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Effects of temperature on *Agrocybe chaxingu* quality stored in modified atmosphere packages with silicon gum film windows

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Abstract

The effects of three storage temperatures (1, 3, and 5 °C) were determined on the quality of the edible mushroom *Agrocybe chaxingu* stored in modified atmosphere packages (MAP) with and without (control) silicon gum film windows. Results showed that the storage temperature had clear effects on headspace gas concentrations of O_2, CO_2 and ethylene, sensory characteristics, respiration rate, ascorbic acid content, soluble solid content and electrolyte leakage. The higher storage temperature (5 °C) resulted in more rapid changes in the different quality parameters for the stored mushroom except in the case of storage at 1 °C where chilling injury occurred. The MAP with silicon gum film windows at 3 °C provided the best atmosphere for mushroom *A. chaxingu* as shown by a fact that the MAP packs with windows at 3 °C had better quality than the control.

Keywords: MAP; Permeability; Mushroom; Storage temperature; Chilling injury; Ethylene

1. Introduction

With high nutritive components such as protein, amylose, essential amino acids and mineral elements, the edible *Agrocybe chaxingu* is becoming one of the most valuable and popular mushrooms in China (Li & Zhang, 2007; Zhang, Zhang, & Shrestha, 2005), resulting in increased production and consumption in recent years (Deng & Wu, 2005). Like other mushroom species, *A. chaxingu* is also highly perishable, and it has a short shelf-life of 3–4 days at ambient temperatures. Modified atmosphere packaging (MAP) is one of the number of technologies available to control product deterioration by providing an appropriate protective atmosphere around the product (Wszelaki & Mitcham, 2003; Zhou et al., 2000). Silicon membrane has been studied and developed successfully as packaging materials for storing vegetables and fruit (Gariepy, Raghavan, & Theriault, 1986; Stewart, Raghavan, Golden, & Gariepy, 2005; Vigneault, Orsat, Panneton, & Raghavan, 1992) because of its high permeability to gases. Silicon gum film windows with a given window size of 0.9 cm^2 at an initial concentration of 50 mL/L O_2 and 100 mL/L CO_2 have shown extending the storage life of mushroom *A. chaxingu* at a selected temperature of 3 °C (Li, Zhang, & Wang, 2007).

Storage temperatures influence the rate of many deteriorative processes and transpiration because the temperature is one of the most important factors in the maintenance of produce quality (Cliffe-Byrnes & O'Beirne, 2005; Kader, 1987). The influenced quality parameters include sensory attributes, vitamins and other nutrients in many fruit and vegetables (Gil, Conesa, & Artes, 2002; Paull, 1999). Generally, higher storage temperatures result in more rapid quality losses of produce, including sensory changes, such as general appearance, firmness, and odor, and chemical changes, such as decreases in ascorbic acid content, solid soluble content, and titratable acid, and increases in respiration rate, cell membrane permeability and the symptoms of senescence (Ding, Chachin, Yasunori,

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Yasunori, & Yasunori, 1998; Jacxsens, Devlieghere, & Debevere, 2002a; Maalekuu, Elkind, Leikin-Frenkel, Lurie, & Fallik, 2006; Maskan, 2001). However, chilling injury may occur for some chilling sensitive crops at low storage temperatures, which also induces rapid quality losses (Jacxsens, Devlieghere, & Debevere, 2002b; Lurie & Crisosto, 2005).

A. chaxingu is a new kind of edible mushroom, and the consumption has been increasing substantially in recent years in China and other countries. It is necessary to develop some feasible methods for storing and preserving the quality of the mushroom. So far, there have been few reports on MAP with permeable films as a window for gas exchange to store mushrooms at different temperatures. The objectives of this study were to determine the optimal storage temperature to extend the quality of *A. chaxingu* mushroom using MAP with a permeable silicon gum window for gas exchange. The effects of three different storage temperatures (1, 3 and 5 °C) on the sensory, physical, chemical and physiological characteristics were examined.

2. Materials and methods

2.1. Plant material and equipment

A. chaxingu used in this study was obtained 3 h after harvesting, at Qingshan market, Wuxi City, Jiangsu Province, China, and then taken to laboratory immediately and treated within 2 h.

The MAP equipment (ADFM-V3000, air controlled atmosphere packing machine, Hengzhong Packing Co., Lianyungang City, Jiangsu Province, China) was connected to the mixing cylinder of the gas supply system, in which air was removed by a vacuum pump. The gas composition that established in the packages was checked using a gas analyzer (CYES-II, Xuelian Analytical Instrument Co. Ltd., Shanghai, China) with a system accuracy of $\pm 0.5\%$. A modified atmosphere of 50 mL/L O_2, 100 mL/L CO_2, and 850 mL/L N_2 was maintained in this study as previously determined as the optimal initial concentration (Li et al., 2007).

2.2. Experimental design

The polystyrene (PS) packaging trays (18 cm length × 12 cm width × 4 cm depth) were divided into two groups. The first group with a 0.9 cm^2 window was used for gas exchange as the same in the previous test (Li et al., 2007). A window was cut at the central part on the side of each tray and covered with high permeability film (FC-8 silicon gum film, Lanzhou Physical & Chemical Research Institute of the Academy of Sciences of China, Lanzhou, China), which was made by spreading 50 ± 5 g silicon gum on 1 m^2 cloth to achieve an O_2 permeability of 4.08×10^{-9}/mol/s/m^2/Pa and CO_2 permeability of 12.24×10^{-9}/mol/s/m^2/Pa at 20 °C and 90% RH (Li et al., 2007). The second group was kept unchanged as the control. Sixty-three trays with a 0.9 cm^2 window and other 63 control trays without windows were totally stored at 1, 3, and 5 °C, respectively, based on three replicates with seven time measurements for each treatment. In each tray, approximately 115 g of mushrooms were packaged and sealed with 35 μm thick polypropylene (PP) membrane. All the packages were stored for 20 days under the relative humidity of 95–100% inside the packages and about 85% in the storage rooms.

2.3. Gas analysis

The headspace gas concentrations of O_2 and CO_2 in the sealed trays during storage were measured in each package before opening using the gas analyzer on 12 and 24 h on the 1st day and then at every 4 days thereafter during storage.

The headspace gas concentration of ethylene was analyzed every 4 days, using a gas chromatograph (Shimadzu GC-2010, Japan) equipped with a flame ionization detector (FID) and a DB-1 column. Nitrogen was used as a carrier gas, and the flow rate was 10 mL/min.

2.4. Sensory quality

Jacxsens' method with some modifications was used to evaluate the sensory quality. A panel of ten trained judges evaluated the sensory quality characteristics of all the mushrooms from each tray. The typical characteristics of the mushrooms and the possibilities of deterioration were explained before the experiment started. All sensory tests (general appearance, firmness and odor) were performed in a special taste room with separated boxes. General appearance was judged under normal light and the sensory characteristics such as firmness and odor were evaluated under IR light to exclude the influence of the visual characteristics. General appearance was evaluated on a scale of 9–1, where 9 represents excellent without any rotten areas or water-soaked areas, 7 represents good without any rotten areas or water-soaked areas, 5 represents fair and limit marketability with 1–2 0.5 mm^2 rotten areas or water-soaked areas, 3 represents poor and limit usability with 3–6 0.5 mm^2 rotten areas or water-soaked areas, and 1 represents very poor and inedible with more than 7 0.5 mm^2 rotten areas or water-soaked areas. Firmness was evaluated by pressing the mushroom between the thumb and index finger, on a scale of 9–1, where 9 represents very firm and turgid, 7 represents firm, 5 represents moderately firm, 3 represents soft, and 1 represents very soft. Off-odors, mainly because of fermentation, were evaluated on a scale of 9–1, where 9 represents none, 7 represents slight, 5 represents moderate, 3 represents moderate severe, and 1 represents severe. The cut-off score was set at score 5. Above this score, the sample was acceptable (Jacxsens, Devlieghere, Van der Steen, Siro, & Debevere, 2001).

2.5. Physical and chemical analysis

2.5.1. Respiration rate

A static method was used to assess respiration rate. Before assessment, the mushrooms (115 g ± 5 g) were taken out from the packages and exposed to ambient conditions in a storage room (3000 L) for 1 h so that the CO_2 accumulated in the tissue diffused into air, and then the sample was put into a gas-tight container 260 mm in diameter with 10 mL 0.4 mol NaOH in a Petri dish, and the jars were placed at 1, 3, and 5 °C, respectively. The Petri dish was taken out after 30 min and the NaOH titrated with 0.1 mol oxalic acid ($C_2H_2O_4$) immediately, and the accuracy is 0.01 mL. The change of concentration of CO_2 was used to estimate respiration rates (Yang & Zhang, 2000).

2.5.2. Ascorbic acid

Ascorbic acid was determined by the indophenol titration method (Association of Vitamin Chemists, 1966; Favell, 1998). A 10 g sample was ground in a mortar with the same quantity of 2 g/100 g oxalic acid solution. A 1 g/100 g oxalic acid solution was used to wash the paste into a 100 mL volumetric flask and made to volume. Ten mL filtered solution was titrated with 2,6-dichlorophenol indophenols solution until the distinct light rose pink color persisted for more than 5 s.

2.5.3. Soluble solids content

Measurements of the percentage of soluble solids were made with an ABBE Bausch and Lomb refractometer (2WAJ, Shanghai optical instruments factory, Shanghai, China) on juice squeezed from undamaged pieces of tissue cut from the mushrooms for each treatment. These observations were obtained initially and every 4 days during storage.

2.5.4. Electrolyte leakage

Electrolyte leakage was used to assess cell membrane permeability according to the procedure that Kaya described in 2002 (Kaya, Kirnak, Higgs, & Saltali, 2002). In order to remove the surface contamination, mushroom discs (3 mm thick, 3 mm diameter, 5 g total) were immersed in 50 mL distilled water for 1 h, then the mushroom discs were taken out and immersed in another 50 mL distilled water and incubated at ambient temperature (20 ± 3 °C). Conductivity of the suspending solution was measured at 3 h and after boiling for 30 min with an electrical conductivity meter (DDB-303A, Leici Instrument Co., Shanghai, China). Relative electrolyte leakage (%) was calculated as the ratio of the electrolyte leakage after 3 h of submersion to the total value.

2.6. Statistical analysis

All experiments were repeated three times for the 20-day storage. The average values with standard deviations were obtained over the three replicates and used in the analysis. Most of the data were evaluated to determine the effects of storage temperatures and windows by multi-factorial analysis of variance (ANOVA) using the SAS System. To determine statistical differences, mean comparisons between control and treatments were performed using Duncan tests at the significant level of $P<0.05$.

3. Results and discussion

3.1. Gas concentrations

The O_2 concentration decreased rapidly in the 1st day for all treatments and dropped slowly from 1 to 8 storage day, and then remained relatively stable except for the MAP treatment with silicon gum film window at 1 °C during the following storage days (Fig. 1a). The O_2 concentration of MAP with silicon gum film window at 1 °C had sharp drop

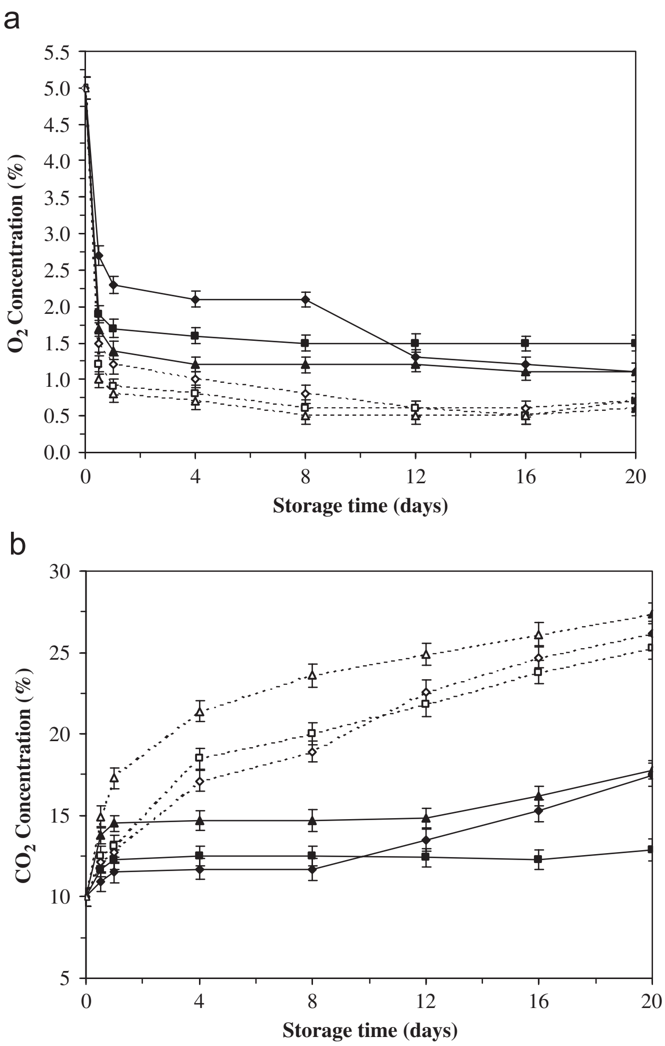

Fig. 1. Changes in concentrations (Mean ± SD for three replicates) of O_2 (a), CO_2 (b) in MAP stored at different temperatures. (◆) 1 °C, W; (◇) 1 °C, NW; (■) 3 °C, W; (□) 3 °C, NW; (▲) 5 °C, W; (△) 5 °C, NW. W, MAP with silicon gum film windows; NW, MAP without silicon gum film windows.

Table 1
Mean squares and mean values for ethylene concentrations in packages of *Agrocybe chaxingu* at 1, 3 and 5 °C over 20 days storage

Source	d.f.	Ethylene concentration (μL/L)				
		4 days	8 days	12 days	16 days	20 days
Mean squares						
Window (WI)	1	0	1.5558[a]	24227.43[a]	179181.94[a]	189038.19[a]
Temperature (T)	2	0	0.0075	638.01[a]	1719.4[a]	2013.07[a]
WI × T	2	0	0.0024	11.06	71.91	135.04
Means						
Window						
W		0	0.22a	11.43a	44.41a	48.71a
NW		0	0.83b	86.44b	236.69b	243.7b
Temperature						
1 °C		0	0.51a	48.42a	163.1a	169.78a
3 °C		0	0.48a	44.28a	119.18a	121.5a
5 °C		0	0.59a	54.12a	139.38a	147.35a
W + temperature						
W + 1 °C		0	0.19 ± 0.02a	9.31 ± 0.42a	67.59 ± 3.86a	74.13 ± 4.17a
NW + 1 °C		0	0.83 ± 0.06b	87.53 ± 4.61b	258.61 ± 11.7b	265.43 ± 12.3b
W + 3 °C		0	0.17 ± 0.02a	7.14 ± 0.37a	19.31 ± 0.89c	21.18 ± 0.95c
NW + 3 °C		0	0.79 ± 0.07b	81.41 ± 3.67b	219.04 ± 9.37b	221.81 ± 10.9b
W + 5 °C		0	0.31 ± 0.04a	17.85 ± 0.81c	46.34 ± 2.96a	50.83 ± 3.16a
NW + 5 °C		0	0.87 ± 0.07b	90.38 ± 4.22b	232.42 ± 10.5b	243.87 ± 19.4b

Different letters in the same column indicate that means are significantly different ($P<0.05$).
W: packaged with silicon gum film windows; NW: packaged without silicon gum film windows.
[a]Main effects and interactions are significant at $P<0.05$; d.f., degree of freedom.

at the 8th storage day. The O_2 concentrations in MAP with the silicon gum film windows were higher than those without the silicon gum film windows. The O_2 concentrations in MAP with the silicon gum film windows were at least higher than 11 mL/L during the whole storage period, while the O_2 concentrations in packages without the silicon gum film windows were lower than 10 mL/L after 4 days of storage, and some of them were only 5 mL/L. The CO_2 concentrations increased with prolonged storage time in MAP without the silicon gum film windows and exceeded 253 mL/L at the end of storage (Fig. 1b). By contrast, the CO_2 concentration increased slowly in MAP with the silicon gum film windows over the first 4 days and remained relatively stable to the 8th, 16th and 12th storage day at 1, 3 and 5 °C respectively, and then increased over the later storage times. At the end of storage, the CO_2 concentration was under 178 mL/L for all MAP with the silicon gum windows. These results suggest that the silicon gum film windows have a higher permeability to O_2 and CO_2. Currently, the lower tolerance limit of O_2 concentrations is about 10 mL/L for many apple cultivars (Kupferman, 1997) and vegetables (Saltveit, 1997). Lopez-Briones et al. (1992) reported that fermentation did not occur in Agaricus mushrooms stored at O_2 concentrations between 10 and 20 mL/L. Villaescusa and Gil (2003) found that fermentation was detected in Pleurotus mushrooms kept in PVC and low density polyethylene (LDPE) packages that contained 20 mL/L O_2. Excessive accumulations of carbon dioxide inside the package can cause physiological injuries to the product, which in the case of mushrooms, results in severe browning (Lopez-Briones et al., 1992; Nichols & Hammond, 1973). Ares, Parentelli, Gambaro, Lareo, and Lema (2006) reported that CO_2 concentrations in packs higher than 90 mL/L accelerated mushroom shiitake deterioration, and Villaescusa and Gil (2003) found that steady-state MAP conditions with concentrations of 2 kPa O_2 + 12 kPa CO_2 for LDPE maintained good visual quality of Pleurotus mushrooms for 7 days. In our previous study, the lower limit of O_2 for mushroom *A. chaxingu* was 11 mL/L since ethanol was detected if the O_2 level was lower than 11, and 100–150 mL/L CO_2 level was optimal (Li et al., 2007). In this study, the O_2 concentrations of MAP with silicon gum film windows at 1, 3 and 5 °C were all higher than 11 mL/L during the whole storage period, suggesting fermentation would not occur. MAP with silicon gum film windows at 3 °C kept 100–150 mL/L CO_2 level, which was beneficial for mushroom *A. chaxingu* storing.

The change in ethylene concentration is shown in Table 1. There was modest ethylene production from days 0 to 8, and the ethylene concentration increased strongly from the 8th storage day until the end of storage for all treatments. Significant differences were observed in the ethylene concentration among the treatments ($P<0.05$) during the days 8–20. The ethylene concentration in the MAP without silicon gum film windows was more than three times higher than that in the MAP with silicon gum film windows at 1, 3 and 5 °C. Silicon gum film with high gas permeability resulted in lower concentration ethylene in the MAP with windows. Ethylene accumulation in the packages has previously been shown to induce protein degradation and accelerated senescence of mushroom *A. chaxingu* (Li et al., 2007). The lower concentration ethylene in the MAP is, the more beneficial for storing mushroom is. In this study, the MAP with silicon gum film windows at 3 °C had the lowest ethylene concentration and had the optimal atmosphere during storage period.

3.2. Sensory evaluation

Fig. 2 shows a general trend of appearance, firmness, and odor for *A. chaxingu* at three temperatures, in which all the scores decreased with storage time irrespective of treatments. Fig. 2a showed that there were significant differences ($P<0.05$) in the appearance scores among these treatments after 4 days of storage, and the differences were found for the different storage temperatures and use of the windows of silicon gum film. The appearance scores of mushrooms stored in MAP at 5 °C decreased faster than those at 1 and 3 °C both for with and without the windows. The appearance scores of mushrooms stored in MAP at 1 °C decreased slowly before the 4th storage day, and then decreased quickly because of chilling injury (water-soaked appearance) both for with and without the windows. Based on the acceptable score, the only mushrooms in MAP with the silicon gum film window at 3 °C could be stored for 20 days.

Fig. 2b shows the similar trend for firmness to that of general appearance observed in Fig. 2a. The scores for mushrooms stored in MAP with silicon gum film window at 3 °C decreased slowly with storage time, and was the only treatment that scored above 5.0 at the end of storage. The scores for mushrooms stored in MAP with and without silicon gum film windows at 1 °C decreased slowly before the 8th and 4th storage days, respectively, and then decreased quickly because of chilling injury. The scores for mushrooms stored in MAP without silicon gum film windows at 1 and 5 °C were under the acceptable limit of 5.0 after the 12th storage day.

There were significant differences ($P<0.05$) in the scores for odor among the mushrooms stored in MAP with and without silicon gum film window at the three temperatures from the 4th storage day (Fig. 2c). Storage temperature had significant effects on the odor, especially for the packages with the window after storage for 12 days. The odor scores for mushrooms stored in MAP with silicon gum film windows was all above the acceptable value of 5.0 except for the last storage day at 5 °C. For the mushrooms stored in MAP without silicon gum film windows, all of the scores were below 5.0 after 12-day storage.

It is well known that storage of fruit and vegetables at low temperatures from harvest until consumption is an effective means for preserving quality and nutritional value (Alique, Zamorano, Martinez, & Alonso, 2005; Concellon, Anon, & Chaves, 2007). Jacxsens et al. (2002b) reported

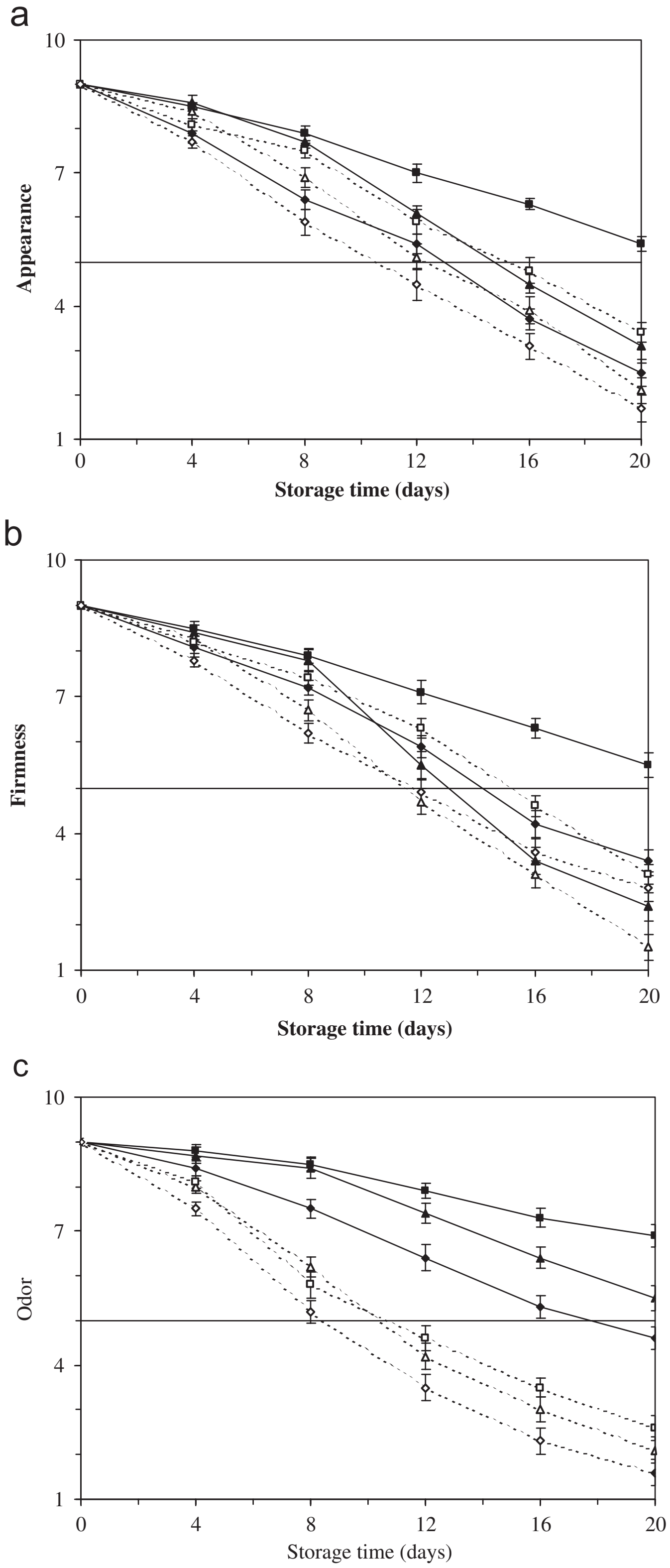

Fig. 2. Changes in scores (Mean ± SD for three replicates) of appearance (a), firmness (b), and odor (c) for *Agrocybe chaxingu* in MAP stored at different temperatures. (◆) 1 °C, W; (◇) 1 °C, NW; (■) 3 °C, W; (□) 3 °C, NW; (▲) 5 °C, W; (△) 5 °C, NW. W, MAP with silicon gum film windows; NW, MAP without silicon gum film windows. 'Horizontal line' represents the score line 5.0, and the scores under this line is unacceptable quality.

that temperature has a significant effect on the sensory quality of fresh produce. Storage recommendations for vegetables are generally to store at the minimum temperature to provide the maximum shelf-life (Paull, 1999). Without chilling injury, the scores for mushrooms stored were higher at lower storage temperatures (Fig. 2). On other hand, modified atmosphere have some effects on the sensory quality of fresh produce. For Agaricus mushrooms it has been reported that CO_2 concentrations higher than 120 mL/L cause loss of firmness (Nichols & Hammond, 1973), and Ares et al. (2006) reported that CO_2 concentrations higher than 90 mL/L caused loss of appearance and induce off-odor. In this study, mushroom stored in MAP with silicon gum film window at 3 °C can keep atmosphere in a suitable value (O_2: 15–19 mL/L, CO_2: 100–129 mL/L). Based on the sensory evaluation, the optimal temperature for storing mushroom *A. chaxingu* was 3 °C in MAP with the windows.

3.3. Respiration rate

Fig. 3 shows the changes in respiration rates during storage for mushrooms *A. chaxingu* stored in MAP with and without silicon gum film window at 1, 3 and 5 °C. The initial respiration rates were very high, reaching 208.5 ± 3.4 mg CO_2/kg/h, which was also found in the previous study (Li et al., 2007). The similar results were reported by Villaescusa and Gil (2003) in which Pleurotus mushrooms had a high initial respiration rate followed by lower levels that lasted 10 days and then a subsequent rapid rise. These high initial respiration rates were probably caused by stress during the harvesting process just before storage. In our experiments for all treatments, the respiration rate dropped by 27.4–40.3% over the first 4 days. After the initial drop, the respiration rate of the mushrooms stored in MAP with and without the window at 1 °C rapidly increased with storage time. The abrupt increase in the respiration rates at 1 °C was likely a result of the chilling injury as shown in Fig. 2. The respiration rate remained stable from 4 to16 days with the mushrooms stored in MAP for the silicon gum film window at 3 °C, and was then followed by a subsequent rapid rise (Fig. 3). The respiration rates of mushrooms stored in MAP without silicon gum film windows were higher than that of mushrooms stored in MAP with silicon gum film windows at the same storage temperature.

Fig. 3 also showed that the respiration rate of the mushrooms stored in 5 °C was higher than that of the mushrooms stored in 3 °C irrespective of treatment except for the highest respiration rates at 1 °C because of chilling injury. Storage temperatures dominated the respiration rate of fresh produce (Alique et al., 2005; Jacxsens et al., 2002b). For example, the respiration rate increased with the increasing storage temperature both for mushroom *Agaricus bisporus* (Varoquaux, Gouble, Barron, & Yildiz, 1999) and eggplant fruit (Concellon et al., 2007). Day (2001) and McLaughlin and O'Berne (1999) found that control of the respiration rate is very important and lowering the respiration rate could extend the shelf-life and preserve the quality of products.

3.4. Ascorbic acid content

The initial ascorbic acid content of 5.65 mg 100 g FW^{-1} decreased gradually during storage for all treatments (Fig. 4). Significant differences ($P < 0.05$) in ascorbic acid content were observed among treatments for the three storage temperatures and between the packages with and without the windows after 4 days storage. At the same storage temperature, the ascorbic acid content for mushrooms stored in MAP without silicon gum film windows decreased faster than those with the windows. Mushrooms

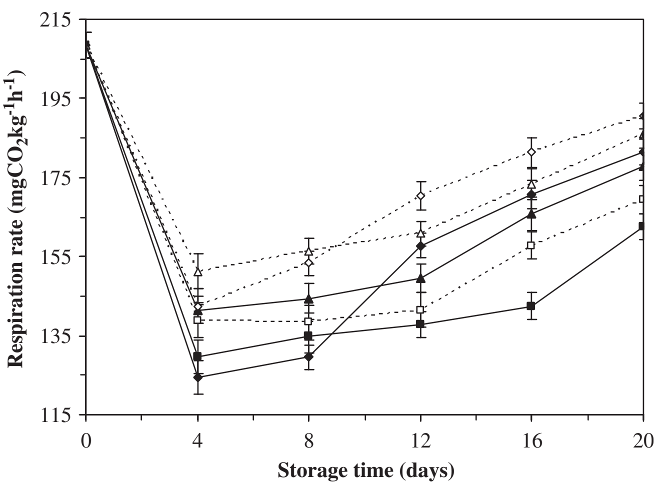

Fig. 3. Respiration rate changes (Mean ± SD for three replicates) of *Agrocybe chaxingu* in MAP stored at different temperatures. (◆) 1 °C, W; (◇) 1 °C, NW; (■) 3 °C, W; (□) 3 °C, NW; (▲) 5 °C, W; (△) 5 °C, NW. W, MAP with silicon gum film windows; NW, MAP without silicon gum film windows.

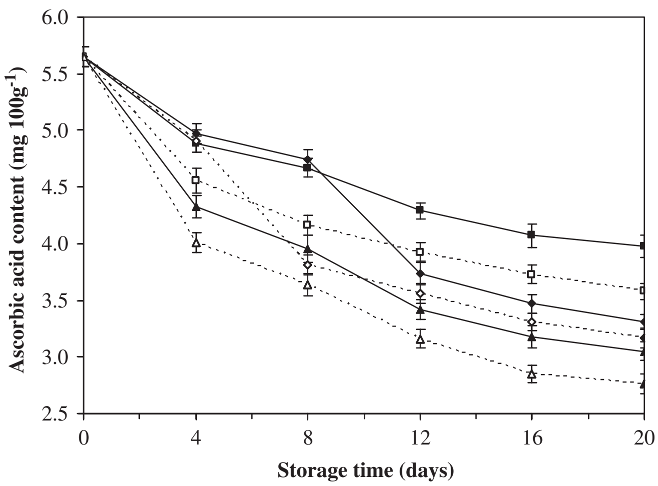

Fig. 4. Ascorbic acid content (Mean ± SD over three replicates) changes of *Agrocybe chaxingu* in MAP stored at different temperatures. (◆) 1 °C, W; (◇) 1 °C, NW; (■) 3 °C, W; (□) 3 °C, NW; (▲) 5 °C, W; (△) 5 °C, NW. W, MAP with silicon gum film windows; NW, MAP without silicon gum film windows.

stored in MAP without the silicon gum film window at 5 °C had the greatest decrease in ascorbic acid content with the lowest value of 2.76 mg/100 g/FW at the end of storage (20 storage days). Mushrooms stored in MAP with silicon gum film windows at 1 °C and 3 °C had similar decreases in ascorbic acid before the 8th storage day and the sharp loss at 1 °C from the 8th storage day was probably caused by chilling injury. The ascorbic acid content of mushrooms stored in MAP with silicon gum film windows at 3 °C had the slowest decrease with the highest content of 3.98 mg/100/g/FW at the end of storage (20 days).

Ascorbic acid is one of the most sensitive materials to destruction when the fresh produce is subjected to adverse handling and storage conditions. Losses are enhanced by many factors, including extended storage, higher storage temperatures and chilling injury (Lee & Kader, 2000; Paull, 1999; Watada, 1987). In this study, higher storage temperature (5 °C) and chilling injury (1 °C) resulted in more losses of ascorbic acid for mushrooms stored in MAP with or without a silicon gum film windows. As observed in the previous study (Li et al., 2007), the silicon gum film window on the MAP helped to retain high ascorbic acid content in mushrooms during the storage period.

3.5. Soluble solid contents

Fig. 5 shows the change in soluble solid contents as affected by storage temperatures. As found in the previous study (Li et al., 2007), the soluble solid contents of all treated samples increased at the beginning of storage, reached a peak value later, and finally decreased. The soluble solid content for all treatments peaked at either the 8th and 12th storage days, except for mushrooms stored in MAP with silicon gum film windows at 3 °C, the soluble solid contents decreased quickly after the 8th storage day and the 12th storage day. These rises coincided increases in respiration rates on the same storage days. Tao, Zhang, Yu, and Sun (2006) reported that the soluble solid contents of Agaricus mushrooms reached the highest levels after about 5 days storage, and then declined. Respiration is a major factor contributing to post-harvest losses, which converts stored soluble solid (sugar mainly) into energy in the presence of an oxygen substrate (Nourian, Ramaswamya, & Kushalappa, 2003). The soluble solid contents of the mushrooms stored in MAP with silicon gum film windows at 3 °C remained relatively stable at a low value ranging from 5.8% to 6.2% probably because of the relatively low and stable respiration rate which occurred with this treatment.

3.6. Electrolyte leakage

Fig. 6 shows the relative electrolyte leakage of the treated samples as influenced by the storage temperatures. The leakage increased with the increasing storage time for all treatments, suggesting that membrane systems became more vulnerable to leakage. Tao et al. (2006) showed similar results in stored Agaricus mushrooms. Amongst treatments the relative cell membrane permeability of *A. chaxingu* mushrooms were significantly different ($P<0.05$) after 4 days storage. Storage temperature and the absence of silicon gum windows contributed to increases in the relative electrolyte leakage, which were also observed by Nourian et al. (2003). The relative cell membrane permeability of mushrooms stored in MAP with the window at 1 °C increased considerably from the 8th storage day until the end of storage most likely due to chilling injury. Chilling injury is associated with changes in proteins (Hausman, Evers, Thiellement, & Jouve, 2000) and membrane structure that lead to increased permeability

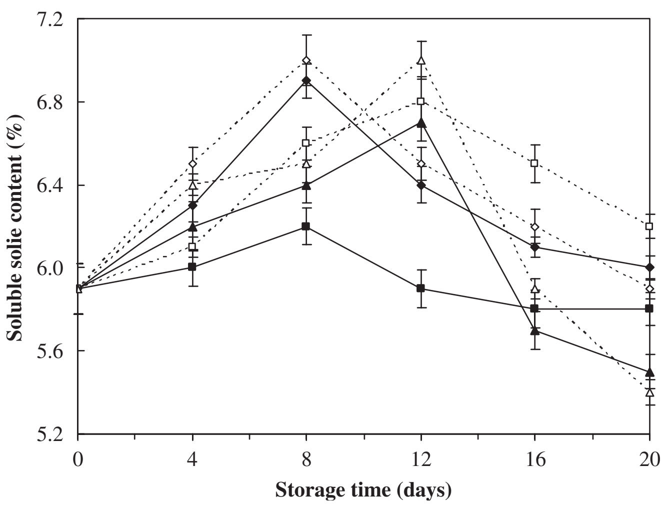

Fig. 5. Soluble solid content (Mean ± SD over three replicates) changes of *Agrocybe chaxingu* in MAP stored at different temperatures. (◆) 1 °C, W; (◇) 1 °C, NW; (■) 3 °C, W; (□) 3 °C, NW; (▲) 5 °C, W; (△) 5 °C, NW. W, MAP with silicon gum film windows; NW, MAP without silicon gum film windows.

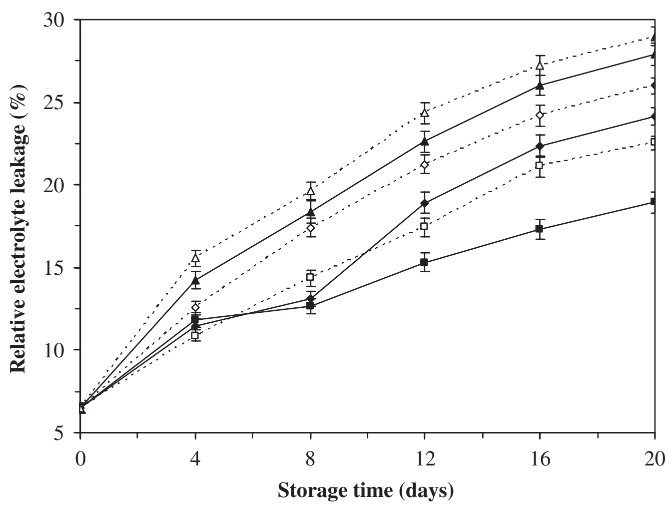

Fig. 6. Membrane permeability (Mean ± SD over three replicates) changes of *Agrocybe chaxingu* in MAP stored at different temperatures. (◆) 1 °C, W; (◇) 1 °C, NW; (■) 3 °C, W; (□) 3 °C, NW; (▲) 5 °C, W; (△) 5 °C, NW. W, MAP with silicon gum film windows; NW, MAP without silicon gum film windows.

and ion leakage (Friedman & Rot, 2006; Murata, 1990; Saltveit, 2002). High CO_2 and low O_2 concentrations often caused physiological damage, which can explain that the relative cell membrane permeability of mushrooms stored in MAP without a silicon gum film window was higher than that of mushrooms stored in MAP with a silicon gum film window at a same storage temperature. Nichols and Hammond (1973) found that CO_2 concentrations higher than 120 mL/L cause cell membrane damage for Agaricus mushrooms. The relative cell membrane permeability of mushrooms stored in MAP without the window at 5 °C had the fastest increase and reached the highest (28.96%) at the end of storage (20 days), whereas mushrooms stored with a window at 3 °C had the slowest increase with the lowest value (17.55%) at 20 days storage.

4. Conclusion

The high storage temperature (5 °C) resulted in rapid changes in the headspace gas concentrations of O_2, CO_2 and ethylene and the different quality parameters of mushroom *A. chaxingu*, including general appearance, firmness, odor, respiration rate, ascorbic acid content, soluble solid content and electrolyte leakage. The chilling injury occurred in mushrooms when stored at 1 °C. Mushrooms stored in MAP with silicon gum film windows had a better storage atmosphere and consequently a slower change of quality parameters than the control packs at a same storage temperature. The storage temperature of 3 °C was the optimal for mushroom *A. chaxingu* in MAP with silicon gum film windows.

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