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Fermentation and Quality of *Kimchi* Prepared with Chinese Cabbages Harvested from Field and Hydroponic Cultivation

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Abstract

The potential of hydroponic cultivated Chinese cabbage as a *kimchi* material was evaluated. The hydroponic-grown (HG) Chinese cabbage was heavier in weight, taller in height, wider in width, but less in number of leaves compared with the field-grown (FG) Chinese cabbage. The former showed higher contents of calcium, iron, vitamin A and niacin, and lower lipid and vitamin C than the latter. During fermentation for 28 days at 10°C, FG and HG *kimchis* showed comparable pH and acidity values, besides that the FG and HG *kimchis* showed a pH value of 4.2 and 4.0, respectively, at the 14th day. The FG *kimchi* showed higher numbers of total microbes as well as total and typical lactic acid bacteria than the HG *kimchi* at the 7th day. However, both *kimchis* did not show any difference at 14th day. There was no significant difference in the L* value between FG and HG *kimchis*. However, HG *kimchi* showed a more reddish hue than FG *kimchi* between the 7th and 14th day of fermentation. In sensory evaluation, the HG *kimchi* revealed a slightly more sour taste and a less crispy texture than the FG *kimchi* at the 14th day. However, both *kimchis* did not show any difference in overall quality until the 21st day of fermentation.

Key words: *kimchi*, fermentation, hydroponic cultivation, Chinese cabbage

INTRODUCTION

Kimchi has long been consumed as a traditional fermented food in Korea. *Kimchi* is classified into many different kinds by raw materials used (1,2); however, the most popular one is made from Chinese cabbage. In 1997, approximately 300 million tonnes of Chinese cabbage were produced throughout the country and around 200 million tonnes were used for making *kimchi* (3,4).

Chinese cabbage is harvested in June, July, and November each year from fields (5) and there is a shortage in Chinese cabbage for making *kimchi* in March, April, August, and October. It is recognized that year-round production of Chinese cabbage is needed to meet the increasing consumer demand for *kimchi*.

Production of Chinese cabbage by hydroponic cultivation may overcome the limited production by field cultivation. Hydroponic cultivation is divided into two systems. In an open system, the nutrient solution used is drained while in a closed system, the drained water is reused (6). This cultivation has been increasingly used, often with deep flow techniques, for leafy vegetables since 1980. However, there is no available information on use of hydroponic-grown Chinese cabbage as a raw material for making *kimchi*.

The objective of this research was to evaluate the possibility of the use of hydroponic-cultivated Chinese cabbage as a raw *kimchi* material. For this, the characteristics and chemical compositions of field and hydroponic-grown Chinese cabbages were compared. The quality of *kimchis* made from both Chinese cabbages also was evaluated during fermentation at 10°C for 28 days.

MATERIALS AND METHODS

Materials

Field- (FG) and hydroponic-grown (HG) Chinese cabbages, with average weight of 3 kg, were obtained from the Hanhwa *Kimchi* Research Center (Seoul). Red pepper powder, garlic, ginger, green onion, onion, sugar, and fermented anchovy juice used were purchased from a local market.

Field and hydroponic cultivation of Chinese cabbage

Seedlings, previously grown for 30 days after sowing (July 20, 1999), were planted into fields or on the cultivation beds at 33 cm intervals and then grown for 70 days. In hydroponic cultivation, seedlings were watered with underground water for the first three days to settle the roots safely, followed by a nutrient solution (electric conductivity of 1.5~2.5 µs/ cm, flow rate of 55 L/hr, and temperature of 10~25°C).

Compositions of the nutrient solution developed by the Korean Horticultural Research Institute (Suweon) are as follows: 250 ppm KNO_3, 260 ppm $MgSO_4 \cdot 7H_2O$, 450 ppm $Ca(NO_3)_2 \cdot 4H_2O$, 55 ppm $(NH_4)_2PO_4$, 20 ppm Fe-EDTA, 3 ppm H_3BO_3, 0.22 ppm $MnSO_4 \cdot 7H_2O$, 0.22 ppm $AnSO_4 \cdot 7H_2O$, 0.25 ppm $CuSO_4$, and pH 6.0.

Characteristics and analyses

The characteristics of Chinese cabbage such as weight, number of leaves, height and diameter, were measured. Moisture,

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protein, lipid, vitamin A, B_1, C, and niacin were determined according to AOAC methods (7). The contents of calcium and iron were measured using an atomic absorption spectrophotometer (8).

Preparation and fermentation of *kimchi*

Chinese cabbage was cut into four pieces after removing the outer leaves, salted in 10% brine [1.5 times (v/w) of the cabbage] for 24 hrs at room temperature, and rinsed in running tap water three times to obtain the final salt concentration of 2.5%. After draining for 2 hrs at 4°C, 300 g of the Chinese cabbage was mixed with 12.6 g of red pepper powder, 6.3 g of garlic, 1.9 g of ginger, 2.0 g of green onion, 2.0 g of onion, 3.0 g of sugar, and 14.5 g of fermented anchovy juice. The mixture was then placed in 400 ml screw-capped glass bottles and fermented for 28 days at 10°C.

Measurement of pH and titratable acidity

Whole *kimchi* in a bottle was homogenized with a Polytron homogenizer (PT-1200C, Switzerland) and filtered using 3 layers of cheesecloth. The pH of the filtrate was measured with a pH meter. Titratable acidity was determined by titrating with 0.1 N NaOH to pH 8.2 and expressed as a percentage of lactic acid (9).

Microbial analysis

The filtrate obtained above was diluted with 0.1% (w/v) peptone solution and inoculated on plate count agar (Difco, USA) for total microbes and on MRS agar (Difco, USA) containing 0.02% (w/v) sodium azide and 0.06% (w/v) bromocresol purple for lactic acid bacteria. Colony forming units (CFU) were counted after incubation for 48 hrs at 37°C.

Color measurement

The color of *kimchi* was measured with a color meter (Minolta CR-200, Japan) using the midrib of inner leaves 4 cm apart from bottom of the Chinese cabbage.

Sensory evaluation

Sensory characteristics of *kimchi* such as sourness, crispness and overall quality, were evaluated by 10 panels using a five-points scale (1: very low or poor to 5: very strong or good) test (10).

Statistical analysis

All experiments were carried out in triplicate and means ± standard deviations are reported. The data were analyzed by analysis of variance. Means of the main effects were separated by T-test and Duncan's multiple-range test using the SAS software package.

RESULTS AND DISCUSSION

Characteristics and chemical compositions of FG and HG Chinese cabbages

Characteristics of FG and HG Chinese cabbages were compared, and the results are given in Table 1. Data represents an average of 100 Chinese cabbages. Significant differences ($P<0.05$) in average weight, height, width, and number of leaves were observed between FG and HG Chinese cabbages. The HG Chinese cabbage was heavier in weight, taller in height, and wider in width compared with the FG Chinese cabbage. However, the average number of leaves was less in the former than in the latter.

Table 1. Characteristics of field- (FG) and hydroponic-grown (HG) Chinese cabbages

	FG	HG
Weight (kg)	2.3±0.3[1)b2)]	2.6±0.5[a]
Height (cm)	35.4±1.3[b]	39.6±1.5[a]
Width (cm)	22.0±1.2[b]	28.1±2.2[a]
Leaf number	54±1.4[b]	50±1.2[a]

[1)]Data represent mean±standard deviation of 100 Chinese cabbages
[2)]Different superscripts within a row indicate significant differences ($p<0.05$).

Chemical compositions of FG and HG Chinese cabbages are shown in Table 2. As seen in Table 2, there were no significant differences ($p>0.05$) in moisture, protein, and vitamin B_1. However, the HG Chinese cabbage showed higher contents of calcium, iron, vitamin A, and niacin than the FG Chinese cabbage. The former contained less lipid and vitamin C than the latter.

These data clearly indicate that the HG Chinese cabbage has potential as a *kimchi* material in view of the characteristics and chemical compositions.

Fermentation of *kimchi*

pH and acidity

Changes in pH and acidity of *kimchis* prepared with FG and HG Chinese cabbages (designated FG and HG *kimchi*, respectively) during fermentation at 10°C are shown in Table 3. Both *kimchis* showed comparable pH and acidity values during fermentation for 28 days, except for the 14th day.

Many researchers have reported that *kimchi* is the most delicious at a pH value of 4.2 and an acidity value of about 0.7% (designated optimum pH and acidity) (11,12), and that acidification begins at pH 4.0 (11). At the 14th day, the pH of FG and HG *kimchis* was 4.2 and 4.0, respectively. This indicates that the FG *kimchi* reached the optimum pH, while

Table 2. Chemical compositions of field- (FG) and hydroponic-grown (HG) Chinese cabbages

		FG	HG
Moisture (%)		95.4±0.4[1)a2)]	95.8±0.4[a]
Protein (%)		1.3±0.0[a]	1.4±0.0[a]
Lipid (%)		0.2±0.0[a]	0.1±0.0[b]
Calcium (mg%)		70±2[b]	145±4[a]
Iron (mg%)		0.3±0.0[b]	7.6±0.0[a]
Vitamin	A (IU)	255±12[a]	465±16[b]
	B_1 (mg%)	0.06±0.00[a]	0.06±0.00[a]
	C (mg%)	28.0±0.5[a]	15.5±0.3[b]
	Niacin (mg%)	0.4±0.0[b]	1.8±0.1[a]

[1)]Values are mean±standard deviation of three replicates.
[2)]Different superscripts within a row indicate significant differences ($p<0.05$).

Table 3. Changes in pH and acidity of *kimchi* prepared with field- (FG) and hydroponic-grown (HG) Chinese cabbages during fermentation at 10°C

	Kimchi	Fermentation days				
		0	7	14	21	28
pH	FG	$5.2\pm0.1^{1)a2)}$	5.0 ± 0.1^{a}	4.2 ± 0.1^{a}	3.9 ± 0.1^{a}	3.8 ± 0.1^{a}
	HG	5.2 ± 0.1^{a}	5.1 ± 0.1^{a}	4.0 ± 0.0^{b}	$4.0\pm0\ 1^{a}$	3.9 ± 0.1^{a}
Acidity (lactic acid %)	FG	0.48 ± 0.06^{a}	0.59 ± 0.05^{a}	0.85 ± 0.03^{b}	1.19 ± 0.06^{a}	1.23 ± 0.08^{a}
	HG	0.47 ± 0.05^{a}	0.57 ± 0.04^{a}	1.09 ± 0.02^{a}	1.16 ± 0.05^{a}	$1.20\pm0\ 07^{a}$

1)Values are mean±standard deviation of three replicates.
2)Different superscripts within a column indicate significant differences ($p<0.05$).

the HG *kimchi* began acidification.

Fermentation rate of *kimchi* was reported to be faster at lower salt concentrations and higher temperatures (13,14). Although both *kimchis* were fermented under conditions of comparable saltiness and fermentation temperature, the HG *kimchi* proceeded faster to the optimum pH compared with the FG *kimchi*. This phenomenon may be due to a difference in tissue state caused by different cultivation environments. Further research is needed to clearly explain this difference.

Microbial changes

Changes in numbers of total microbes, and total and typical lactic acid bacteria in FG and HG *kimchis* during fermentation are given in Table 4. Overall, the numbers of total microbes, and total and typical lactic acid bacteria increased until the 14th day of fermentation and then decreased. In comparison of FG and HG *kimchis*, the former showed higher numbers of total microbes as well as total and typical lactic acid bacteria than the latter at the 7th day. However, both *kimchis* did not show any difference at the 14th day.

Lactic acid bacteria have antibiotic ability against harmful microbes. Therefore, the growth of harmful bacteria could be inhibited by lactic acid bacteria produced during fermentation. When acidification begins, however, the growth of lactic acid bacteria is inhibited by high levels of lactic acid. Reduction in antibiotic ability of lactic acid bacteria results in an increase in total microbes (15). Softening of the *kimchi* tissue also occurs during this period (16,17).

The typical lactic acid bacteria in *kimchi* are hetero-fermentative bacteria *Leuconostoc* such as *Leu. mesenteroides*, and *Lactobacilli* such as *Lac. plantarum* and *Lac. brevis* (18). *Leu. mesenteroides* appears in the early stage and *Lactobacilli* in the later stage of fermentation. *Lac. plantarum* and *Lac. brevis* have strong tolerances to lactic acid and produce high levels of lactic acid (19), showing characteristics similar to homo-fermentative bacteria (20). Changes in phase from *Leuconostoc* to *Lactobacilli* within the fermentation period also occurred in the present study (Table 4).

Color of *kimchi*

Color of *kimchi* is one of the most important factors in evaluating the quality of *kimchi* (21,22). During fermentation, green leaves of Chinese cabbage generally turn to yellowish green by acid, while white leaves turn to yellowish red by red pepper powder incorporation (23). Under abnormal fermentation, leaves turn to dark color by oxidation.

Table 5 shows changes in color of FG and HG *kimchis* during fermentation for 28 days at 10°C. The L^* and H^o color values of both *kimchis* slightly decreased while the a^* value increased with fermentation time. There was no significant difference ($p>0.05$) in L^* value between FG and HG *kimchis*. However, HG *kimchi* showed a more reddish hue than FG *kimchi* between the 7th and 14th day of fermentation, based on lower H^o and higher a^* values. Appearance of *kimchi* color to a more reddish hue may enhance consumer acceptability of the product.

Table 4. Changes in the number of total microbe and total lactic acid bacteria, *Leuconostoc* and *Lactobacilli* of *kimchi* prepared with field- (FG) and hydroponic-grown (HG) Chinese cabbage during fermentation at 10°C

	Kimchi	Fermentation days				
		0	7	14	21	28
Total microbe	FG	$5.5\pm0.2^{1)a2)}$	6.9 ± 0.2^{a}	8.9 ± 0.1^{a}	8.4 ± 0.1^{a}	7.8 ± 0.2^{b}
($\log_{10}$ CFU/ml)	HG	5.4 ± 0.2^{a}	6.0 ± 0.1^{b}	$8\ 8\pm0.2^{b}$	8.5 ± 0.1^{a}	8.4 ± 0.1^{a}
TL[3)]	FG	5.2 ± 0.1^{a}	6.8 ± 0.2^{a}	8.8 ± 0.1^{a}	8.3 ± 0.1^{a}	7.7 ± 0.2^{b}
($\log_{10}$ CFU/ml)	HG	5.1 ± 0.1^{a}	5.9 ± 0.4^{b}	8.7 ± 0.1^{a}	8.4 ± 0.0^{a}	8.3 ± 0.0^{a}
Leuconostoc	FG	4.7 ± 0.1^{a}	6.6 ± 0.2^{a}	8.6 ± 0.3^{a}	7.9 ± 0.2^{a}	7.2 ± 0.3^{a}
($\log_{10}$ CFU/ml)	HG	4.8 ± 0.1^{a}	5.8 ± 0.2^{b}	8.4 ± 0.3^{a}	8.0 ± 0.3^{a}	7.9 ± 0.3^{a}
Lactobacilli	FG	4.8 ± 0.2^{a}	6.2 ± 0.3^{a}	8.5 ± 0.2^{a}	8.0 ± 0.3^{a}	7.5 ± 0.2^{b}
($\log_{10}$ CFU/ml)	HG	4.7 ± 0.2^{a}	5.3 ± 0.2^{b}	8.4 ± 0.2^{a}	8.1 ± 0.2^{a}	8.1 ± 0.3^{a}

1)Values are mean±standard deviation of three replicates.
2)Different superscripts within a column indicate significant differences ($p<0.05$).
3)TL: Total lactic acid bacteria

Table 5. Changes in color of *kimchi* prepared from field- (FG) and hydroponic-grown (HG) Chinese cabbage during fermentation at 10°C

Color	*Kimchi*	Fermentation days				
		0	7	14	21	28
L*	FG	69.9±2.1$^{1)a2)}$	67.6±2.0^{a}	66.4±1.8^{a}	62.5±1.5^{a}	54.6±1.2^{a}
	HG	67.9±2.1^{a}	66.0±2.0^{a}	67.1±2.0^{a}	62.9±1.6^{a}	55.2±1.4^{a}
a*	FG	-1.2±0.1^{a}	0.1±0.0^{b}	0.5±0.1^{b}	1.4±0.2^{b}	2.5±0.1^{a}
	HG	-1.2±0.1^{a}	1.3±0.1^{a}	1.4±0.2^{a}	1.9±0.1^{a}	2.5±0.2^{a}
b*	FG	10.0±0.3^{a}	17.6±0.4^{a}	14.7±0.4^{a}	13.6±0.3^{a}	20.4±0.2^{a}
	HG	10.0±0.3^{a}	17.2±0.3^{a}	13.1±0.3^{b}	13.3±0.3^{a}	17.9±0.3^{b}
H°	FG	96.7±0.5^{a}	89.8±1.2^{a}	87.9±1.1^{a}	84.0±1.2^{a}	82.3±1.4^{a}
	HG	96.7±0.4^{a}	85.7±1.2^{b}	84.7±1.1^{b}	82.7±1.2^{a}	82.0±1.5^{a}

$^{1)}$Values are mean±standard deviation of three replicates.
$^{2)}$Different superscripts within a column indicate significant differences ($p<0.05$).

Table 6. Changes in sensory evaluation of *kimchi* prepared with field- (FG) and hydroponic-grown (HG) Chinese cabbage during fermentation at 10°C

Attributes	*Kimchi*	Fermentation days				
		0	7	14	21	28
Sourness	FG	1.0±0.0$^{1)Aa}$	1.5±0.1^{Ab}	3.4±0.1^{Bc}	4.0±0.1^{Ad}	4.4±0.3^{Ae}
	HG	1.0±0.0^{Aa}	1.4±0.1^{Ab}	3.8±0.1^{Ac}	4.2±0.2^{Ad}	4.5±0.2^{Ad}
Crispness	FG	4.8±0.1^{Ac}	4.6±0.3^{Ac}	3.0±0.1^{Ab}	2.5±0.3^{Aa}	2.4±0.1^{Aa}
	HG	4.7±0.2^{Ab}	4.3±0.2^{Ab}	2.6±0.1^{Ba}	2.5±0.4^{Aa}	2.3±0.3^{Aa}
Overall quality	FG	1.7±0.1^{Aa}	2.8±0.3^{Ab}	3.6±0.2^{Ac}	3.2±0.3^{Ab}	3.1±0.2^{Ab}
	HG	1.5±0.1^{Aa}	2.5±0.3^{Ab}	3.3±0.2^{Ac}	2.9±0.4^{Abc}	2.7±0.3^{Bbc}

$^{1)}$Values are mean±standard deviation of three replicates.
^{A,B}Different superscripts within a column indicate significant differences ($p<0.05$).
$^{a\sim c}$Different superscripts within a row indicate significant differences ($p<0.05$).
Scores of sourness and crispness were evaluated as very low (1 point) to very strong (5 points). The overall quality was evaluated as very poor (1 point) to very good (5 points).

Sensory quality

Sourness, crispness, and overall quality are important attributes in evaluation of *kimchi* quality (24,25). Sensory characteristics of FG and HG *kimchis* during fermentation were compared, and the results are given in Table 6.

Overall, sourness increased and crispness decreased with fermentation time. There were no significant differences ($p>0.05$) in sourness and crispness between FG and HG *kimchis*, except for the 14th day. At the 14th day, the HG *kimchi* revealed slightly more sourness and less crispness than the FG *kimchi*. These sensory results coincide with the result shown in Table 1. In evaluation of overall quality, both *kimchis* did not show any difference by the 21st day of fermentation.

In conclusion, this study has demonstrated that HG Chinese cabbage has potential as a *kimchi* material. Production of HG Chinese cabbage may overcome the limited production by field cultivation, resulting in year-round preparation of *kimchi* in plants. The HG Chinese cabbage showed better characteristics and chemical compositions than the FG Chinese cabbage. However, a slightly faster fermentation rate of the HG *kimchi* compared with the FG *kimchi* may reduce the edible period of *kimchi*. Extension of edible periods should be carefully considered. Further work is needed with various HG Chinese cabbages to adequately extrapolate the present data to commercial *kimchi* preparation plants. Pilot-scale studies also are needed to commercialize the HG *kimchi*.

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