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Preservation of mushroom in storage after vacuum cooling treatment**

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A b s t r a c t. Vacuum cooling has been used as a rapid cooling method for mushrooms. In the current study, experiments were carried out to evaluate the effect of different storage conditions on weight loss, respiration rate, soluble solid content, membrane permeability and degree of mushroom browning. To investigate the influence of storage conditions on the properties of mushrooms, mushrooms were stored in three different conditions: 1) cold room, 2) hypobaric room, and 3) modified atmosphere packaging (MAP), and their cooling processes were also investigated. The results showed that modified atmosphere packaging (MAP) provided the optimum storage conditions. The results also indicated that weight loss, respiration rate, soluble solid content, membrane permeability and degree of mushroom browning were significantly different under different conditions during storage.

K e y w o r d s: mushroom, vacuum cooling, storage conditions

INTRODUCTION

Consumption of mushrooms has increased substantially due to their delicacy, flavor and nutritional value. Mushrooms are an excellent source of several essential amino acids, vitamins (B2, niacin, and folates) and minerals (potassium, phosphorus, zinc and copper) (Manzi *et al*., 2001; Mattila *et al*., 2001; Shivhare *et al*., 2004). Mushrooms have a short shelf life of 3-4 days compared to most vegetables at ambient temperatures because that they have no cuticle to protect them from physical or microbial attack or water loss (Martine *et al*., 2000).

Vacuum cooling is a rapid cooling technique extensively used for the cooling of some agricultural and food products (Thompson and Rumsey, 1984; Sun and Wang, 2000; McDonald and Sun, 2000; McDonald *et al*., 2000). It is achieved by the evaporation of moisture from the produce. The evaporation is speeded and made more efficient by reducing the pressure to the point where water boiling takes place at a low temperature (Tambunan, 1994). Vacuum cooling has been adopted commercially on some mushroom farms in the U.S.A (Lane, 1972), and investigated in the U.K (Barnard, 1974), and more recently adopted on some U.K farms. Vacuum cooling is rapid and cools mushrooms uniformly within a stack, but the capital and operating costs are high and weight losses are incurred (Barger, 1963).

There are few published reports on the effect of storage conditions on the post-harvest characteristics of mushroom after vacuum cooling. The aims of this paper are to compare the storage conditions of mushroom after vacuum cooling by evaluating the impact of storage on some physical and chemical properties.

MATERIALS AND METHODS

Materials

Mushrooms (*Agaricus bisporus, Monad*, 2796) used in this study were harvested in the first week of May from a local field in Wuxi, China. The mushrooms were carried into the laboratory one hour after harvest and processed in two hours. The replicate plots were arranged in a completely randomized pattern.

Treatment

The ZY0.1 vacuum cooler (Qihong Cold-Making Co. Ltd., Wuxi, China) used in the experiment is shown in Fig. 1.

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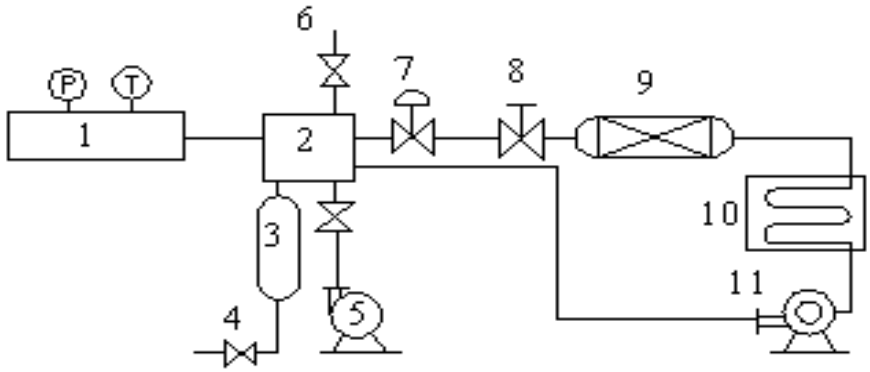

Fig. 1. Schemate of the vacuum cooler: 1 – vacuum chamber, 2 – steam condenser, 3 – condensing unit, 4 – draining valve, 5 – vacuum pump, 6 – vent valve, 7 – expansion valve, 8 – solenoid electric valve, 9 – filter dryer, 10 – condenser, 11 – compressor.

In the experiment, special care was taken with respect to the position of the thermocouples. One thermocouple was placed into the mushroom that determined the end of the experiment, the other thermocouple was placed in the surface of the mushroom.

The mushrooms were vacuum cooled to 5°C and then stored under different storage conditions. The end chamber pressure for reaching 5°C was 0.5 kPa.

Storage conditions

To study the effect of storage conditions on chemical and physical properties of mushroo m after vacuum cooling, products were stored for 15 days under three specific conditions:

1) cold room (ZB-1.5 cold room, Qihong Cold-Making Co. Ltd., Wuxi, China): storage temperature 4±1°C and relative humidity about 75%;

2) hypobaric room (ZY-2 M3 Hypobaric room, Qihong Cold-Making Co. Ltd., Wuxi, China): mushrooms were stored hypobarically in air at 20-30 kPa total pressure and temperature of 4±1°C with relative humidity about 75%;

3) modified atmosphere packaging (ADFM-V3000 air controlled atmosphere packing machine, Hengzhong Packing Co., Lianyungang, China): mushrooms were placed also in modified atmosphere packaging (MAP) at 5±1% O_2 with 3±1% CO_2 and sealed in 25 μm low-density polyethylene (LDPE) membrane. The storage temperature was 4±1°C with relative humidity about 75%.

Analysis

Measurements of the percentage soluble solids content were made with ABBE Bausch and Lomb refractometer on juice squeezed from undamaged pieces of tissue cut from the mushroom. These observations were made initially and after 4, 7, 10 and 15 days.

Mushroom quality was assessed by the extent of browning of the cap, measured using the reflectometer function of a Hunter Colormeter (Shanghai Precision Instrument Co. Ltd., Shanghai, China). Each mushroom was measured at three equidistant points of the cap of the mushroom. To analyze the reflectance data (L), they were first transformed by the function: Y=logn (100-L), where Y can be described as the degree of browning (Burton *et al*., 1987; Gormley, 1975). For the mushroom stored continuously at 4°C under three storage conditions the measurements were made on days 0, 4, 7, 10 and 15. Ten mushrooms were measured from each treatment-day interaction.

Electrolyte leakage was used to assess membrane permeability. This procedure was based on Kaya *et al*. (2002). Fresh mushroom discs (5 mm thick, 10 mm diameter, 2 g total mass) were placed in 20 ml of distilled water, after 1 h immersed in 30 ml of distilled water to remove surface contamination and incubated at ambient temperature. Conductivity of the suspending solution was measured after 1 h and again after boiling for 30 min (taken as 100%) with a DDS-11A electrical conductivity meter (DDS-11A, Leici Instrument Co., Shanghai, China).

The static method was used to assess the respiration rate. Mushrooms (200 g) were put into a gas-tight container of 260 mm diameter with 10 ml 0.4 N NaOH in a Petri-dish, containing ambient air as the initial atmosphere. The Petri-dish was taken out and titrated with 0.2 N oxalic acid ($C_2H_2O_4$) after 30 min. The change in the concentration of CO_2 was used to estimate respiration rates (Yang and Zhang, 2000).

All experiments were replicated three times and the average values were used in the analysis. Data were subjected to ANOVA and LSD at P=0.05 or Duncan's multiple range tests ($P<0.05$). No consistent statistically significant differences were detected within the treatments between the experiments, so the means presented in this paper are combined averages.

RESULTS AND DISCUSSION

Vacuum cooling process

Figure 2 shows the change of the temperature and pressure of the mushrooms during vacuum cooling. The vacuum cooling process itself occurred in two fairly distinct phases. Robertson (1978) and Lovelidge (1972) had the same results with their study. In phase one, the pressure in the vacuum chamber was reduced from atmospheric to about 0.5 kPa and, during this time, temperature of the mushrooms changed very slowly until saturation pressure at this temperature was reached. At approximately this pressure the flash point would occur, this was the point that the temperature of mushroom declined sharply but the pressure was reduced very little.

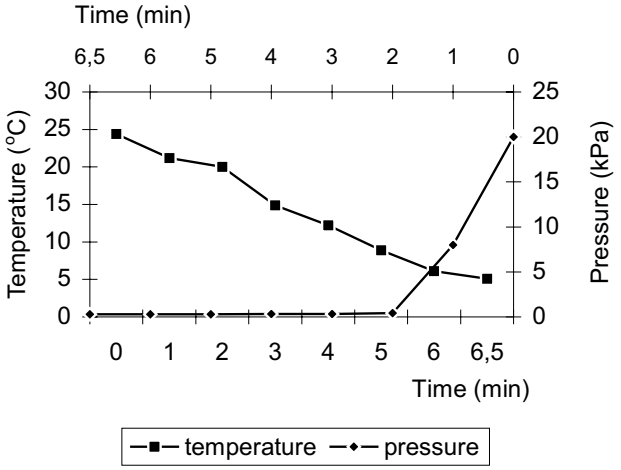

Fig. 2. Temperature and pressure change during vacuum cooling.

Weight loss

The average percentage loss of weight after vacuum cooling under different storage conditions during storage is shown in Fig. 3. The percent weight loss increased with duration of storage. The weight loss of the mushrooms stored under modified atmosphere packaging (MAP) was the lowest among the three storage conditions. Its weight loss was always below 1% during storage. The mushrooms stored in the cooling room and hypobaric room had a weight loss of 10.12 and 14.78%, respectively, at the end of the storage. The results showed that different storage conditions had a significant effect on the weight loss of the mushrooms ($P<0.05$).

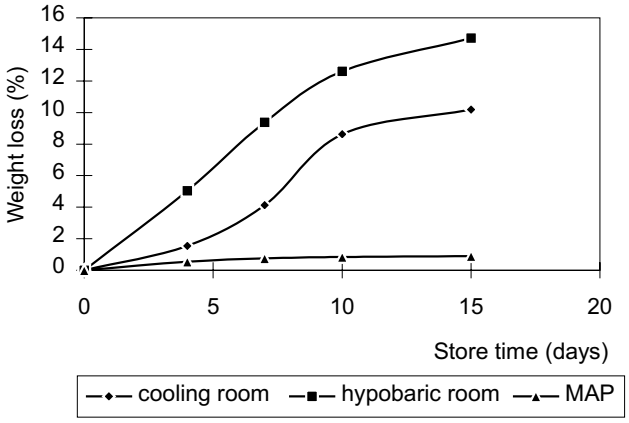

Fig. 3. Weight loss as percentage of original weight at different conditions after storage at 4, 7, 10 and 15 days. Statistical significance at $P<0.05$.

Respiration rate

The change of respiration rate under different storage conditions is shown in Table 1. The first measurements of the experiment showed high respiratory activity. This was probably due to harvest stress caused by the cutting process. Similar results were obtained by Villaescusa *et al*. (2003) who reported that mushrooms had a high initial respiration rate. It was shown that, after that, there was a period of slight decline of the mushroom respiration rate that lasted for about 10 days, followed by a period of a quick increase. In the common mushroom, a peak in its high respiration rate is observed during post-harvest development at the moment of cap opening. But Braaksma (1996) believed the high respiration rates of the mushroom during post-harvest period would develop because of the high energy phosphate-bond content.

Significant differences ($P<0.05$) in respiration rate of mushroom was observed between cooling room and hypobaric room or cooling room and MAP, but there was no significant difference between hypobaric room and MAP.

Table 1. The change of mushroom respiration rate under different storage conditions during storage at 4, 7, 10 and 15 days (mg CO_2 kg^{-1} h^{-1})

Storage time (days)	0	4	7	10	15
Cooling room	167.2±4.7	159.59±3.4a	146.67±2.8a	151.56±1.6a	193.29±4.1a
Hypobaric room	167.2±4.7	148.06±4.3b	140.55±4.7ab	136.27±3.9b	143.87±5.3b
MAP	167.2±4.7	145.39±5.1b	134.28±4.2b	130.65±5.3b	132.58±4.8b

Note: Values (mean of three replicates) in the same column followed by the same letter are not significantly different after Duncan's test.

Membrane permeability

Membrane permeability was determined by measuring electrolyte leakage. The results shown in Table 2 clearly proved the drastic effect of storage conditions on the membrane permeability of mushroom. Membrane properties were shown to change during storage (Yamada *et al*., 1999). differences among them (P<0.05). The membrane permeability of mushrooms stored in cooling room was the greatest (16.67%), while the membrane permeability of MAP was only 15% at the end of the storage. All these results suggested a direct relation of membrane permeability to storage conditions.

T a b l e 2. Effect of storage conditions on mushroom membrane permeability (%) during storage at 4, 7, 10 and 15 days

Storage time (day)	0	4	7	10	15
Cooling room	1.33	4.74a	5.83a	8.05a	16.67a
Hypobaric room	1.33	4.14b	5.69a	7.91a	15.5b
MAP	1.33	3.92a	4.62b	6.60b	15.0c

Explanations as in Table 1.

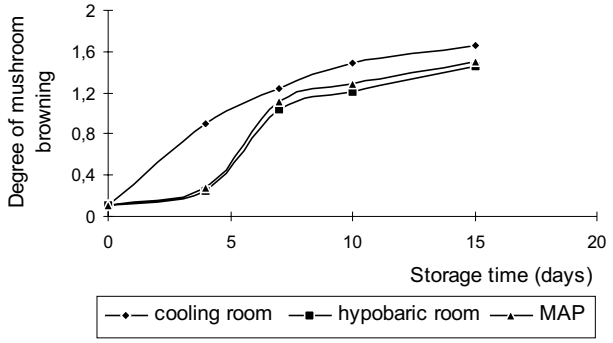

Fig. 4. The degree of browning on the top of the mushroom cap under different storage conditions during storage at 4, 7, 10 and 15 days. Statistical significance at P<0.05.

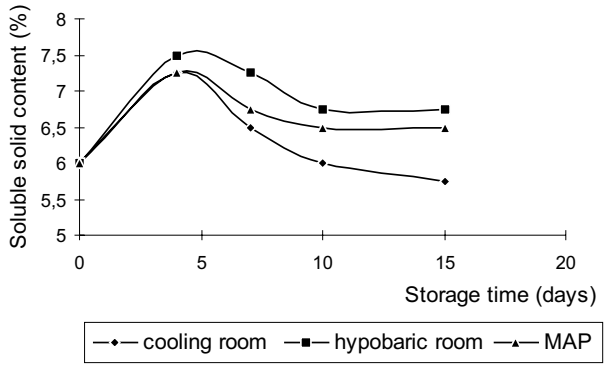

Fig. 5. The change of the soluble solid content of the mushroom under different storage conditions during storage at 4, 7, 10 and 15 days. Statistical significance at P<0.05.

The membrane permeability of the mushroom increased with storage time and showed that membrane systems became more vulnerable to leakage. The membrane permeability of the three storage conditions had significant

Degree of browning

Both storage time and storage conditions significantly (P<0.05) affected the degree of browning of the mushrooms. A significant increase between the initial browning degree and those values at the end of the experiment are shown in Fig. 4. The degree of browning of the mushrooms stored in cooling room increased the most quickly while that of the mushrooms stored in hypobaric room and MAP increased slower. The results indicated that mushrooms stored in hypobaric room and MAP could extend their shelf-life compared to those stored in cooling room.

Soluble solid content

Differences in the percentage soluble solids content between the various storage conditions persisted during storage (Fig. 5). Mushrooms in hypobaric room had the highest percentage soluble solid content, while that in cooling room the lowest. After about five days of storage, the mushrooms reached the highest percentage of soluble solids which averaged 7.25, 7.5 and 7.25%, respectively. There was a significant difference in the percentage soluble solids content not only during the storage time but also under various storage conditions. So the storage conditions had a significant effect on the percentage soluble solids content of the mushrooms (P<0.05).

CONCLUSIONS

1. The conducted experiments showed that, among the three storage conditions, modified atmosphere packaging (MAP) was the most suitable for mushrooms stored after vacuum cooling.

2. The chemical and physical properties of mushrooms after vacuum cooling stored under MAP differed significantly from those stored in hypobaric room and cooling room.

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