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Effects of Cooling Rate on Quality Characteristics of Spring Kimchi Cabbage (*Brassica campestris* L. ssp. *Pekinensis*) During Cold Storage

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Abstract

In this study, we investigated the effects of cooling rate during storage on spring kimchi cabbage from an economic perspective. For long-term storage, kimchi cabbage (KC) should be maintained at a low temperature immediately after harvest; however, a sudden change in temperature during storage may lead to chilling injury in KC. The optimal cooling rate is important for the long-term storage of KC. To identify the optimal cooling rate, KC was cooled at different cooling rates (1°C, 2°C, 4°C, 6°C, 8°C, and 24 °C/day), and then stored at 1°C for 90 days. Thereafter, weight, trimming, total loss, pH, free sugar content, and total bacterial count changes were measured. Spring KC stored at the cooling rate of 6 °C/day presented a lower total loss and better sensory properties than KC stored at other cooling rates; thus, 6 °C/day is an appropriate cooling rate for long-term storage of KC.

Key words: cooling rate, kimchi, spring kimchi cabbage, storage

Introduction

In Korea, kimchi cabbage (*Brassica rapa* L. ssp. *Pekinensis*) is the most popular vegetable and is used in various dishes, especially as the main ingredient in kimchi (Choi et al., 2015). According to the Korean Statistical Information Service (KOSIS), 2.95 million tons of kimchi cabbage was produced in 2018, with 28.4% of spring cabbage, 9.4% of summer cabbage, 47.6% of autumn cabbage, and 14.6% of winter cabbage. There is a growing demand for kimchi cabbage owing to increased consumption and the commodity value of kimchi. However, summer kimchi cabbage is difficult to cultivate because of unpredictable weather conditions, such as high temperatures and typhoons (Bae et al., 2015; Kang et al., 1999; Yang et al., 1993).

For kimchi manufacturers, a stable supply of kimchi cabbage in summer is crucial from an economic perspective. Controlled atmosphere storage (Choi et al., 2019; Park et al., 2015), modified atmosphere packaging with materials such as polyethylene film (Cho et al., 2017; Kim et al., 2001a; Lee et al., 2003; MAFRA, 2013; Yang et al., 1993), and 1-methylcyclopropene (1-MCP) treatment (Hong et al., 2018a; Hong et al., 2018b) have been evaluated to store kimchi cabbage. However, these methods are not appropriate for small and medium-sized kimchi manufacturers owing to their high cost. Kimchi cabbage exhibits physiological activities, such as respiration and transpiration, after harvest. This results in the deterioration of cabbage quality during storage (Kang et al., 1999; Park et al., 2006). Generally, cabbage and other agricultural products are rapidly stored at low temperatures after harvest, and cold storage is an important technique for long-term storage (Martínez-Romero et al., 2003; Nunes et al., 1995; Porter et al., 2003) because low temperature can reduce respiration rate, ethylene production, and pathogen growth (Porter et al., 2003). However, spring kimchi cabbage exhibits different characteristics and post-harvest physiological activities compared with winter kimchi cabbage (Lee et al., 2007; Yang et al., 1993). The post-harvest effects of cooling are different on crops of different temperature origins (Bramlage and Meir, 1990). In particular, rapid cooling of spring kimchi cabbage harvested at high temperatures can cause chilling injury owing to a high internal temperature and moisture (Hyang et al., 2013). Hence, studies on long-term storage methods for spring kimchi cabbage, considering economic feasibility and practical applicability, are needed. The aim of this study was to identify an optimal cooling rate that can be easily utilized in the kimchi industry.

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Materials and Methods

Kimchi cabbage sample

Kimchi cabbages used in this study were spring kimchi cabbages (cultivar: Cheongna) grown in Boeun, Chungcheongbuk-do Province, South Korea in 2019.

Storage method

After harvest, the outer leaves of spring kimchi cabbage were trimmed and 4-5 cabbages were placed in polypropylene boxes (550 mm ×366 mm×323 mm) and loaded on a pallet. Each kimchi cabbage was stored in a pilot-scaled cold storage house in Haneulmaeum Ltd. (Boeun, Korea) that contained 1,300 mm×1,500 mm×2,000 mm panels. At the time of harvest, the initial temperature of kimchi cabbage was approximately 20°C. The kimchi cabbages were stored in 30 boxes and were gradually cooled down to the target temperature (1°C) without controlling the humidity of storage house at the following cooling rates: 1°C/d, very slow cooling; 2°C/d, slow cooling; 4°C/d, low–medium cooling; 6°C/d, medium cooling; 8°C/d, high–medium cooling; 24°C/d, rapid cooling. When the temperature of the storage houses reached 1°C, the kimchi cabbages were stored while maintaining temperature for 90 days. Quality changes in spring kimchi cabbage were measured on 0, 60 and 90th days. Quality analysis of kimchi cabbage and preparation of kimchi were carried out in the World Kimchi Institute (Gwangju, Korea).

Temperature, humidity and gas concentration in the storage house

To determine the optimum cooling rate, real-time temperature and humidity recorders (Saveris 2-H1; Testo, Lenzkirch, Germany) and combined gas meters (GasAlert Micro5; Honeywell, Charlotte, NC, USA) were installed in each storage chamber to analyze the changes in temperature, humidity, and oxygen and carbon dioxide concentrations during the storage period.

Preparation of kimchi

To evaluate the processing suitability of kimchi cabbage, kimchi was prepared using fresh cabbage and cabbages stored for 90 days. The cabbage was cut evenly into 3×3 cm pieces and pickled for 30 min in 20% (w/v) saline using purified salt (Hanju Corp., Ulsan, Korea). The salted kimchi cabbage was washed three times, naturally dehydrated for 60 min, and mixed with 80% salted cabbage and 20% kimchi seasoning (Trechan Co., Gwangju, Korea) containing red pepper powder, radish, garlic, ginger, salted shrimp, anchovy sauce, glutinous rice paste, and green onion (Ryu et al., 2014). The kimchi prepared was packaged in plastic containers (diameter, 11.5 cm; height, 8.3 cm), and then sensory evaluation were analyzed while fermenting at 10°C.

Weight, trimming, and total losses of kimchi cabbage

Weight loss was determined by measuring the weight of kimchi cabbage samples before and after storage at different cooling rates.

$$\text{Weight loss (\%)} = (\text{pre storage weight} - \text{post storage weight}) / \text{pre storage weight} \times 100$$

Trimming loss was determined after removing the non-edible leaves of kimchi cabbages that dried or decayed during storage.

$$\text{Trimming loss (\%)} = \frac{\text{pre trimming weight} - \text{post trimming weight}}{\text{pre trimming weight}} \times 100$$

Total loss was calculated as the sum of storage and trimming loss.

$$\text{Total loss (\%)} = [1 - \{1 - (\text{weight loss}/100)\} \times \{1 - (\text{trimming loss}/100)\}] \times 100$$

pH and free sugar content of kimchi cabbage

In the physicochemical analysis, kimchi cabbages were ground using a hand blender (Hand Blender HHM-630; Hanil Co., Seoul, Korea) and filtered using sterile gauze (Sterile gauze No. 3; Soosung, Yangsan, Korea) to measure the pH and free sugar content. The pH of the sample was measured using an automatic titrator (Titroline easy; Schott Instruments, Mainz, Germany). The content of free sugars, such as sucrose, maltose, fructose, glucose, and galactose, was determined. Each sample (10 μL) was injected into a Dionex Ultimate 3000 HPLC-system (Dionex Corp., Sunnyvale, CA, USA). The system was equipped with a sugar-pak column (300 mm × 6.5 mm: Waters, Milford, MA, USA) and Shodex RI-101 Detector (Showa Denko America Inc., New York, NY, USA). The peak area obtained by high-performance liquid chromatography was used to calculate the free sugar content, based on the methodology reported previously (Choi et al., 2016).

Total bacterial count of kimchi cabbage

Total bacterial count was determined using the plate counting method. Ten grams of trimmed kimchi cabbage samples were placed in a sterile bag (Whirl-pak1195; Nasco, Co., Fort Atkinson, WI, USA), 0.85% saline solution, equivalent to 10 times the weight, was added, and the bag was placed in a homogenizer (Bag Mixer; Inter-science, Co., Nom la Bretèche, France). The sample was homogenized for 60 s. One milliliter of the sample solution was diluted with 0.85% saline solution and spread on plate count agar (Difco, Co., Detroit, MI, USA). The plate was incubated at 30°C for 48 h. The colonies were counted and expressed as colony-forming units/g, based on a previous study (Moon et al., 2019).

Sensory evaluation of kimchi

Sensory evaluation of kimchi was performed to determine the texture and overall preference, which represents the quality of kimchi. The evaluation was conducted by a panel of 12 trained experts, who are researchers at the World kimchi Research Institute. Samples of kimchi prepared using fresh kimchi cabbage (control) and stored kimchi cabbage stored at different cooling rates were evaluated on 0, 8, and 40th days while fermenting at 10℃. Kimchi was prepared by placing approximately 15 g of stem and leaf in a container marked with numbers selected from a random number table. Texture was scored using a seven-point scale method: 1, very weak, 2, weak, 2: slightly weak, 4, moderate, 5: slightly strong 6: strong, 7: very strong. Overall preference was evaluated using a seven-point scale method: 1, very bad; 2, bad; 3, slightly bad; 4, normal; 5, slightly good; 6, good; 7, very good (Ku et al., 1988).

Statistical analysis

The experimental results were evaluated using the analysis of variance (ANOVA) with Minitab 19 (Minitab Inc., State College, PA, USA). The results with a probability value (p) of < 0.05 were considered significant.

Results and Discussion

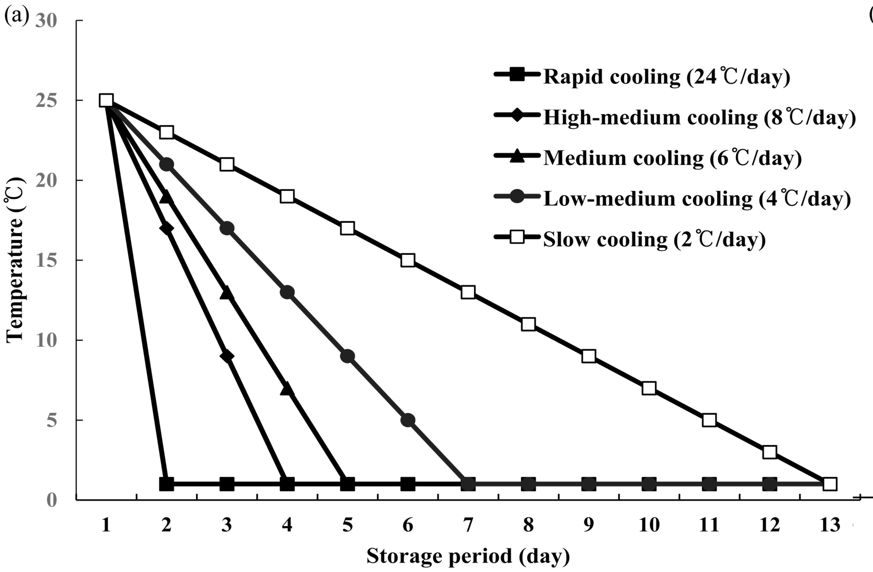
Temperature change in the storage house

The Scheme of temperature changes (a) and actual time to 1°C (b) were shown in Fig. 1. The temperature change in the storage house varied from the beginning of storage, but remained constant after 15 days. The temperature in the storage house reached 1°C in the following order : rapid cooling, high–medium cooling, medium cooling, low–medium cooling, and slow cooling. Because of the respiratory heat of cabbage, as reported by Hyang et al. (2013), very slow cooled kimchi cabbage, which decayed after 4 days, was excluded from the experiment.

Humidity change in the storage house

The relative humidity (a) of the storage house was shown in Fig 2. The relative humidity of the storage house fluctuated for 3 days of storage according to the difference in the cooling rate and remained 95-100% after 3 days without rapid cooling. The faster the cooling rate at the beginning of storage, the lower the relative humidity and the greater the variation. This appears to be due to a considerable change in the amount of water absorbed by the heat exchanger during the frequent

(a)



(b)

Cooling rate	Actual time to reach 1 ℃
Slow	288 h (12 days)
Low–medium	165 h (6.9 days)
Medium	117 h (4.9 days)
High–medium	84 h (3.5 days)
Rapid	24 h (1day)

Fig. 1. Scheme of temperature changes according to the cooling rate (a) and actual time to reach 1°C (b).

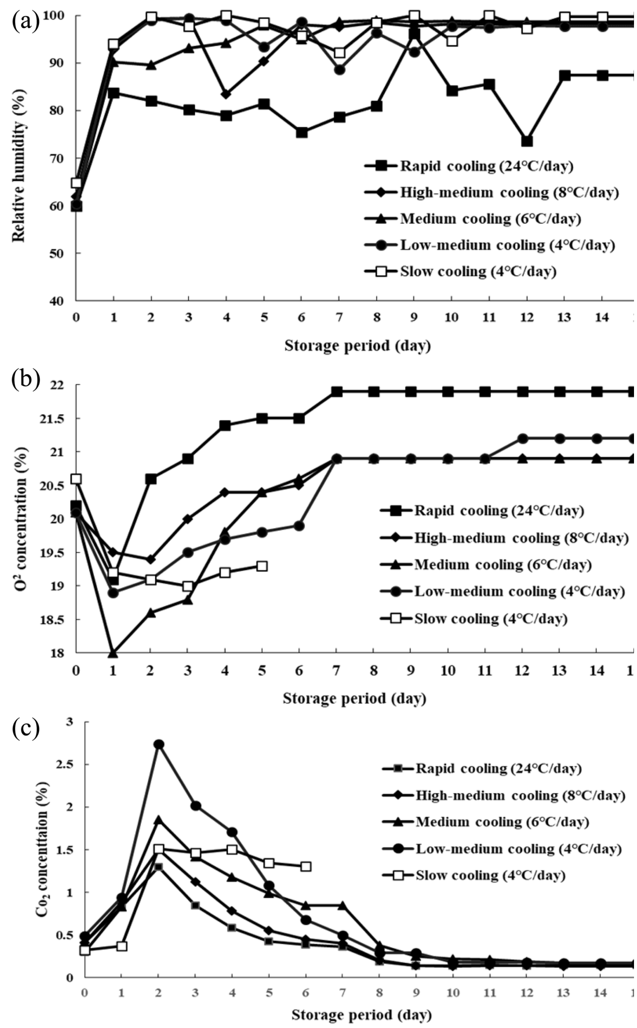


Fig. 2. Relative humidity changes (a), oxygen concentration changes (b), and carbon dioxide concentration changes (c) in the storage house during cold storage at different cooling rates.

operation of the freezer. For the long-term storage of cabbage, quick storage after harvest at a low temperature is important to prevent physiological activities. However, if the temperature and moisture of harvested cabbage are high, rapid cooling can cause chilling injury. When cooled at a very slow rate, bacteria may multiply, resulting in the decay of kimchi cabbage owing to the respiratory heat generated by kimchi cabbage (Hyang et al., 2013; Martínez-Romero et al., 2003; Porter et al., 2003). Therefore, for long-term storage, spring kimchi cabbage should be stored at an appropriate cooling rate, based on their respiration rate, to reach the storage temperature. The cooling rate must control the heat generated during the metabolic process of kimchi cabbage and an appropriate cooling rate should be managed according to the initial temperature of the cabbage and the storage cooler capacity.

Changes in the oxygen and carbon dioxide concentrations in the storage house

The oxygen (b) and carbon dioxide concentrations (b) were shown in Fig. 2. The oxygen and carbon dioxide concentrations in the storage house showed a significant change in the early stage of storage, similar to the changes in humidity with the cooling rate, because the cabbage consumed oxygen and produced carbon dioxide. However, the cooler was not completely sealed inside; therefore, the oxygen and carbon dioxide concentrations only changed at the beginning of storage, and then remained similar to the ambient atmosphere concentrations. The concentrations measured in the initial stage showed that the oxygen concentration decreased by 1.5% from 20-21% to 18.5-19.5% and carbon dioxide concentration increased by 1.5% from 0.3-0.4% to 1.5-2.0% (Fig. 2). The time to reach a specific condition (oxygen 19.1% and carbon dioxide 1.6%) was not significantly different among the slow cooling, low–medium cooling, medium cooling, and high–medium cooling rates. The time to reach this condition with rapid cooling was three times slower than that with the others. This is because, as Porter et al. (2003) reported, the cabbage respiration rate is low at low storage temperatures; thus, the changes in oxygen and carbon dioxide concentrations during storage are slow.

Weight, trimming, and total losses of kimchi cabbage

Weight loss is caused by the transpiration and drying of kimchi cabbage owing to air and vapor pressure differences during storage. Trimming loss is caused by physical pressure during kimchi cabbage storage and pests and microorganisms during cultivation (Ku et al., 1988). The weight loss was 16.83±3.11% with low–medium cooling, and 16.21±1.87% with slow cooling, and these values were higher than those with other cooling rates (Table 1). The slow cooling did not control the temperature of kimchi cabbage. This did not inhibit post-harvest physiological actions and caused a significant weight reduction.

The trimming loss was 23.26±1.20% with slow cooling and 22.54±2.96% with the rapid cooling, and these values were higher than those of other samples (Table 1). The high trimming loss of slow-cooled kimchi cabbage can be attributed to slow cooling could not control the respiration heat of kimchi cabbage, which caused the outer leaves to decompose. The high trimming loss of rapidly cooled cabbage was because the surface of kimchi cabbages was frozen during storage (Fig. 3), and these cabbages were removed from the trimming process. The reason for the

Table 1. Weight, trimming, and total losses of spring kimchi cabbage stored for 90 days at different cooling rates

Cooling rate	Weight loss (%)	Trimming loss (%)	Total loss (%)
Slow (2°C/d)	16.21±1.87$^{a1)}$	23.26±1.20^{a}	35.71±1.26^{a}
Low–medium (4°C/d)	16.83±3.11^{a}	16.88±2.06^{b}	30.88±2.75^{b}
Medium (6°C/d)	13.46±1.11^{b}	14.92±1.70^{b}	26.38±1.23^{c}
High–medium (8°C/d)	15.58±1.31^{a}	19.36±0.78^{b}	31.93±1.27^{b}
Rapid (24°C/d)	15.96±2.79^{a}	22.54±2.96^{a}	34.92±2.79^{ab}

All values are the mean±SD.
[1)] Values within a column with different superscript letters are significantly different (p<0.05, Duncan's multiple range test).

freezing of kimchi cabbage surface was not the storage temperature, but a sudden change in temperature during the cooling process, which frosted the surface of spring kimchi cabbage with high moisture content.

For the long-term storage of spring kimchi cabbage, an appropriate cooling rate is important, and not rapid and slow cooling. Based on the results, the lowest total loss of spring kimchi cabbage in long-term storage can be achieved at the medium cooling rate using stepwise cooling to approximately 6°C/d.

Changes in the pH, total microbes, and total free sugar of kimchi cabbage during storage

The pH of kimchi cabbages stored under different cooling rates was not significantly different among samples, but it tended to increase up to 60 days and then gradually decrease (Table 2). In particular, the pH of rapidly cooled kimchi cabbage increased to 6.67 after 60 days, and then decreased to 6.06±0.37 after 90 days. This may be due to the changes in moisture as the outer leaves of cabbage were frozen. The total bacterial count tended to decrease under all treatments except under medium cooling. This is because the trimmed kimchi

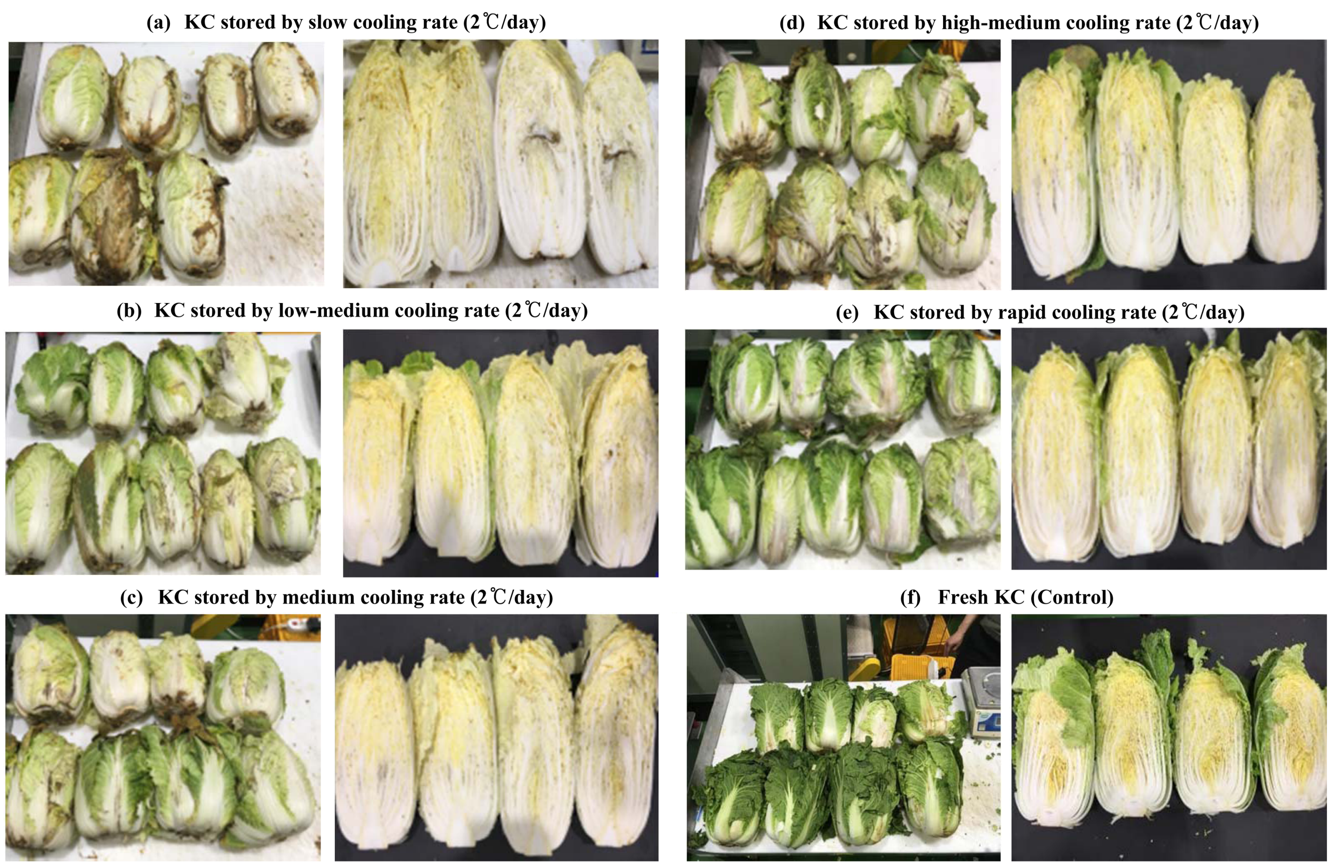


Fig. 3. The photographic of kimchi cabbages (KC) stored for 90 d at different cooling rates (a-e) and fresh kimchi cabbage (f).

Table 2. Changes in the pH, total microbes, and total free sugar content of spring kimchi cabbage during storage at different cooling rates

	Cooling rate	Storage period (days)		
		0	60	90
pH	Slow (2°C/d)	6.18±0.40[a1)]	6.67±0.00[a]	6.06±0.37[a]
	Low–medium (4°C/d)	6.18±0.40[a]	6.47±0.00[a]	6.34±0.03[a]
	Medium (6°C/d)	6.18±0.40[a]	6.51±0.00[a]	6.31±0.02[a]
	High–medium (8°C/d)	6.18±0.40[a]	6.46±0.00[a]	6.32±0.01[a]
	Rapid (24°C/d)	6.18±0.40[a]	6.27±0.00[a]	6.30±0.24[a]
Total microbes (log CFU/g)	Slow (2°C/d)	6.21±0.06[a1)]	5.99±0.08[a]	6.02±0.04[a]
	Low–medium (4°C/d)	6.21±0.06[a]	6.60±0.12[b]	5.71±0.08[b]
	Medium (6°C/d)	6.21±0.06[a]	6.92±0.01[c]	6.23±0.03[a]
	High–medium (8°C/d)	6.21±0.06[a]	5.56±0.14[a]	5.96±0.12[c]
	Rapid (24°C/d)	6.21±0.06[a]	6.51±0.00[b]	6.16±0.03[a]
Total free sugar (g/100 g)	Slow (2°C/d)	2.460±0.003[a]	2.485±0.014[a]	2.054±0.013[a]
	Low–medium (4°C/d)	2.460±0.003[a]	1.997±0.014[b]	2.350±0.028[b]
	Medium (6°C/d)	2.460±0.003[a]	2.478±0.010[a]	2.572±0.021[c]
	High–medium (8°C/d)	2.460±0.003[a]	2.266±0.025[c]	2.438±0.011[bc]
	Rapid (24°C/d)	2.460±0.003[a]	2.258±0.017[c]	1.893±0.001[d]

All values are mean±SD.
[1)] Values within a column with different superscript letters are significantly different (p<0.05, Duncan's multiple range test).

Table 3. Sensory evaluation of kimchi prepared using stored spring kimchi cabbage at different cooling rates

Fermentation period		Texture			Overall preference		
		0	8	40	0	8	40
Fresh kimchi cabbage		4.60±1.26[a1)]	4.00±1.54[a]	4.56±1.24[a]	4.80±0.92[a]	4.17±0.94[a]	4.33±1.41[a]
Cooling rate of stored kimchi cabbage	Slow (2°C/d)	3.30±1.49[b]	3.92±0.90[a]	3.69±1.32[ab]	3.90±1.29[a]	4.42±1.00[a]	3.78±1.48[a]
	Low–medium (4°C/d)	4.10±1.20[ab]	4.33±1.30[a]	4.78±1.20[a]	3.90±1.52[a]	4.00±1.35[a]	4.67±1.50[a]
	Medium (6°C/d)	5.10±1.52[a]	4.10±1.60[a]	4.43±1.13[a]	4.60±1.35[a]	4.50±0.90[a]	4.22±1.09[a]
	High–medium (8°C/d)	4.60±1.43[ab]	3.92±0.79[a]	4.33±1.41[a]	4.00±1.16[a]	4.25±1.14[a]	3.56±1.74[a]
	Rapid (24°C/d)	3.60±1.35[ab]	4.00±1.54[a]	2.89±0.93[b]	4.70±1.16[a]	4.50±1.09[a]	3.89±0.93[a]

All values are mean±SD.
[1)]Values within a column with different superscript letters are significantly different (p<0.05, Duncan's multiple range test).

cabbages were used as a sample for analysis. Slow-cooled kimchi cabbages (Fig. 3) showed sores on the outer leaves, but removing these leaves did not affect the microbial count during the selection process. Therefore, the changes in the total bacterial count in trimmed spring kimchi cabbage were not significantly different according to the cooling rate.

Regarding the content of free sugars in cabbage, sucrose was not detected in the same manner as in the study by Lee et al. (2013); therefore, it was expressed as total free sugar based on the sum of glucose and fructose content. The content of free sugars during the storage period tended to decrease slightly (Table 2). The result was similar to that of Kim et al. (2001b), who reported that the free sugar content decreases for 120 days. This shows that sugars are consumed in the transpiration process during storage; therefore, the slow cooling rate tends to decrease the free sugar content. However, the changes in the content of free sugars in spring kimchi cabbage were not significantly different according to the cooling rate if cooled at a rate of more than 2°C/d to prevent the transpiration process (high-medium, low-medium, and medium). Further research is required to clarify why the free sugar content in kimchi cabbage decreased in the outer leaves when frozen.

Sensory evaluation of kimchi

A sensory evaluation of kimchi prepared using fresh cabbage and stored cabbage for 90 days at different cooling rates was performed (Table 3). As kimchi fermented, sensory evaluation was examined on the day 0 (pH 5.8-6.0), day 8 (pH 4.5-4.7) and day 40 (pH 3.8-3.9). Texture of kimchi made with stored cabbage tended to be weaker than kimchi made with fresh cabbage (not significant), but kimchi made with stored cabbage cooled by medium cooling and slow–medium cooling rates was relatively superior. The overall preference of kimchi prepared using cabbage stored at medium cooling and slow–medium cooling rates was higher than that of kimchi prepared using cabbage stored at other cooling rates, and not significantly different from kimchi prepared using fresh cabbage. Thus, we showed that the medium- and slow–medium-cooled storage of spring kimchi cabbage for 90 days did not affect the sensory quality of kimchi.

Conclusions

In the kimchi industry, it is important to obtain kimchi cabbage in the summer because of the difficulty in cultivation. Thus, several studies have been conducted to utilize spring kimchi cabbage in summer. Nevertheless, most studies have been limited in terms of practicality because storage method is complicated and expensive. Therefore, in this study, a method of long-term spring cabbage storage was investigated to improve the economic feasibility of kimchi cabbage storage. The long-term storage of kimchi cabbage is important to control respiration; however, rapid temperature changes result in physiological disorders. Therefore, the appropriate cooling rate is effective to enhance the quality of spring kimchi cabbage for long-term storage. We showed that spring kimchi cabbages stored at the cooling rate of 6°C/d had lower total loss and better quality properties than those stored at other cooling rates. However, additional studies are required to identify suitable storage conditions depending on the kimchi cabbage condition at the time of harvest, size of the storage container, and efficiency of the cooler.

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