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Low temperature storage maintains postharvest quality of cabbage (*Brassica oleraceae* var. *capitata* L.) in supply chain

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Abstract: Leaf yellowing and wilting are the common postharvest problems of cabbage in supply chain that are encountered at the collection or consolidation stage. This study simulated the conditions at the collection center and determined the effects of low temperature storage on cabbage quality. Storage at 4 and 10°C effectively delayed leaf yellowing and maintained leaf chlorophyll content. Weight loss, respiration rate and ethylene production were also reduced at low temperatures and head firmness was maintained. Moreover, total soluble solids and ascorbic acid contents were higher in cabbages kept at 4 and 10°C than those stored at ambient condition (28°C). Cabbage can be stored successfully at 4°C for 18 days and 12 days at 10°C. At ambient, cabbage deteriorated rapidly and lasted for only 4 days.

Keywords: Cabbage, cold storage, supply chain, shelf life

Introduction

Cabbage (*Brassica oleraceae* var. *capitata* L.) is an economically important crop in Thailand and one of the most widely cultivated vegetables in Northern Thailand particularly in Petchaboon province. Traditional supply chain for cabbage is generally long and complex (Figure 1). Before cabbages reach the market, they are traded by collecting agents at the village and district levels. Green-colored heads are preferred by traders and consumers. Provincial traders then sell the cabbages to traders or consignees who bring the produce to the wholesale markets in Bangkok or other provinces. Often, cabbages have to be transported over long distances from the production areas to the market. Poor handling consequently results in significant product losses. Quality losses are in the forms of yellowing of outer leaves, core elongation, internal yellowing in the apex region, leaf abscission and sometimes rootlet development at the core-end (Cantwell and Suslow, 2007). Cabbage is a highly seasonal crop with an oversupply during production peaks and undersupply during lean season resulting in highly fluctuating prices (Figure 2). Cabbages reach the retail markets at least one or two days after harvest thus, quality has significantly decreased. Therefore, maintaining the postharvest quality of cabbage at collection center while waiting for more favorable price is important. Low temperature or cold storage is the single most effective method of prolonging the postharvest life of fresh produce. It reduces respiration rate, ethylene production and sensitivity, moisture loss, and growth of pathogens (Mitchell, 1992). Its integration in cabbage supply chain management could improve profitability and sustainability. This study was therefore conducted to determine the efficacy of low temperature storage in maintaining the quality of cabbages at the collection stage in the supply chain.

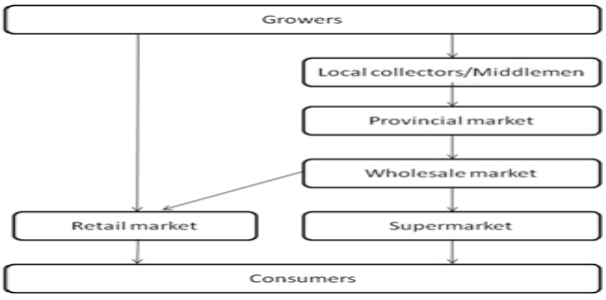

Figure 1. Supply chain of cabbage in Petchaboon province, Thailand

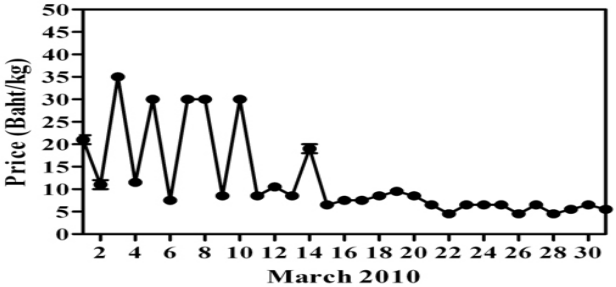

Figure 2. Price of cabbage at the collection center of Petchaboon provincial market, Thailand, March 2010. (1 USD is approximately 31.58 Baht)

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Materials and Methods

Plant material

Cabbages at commercial maturity (compact heads, about 90 days after planting) were harvested from a commercial farm in Petchaboon Province, Northern Thailand. Heads were selected for uniformity of size and color, randomly divided into three groups, packed in commercially used polyethylene (PE) bags (10 kg/bag) with holes, and transported to the laboratory under temperature-controlled conditions (23-25°C) within 6 h after harvest. The bags of cabbages were stored at 4, 10 or 28°C (ambient condition) and 95±1% RH. Cabbage samples were taken at 2-day interval for measurement of physiological, biochemical, and physical changes.

Weight loss and firmness measurement

The fresh weight of each cabbage head was monitored at 2-day interval and weight loss was calculated as percentage of the initial weight. Head firmness was measured on the top sides of each head using a texture analyzer (TA-XT2, Stable Micro Systems Ltd., UK) with a 5 mm diameter plunger and a constant moving rate of 20 mm min^{-1} for a 5 mm depth. The mean values for maximum force are expressed in Newton (N).

Measurement of respiration rate and ethylene production

A cabbage head was placed in 4 L sealed plastic chambers fitted with gas sampling ports and incubated at different storage temperatures for 2 h. Gas samples (1 mL each) were withdrawn from the headspace for measuring respiration rate and ethylene production. Respiration rate was determined using a GC-8A (Shimadzu, Japan) fitted with a 80/100 mesh Porapack Q column and a thermal conductivity detector (TCD). Ethylene production was measured with a GC-2014A (Shimadzu, Japan) equipped with a 80/100 mesh Porapack Q column and a flame ionization detector (FID).

Measurement of color changes

Leaf yellowing was estimated from the total yellow area on each leaf surface using a scoring index of 1 (no yellowing) to 5 (full yellowing). When leaves reached a score >3, they were considered unmarketable. Objective color measurement was also done using a Minolta chromameter (model CR-400, Osaka, Japan). The values were expressed as L^* and b^*. L^* value refers to the lightness, ranging from 0 = black to 100 = white. Negative (-) and positive (+) values of b^* refer to blue and yellow colors, respectively.

The chlorophyll contents were extracted from cabbage leaves with *N*, *N*-dimethylformamide (1:20, w/v) (Moran, 1982). The extraction process was carried out for 24 h at 4°C in the dark to minimize photodegradation of chlorophyll and the quantification was performed with a spectrophotometer (UV-1800 Shimadzu Kyoto, Japan). The chlorophyll content was expressed as mg 100 g^{-1} of fresh weight.

Total soluble solids and ascorbic acid analysis

Total soluble solids (TSS) content was measured from the leaf extract using a digital refractometer (PAL-1, Atago, Tokyo, Japan). The total ascorbic acid (AA) or vitamin C content was measured according to the method of Hashimoto and Yamafuji (2001). Five grams of leaf samples were mixed with 20 mL of cold 5% metaphosphoric acid, and filtered through Whatman No.1 paper. A 0.4 mL aliquot of the filtrate was mixed with 0.2 mL of 2% di-indophenol. The mixture was then added to 0.4 mL of 2% thiourea and 0.2 mL of 1% dinitrophenol hydrazine, and incubated at 37°C for 3 h. After incubation, 1 mL of 85% sulphuric acid was added, and the resultant solution was incubated again at room temperature for 30 min. Total ascorbic acid was determined by measuring the absorbance at 540 nm using a spectrophotometer (UV-1601; Shimadzu Co., Kyoto, Japan) and was expressed as mg 100 g^{-1} of fresh weight.

Statistical analysis

The experiment was laid out in a completely randomized design (CRD) with three replicates. Analysis of variance (ANOVA) was performed using Statistical Analysis System (SAS), version 8.0 (SAS, Institute Inc., Cary, NC, USA). Treatment means were compared by Least Significant Difference (LSD) test at $P \leq 0.05$. Treatment means are also presented with standard error (SE) values.

Results and Discussion

Weight loss and firmness

Weight loss increased with storage much more rapidly at ambient (28°C) than at 4 or 10°C (Figure 3A). Cabbages held at 4°C had the lowest weight loss throughout the storage period. On the other hand, firmness of cabbage heads decreased with storage (Figure 3B). It was most rapid at ambient and least at 4°C.

Losses in weight and firmness of cabbages could occur at any stage in the supply chain (Figure 1). To reduce these losses, proper temperature management is important as illustrated by the effects of low

temperature obtained in the present study. Daly and Tomkins (1998) found that weight loss of Chinese cabbage was reduced at lower temperatures. At higher temperatures, vapor pressure deficit increases resulting in increased water loss which mainly accounts for weight and turgidity losses.

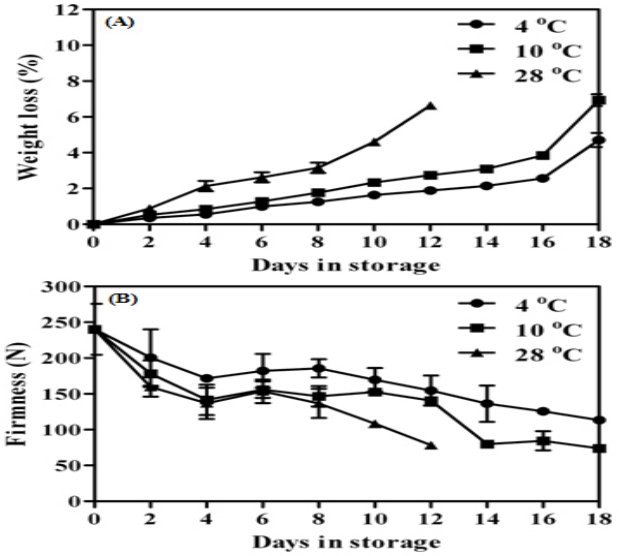

Figure 3. Weight loss (A) and firmness (B) changes in cabbage during storage at 4, 10 and 28°C

Respiration rate and ethylene production

Respiration rate was about 2-3 times higher at 28°C than at 4-10°C throughout the storage period (Figure 4A). Cabbages stored at the lowest temperature also showed the lowest rate of respiration. Ethylene production increased with increasing period of storage at ambient; this was inhibited during storage at low temperatures (Figure 4B). The results compare well with that of previous studies. Porter *et al*. (2003) reported that the respiration rates of Chinese cabbage were higher at 20°C than at lower temperatures. With the onset of senescence, respiration rates would increase dramatically. This could be accompanied by corresponding increases in ethylene production (Kader, 1992). Ethylene, even at low levels, is known to promote senescence and increased levels of production would accelerate deterioration and shorten the postharvest life (Wills *et al*., 1999).

Color changes

Yellowing of outer leaves of cabbage developed very quickly at 28°C and was already perceptible after 2 days storage (Figure 5-6). In contrast, cabbages stored at low temperatures showed much delayed yellowing, with storage at 4°C being more effective than at 10°C. Yellowing scores (Figure 5A) were objectively supported by the L^* and b^* values which were highest at 28°C and lowest at 4°C (Figure 5B-C). Similarly, chlorophyll contents decreased with storage most rapidly at 28°C and only gradually at 4°C (Figure 5D). Average chlorophyll loss was 65.6 % at 28°C, 39.6% at 10°C, and 4.2% at 4°C.

Chlorophyll breakdown leading to yellowing of outer leaves is the first visible sign of senescence in cabbage. This has also been obtained in other leafy vegetables such as spinach (Yamauchi *et al*., 1985), parsley and garland chrysanthemum (Yamauchi *et al*., 1980), pak-choi, water convolvulus and spinach (Hirata *et al*., 1987), mitsuba leaves (Yamauchi *et al*., 1995) and jute leaves (Tulio *et al*., 2002). In all these studies, yellowing was more favored at higher storage temperatures.

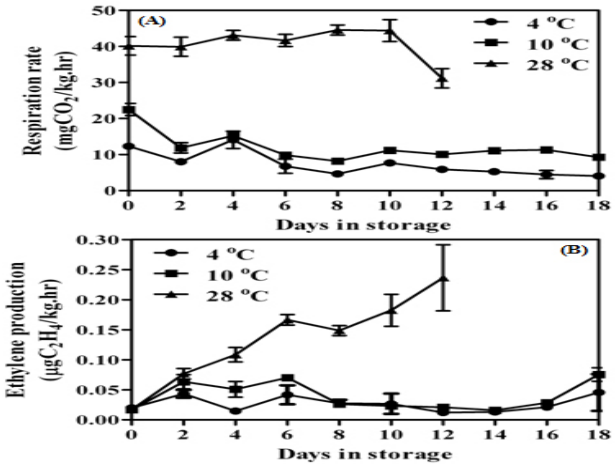

Figure 4. Respiration rate (A) and ethylene production (B) of cabbage during storage at 4, 10 and 28°C

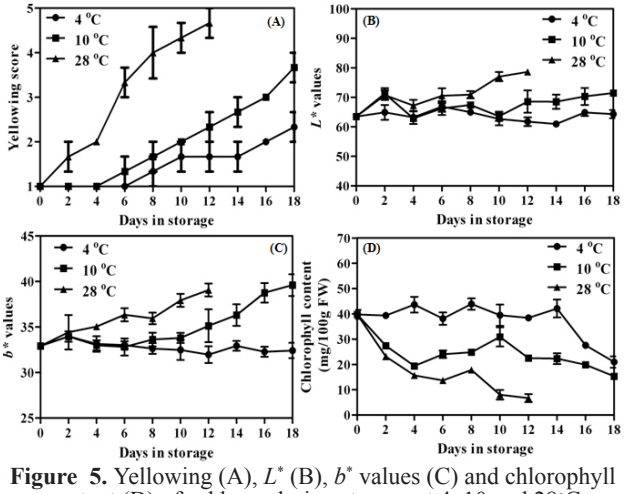

Figure 5. Yellowing (A), L^* (B), b^* values (C) and chlorophyll content (D) of cabbage during storage at 4, 10 and 28°C

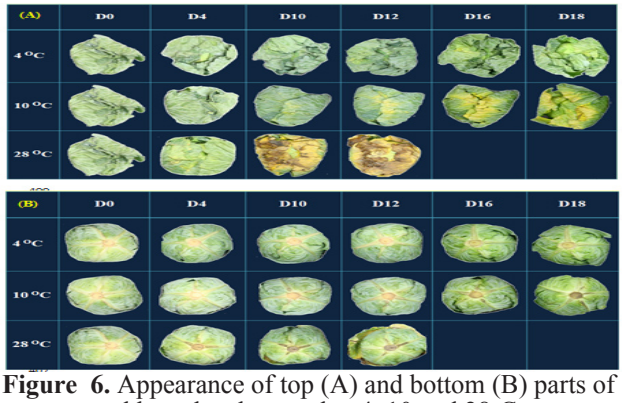

Figure 6. Appearance of top (A) and bottom (B) parts of cabbage heads stored at 4, 10 and 28°C

Total soluble solids and ascorbic acid contents

TSS content remained almost unchanged during the first 4 days of storage at all storage temperatures but later, it decreased rapidly at 28°C (Figure 7A). Such decrease in TSS occurred only after 14 days storage at 4°C or 10°C; both temperatures had comparable effect. In an earlier study, decreases in fructose, glucose, sucrose and soluble solids contents were also observed in cabbage stored for 6 months at 0-1°C (Nilsson, 1993). On the other hand, ascorbic acid content decreased after 2 days of storage and fluctuated thereafter (Figure 7B). However, cabbages stored at 4°C had consistently the highest ascorbic acid content while those stored at 28°C, the lowest. Fawusi (1983) previously reported that jute leaves stored at 4°C lost about 77% ascorbic acid over a 4-week storage period, much smaller than those stored at ambient (25-28°C) which incurred a 93% loss within only 4 days of storage. Hirata *et al*. (1987) also found that in leafy vegetables such as pak-choi (*Brassica chinensis* L.), edible amaranth (*Amaranthus mangostanus* L.), and soup celery (*Apium graveolens* L. var. *secalinum* Aleff.), the decrease in ascorbic acid contents was retarded by low temperature storage.

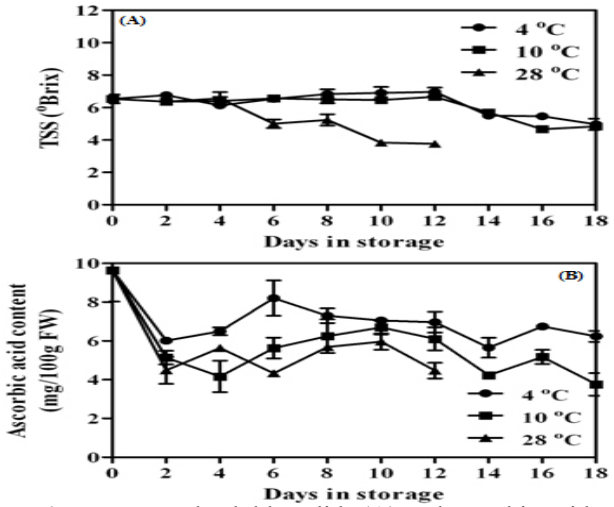

Figure 7. Total soluble solids (A) and ascorbic acid content (B) of cabbage during storage at 4, 10 and 28°C

Storage life

Low temperature storage remarkably increased storage life of cabbage (Figure 8). Storage life was about 18 days at 4°C and 12 days at 10°C compared with only 4 days at 28°C. The extension of storage life was due to the reduction of losses in chlorophyll and water content thus maintaining the green color and turgidity of the leaves. Respiration rate and ethylene production were likewise retarded with low temperature storage thus delaying senescence. In addition, low temperature storage reduced the losses in soluble solids and ascorbic acid contents thereby preserving the nutritional value of cabbage.

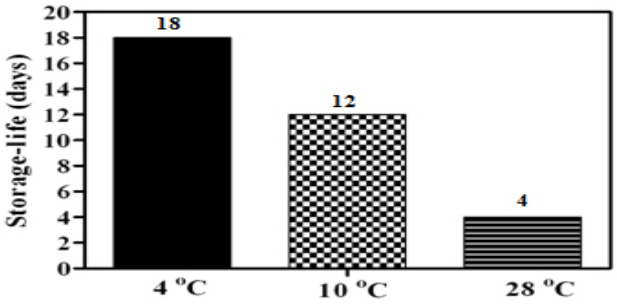

Figure 8. Storage life of cabbage at 4, 10 and 28°C

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