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The Effects of Red Pepper Seed on *Kimchi* Quality During Fermentation

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ABSTRACT In this study, we examined the effects of different concentrations of red pepper seed (0%, 1%, 3%, 5%, and 7%) on pH, total acidity, color, reducing sugar content, total microbes, lactic acid bacteria, and sensory quality, in terms of prolonging the shelf-life of *kimchi.* The additions of red pepper seed resulted in higher pH levels, while total acidity was lower than that of the control. The *kimchi* with red pepper seed had higher reducing sugar contents than the control. Furthermore, the *kimchi* with red pepper seed showed higher b-values than the control. During fermentation, the amounts of lactic acid bacteria and total microbes were higher in the *kimchi* with red pepper seed than in the control, and the higher ratios resulted in higher quality *kimchi.* The additions of red pepper seed also resulted in changes of color, flavor, taste, and texture, having a large influence on overall product quality. In conclusion, in terms of preservation and consumption, the 3% and 5% red pepper seed concentrations offered enhanced shelf-life and better quality *kimchi* products.

KEYWORDS: *red pepper seed kimchi, optimum aging period, sensory evaluation*

INTRODUCTION

In Korea, *Kimchi* is a traditional fermented food made of vegetables, and it is consumed every day as a main side dish. *Kimchi* is widely known to be a nutritious and health promoting food (1-3). Fermented *kimchi* generally contains high levels of lactic acid bacteria (10^{7-9} CFU/mL), organic acids, and other nutrients such as vitamins, minerals, and dietary fiber, as well as functional components resulting from its fermentation (4). Many health benefits of *kimchi* have been reported, including antimutation and anticancer effects, hypolipidemic effects, antioxidant and antiaging effects, and the activation of detoxifying components (4-7).

Although *kimchi* clearly has healthful qualities, the over-ripening of *kimchi* during storage is a major concern in the *kimchi* industry. Various studies have reported ways to extend the shelf-life of *kimchi*, such as by additions of salt (8), the use of natural herbs (9-11), and gamma-irradiation (12). However, these processes alone, without temperature control, are not enough to make better commercial *kimchi* products (13). Therefore, the need for a novel method using a natural ingredient, to extend the shelf-life of *kimchi* without degrading its sensory qualities, has been recognized (14).

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In Korea, hot red pepper (*Capsicum annuum* L.) is an important ingredient in *kimchi*, contributing to its characteristic sensory qualities such as a red color and hot taste (15). Studies examining the biological effects of red pepper on lipid metabolism have shown that red pepper accelerates digestion, has a beneficial hypocholesterolemic effect on cholesterol in gallstone disease and diabetic nephropathy, as well as a beneficial antioxidant influence in inflammatory disease (16). Red pepper is known for its rich antioxidant content, and fresh red peppers are especially high in ascorbic acid, with 116 mg per 100 g. Furthermore, their attractive red color is due to various carotenoid pigments, including β-carotene with pro-vitamin A activity, and oxygenated carotenoids such as capsanthin, capsorubin, and cryptocapsin, which are distinct to the genus and are shown to be effective free radical scavengers (17). Red peppers also contain high levels of natural phenolics and flavonoids such as quercetin, luteolin, and capsaicinoids (18). The antioxidant effects of red pepper seed and red pepper pericarp powder have been evaluated by various antioxidant assays. Both showed strong antioxidant activities, based on the testing methods used. Yet, higher scavenging activity was exhibited by the red pepper pericarp powder than the red pepper seed powder (19). Thus, we expect red pepper seed to also have high antioxidant activity, and even synergism among its antioxidants. In another study, red pepper seed exhibited antimutagenicity *in vitro* against aflatoxin B_1 and MNNG, in an Ames test and SOS chromotest, respectively. Also, red pepper seed has exhibited strong anticancer effects in human cancer cells (20). Among the many standards for measuring optimum ripening, pH, and total acidity in *kimchi,* there are some generally acknowledged conditions (21). For example, a pH of 4.2 and an acidity of 0.6-0.8% are suitable end points for an optimum ripening period (22,23). Red pepper has higher bacterial counts than other types of seasonings, especially for *Lactobacillus* sp. So far, there have been some attempts to investigate the antioxidant, anticancer, and quality effects of red pepper seed in food products; however, there is limited information available on the quality effects of adding red pepper seed to *kimchi.* Therefore, we added different concentrations of red pepper seed to *kimchi* to examine the quality effects, more specifically, the effects on pH, total acidity, reducing sugar content, microbial counts, and sensory characteristics during fermentation. Finally, we examined the effects of the different concentrations of added red pepper seed in an attempt to prolong the shelf-life and optimize the quality of *kimchi.*

MATERIAL AND METHODS

Materials

Chinese cabbage, garlic, scallions, ginger, onion, fermented anchovy juice, and salt were purchased at a local market in Seoul, Korea, and stored in a refrigerator at 5°C. The red pepper seed was purchased from Banhemaru Co. (Umsung, Korea). The Chinese cabbage was cut into 4 pieces and soaked in 10% salt water for 12 hr, and then rinsed three times with water. The standardized recipe for *kimchi* was 3.0 g of onion, 1.0 g of garlic, 1.0 g of scallions, 1.0 g of fermented anchovy juice, 1.0 g of glutinous rice flour paste, 0.5 g of ginger, 0.2 g of sugar, and 0.3 g of salt in proportion to 100 g of the salted Chinese cabbage; the final salt concentration of the salted cabbage was raised to 2.5% (w/v). For the *kimchi* with added red pepper seed, the control recipe was made with additions of 1, 3, 5, and 7% whole red pepper seed, which were added in proportion to 100 g of the salted Chinese cabbage. The prepared *kimchi* (0 day) was put into jars and fermented for 0, 3, 6, 9, and 12 days at 14°C. For the chemical analyses, 25 g of *kimchi* and 100 mL of distilled water were homogenized (PH 91, SMT co., Ltd, Japan) and then filtrated with 3 layers of cheese cloth. The filtrate was used to determine the pH and total acidity.

pH and total acidity

The pH of the filtrate was measured with a pH meter (Corning 340, Mettler Toledo, UK). The total acidity was determined by the titration of 10 mL of filtrate with 0.1 N NaOH to adjust the pH to 8.4, and was expressed as the amount of lactic acid in the *kimchi* (24).

Color measurement

The Hunter L (lightness), +a (redness), and +b (yellowness) values of the filtrate were measured using a Chromameter (CR-300, Minolta Co., Ltd., Oaka, Japan) (7).

Reducing sugar

The reducing sugar was measured by its absorbance at 550 nm using a spectrophotometer (Jasco V-530, Jasco Co., Ltd., Kyoto, Japan) and the 3,5-dinitro-salicylic acid (DNS) method. The amount was expressed as the glucose concentration of the *kimchi* (25).

Microbial analysis

Fifteen grams of *kimchi,* prepared under aseptic conditions, were placed in a sterilized bag (10×15 cm; Sunkyung Co. Ltd., Seoul, Korea) with 135 mL of peptone water (0.1%), and stomached in a stomacher (Stomacher 400W, Seward, USA) for 2 min. The stomached solution of sample was used to test for the total viable cell growth and numbers of lactic acid bacteria in plate count agar and MRS agar (Difco, St. Louis, USA), respectively. The plates were prepared in triplicate and incubated at 37°C for 48 hr. The viable cell numbers on the plates were determined as colony forming units (log cfu) per gram (26).

Sensory evaluation of *kimchi*

The sensory panel was composed of 7 graduate students. Evaluations for color, flavor, taste, texture, and overall *kimchi* quality were carried out in triplicate using a seven-point hedonic scale method, where very poor (weak) corresponded to 1 point, and very good corresponded (powerful) to 7 points. Steamed rice was given as a delivery aid in each test (26).

Statistical analysis

The results of the treatments are expressed as the mean ± standard deviation (SD). The data were analyzed by two-way analyses of variance (ANOVA) using SPSS (Statistical Analysis Program, version 12.0), to determine the effects of the red pepper seed ratio and fermentation time on the sensory qualities, pH, total acidity, color, and reducing sugar content of the *kimchi.* Significant differences between treatment means were determined by Duncan's multiple range tests ($p < 0.05$).

RESULTS AND DISCUSSION

pH and total acidity

The pH of the *kimchi* was measured throughout the fermentation period, and the changes in pH and total acidity are shown in Tables 1 and 2, respectively. All treatments showed similar results, and the red pepper seed additions resulted in higher pH than the control. Also, the greater the amount of red pepper seed added, the higher the level of pH that was maintained as the fermentation period progressed. The total acidities of the red pepper seed *kimchis* increased with fermentation time, yet they were slightly lower than the level of the control. Therefore, both the pH and total acidity of the *kimchi* were not greatly affected by increasing the red pepper seed concentration. For the control, pH and total acidity were 5.50 and 0.54%, respectively, at the start of fermentation. Then, after 12 days of fermentation at 14°C, the pH decreased to 3.88 and the total acidity reached 1.92%; whereas the red pepper seed *kimchis* showed higher pH values (3.94-3.91) and lower acidities (1.89-1.81%) than the control at 12 days of fermentation. In general, *kimchi* has its best taste when the pH is near 4.2 and the total acidity is 0.6-0.8% (12,21). Based on these levels of pH (4.2) and acidity (0.6-0.8%), the optimum ripening period for the 7% red pepper seed *kimchi* was 3 days at 14°C. As shown in Table 1, the pH dropped sharply between 0-6 days of fermentation, but then dropped slowly between 6-12 days. More specifically, the pH dropped remarkably between 0-3 days of fermentation at 14°C, which reflects the characteristic drop in pH that occurs during the initial fermentation period. Previous studies of *kimchi* have found that initial pH values (pH 5.5-5.8) fall to 4.2-4.5 at optimum ripening, and to pH 4.0 upon over-ripening (27). But when the pH drops below 4.0, homofermentative *Lactobacillus plantarum* strains, which generally proliferate in the later stage of fermentation, reportedly play important roles in over-fermentation (28). In this study, the combined treatment of adding 7% red pepper seed, with 5 days of fermentation time, controlled over-fermentation. This may be explained by the notion that the red pepper seed neutralized the lactic acid being produced during fermentation. These results are further supported by previous studies in which the antimicrobial effects of red pepper seed were discussed (30).

Reducing sugar

The trends for changes in reducing sugar content are described in Table 3. At the start of fermentation, the reducing sugar contents of the *kimchis* with added red pepper seed (3.27-4.08 mg/mL) were higher than the level of the control (3.16 mg/mL). This might be attributed to the red pepper seed contributing high concentrations of reducing sugar. However, at 6 days of fermentation the amounts of reducing sugar in the red pepper seed *kimchis* decreased more rapidly, and after 12 days of fermentation had reached 1.13-1.37 mg/mL. These observations correspond with the results for pH and acidity. After reaching the optimal ripening time, the decreasing rates of reducing sugar in the experimental groups were similar. On the initial day of fermentation, reducing sugar content increased with increasing red pepper seed concentration, and all concentrations showed similar trends. However, a reduction in reducing sugar content was shown with increasing fermentation time, rather than by the increases in red pepper seed concentration. The red pepper seed *kimchis* showed higher reducing sugar contents than the control, owing to the utilization of the sugar by microorganisms during fermentation. These results are indicative of the red pepper seed's affect on extending shelf-life (7,11).

Table 1. Changes in pH of *kimchi* with added red pepper seed during fermentation at 14°C

Treatment	Storage at 14 (days)				
	0	3	6	9	12
Control	$5.50 \pm 0.02^{a1)E2)}$	4.41 ± 0.02^{aD}	3.96 ± 0.02^{aC}	3.92 ± 0.01^{aB}	3.88 ± 0.01^{aA}
Red pepper seed 1%	5.54 ± 0.01^{cE}	4.41 ± 0.01^{cD}	3.98 ± 0.01^{cC}	3.95 ± 0.01^{cB}	3.91 ± 0.01^{cA}
Red pepper seed 3%	5.63 ± 0.01^{abE}	4.30 ± 0.01^{abD}	3.91 ± 0.01^{abC}	3.95 ± 0.01^{abB}	3.92 ± 0.01^{abA}
Red pepper seed 5%	5.33 ± 0.01^{aE}	4.39 ± 0.01^{aD}	4.05 ± 0.01^{aC}	3.96 ± 0.01^{aB}	3.92 ± 0.01^{aA}
Red pepper seed 7%	5.48 ± 0.01^{bE}	4.27 ± 0.01^{bD}	4.03 ± 0.01^{bC}	4.00 ± 0.01^{bB}	3.94 ± 0.01^{bA}

1)a-c Values with different letters within a column differ significantly ($p < 0.001$).
2)A-E Values with different letters within a row differ significantly ($p < 0.001$).

Table 2. Changes in total acidity of *kimchi* with added red pepper seed during fermentation at 14°C

Treatment	Storage at 14 (days)				
	0	3	6	9	12
Control	$0.54 \pm 0.07^{a1)A2)}$	0.85 ± 0.07^{aB}	1.20 ± 0.07^{aC}	1.40 ± 0.05^{aD}	1.92 ± 0.01^{aE}
Red pepper seed 1%	0.52 ± 0.06^{aA}	0.84 ± 0.06^{aB}	1.29 ± 0.12^{aC}	1.42 ± 0.01^{aD}	1.89 ± 0.03^{aE}
Red pepper seed 3%	0.49 ± 0.02^{bA}	0.83 ± 0.07^{bB}	1.61 ± 0.01^{bC}	1.38 ± 0.03^{bD}	1.89 ± 0.02^{bE}
Red pepper seed 5%	0.54 ± 0.02^{aA}	0.84 ± 0.05^{aB}	1.27 ± 0.04^{aC}	1.37 ± 0.07^{aD}	1.85 ± 0.05^{aE}
Red pepper seed 7%	0.45 ± 0.05^{aA}	0.80 ± 0.06^{aB}	1.26 ± 0.03^{aC}	1.34 ± 0.02^{aD}	1.81 ± 0.01^{aE}

1)a-b Values with different letters within a column differ significantly ($p < 0.01$).
2)A-E Values with different letters within a row differ significantly ($p < 0.001$).

Table 3. Changes in reducing sugar content of *kimchi* with added red pepper seed during fermentation at 14°C

Treatment	Storage at 14 (days)				
	0	3	6	9	12
Control	3.16 ± 0.06^a1)E2)^	3.21 ± 0.17^aD^	2.45 ± 0.08^aC^	1.53 ± 0.15^aB^	1.06 ± 0.06^aA^
Red pepper seed 1%	3.27 ± 0.13^aE^	3.00 ± 0.06^aD^	2.81 ± 0.07^aC^	1.22 ± 0.18^aB^	1.13 ± 0.05^aA^
Red pepper seed 3%	4.08 ± 0.04^bE^	3.00 ± 0.14^bD^	2.84 ± 0.14^bC^	1.29 ± 0.13^bB^	1.16 ± 0.03^bA^
Red pepper seed 5%	3.97 ± 0.06^cE^	3.68 ± 0.21^cD^	4.07 ± 0.18^cC^	1.76 ± 0.07^cB^	1.22 ± 0.03^cA^
Red pepper seed 7%	3.89 ± 0.07^cE^	3.86 ± 0.23^cD^	3.82 ± 0.37^cC^	1.68 ± 0.23^cB^	1.37 ± 0.02^cA^

1)a-c Values with different letters within a column differ significantly ($p < 0.001$).
2)A-E Values with different letters within a row differ significantly ($p < 0.001$).

Table 4. Changes in L-, a-, and b-values of *kimchi* with added red pepper seed during fermentation at 14°C

	Treatment	Storage at 14 (days)				
		0	3	6	9	12
L value	Control	19.13 ± 0.31^b1)^	18.71 ± 0.12^b^	18.72 ± 0.56^b^	18.79 ± 1.80^b^	19.20 ± 1.77^b^
	Red pepper seed 1%	17.43 ± 1.16^a^	17.42 ± 0.60^a^	17.94 ± 0.68^a^	18.46 ± 1.80^a^	17.06 ± 0.97^a^
	Red pepper seed 3%	17.89 ± 0.78^a^	16.89 ± 0.90^a^	17.43 ± 0.60^a^	18.51 ± 1.66^a^	17.76 ± 1.32^a^
	Red pepper seed 5%	17.40 ± 0.68^a^	17.68 ± 1.08^a^	17.79 ± 1.65^a^	17.58 ± 0.47^a^	18.48 ± 0.52^a^
	Red pepper seed 7%	18.46 ± 1.63^a^	17.75 ± 0.28^a^	16.57 ± 3.10^a^	17.52 ± 0.36^a^	17.91 ± 0.93^a^
a value	Control	-0.98 ± 0.30^a3)A2)^	-0.68 ± 0.17^aB^	0.20 ± 0.04^aD^	0.15 ± 0.13^aC^	0.01 ± 0.06^aC^
	Red pepper seed 1%	-0.74 ± 0.16^bA^	-0.19 ± 0.35^bB^	0.25 ± 0.11^bD^	0.26 ± 0.09^bC^	0.07 ± 0.02^bC^
	Red pepper seed 3%	0.06 ± 0.02^cA^	-0.25 ± 0.18^cB^	0.25 ± 0.04^cD^	0.10 ± 0.08^cC^	0.11 ± 0.03^cC^
	Red pepper seed 5%	-0.70 ± 0.12^aA^	-0.79 ± 0.17^aB^	0.31 ± 0.10^aD^	0.09 ± 0.10^aC^	0.57 ± 0.05^aC^
	Red pepper seed 7%	-0.41 ± 0.13^bA^	-0.09 ± 0.06^bB^	0.22 ± 0.12^bD^	0.07 ± 0.02^bC^	0.02 ± 0.03^bC^
b value	Control	2.71 ± 0.07^bc3)C4)^	2.38 ± 0.37^bcC^	0.81 ± 0.31^bcA^	0.71 ± 0.36^bcB^	0.42 ± 0.21^bcA^
	Red pepper seed 1%	2.45 ± 0.21^aC^	1.97 ± 0.17^aC^	0.39 ± 0.13^aA^	0.93 ± 0.38^aB^	0.48 ± 0.08^aA^
	Red pepper seed 3%	2.44 ± 0.44^bcC^	2.37 ± 0.09^bcC^	0.84 ± 0.08^bcA^	0.99 ± 0.36^bcB^	0.59 ± 0.17^bcA^
	Red pepper seed 5%	2.78 ± 0.24^bC^	2.57 ± 0.44^bC^	0.83 ± 0.19^bA^	0.90 ± 0.21^bB^	0.76 ± 0.31^bA^
	Red pepper seed 7%	2.05 ± 0.32^cC^	2.76 ± 0.25^cC^	0.78 ± 0.26^cA^	1.05 ± 0.40^cB^	0.90 ± 0.52^cA^

1)a-b Values with different letters within a column differ significantly ($p < 0.05$).
2)A-D Values with different letters within a row differ significantly ($p < 0.001$).
3)a-c Values with different letters within a column differ significantly ($p < 0.001$).
4)A-C Values with different letters within a row differ significantly ($p < 0.001$).

Color measurement

The color of *kimchi* is a primary factor in evaluating its quality. During *kimchi* fermentation, green vegetable leaves generally turn yellowish-green by acid, while white leaves turn a yellowish-red by the addition of red pepper seed (30); under abnormal fermentation, the leaves will turn a dark color due to oxidation (31). Table 4 shows the color changes in the red pepper seed *kimchis* and the control during fermentation for 12 days at 14°C. The b-values of the red pepper seed *kimchis* slightly decreased, while the a-values increased with fermentation time. Increasing concentrations of red pepper seed resulted in increases for both the a- and b-values, while the L-value decreased. The red pepper seed *kimchis* showed higher a- and b-values than the control, although the increasing values were not consistent over the different concentrations of red pepper seed. The changing patterns of the Hunter color values during the fermentation period of this study were similar to those in a previous report (31). However, the red pepper seed *kimchis* showed more reddish color than the control at 0 and 12 days of fermentation, based on their higher a-values. Greater reddish color may increase consumer acceptability of *kimchi* products (7).

Total microbes and lactic acid bacteria

Figures 1 and 2 show the numbers of total microbes and lactic acid bacteria, respectively, in the red pepper seed *kimchi* over the fermentation period. Lactic acid bacteria have antibiotic capabilities against harmful microbes (31). Consequently, harmful bacterial growth can be inhibited by the growth of lactic acid bacteria. When acidification begins, the growth of lactic acid bacteria is inhibited by high levels of lactic acid, and a decrease in the antibiotic ability of

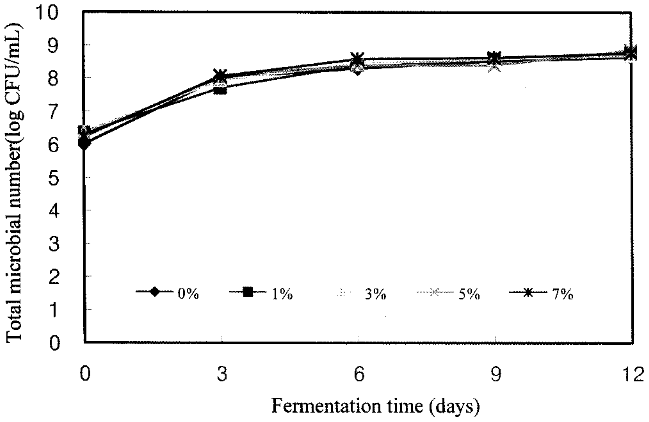

Fig. 1. Changes in total microbes of *kimchi* with added red pepper seed during fermentation at 14°C.

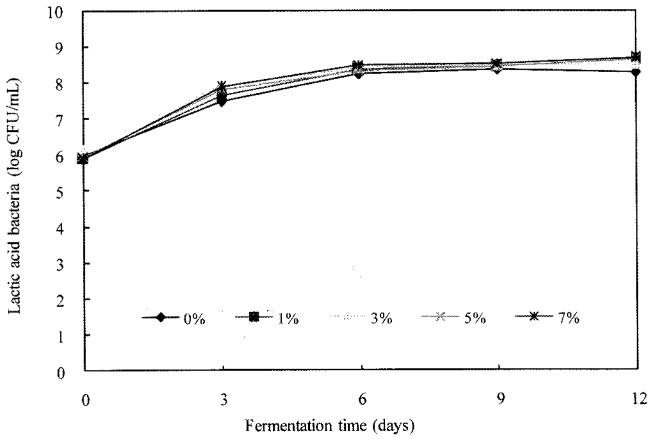

Fig. 2. Changes in lactic acid bacteria of *kimchi* with added red pepper seed during fermentation at 14°C.

the lactic acid bacteria can result in increased numbers of total microbes (30). Also during this period, the softening of *kimchi* tissue occurs.

As the pH drops to 4.6-4.9, *Leuconostoc mesentroides* becomes inhibited, but other lactic acid bacteria such as *Lactobacillus brevis* and *Lactobacillus plantarum* continue the fermentation process. In this study, the patterns of microbial change for *Leuconostoc* sp. and *Lactobacillus* sp. between the control and red pepper seed *kimchis* were similar, but the times for reaching maximum population levels were different. In the red pepper seed *kimchis* as compared to the control, the growths of *Leconostoc* sp. and *Lactobacillus* sp. were delayed. Among the red pepped seed *kimchis*, as the red pepper seed concentration increased, the growth of lactic acid bacteria also slowly increased. Previously, it was reported that the growth of *Lactobacillus brevis* in *kimchi* was slowed by the addition of green tea extract (32). Due to the antimicrobial activity of red pepper, adding red pepper seed to *kimchi* seems to delay over-ripening (29).

The numbers of lactic acid bacteria rapidly increased until the 3rd day of fermentation, and then they increased more slowly. The change in numbers of lactic acid bacteria showed a similar trend to the change in total microbes. Cho and Rhee (33) reported that numbers of lactic acid bacteria increased as pH decreased, which is in agreement with our results. The ratios of lactic acid bacteria to total microbes during fermentation were higher in the red pepper seed *kimchis* than in the control. Lee *et al.* (34) reported on the ratio of lactic acid bacteria to total microbes, where in the beginning of fermentation total microbes increased, due to the growth of aerobic and non-aerobic bacteria. As fermentation proceeded, organic acids were produced, and the level of acid-durable non-aerobic bacteria increased. Thereby, the number of lactic acid bacteria increased, and consequently, the ratio of lactic acid bacteria increased during the late stages of *kimchi* fermentation, which is consistent with the results of this experiment. During the initial fermentation period, the high reducing sugar contents in the *kimchis* with red pepper seed may have been produced from lactic acid bacteria metabolism, resulting in their higher reducing sugar concentrations than the control (35).

The ratios of lactic acid bacteria to total microbes during fermentation were higher in the treatment groups than in the control, and the higher ratios resulted in higher quality *kimchi* and more hygienic products. Based on previous reports, as the number of lactic acid bacteria increases during fermentation, the ratio of lactic acid bacteria to total microbes also increases, which is consistent with the results of this experiment (13).

Sensory evaluation

The sensory evaluation results for the control and red pepper seed *kimchis* are shown in Table 5. The 3% red pepper seed *kimchi* received the highest scores according to the performed sensory evaluations. Even though the control and 1% added red pepper seed *kimchi* received lower scores than those of the 3, 5, and 7% red pepper seed *kimchis*, the acceptance of the 3% red pepper seed *kimchi* was prominently different.

The color of *kimchi* is very important in terms of product quality. The color scores of the red pepper seed *kimchis* were significantly higher than the scores for the control ($p < 0.01$). These sensory results are consistent with those of experimental color analyses. The flavor and taste scores of the red pepper seed *kimchis* were higher than those of the control, and the differences were significant ($p < 0.001$). The texture of *kimchi* is closely correlated to the hardness of the vegetable tissue (23), which is related to cell wall polysaccharides such as pectin (36). The texture of the control was 4.71 points, which was the highest at the start of fermentation, but scores decreased as fermentation continued, and the red pepper seed *kimchis* maintained higher texture scores than

Table 5. Sensory evaluations of *kimchi* treated with different concentrations of red pepper seed during fermentation at 14°C

	Treatment	Storage at 14 (days)				
		0	3	6	9	12
Color	Control	4.86 ± 2.34[a1)]	4.71 ± 1.80[a]	3.43 ± 1.40[a]	3.86 ± 1.57[a]	3.43 ± 1.40[a]
	Red pepper seed 1%	5.00 ± 1.83[ab]	5.29 ± 1.70[ab]	4.29 ± 1.11[ab]	4.71 ± 1.38[ab]	4.00 ± 1.00[ab]
	Red pepper seed 3%	5.43 ± 1.72[c]	5.14 ± 1.58[c]	5.71 ± 1.50[c]	5.86 ± 1.07[c]	5.14 ± 1.35[c]
	Red pepper seed 5%	5.86 ± 1.07[bc]	3.57 ± 1.51[bc]	5.43 ± 0.98[bc]	5.43 ± 1.40[bc]	5.14 ± 1.35[bc]
	Red pepper seed 7%	4.14 ± 2.34[ab]	4.29 ± 1.38[ab]	4.71 ± 0.95[ab]	4.57 ± 0.98[ab]	5.43 ± 1.72[ab]
Flavor	Control	4.14 ± 1.57[a1)]	3.71 ± 1.25[a]	3.71 ± 1.70[a]	3.57 ± 1.27[a]	3.43 ± 1.40[a]
	Red pepper seed 1%	5.57 ± 0.98[b]	4.29 ± 1.38[b]	4.43 ± 1.51[b]	4.00 ± 1.16[b]	4.29 ± 1.38[b]
	Red pepper seed 3%	4.43 ± 0.98[bc]	5.29 ± 1.11[bc]	5.29 ± 1.80[bc]	5.29 ± 1.11[bc]	5.43 ± 1.13[bc]
	Red pepper seed 5%	4.71 ± 1.80[c]	4.86 ± 1.07[c]	5.57 ± 1.51[c]	5.86 ± 1.21[c]	5.43 ± 1.13[c]
	Red pepper seed 7%	4.29 ± 1.60[bc]	5.14 ± 0.90[bc]	5.29 ± 0.76[bc]	5.29 ± 0.76[bc]	5.00 ± 1.29[bc]
Taste	Control	3.86 ± 1.35[a1)]	2.86 ± 0.69[a]	4.00 ± 1.92[a]	3.71 ± 0.95[a]	3.43 ± 1.51[a]
	Red pepper seed 1%	3.14 ± 1.57[a]	4.71 ± 0.95[a]	4.71 ± 1.50[a]	4.29 ± 1.50[a]	3.00 ± 0.82[a]
	Red pepper seed 3%	4.29 ± 1.50[c]	5.43 ± 1.40[c]	5.57 ± 1.72[c]	5.57 ± 1.13[c]	5.71 ± 1.11[c]
	Red pepper seed 5%	4.29 ± 2.06[bc]	3.86 ± 1.47[bc]	4.71 ± 1.38[bc]	5.00 ± 1.73[bc]	5.71 ± 1.11[bc]
	Red pepper seed 7%	3.86 ± 2.12[ab]	3.71 ± 1.89[ab]	4.71 ± 1.38[ab]	4.71 ± 1.60[ab]	3.43 ± 1.51[ab]
Texture	Control	4.71 ± 1.60[a1)]	5.00 ± 1.53[a]	4.86 ± 1.22[a]	3.57 ± 0.98[a]	4.43 ± 1.72[a]
	Red pepper seed 1%	5.00 ± 1.15[ab]	5.14 ± 1.22[ab]	5.14 ± 1.07[ab]	4.43 ± 0.98[ab]	4.57 ± 1.62[ab]
	Red pepper seed 3%	4.86 ± 1.60[bc]	5.86 ± 0.69[bc]	5.29 ± 1.38[bc]	5.57 ± 1.27[bc]	5.43 ± 0.98[bc]
	Red pepper seed 5%	5.57 ± 1.27[c]	5.71 ± 0.76[c]	5.86 ± 1.07[c]	6.00 ± 1.41[c]	5.43 ± 0.98[c]
	Red pepper seed 7%	5.71 ± 1.25[bc]	5.71 ± 0.76[bc]	5.57 ± 1.27[bc]	5.14 ± 1.67[bc]	4.14 ± 1.46[bc]
Overall quality	Control	3.71 ± 1.98[a1)]	3.43 ± 1.13[a]	3.43 ± 1.13[a]	3.00 ± 1.00[a]	3.57 ± 1.51[a]
	Red pepper seed 1%	4.00 ± 2.31[b]	5.00 ± 1.29[b]	4.86 ± 1.22[b]	4.14 ± 1.46[b]	3.71 ± 1.60[b]
	Red pepper seed 3%	5.29 ± 0.95[c]	6.14 ± 0.69[c]	5.71 ± 1.50[c]	5.43 ± 1.13[c]	5.57 ± 0.79[c]
	Red pepper seed 5%	4.57 ± 1.72[bc]	3.86 ± 1.07[bc]	5.57 ± 1.27[bc]	5.57 ± 1.61[bc]	5.57 ± 0.79[bc]
	Red pepper seed 7%	4.14 ± 1.95[b]	4.57 ± 1.51[b]	4.86 ± 0.69[b]	4.43 ± 1.40[b]	4.57 ± 1.40[b]

[1)a-c]Values with different letters within a column differ significantly ($p < 0.01$).

the control. This may be explained by the notion that the red pepper seed prevented the growth of *Lactobacillus plantarum* strains during fermentation, and thus, softening of the *kimchi* tissue was inhibited. In terms of overall texture quality, the red pepper seed treatments were tougher than the control, and there were significant differences ($p < 0.001$) between them.

For overall product quality, the control was rated lower than the *kimchi* with added red pepper seed. Hence, the red pepper seed treatments were evaluated for extended shelf-life. In particular, we found that *kimchi* over-fermentation may be delayed by adding red pepper seed at 3, 5, and 7% concentrations.

The addition of red pepper seed is known to change the color, flavor, taste, and texture of *kimchi*, thus having a large influence on overall product quality. Therefore, red pepper seed plays an important role in shelf-life enhancement and product quality, not only by neutralizing acids, but also by inhibiting tissue softening, which is easily perceived.

CONCLUSIONS

The effects of red pepper seed additions (0, 1, 3, 5, and 7%) in *kimchi* on pH, total acidity, color, reducing sugar content, total microbes, lactic acid bacteria, and sensory characteristics were studied, in terms of prolonging product shelf-life and quality during storage at 14°C for 12 days. With the addition of red pepper seed, changes in pH, total acidity, and reducing sugar content were slowed, resulting in more gradually changed, and then higher final pH levels and reducing sugar contents as compared to the control; however, total acidity was lower than the control. Furthermore, the *kimchis* with added red pepper seed showed higher b-values than the control. Counts of lactic acid bacteria increased with fermentation time, both in the control and in the red pepper seed *kimchis,* and were highest in the 7% added red pepper seed *kimchi*. During fermentation, the amounts of lactic acid bacteria and total microbes were higher in the *kimchis* with added red pepper seed than in the control. The flavor, taste, and overall quality of the 3% and 5% red pepper seed *kimchis* were remarkably improved. Also, the texture of the 7% red pepper seed *kimchi* was lower than the control. To conclude, in terms of preservation and consumption, the 3% and 5% added red pepper seed concentrations resulted in prolonged shelf-life and better quality *kimchi* products.

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