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Effect of moisture-proof corrugated boxes on water loss from cabbage during storage

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Summary

Reducing water loss from cabbages during storage is essential to extend the shelf life of this widely consumed horticultural crop. In this study, we evaluated the effect of moisture-proof corrugated boxes (MPBs) on water loss from cabbages during storage. We first evaluated the water vapour barrier property of MPB material and found it to be superior to that of conventional corrugated box (CCB) material. Cabbages were then stored in MPBs and CCBs for 9 days, during which their water loss was measured. Cabbages stored in MPBs showed significantly less water loss than those in CCBs. Moreover, storage in the MPBs did not negatively affect the fundamental qualities of the cabbages, such as the green colouration, the soluble solid content, and the ascorbic acid content. The use of MPBs was demonstrated to be an effective and viable way to reduce water loss from cabbages during storage.

Keywords: corrugated box, moisture-proof, storage, water loss, water vapour barrier property

Introduction

Cabbage is one of the most widely grown, traded, and consumed horticultural crops worldwide. In Japan, approximately half of all produced cabbages are used for processed foods (Takada, 2012). Therefore, the maintenance of cabbage qualities such as colour, nutrition, and water content is important. However, leafy vegetables, especially cabbages, are known to have generally low storage potentials in terms of their quality traits and a high perishability as a result of high respiration and water loss during the post-harvest period (Kays and Paull, 2004; Wang, 2003). Water loss is one of the major causes of post-harvest deterioration because it directly results in quantitative losses (loss of saleable weight) and qualitative losses such as wilting and decreased textural quality (i.e. loss of crispness, softening, and flaccidity) (Nunes and Emond, 2007). Therefore, the prevention of water loss from cabbages is a major concern for the maintenance and extension of the shelf life of fresh produce.

Past studies have demonstrated the effectiveness of certain edible coatings in reducing water loss from fresh produce (Ali et al., 2015; De León-Zapata et al., 2015). However, considering the size and structure of cabbage heads, and depending on the regulation on agrichemicals and food additives, it is difficult to coat cabbages with such agents to reduce their transpiration. Nevertheless, advances in packaging technology, including modified atmospheres, have provided possibilities for quality improvement and shelf life extension of horticultural crops, including leafy vegetables (Li et al., 2014; Scully and Horsham, 2007; Srinivasa et al., 2006; Zagory and Kader, 1988).

The use of packaging materials with moisture-proof abilities are expected to reduce water loss from cabbages during the storage period. However, previous studies on modified atmosphere packaging using plastic films, which usually have a high water vapour barrier property (WVBP), focused on the control of oxygen and carbon dioxide inside the packaging. Recently, the use of corrugated boxes has been proposed for the modified atmosphere packaging of fresh produce. It is important that such box materials maintain their WVBP as well as their oxygen and carbon dioxide permeability because the water vapour permeability of paper-based materials is usually higher than that of plastic-based materials. However, little is known about the relationship between WVBP of such paper-based packaging materials and water loss from cabbages during storage. Therefore, in this study, we investigated the storage potential of moisture-proof corrugated boxes (MPBs) with regards to their effectiveness in preventing water loss from cabbages. We also investigated the changes in fundamental qualities of cabbages, such as the green colour, soluble solids content, and ascorbic acid, throughout the experimental storage duration.

Materials and methods

Corrugated boxes

We used two different types of single-layered corrugated boxes: a conventional corrugated box (control, CCB; DA012, Danball One, Japan) without any coating on the surface of the linerboard of the box and an MPB (Damp-Proof 2, Rengo, Japan) with dried latex films and a filler on both surfaces of the linerboard of the box. The thickness of both the corrugated boards was ~5 mm, and the kind of corrugating medium was ‘A flute’. The external dimensions of both the boxes were approximately 400 × 600 × 180 mm (width × length × height).

Evaluation of WVBP of corrugated boards (Experiment 1)

We used a gas-tight acrylic chamber and a beaker containing water to evaluate the WVBP of the boards of both corrugated boxes (Fig. 1). The corrugated boards of CCB and MPB were cut into discs with a diameter of 120 mm. The discs were then placed in a room at 10 °C for 48 h to equilibrate the materials to this room temperature. The relative humidity of the room was 85-90%.

A 100-mL glass beaker containing 50 g (mL) water was placed into the gas-tight chamber with 1 L capacity. The disc of the corrugated boards was placed between the chamber and a ring made of acrylic resin, which had the same internal and external diameters as the gas-tight chamber. This assembly comprising the opening of the chamber, the ring, and the disc of the corrugated boards was sealed with a piece of stretch paraffin film (Parafilm® M, Bemis, WI, U.S.A.) to avoid the leakage of water vapour. In addition, the stretch film was secured using plastic polyvinyl chloride tape (19 mm; Yamato, Tokyo, Japan).

The gas-tight chamber, which contained 50 g (mL) of water and the discs of the corrugated boards and the acrylic ring, was kept in the same room to equilibrate the discs of the corrugated boards to the temperature of the storage room. The experiments commenced on

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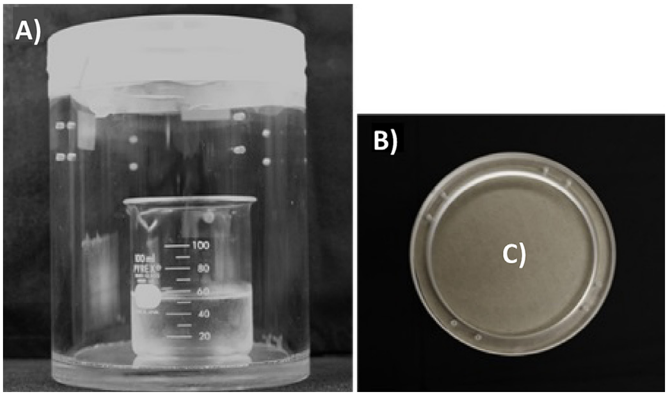

Fig. 1: Method for evaluation of the water vapour barrier property of corrugated boards. A) Gas-tight chamber containing a beaker with 50 mL of water. B) Top view of the assembly. C) Disc of corrugated board.

15 April 2019. The weight change of each beaker was measured on days 2, 4, 7, and 10 of the experimental periods. The chamber was opened each day for a maximum of 3 min.

Analysing the effects of MPB on the quality of cabbages during storage (Experiment 2)

Cabbages: Cabbages (*Brassica oleracea* var. *Capitata*) with compact heads were harvested from a commercial farm in Aichi Prefecture, Japan. The cultivar was unknown. The initial weights of the cabbages were ~1.4 kg ± 0.14 of standard deviation. The cabbages were randomly divided, packed in CCBs, and transported to a laboratory at the Food Research Institute, Tsukuba, Japan. All cabbages were stored overnight at 5 °C with ~90% of relative humidity before commencing with the storage experiments.

Storage conditions: The experiment commenced on 16 April 2019. The cabbages were stored at 10 °C with a relative humidity of 85-90% under dark conditions. Eight cabbages were placed into each box type. In total, eight boxes were prepared: four CCBs and four MPBs. All boxes were stacked in four columns with five tiers each (Fig. 2). The column space between the boxes was set at ~40 mm (for air circulation). Both the samples (n = 4 boxes for CCB and n = 4 boxes for MPB) were randomly placed (dark grey boxes in Fig. 2) in front of the cooling fan (23 m^3 h^{-1}, 70 W). The other boxes (light grey boxes in Fig. 2) were used as balancers or dummy boxes. The boxes were shuffled every day throughout the experimental storage duration.

Weight loss and colour change: Weight loss and colour change are related to the apparent quality of cabbage, and the change in weight is assumed to be the result of water loss. The change in cabbage weight during storage was measured on days 0 (16 April 2019, initial weight before storage), 2, 3, 6, and 9 of the experimental storage period. The change in green colour of the leaves was also measured on the same sampling days, using a non-destructive chlorophyll meter (SPAD-502Plus, Konica Minolta Optics, Tokyo, Japan). The fourth to sixth leaves from the outer part of five cabbages were used. Three parts on each leaf were selected randomly and their Soil Plant Analysis Development (SPAD) values were measured using the chlorophyll meter, and the three measured values were averaged. The SPAD value is used for indirect measurement of the chlorophyll content of plant leaves (Kasim and Kasim, 2017; León et al., 2007).

Soluble solids content and ascorbic acid: To measure the soluble solids content (Brix %) and ascorbic acid (L-ascorbic acid), stored cabbages were cut diagonally into eight parts and the core part was removed. After cutting the sample into small pieces and thoroughly mixing the cut pieces, ~5 g was sampled for use in the analysis of the soluble solids content (Brix %), and ~10 g was sampled for use in the analysis of the ascorbic acid. The exudates from the 5-g cabbage samples, obtained with the use of an extractor, were dropped onto the prism of a saccharimeter (PR-201α, Atago, Tokyo, Japan), which was used to measure the soluble solids content.

To analyse the ascorbic acid of the 10-g samples, the cabbage pieces were immediately placed into 90 mL of 5% metaphosphoric acid solution, homogenised using a homogeniser (HG30, Hitachi Koki, Tokyo, Japan), and filtrated using filter paper (No. 6, 110 mm, Advantech Toyo, Tokyo, Japan). The content of the ascorbic acid in the filtered liquid was measured using a reflectometer (RQflex 20, Merck, Darmstadt, Germany). Both the soluble solids content and ascorbic acid analyses were conducted with five replications and on the same sampling days as the weight loss and colour changes were measured.

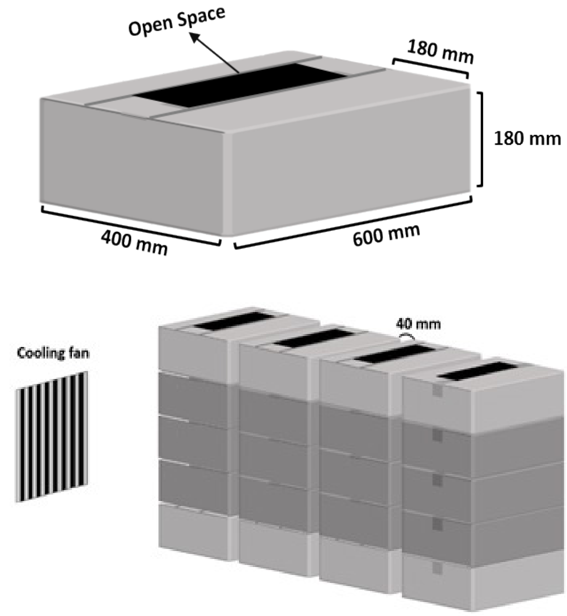

Fig. 2: Position of corrugated boxes inside the storage room. Dark grey boxes indicate the positions of the sample boxes. Light grey boxes in the top and bottom rows and one third of dark grey boxes indicated empty boxes for balance.

Statistical analysis

All results are shown as means ± standard deviations. We used Welch's *t*-test for pairwise comparisons of data within the same measurement period using a spreadsheet program (Excel 2016, Microsoft Japan, Tokyo Japan). *p*-values < 0.05 were considered statistically significant.

Results

WVBPs of the corrugated boards (Experiment 1)

The weights of the water beaker on days 2, 4, 7, and 10 of the storage period were 49.8, 49.6, 49.2, and 48.9 g, respectively, in the experiment with discs from CCB (i.e. CC; Fig. 3) and 49.7, 49.6, 49.4, and 49.1, respectively, in the experiment with discs from MPB (i.e. MP). Significant differences were found between CC and MP on days 7 and 10 of the experimental storage period.

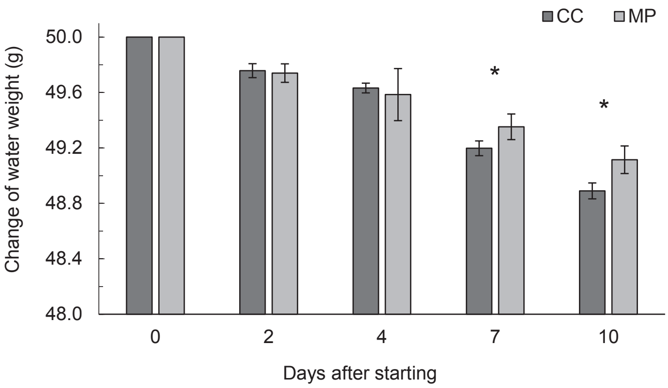

Fig. 3: The change in weight of water inside beakers placed in the gas-tight chambers sealed with conventional corrugated board (CC) and moisture-proof corrugated board (MP) to determine the water vapour permeability of the storage materials. Error bars indicate standard deviations (n = 5). Asterisks indicate significant differences by Welch's t-test ($p < 0.05$).

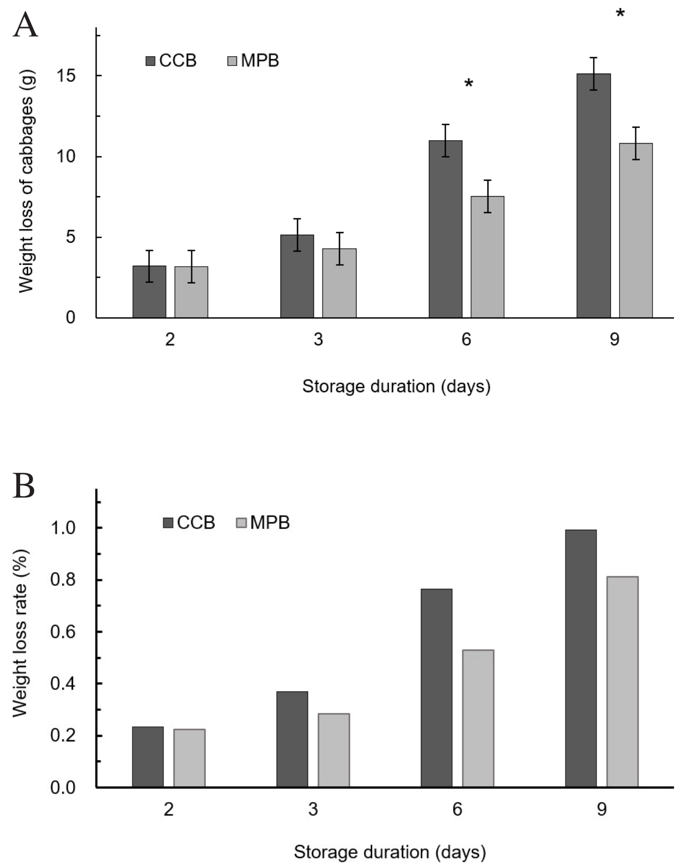

Fig. 4: Effect of storage in different corrugated boxes on weight loss from cabbages. (A) Weight loss from cabbages (g) and (B) weight loss rate (%) for cabbages stored in conventional corrugated boxes (CCBs) and moisture-proof corrugated boxes (MPBs). Error bars indicate standard deviations (n = 5). Asterisks indicate significant differences by Welch's t-test ($p < 0.05$).

Effects of MPB on the quality of cabbages during storage (Experiment 2)

Weight loss: For the control, the weight loss (g) of cabbages on days 2, 3, 6, and 9 after starting the experiment was 3.2, 5.1, 11.0, and 15.1, respectively (Fig. 4A). On the other hand, for the MPB, the values on days 2, 3, 6, and 9 were 3.2, 4.3, 7.5, and 10.8, respectively. Significant differences were found in the cabbage weight loss values for both boxes at 6 and 9 days after starting the experiment; the weight loss for MPB was 30% lower than that of the control during storage (Fig. 4B).

Colour, soluble solids content, and ascorbic acid: The change of green colour (SPAD value), soluble solids content, and ascorbic acid of cabbages during storage for 9 days are shown in Tab. 1. The SPAD values for both boxes decreased in the days after starting the experiment. The values of soluble solids content and ascorbic acid were unchanged during storage. Thus, for all measurement items and periods, there were no significant differences between control and MPB.

Discussion

In the present study, we first evaluated the WVBP of CC and MP. Compared to CC, MP showed lower water vapour permeability (Fig. 3). For CC, a major decrease in the beaker water level was observed on days 7 and 10 of the experiment. In contrast, the decrease in the beaker water level of MP was less significant than that of CC on the same sampling days, indicating that less water was lost.

In accordance with the above-mentioned results, we then conducted storage experiments with cabbages for 9 days. Weight loss analysis revealed significant differences between cabbages stored in the CCBs and MPBs at 6 and 9 days (Fig. 4A). The most important factor of weight loss in fresh produce is the decrease in water content via transpiration (Kays and Paull, 2004; Kitazawa et al., 2011). Although, several factors, including moisture (Bovi et al., 2016; Kader, 2002), affect the degree of transpiration of fresh produce, the maintenance of a high relative humidity inside packaging contributes to the reduction of water loss from fresh produce (Mampholo

Tab. 1: Effects of two types of corrugated boxes on the colour, soluble solids content, and ascorbic acid content of cabbage during storage.

Storage duration (days)	Green colour (SPAD value)		Soluble solids content (Brix %)		Ascorbic acid[z] (mg kg^{-1} FW)	
	CCB	MPB	CCB	MPB	CCB	MPB
0	6.2 ± 2.4[y]		7.2 ± 1.1		530 ± 52	
2	5.8 ± 1.3	5.4 ± 2.6	7.0 ± 0.7	8.0 ± 0.6	554 ± 46	542 ± 54
3	7.1 ± 2.0	5.0 ± 1.7	8.0 ± 0.7	7.0 ± 0.6	542 ± 57	504 ± 27
6	3.4 ± 1.0	3.2 ± 1.0	6.7 ± 1.8	7.5 ± 1.1	520 ± 56	538 ± 23
9	4.0 ± 1.5	2.8 ± 0.7	7.7 ± 1.5	7.6 ± 0.2	522 ± 56	522 ± 31

CCB, Conventional corrugated box (control); MPB, Moisture-proof corrugated box

[z]L-ascorbic acid

[y]Mean ± standard deviation (n = 5)

et al., 2013; Tzoumaki et al., 2009). In experiment 1, we demonstrated that MP had a high WVBP, and experiment 2 showed that the water loss from cabbages stored in MPBs was lower than that from cabbages stored in CCBs.

For leafy vegetables, the loss of green colour usually indicates the end of the shelf life of the produce. We therefore used the SPAD value, which represents the chlorophyll content, to evaluate the decrease in green colour of cabbages leaves. No significant differences were observed in the SPAD value between the CCB and MPB for each measurement period (Tab. 1); however, the values for each box tended to decrease with the increase in storage duration. The loss of green colour of fresh produce is reportedly caused by chlorophyll degradation (King and Morris, 1994; Mampholo et al., 2013; Yamauchi, 2013; Zhuang et al., 1997) and accelerated by the absence of light or dark conditions (Büchert et al., 2011). Thus, the decrease in green colour of cabbages packaged in both types of boxes in the present study was presumably induced by the dark-light conditions during storage. However, our results demonstrate that the use of MPBs, specifically, did not induce any negative changes in the green colour of the cabbages.

There were no significant differences between the soluble solids content and ascorbic acid content of the cabbages stored in the CCBs and MPBs for each measurement period (Tab. 1). The soluble solids content remained stable throughout the storage period in the present study, and this result is consistent with the findings of similar studies on cabbages and asparagus (Brueckner et al., 2010; Nilsson, 1993; Shou et al., 2007). The ascorbic acid content also remained stable throughout the storage period in the present study. Several studies have reported that post-harvest water loss from leafy vegetables results in the rapid loss of ascorbic acid (Lee and Kader, 2000). Therefore, considering the observed water loss from cabbages stored in CCBs, the ascorbic acid content of such cabbages may decrease to a greater extent than that of cabbages stored in MPBs over an extended storage period; however, further studies are needed to confirm this expectation. Nevertheless, the different packaging conditions in the present study did not affect the soluble solids content and ascorbic acid content of cabbages over the storage durations used, and MPB did not induce any negative changes to the assessed fundamental qualities during the storage period.

Conclusion

Our results demonstrate that storage in MPBs effectively reduced water loss from cabbages and did not induce any negative effects on other fundamental qualities; thus, the use of MPBs may effectively extend of the shelf life of cabbages and possibly other leafy vegetables.

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Conflict of interest

The authors declare that they have no conflict of interest.

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