.44) because of mushroom's flavor and its thick and crispy texture. There were no significant difference in the sensory evaluation of samples prepared using vacuum pressures of -60±1.5 kPa and -80±1.5 kPa ($p<0.05$).

Effect of PMVP conditions on the hardness of maitake mushrooms: The variation in the hardness value and the Expansion Ratio (ER) of maitake mushrooms during the PMVP process was measured (Fig. 5). The ER values for maitake mushroom samples increased over puffing time, reaching a maximum at 102 s and then decreased after 102 s. At puffing times greater than 160 s, the material was burnt owing to

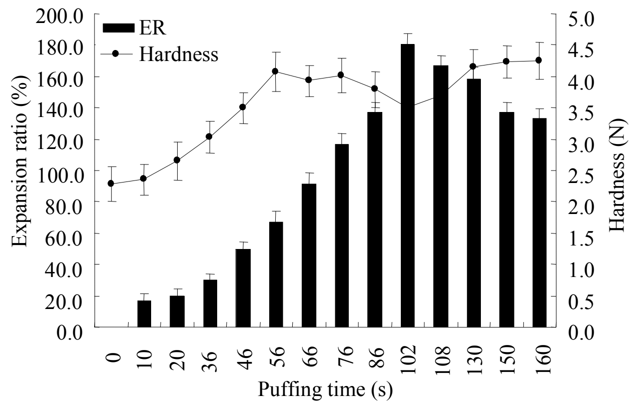

Fig. 5: Variation of hardness and expansion ratio for maitake mushroom samples during the PMVP process (initial moisture content: 40±1.0%; microwave intensity: 150 W/g; vacuum pressure: -70±1.5 kPa, pulse ratio 1.2)

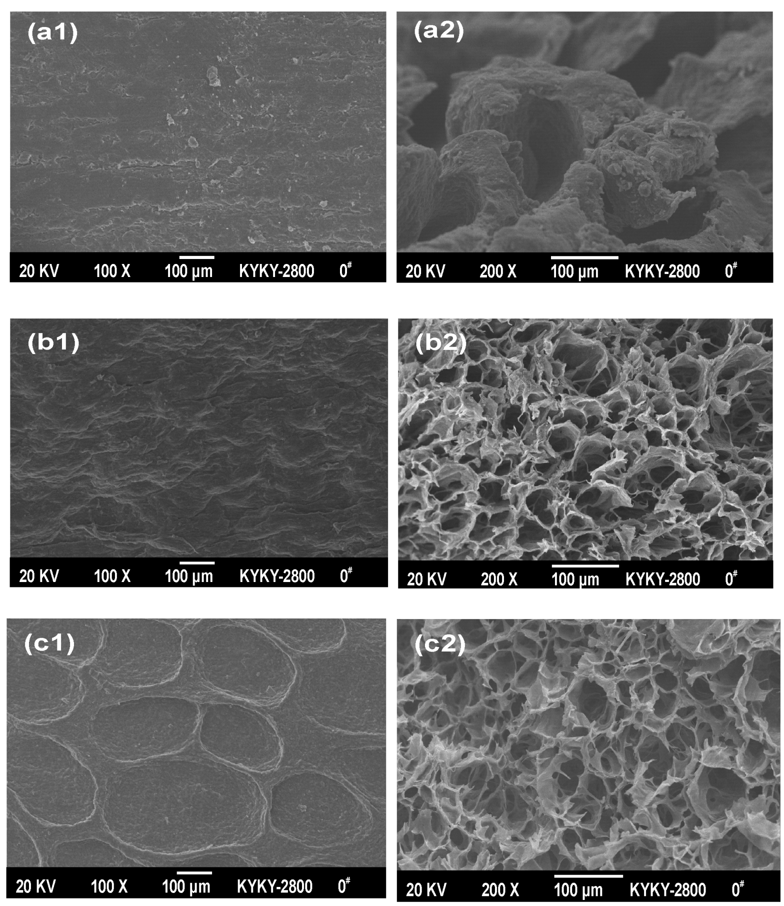

Fig. 6: Effect of the PMVP process on the microstructure of the maitake mushrooms. SEM images of the surface microstructures (a1), (b1) and (c1) expanded 100 times; SEM images of the cross-section microstructures (a2), (b2) and (c2) expanded 200 times; (a1) and (a2) are the microstructures after preliminary drying; (b1) and (b2) are the microstructures after puffing for 70 s; (c1) and (c2) are the microstructures after expanding to a moisture content of 7±1.0%

the increase in temperature. However, the hardness of the samples increased to 4.07 N over time and was reduced to 3.51 N at 102 s, then increased slowly until stable. This trend may be related to the conversion of surface moisture into steam that is accumulated in maitake mushroom center under a high pressure, which makes the mushroom expand rapidly. Moreover, when the expansion ratio is higher, the brittleness of the material increases, thus reducing the hardness (Zheng *et al*., 2013; Rakesh and Datta, 2011). The hardness was found to decrease suddenly at 102 s because the moisture at the material center has evaporated. After 102 s, the maitake dehydration process was dominant, which increased the maitake hardness and resulted in shrinkage of the material surface. The rate of volume contraction was greater than that of volume expansion, resulting in the lower inflation ratio.

Microstructure of maitake mushrooms during the puffing process: The structural changes observed for the maitake mushrooms during the puffing process are shown in Fig. 6. The maitake mushroom surface is very smooth before puffing (Fig. 6a1) and when magnified visibly thicker tissues can be observed. As the sample expanded during the puffing process, small air bubbles were observed on the surface of the samples at 70 s and the structure became looser (Fig. 6b2). After expansion (moisture content: 7±1.0%), the maitake mushroom surface was uniform and scale shapes can be observed in Fig. 6c1. At a magnification of 200 times, small gaps can be observed in the tight structure of the cross section structure before puffing. As the expansion progressed, the cross section appeared to have a loose porous structure. Compared to Fig. 6b, the cross section structure of Fig. 6c had more and larger pores and thinner tissue. These changes may be a result of the moisture gradients inside the materials. Suarez and Viollaz (1991) reported that the dehydration rate increased as a result of increased porosity because the cellular structure facilitated the diffusion of moisture. The moisture removal from maitake mushroom was accompanied by shrinkage and internal structural changes.

CONCLUSION

Microwave power intensity had a significant effect on the dehydration rate, expansion ratio and sensory evaluation of maitake mushroom slices in the PMVP process. Initial moisture content and vacuum pressure had smaller effects on these characteristics. The volume changes of the maitake mushroom samples are influenced by many factors: shrinkage results from the dehydration of the surface of the sample and expansion results from water evaporation in the sample. During the PMVP process, the first stage of maitake puffing until a moisture content of 7±1% the maitake mushroom absorbed microwave energy and converted water into steam to increase its volume. After this stage, the dehydration process is the dominant and volume shrinkage and improve the hardness of mushroom samples increases and to obtain the desired moisture content of the mushroom puffed snack. The microstructure showed that the interior of the maitake mushroom quickly produced bubbles that increased with puffing time prolong, making the tissue loose. Moreover, the volume and shape of the maitake samples reached a relatively stable phase depending on the material, physical and PMVP conditions. These experiments provided the basis for maitake mushroom snack on moisture transfer and microwave energy absorption and transformation for the production of maitake mushroom snack using the PMVP process. These results are helpful for industrial scale production of high-quality maitake mushroom products.

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