JOURNAL OF AGRICULTURAL SCIENCE
Vol. 37, No. 1, pp.73-80, JUNE 2010, CHUNGNAM NATIONAL UNIVERSITY

# Components in Chinese Cabbage (*Brassica rapa* ssp. *campestris*) as Affected by Soil pH: 6.9 vs. 7.6

Man Hyun Jo[1] · In Ki Ham[1] · Eun Mo Lee[1] · Jo-Eun Lee[2] · Nan Jiang[2] · Yong Pyo Lim[3] · Gilhwan An[2*]

# 토양의 pH (6.9 vs. 7.6)에 의한 배추 (*Brassica rapa* ssp. *campestris*) 의 성분에 대한 영향

조만현[1] · 함인기[1] · 이은모[1] · 이조은[2] · 강남[2] · 임용표[3] · 안길환[2*]

ABSTRACT

Functional and nutritional components of 7 cultivars of Chinese cabbage (CC; *Brassica rapa* subspecies *campestris*) from China were analyzed to compare the effects of soil pH (6.9 vs. 7.6). The CC grew on the soil of pH6.9 (CC-6.9) contained significantly increased amounts (2.3~4-fold) of pectin, crude protein, vitamin C and vitamin E compared to the control. The contents of ash and minerals (Ca, Fe, Na, Zn, K and Mn) were also significantly increased in CC-6.9. However, CC-6.9 contained 16-75% lower contents of reducing sugars, cellulose and crude fat than CC-7.6. CC-7.6 contained more glucosinolates than CC-6.9; gluconasturtiin (20.68 vs. 0.84 nmol·$g^{-1}$ wet wt) and gluconapin (202.55 vs. 0.15 nmol·$g^{-1}$ wet wt). In conclusion, CC-6.9 had an improved texture (high pectin and low cellulose) and nutritional value (high in protein, Ca, Fe, Zn, vitamin C, and E), whereas CC-7.6 had better taste (high in reducing sugars) and anticancer functionality (high in glucosinolates).

*Key words:* Chinese cabbage, soil pH, glucosinolate, mineral, texture

## I. Introduction

Chinese cabbage (CC; *Brassicarapa* ssp. *campestris*) is one of the most important *Brassica* crops in Korea, being the major component of Kimchi. About 2.25 million tons of CC is produced annually in Korea (Crop statistics, 2007, Ministry of Agriculture, Fishery, and Food of Korea) and about 90 g·$day^{-1}$ of Kimchi is consumed by the average adult (Nan et al., 2005).

Dietary fibers, vitamins C and E including pectin and cellulose, are beneficial to human health and supplied mainly from plants (Wardlaw, 1999). Reducing sugars could provide a sweet taste. Protein and fat affect not only the taste of vegetables but also nutritional values. Cruciferous plants, including CC, are important sources for anticancer compounds, e.g., β-carotene, vitamin C, fibers (including pectin and cellulose), calcium and glucosinolates (Hayes et al., 2008). Calcium and iron are often used in dietary supplements for women, and they are rich in leafy vegetables (Wardlaw, 1999).

If there is a severe accumulation of salts, the soil pH may be over pH 7.0. This is usually due to the close system that cause accumulation of phosphate and nitrate (5- to 10-fold accumulation than normal soil). This increases osmotic pressure and quantity of ammonia, and thus $Ca(OH)_2$ is hardly absorbed by plants. In case of CC, if the soil pH is >7, growth is poor and inside of it is rotten because of lack of Ca. This also accelerated by insolubilized Mn or B due to a high pH (Ryu et al., 2006).

Many factors including soil, weather, fertilization and others can affect the chemical composition of plants (Tahvonen, 1993). A recent study showed that the soil with pH 6.2 exerted

[1] 충청남도 예산군 신암면 종경리 365번지 충청남도농업기술원 (Chungcheongnam-do Agricultural Research & Extension Services Horticultural Research Division, 365 Jonggyeong-ri, Sinam-myeon, Yesan-gun, Chungcheongman-do 340-861, Korea)
[2] 충남대학교 농업생명공학대학 식품공학과(Department of Food Science and Technology, Chungnam National University, Gung-Dong 220, Yusung-Gu, Daejon 305-764, Korea)
[3] 충남대학교 농업생명공학대학 원예학과(Department of Horticultural Science, Chungnam National University, Gung-Dong 220, Yusung-Gu, Daejon)
* Corresponding author : 안길환
Tel.: +82-42-821-6730 Fax: +82-42-821-6721
E-mail : ghahn@cnu.ac.kr
2010년 4월 25일 투고
2010년 5월 23일 심사완료
2010년 6월 11일 게재확정

significant influence on the contents of general compounds in CC (Lee et al., 2010). In this study, we further surveyed the effects of soil pH at 6.9 vs. 7.6 on the components of CC. Seven cultivars of CC were used not to be confused soil pH effect from cultivar genetic specificity. Moisture content, reducing sugar, pectin, cellulose, protein, fat, vitamin C, vitamin E, glucosinolates, Ca and other minerals in CC were measured for the determination of CC quality.

## II. Materials and Methods

### 1. Field Trials

Seven cultivars of B. rapa ssp. campestris originating from China were obtained from the Korea Brassica Genome Resource Bank (Daejeon, Korea) (Table 1). They were cultivated on the soil of pH6.9 in a side-open greenhouse of the Chungnam National University farm (Daejeon, Korea) and on the soil of pH7.6 in outdoor field of Chungcheongnam-Do Agricultural Research & Extension Services (Yesan, Chungnam Province) from August to October of 2007. Not to be affected by environmental differences, the cultivation conditions of two farms were controlled to be as similar as possible. Two farms are about 40 km apart. The data from soil analyses at each farm are shown in Table 2. The two groups were sampled after confirmation of uniformity in color, shape, and size of the mature plants, based on criteria given by the Korea Seed & Variety Service (Anyang, Kyunggi, Korea). For each trial, a cultivar was grown in eight replicates, and three plants were randomly sampled. For glucosinolates and minerals, only one replication wa sused.

### 2. Sample Preparation for Analyses

The third-layer outer leaves were used for component analyses. The blended samples were kept at -70°C. Before use, analyses using unblended samples, the sample leaves were the blended samples were homogenized with a Polytron® (PT-MR 2100, Kinematica AG, Switzerland). For component kept at 4°C and used within 3 days.

### 3. Analyses for general compounds

Water contents were measured by the Infrared Moisture Determination Balance (FD-240, Kett electric laboratory, Japan). The dried samples used for moisture content were also used for measuring ash contents by furnace combustion at 550°C for 3-6 hours (AOAC, 1995). The minerals in the digested samples (60-62% nitric acid and 30% hydrogen peroxide) were measured by Inductively Coupled Plasma Atomic Emission Spectrometer (Optima 3300DV, Perkin-Elmer Instruments, Shelton, USA). The reducing sugar contents were measured by the DNS (3,5-dinitrosalicylic acid) method (Miller, 1959). The water-insoluble pectin contents were measured by the method of Manabe (Manabe and Naohara, 1986). The homogenized samples for cellulose were digested with cellulose (1.92 $U \cdot mg^{-1}$, Sigma, catalog # C1794) and then the reducing sugar contents in supernatants were measured by the DNS method at 540 nm (Kim et al., 1986). The quantity of crude protein was measured by the method of Bradford (Bradford, 1976). Crude fat in the homogenized samples were transferred to hexane and the weight after drying was determined as crude fat. Vitamin C was measured by the DNP method (AOAC, 1995). The content of vitamin E was measured by the modified method of Aaran and Nikkari (Aaran and Nikkari, 1988). More detailed methods for general compounds were previously reported (Lee et al., 2010)

### 4. Analysis for Glucosinolate

The homogenized sample (3 mL) was mixed with 4 mL of 0.1 M phosphate citrate buffer (pH 7.0). Butyl isothiocyanate was used as the internal standard at 50 $nmol \cdot mL^{-1}$. The sample was mixed with 2 mL of DCM and 0.3 unit of thioglucosidase

**Table 1. The seven Chinese cabbage cultivars (Brassica rapa ssp. campestris) used in this study.**

| Entry Name | Access no[a] |
|---|---|
| Jinguanwang | 26107 |
| Qiouyuyihao F1 | 26110 |
| Aoxing 70 | 26113 |
| Aoxing 75 | 26125 |
| Beijingxinsanhao F1 | 26131 |
| M-988 F1 | 26133 |
| Shenyangkuaicai | 26135 |

[a]Access number in Korea Brassica Genome Resource Bank (Daejeon, Korea)

(Sigma, catalog # T4528). After incubation at 30°C for 3 h with mild shaking, the samples were centrifuged (2,100 × g, 10 min), and the upper DCM layer was collected. To identify isothiocyanates, GC-MS (gas chromatography-mass spectrometry) was used (HP 5890 GC/5972MSD, Palo Alto, CA), with a DB-5MS column (0.25 mm × 30 m, 0.25 µm, Agilent, Santa Clara, CA). For routine analysis, GC-FPD (Flame photometric detector detecting S compounds; Shimadzu GC-14B, Kyoto, Japan) was used under the same conditions as for GC-MS.

### 5. Statistical Analysis

SPSS 14.0 was used for statistical analysis. For average comparison between two groups, one-way ANOVA were performed. Pearson correlation coefficients were calculated for the correlations between dependent variables.

## III. Results

The pH of soil was determined by measuring the pH after addition of 10 volumes of distilled water. The pH of the soil in the side-open greenhouse was 6.9, whereas that of the outdoor soil was 7.6 (Table 2). Not to be biased by the genetic traits, 7 cultivars were the randomly selected from the list of Korea Brassica Genome Resource Bank and the components were analyzed to measure the effect of soil pH.

### 1. Nutritional Components

Moisture contents of CC-6.9 were lower than those of CC-7.6 (Table 3). This was due to the limited availability of rain by the roof of the green house (but the sides were completely open) (USDA, 2009). Reducing sugars in CC-6.9 were 61% of those in CC-7.6 (Table 3). The reducing sugars, including glucose, are important for the quality of CC because they affect the taste. The high reducing sugar content could also cause fast fermentation (acetic and lactic acid production) in Kimchi (Jung et al., 1985; Hong and Kim, 2006). The crude protein contents of CC-6.9 were 2.2-fold higher than those in CC-7.6 (Table 3). However, the crude fat content in CC-6.9 was half that of CC-7.6 (Table 3).

CC-6.9 contained significantly increased vitamins C and E compared to CC-7.6 (Table 3). Vitamins C and E are important antioxidants for human beings (Schneider, 2005), the RDA for vitamin C is 60 $mg \cdot day^{-1}$ and for vitamin E is 15 $mg \cdot day^{-1}$ (Wardlaw, 1999). Thus, a person consuming more than 85 g of cultivar #26110 grown on the soil at pH6.9 would be provided with the daily requirement of vitamin C. Similarly, 100 g of cultivar #26133 would provide a daily requirement of vitamin E. Therefore, regarding the nutritional aspect of vitamin content, CC-6.9 was higher in quality than CC-7.6. The vitamin contents in certain cultivars showed significantly different trends by the soil pH, e.g. the cultivar #26110 was highest in vitamin content in CC-6.9 but lowest in CC-7.6.

### 2. Texture-related Dietary Fibers

Examining dietary fiber, the contents of pectin and cellulose were analyzed. CC-6.9 in the greenhouse contained significantly increased pectin by 3.74-fold, compared to CC-7.6 (Table 3). Cellulose levels in CC-6.9 were about half that of CC-7.6 (Table 3). Both pectin and cellulose are important dietary fibers (Wardlaw, 1999; Khokhar and Kapoor, 1990) but the effect on texture is quite different. Pectin usually gives a good texture but cellulose gives a woody mouth-feel. Therefore, regarding the texture, CC-6.9 had better characteristics than

**Table 2. Minerals in soil**

| Mineral | Soil dissolved in 0.1N HCl pH6.9 | Soil dissolved in 0.1N HCl pH7.6 | Ratio | Soil dissolved in distilled water pH6.9 | Soil dissolved in distilled water pH7.6 | Ratio |
|---|---|---|---|---|---|---|
| | ($mg \cdot g^{-1}$ wet wt) | | | ($mg \cdot g^{-1}$ wet wt) | | |
| Ca | 2.417 ± 0.512 | 1.460 ± 0.406 | 1.7 | 1.013 ± 0.196 | 0.937 ± 0.176 | 1.1 |
| Fe | 0.528 ± 0.191 | 0.163 ± 0.011 | 3.2 | 0.128 ± 0.019 | 0.075 ± 0.042 | 1.7 |
| K | 0.129 ± 0.007 | 0.214 ± 0.047 | 0.6 | 0.261 ± 0.037 | 0.261 ± 0.104 | 1.0 |
| Mg | 0.659 ± 0.129 | 0.437 ± 0.109 | 1.5 | 0.130 ± 0.034 | 0.221 ± 0.081 | 0.6 |
| Mn | 0.110 ± 0.023 | 0.132 ± 0.022 | 0.8 | 0.033 ± 0.011 | 0.049 ± 0.005 | 0.7 |
| Na | 0.066 ± 0.015 | 0.020 ± 0.003 | 3.3 | 0.103 ± 0.019 | 0.044 ± 0.043 | 2.3 |
| Zn | 0.016 ± 0.004 | 0.004 ± 0.001 | 3.9 | 0.005 ± 0.002 | 0.005 ± 0.006 | 1.0 |
| B | ND[a] | ND | | 0.009 ± 0.011 | 0.032 ± 0.061 | 0.3 |
| pH | | | | 6.9 ± 0.28 | 7.6 ± 0.39 | |

[a]ND: not detected

**Table 3. Nutritional components in 7 Chinese cabbage cultivars cultivated on soils of different pH.**

| Access[a] number | Moisture** (%) pH6.9 | Moisture** (%) pH7.6 | Reducing Sugar** ($mg \cdot g^{-1}$ wet wt) pH6.9 | Reducing Sugar** ($mg \cdot g^{-1}$ wet wt) pH7.6 | Crude Protein** ($mg \cdot g^{-1}$ wet wt) pH6.9 | Crude Protein** ($mg \cdot g^{-1}$ wet wt) pH7.6 |
|---|---|---|---|---|---|---|
| 26107 | 88.13 ± 1.09 | 93.26 ± 0.83 | 13.94 ±0.08 | 25.01 ± 0.38 | 3.49 ± 0.34 | 0.89 ± 0.00 |
| 26110 | 89.48 ± 2.02 | 91.15 ± 0.53 | 11.67 ±0.37 | 22.15 ± 1.11 | 1.39 ± 0.18 | 1.51 ± 0.02 |
| 26113 | 85.77 ± 1.57 | 89.21 ± 1.54 | 25.07 ±0.41 | 38.40 ± 0.80 | 3.31 ± 0.48 | 0.97 ± 0.02 |
| 26125 | 86.06 ± 0.61 | 93.77 ± 0.14 | 20.26 ±0.47 | 27.39 ± 0.19 | 1.58 ± 0.08 | 0.68 ± 0.02 |
| 26131 | 84.97 ± 1.99 | 91.72 ± 0.40 | 20.35 ±0.17 | 35.16 ± 2.20 | 3.36 ± 0.08 | 1.21 ± 0.00 |
| 26133 | 85.86 ± 1.19 | 90.50 ± 0.91 | 9.79 ±0.11 | 29.20 ± 2.10 | 2.79 ± 0.11 | 1.29 ± 0.00 |
| 26135 | 88.33 ± 0.44 | 89.88 ± 0.09 | 24.37 ±0.24 | 28.89 ± 2.02 | 1.75 ± 0.04 | 1.40 ± 0.00 |
| Average | 86.94 ± 1.68 | 91.36 ± 1.69 | 17.92 ±6.13 | 29.46 ± 5.63 | 2.52 ± 0.92 | 1.14 ± 0.30 |
| Ratio | 0.95 | | 0.61 | | 2.22 | |

| Access[a] number | Crude Fat** ($mg \cdot g^{-1}$ wet wt) pH6.9 | Crude Fat** ($mg \cdot g^{-1}$ wet wt) pH7.6 | Pectin** ($mg \cdot g^{-1}$ wet wt) pH6.9 | Pectin** ($mg \cdot g^{-1}$ wet wt) pH7.6 | Cellulose** ($mg \cdot g^{-1}$ wet wt) pH6.9 | Cellulose** ($mg \cdot g^{-1}$ wet wt) pH7.6 |
|---|---|---|---|---|---|---|
| 26107 | 17.33 ± 1.15 | 70.67 ± 3.06 | 2.46 ± 0.08 | 0.71 ± 0.03 | 27.77 ± 0.47 | 50.42 ± 2.36 |
| 26110 | 35.00 ± 1.41 | 70.33 ± 2.08 | 5.06 ± 0.31 | 0.20 ± 0.01 | 26.34 ± 0.60 | 60.25 ± 1.53 |
| 26113 | 29.67 ± 8.39 | 47.33 ± 5.51 | 5.36 ± 0.08 | 1.59 ± 0.07 | 29.47 ± 0.88 | 84.90 ± 3.67 |
| 26125 | 25.33 ± 7.51 | 43.33 ± 3.21 | 7.62 ± 0.05 | 1.65 ± 0.15 | 27.74 ± 0.34 | 43.64 ± 0.99 |
| 26131 | 30.50 ± 3.54 | 42.67 ± 3.79 | 9.40 ± 0.07 | 2.49 ± 0.21 | 32.82 ± 1.21 | 80.70 ± 3.57 |
| 26133 | 27.00 ± 3.00 | 54.00 ± 1.00 | 3.91 ± 0.06 | 1.70 ± 0.13 | 27.32 ± 0.79 | 74.16 ± 2.43 |
| 26135 | 21.50 ± 6.36 | 51.67 ± 1.15 | 8.75 ± 0.66 | 3.04 ± 0.07 | 30.30 ± 1.03 | 67.03 ± 0.68 |
| Average | 26.62 ± 5.90 | 54.29 ± 11.80 | 6.08 ± 2.58 | 1.63 ± 0.97 | 28.82 ± 2.21 | 65.87 ± 15.37 |
| Ratio | 0.49 | | 3.74 | | 0.44 | |

| Access[a] number | Vitamin C** ($\mu g \cdot g^{-1}$ wet wt) pH6.9 | Vitamin C** ($\mu g \cdot g^{-1}$ wet wt) pH7.6 | Vitamin E** ($\mu g \cdot g^{-1}$ wet wt) pH6.9 | Vitamin E** ($\mu g \cdot g^{-1}$ wet wt) pH7.6 | Ash** ($\mu g \cdot g^{-1}$ wet wt) pH6.9 | Ash** ($\mu g \cdot g^{-1}$ wet wt) pH7.6 |
|---|---|---|---|---|---|---|
| 26107 | 400.83 ± 7.05 | 222.03 ± 6.75 | 42.09 ± 13.92 | 14.16 ± 1.15 | 19.10 ± 0.82 | 6.73 ± 0.77 |
| 26110 | 707.67 ± 65.04 | 156.36 ± 4.48 | 95.87 ± 9.21 | 19.63 ± 0.71 | 19.65 ± 5.39 | 9.58 ± 2.09 |
| 26113 | 461.69 ± 2.14 | 240.72 ± 3.35 | 85.50 ± 17.91 | 23.00 ± 2.06 | 15.76 ± 3.80 | 8.45 ± 1.73 |
| 26125 | 464.56 ± 30.75 | 205.85 ± 2.36 | 59.04 ± 6.26 | 16.83 ± 1.74 | 21.88 ± 2.60 | 4.89 ± 0.22 |
| 26131 | 454.33 ± 41.36 | 369.66 ± 5.21 | 102.38 ± 19.89 | 31.40 ± 1.26 | 25.52 ± 2.77 | 5.49 ± 0.39 |
| 26133 | 511.44 ± 21.21 | 258.26 ± 4.56 | 147.06 ± 8.10 | 20.59 ± 2.57 | 25.27 ± 2.10 | 7.32 ± 1.04 |
| 26135 | 488.06 ± 19.16 | 83.90 ± 1.48 | 101.52 ± 4.67 | 31.40 ± 3.01 | 16.15 ± 1.93 | 9.91 ± 0.60 |
| Average | 498.37 ± 98.34 | 219.54 ± 88.57 | 90.49 ± 33.79 | 22.43 ± 6.73 | 20.48 ± 3.96 | 7.48 ± 1.94 |
| Ratio | 2.27 | | 4.03 | | 2.74 | |

[a] Access number in Korea Brassica Genome Resource Bank (Daejeon, Korea)
[b] Average: t-test of all average comparisons between the two conditions were all statistically significant ($p<0.01$).
* Average difference by one-way ANOVA was significant at the level of $p<0.05$.
**Average difference by one-way ANOVA was significant at the level of $p<0.01$.

CC-7.6. However, from the standpoint of total dietary fibers, CC-7.6 had a higher value than CC-6.9.

## 3. Ash and Minerals

The ash contents of CC-6.9 were significantly higher (2.74-fold) than those of CC-7.6 (Table 3). Iron, zinc, copper, calcium, magnesium, selenium and iodine are frequently deficient in human diets (White and Broadley, 2009). Therefore, the levels of several important minerals were determined in this study.

The differences in Ca in two soils (1.1∼1.6-fold) (Table 2) were less severe than those in two CC groups (4.6-fold) (Table 4). In case of Mg, the content differences between two soils and two CC groups were similar (Table 4). Interestingly, the cultivar #26135 grown in the soil at pH7.6 contained significant amount of Mg, showing different trend from other cultivars.

The soil at pH 6.9 released 3∼4-fold increased contents of Fe, Na, and Zn in 0.1N HCl compared to in distilled water (Table 2). Contents of these salts in CC-6.9 were higher than those in CC-7.6 by 4.73-, 3.56-, and 2.27-fold, respectively (Table 4). These salts had accumulated in the soil of pH6.9, and their absorption by the plants was probably increased by relatively lowered pH of soil. In the soil of pH7.6, cultivar #26135 contained a relatively outstanding amount of Ca, Mg, Fe, Zn, Na, and Mn (Table 4).

The contents of Mn in the soils were not significantly different but were significantly higher in CC-6.9 than in CC-7.6 (Table 4). The Mn levels in CC-6.9 varied widely compared to other minerals.

### 4. Glucosinolates

Glucosinolates are the source of isothiocyanates (ITCs), giving a pungent flavor in the *Brassica* family (Zang et al., 2008). Gluconasturtiin (detected as phenylethyl ITC) and gluconapin (detected as butenyl ITC) were the major glucosinaloates found in most of cultivars (Table 5). Interestingly, butenyl ITC and phenylethyl ITC were accumulated in CC-7.6 but not significantly in CC-6.9. Phenylethyl ITC is a very effective anticancer compound (Hayes et al., 2008; Wang et al., 2009). Considering the extraordinary amount of phenylethyl ITC in cultivar #26110, it can be recommended as an anticancer CC (Table 5). However, glucosinolate at extremely high contents might hinder acceptance by consumers due to its bitterness, and thus a careful consideration is recommended.

## VI. Discussion

The variations within cultivars were significant. For example, the variation of crude fat in CC-6.9 was 17-35 $mg·g^{-1}$ wet wt (Table 3), and that of phenylethyl isothiocyanate in CC-7.6 was 2-111 $nmol·g^{-1}$wet wt (Table 5).

The effect of soil pH on the levels of these components in

**Table 4. Minerals in 7 Chinese cabbage cultivars cultivated on soils of different pH.**

| Access no | Ca** | | Mg* | | Fe** | | Zn* | | Na** | | K** | | Mn** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH6.9 | pH7.6 | pH6.9 | pH7.6 | pH6.9 | pH7.6 | pH6.9 | pH7.6 | pH6.9 | pH7.6 | pH6.9 | pH7.6 | pH6.9 | pH7.6 |
| | $mg·g^{-1}$wetwt | | | | | | | | | | | | | |
| 26107 | 4.95 | 0.33 | 0.42 | 0.14 | 0.05 | 0.01 | 0.01 | 0.00 | 0.36 | 0.13 | 4.22 | 2.44 | 0.01 | 0.00 |
| 26110 | 3.48 | 0.65 | 0.36 | 0.19 | 0.05 | 0.01 | 0.01 | 0.00 | 0.37 | 0.06 | 3.69 | 2.38 | 0.01 | 0.00 |
| 26113 | 2.80 | 0.24 | 0.25 | 0.15 | 0.06 | 0.01 | 0.01 | 0.00 | 0.34 | 0.11 | 3.62 | 2.63 | 0.02 | 0.00 |
| 26125 | 4.40 | 0.24 | 0.52 | 0.14 | 0.07 | 0.01 | 0.01 | 0.00 | 0.37 | 0.07 | 2.98 | 2.24 | 0.02 | 0.00 |
| 26131 | 4.78 | 0.92 | 0.49 | 0.22 | 0.07 | 0.01 | 0.01 | 0.00 | 0.47 | 0.12 | 3.81 | 1.97 | 0.01 | 0.02 |
| 26133 | 3.67 | 1.11 | 0.40 | 0.25 | 0.05 | 0.01 | 0.01 | 0.00 | 0.30 | 0.09 | 3.89 | 2.92 | 0.01 | 0.00 |
| 26135 | 2.87 | 2.40 | 0.33 | 0.53 | 0.05 | 0.03 | 0.01 | 0.01 | 0.39 | 0.16 | 3.80 | 2.46 | 0.02 | 0.01 |
| Average | 3.85 | 0.85 | 0.40 | 0.23 | 0.06 | 0.01 | 0.01 | 0.00 | 0.37 | 0.10 | 3.71 | 2.43 | 0.01 | 0.00 |
| SD | 0.87 | 0.77 | 0.09 | 0.14 | 0.01 | 0.01 | 0.00 | 0.00 | 0.05 | 0.04 | 0.38 | 0.30 | 0.01 | 0.00 |
| Ratio | 4.57 | | 1.73 | | 4.73 | | 2.27 | | 3.56 | | 1.53 | | 3.13 | |

*Average difference by one-way ANOVA was significant at the level of $p<0.05$.
**Average difference by one-way ANOVA was significant at the level of $p<0.01$.

**Table 5. Glucosinolates in 7 Chiese cabbage cultivars cultivated on soils of different pH.**

| Access no[a] | Butenyl isothiocyanate[b]* | | Phenethyl isothiocyanate | |
|---|---|---|---|---|
| | pH6.9 | pH7.6 | pH6.9 | pH7.6 |
| | $nmol·g^{-1}$ wet wt | | | |
| 26107 | ND | 308.32 | 0.97 | 8.55 |
| 26110 | 0.31 | 589.52 | 4.52 | 111.12 |
| 26113 | 0.18 | 181.21 | 0.33 | 10.72 |
| 26125 | ND | 294.44 | ND | 4.44 |
| 26131 | ND | 8.23 | ND | 4.19 |
| 26133 | ND | 3.01 | ND | 1.55 |
| 26135 | 0.56 | 33.15 | 0.09 | 4.19 |
| Average | 0.15 | 202.55 | 0.84 | 20.68 |
| SD | 0.22 | 214.52 | 1.66 | 40.00 |

[a] Access number in Korea Brassica Genome Resource Bank (Daejeon, Korea)
[b] Butenyl isothiocyanate: tentatively identified as butenyl isothiocyanate by GC-MS
*Average difference by one-way ANOVA was significant at the level of $p<0.05$.
[a] ND: not detected.

CC was extremely significant, as shown in Table 3-5. In this report, we showed that the effect of soil pH on the content ratios of CC-6.9 to CC-7.6 were, on average, as follows: moisture, 0.95; reducing sugar, 0.61; crude protein, 2.22; crude fat, 0.49; pectin, 3.74; cellulose, 0.44; vitamin C, 2.27; vitamin E, 4.03; ash, 2.74 (Table 3); Ca, 4.57; Mg, 1.73; Fe, 4.73; Zn, 2.27; Na, 3.56; K, 1.53; Mn, 3.13 (Table 4); butenyl ITC, 0.001; and phenylethyl ITC, 0.041 (Table 5). The statistical comparison of averages showed that all chemical components and many minerals were significantly ($p<0.05$) affected by the soil pH (Table 3 and 5).

Several reports have indicated that the health-beneficial components of Brassica plants are fibers, vitamin C (Divisi et al., 2006), glucosinolates (Hayes et al., 2008) and etc. The effect of soil pH on the components was dependent on genetic sources. For example, the vitamin C in the cultivars #26113, #26125 and #26135 from the soil of pH6.9 were similar (461.69, 464.56 and 488.06 $\mu g \cdot g^{-1}$ wet wt, respectively) but from the soil of pH7.6 were quite different(240.72, 205.85 and 83.90 $\mu g \cdot g^{-1}$ wet wt, respectively) (Table 3). Therefore, the content changes in vitamin C by soil pH were quite dependent on the cultivars. Considering functional components like glucosinolates, the variation between cultivars was more pronounced than for nutritional components like vitamin C (Table 3 and 5).

There were positive correlations (0.62 and 0.75) between reducing sugar and cellulose in CC-6.9 and CC-7.6 (Table 6). Similarly, positive correlations between reducing sugar and pectin were present. Cellulose and pectin are polymers of sugar moieties and thus the production of these compounds requires sugar.

Ca and Mg levels were strongly correlated with each other in both CC groups (0.84 in CC-6.9 and 0.99 in CC-7.6) (Table 6). These minerals are important components of bone (Wardlaw, 1999). They prevent absorption of lipids by saponification of fatty acids (Vaskonen, 2003), causing a healthful cardio-vascular system. Several cultivars, e.g., #26107, #26125 and #26131 were a good source of Ca, Fe, and Mg, which are deficient in many diets and important for pregnant women (White and Broadley, 2009). Other significant correlations remain unknown at this time, and thus further study of the physiology of CC is required.

The anticancer activity of phenylethyl ITC is excellent, as it induces cytoprotective genes mediated by Nrf2 and AhR transcription factors, represses NF-κB and inhibits cytochrome P450 and histone deactylase (Hayes et al., 2008; Lampe and Peterson, 2002). Glucosinolates are produced from amino acids including tryptophan, tyrosine, phenylalanine, isoleucine, leucine, valine, alanine and methionine (Grubb and Abel, 2006). Phenylethyl ITC can be produced from phenylalanine and thus the contents of the amino acids in CC need to be measured for future breeding. Cultivar #26110 is recommended as a vegetable source of anticancer compounds and as a breeding stock for new cultivars (Table 5). Furthermore, butyl-ITC and phenylethyl-ITC showed a strong correlation at high glucosinolate producing condition in CC-7.6. Therefore, at early steps in the biosynthesis of glucosinolate might be activated in CC-7.6.

In conclusion, CC-6.9 had a better texture than CC-7.6 because it contained increased pectin and lowered cellulose. CC-6.9 was also nutritionally enhanced by increased contents of protein, Ca, Fe, vitamin C and vitamin E. CC-7.6, conversely, was better in taste due to its high content of reducing sugars. It was also good as a nutraceutical vegetable because it contained large amounts of anticancer compounds such as glucosinolates.

## Ⅴ. Abbreviations

CC, Chinese cabbage; CC-6.9, Chinese cabbage on greenhouse soil of pH6.9; CC-7.6, Chinese cabbage on the outdoor soil of pH7.6; ITC, isothiocyanate; DNS, dinitrosalicylic acid; DNP, 2,4-dinitrophenyl hydrazine; DCM, dichloromethane; RDA, recommended daily allowance.

본 연구는 농림수산식품부 농림기술개발사업(308023-03-2-HD110 and 607003-05-3-SB120)의 지원에 의해 이루어졌다.

## References

1. Aaran, R. K and T. Nikkari. 1988. HPLC method for the simultaneous determination of beta-carotene, retinol and alpha-tocopherol in serum. J. Pharma. Biomed. Anal. 6 : 853-857.
2. AOAC. 1995. Official Method of Analysis. 16th ed. The Association of Offiice in Analytical Chemistry. Washington DC.
3. Bradford, M. M. 1976. A rapid and sensitive methods for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Anal. Biochem. 72 : 248-254.

**Table 6. Pearson correlation coefficients among components of Chinese cabbage.**

| | Moisture | Reducing Sugar (RS) | Crude Protein (CP) | Crude Fat (CF) | Pectin | Cellulose | Vitamin C (VC) | Vitamin E (VE) | Ash | Butenyl isothiocyanate (B-ITC) | Phenylethyl isothiocyanate (P-ITC) | Ca | Mg | Fe | Zn | Na | K | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moisture | Acidified Soil (pH6.9) | | | | | | | | | | | | | | | | | |
| RS | -0.23 | | | | | | | | | | | | | | | | | |
| CP | -0.39 | 0.04 | | | | | | | | | | | | | | | | |
| CF | -0.10 | -0.10 | -0.15 | | | | | | | | | | | | | | | |
| Pectin | -0.26 | 0.65** | -0.29 | 0.18 | | | | | | | | | | | | | | |
| Cellulose | -0.49* | 0.62** | 0.37 | -0.09 | 0.68** | | | | | | | | | | | | | |
| VC | 0.46* | -0.40 | -0.62** | 0.56** | -0.06 | -0.43 | | | | | | | | | | | | |
| VE | -0.26 | -0.24 | -0.10 | 0.32 | 0.13 | 0.15 | 0.35 | | | | | | | | | | | |
| Ash | -0.58** | -0.42 | 0.09 | 0.21 | 0.11 | 0.15 | -0.03 | 0.42 | | | | | | | | | | |
| B-ITC | 0.50* | 0.37 | -0.52* | 0.02 | 0.31 | 0.06 | 0.39 | 0.15 | -0.56** | | | | | | | | | |
| P-ITC | 0.60** | -0.48* | -0.42 | 0.41 | -0.31 | -0.52* | 0.82** | -0.07 | -0.15 | 0.29 | | | | | | | | |
| Ca | -0.17 | -0.34 | 0.32 | -0.23 | -0.08 | 0.09 | -0.37 | -0.41 | 0.50* | -0.74** | -0.12 | | | | | | | |
| Mg | -0.25 | -0.26 | -0.08 | -0.10 | 0.25 | 0.06 | -0.21 | -0.19 | 0.62** | -0.62** | -0.21 | 0.84** | | | | | | |
| Fe | -0.59** | 0.46* | 0.18 | -0.02 | 0.59** | 0.53* | -0.53* | -0.27 | 0.33 | -0.52* | -0.59** | 0.51* | 0.66** | | | | | |
| Zn | 0.17 | 0.50* | -0.16 | -0.27 | 0.40 | 0.37 | -0.12 | 0.28 | -0.39 | 0.79** | -0.31 | -0.60** | -0.49* | -0.27 | | | | |
| Na | -0.11 | 0.40 | 0.02 | 0.12 | 0.75** | 0.71** | -0.09 | -0.17 | 0.17 | 0.06 | -0.04 | 0.39 | 0.40 | 0.56** | 0.07 | | | |
| K | 0.22 | -0.36 | 0.56** | -0.26 | -0.47* | 0.09 | -0.12 | 0.14 | -0.03 | 0.04 | 0.09 | 0.12 | -0.30 | -0.54* | 0.21 | -0.08 | | |
| Mn | -0.04 | 0.47* | -0.59** | -0.13 | 0.32 | -0.18 | -0.07 | -0.15 | -0.28 | 0.28 | -0.29 | -0.39 | 0.01 | 0.24 | 0.26 | -0.23 | -0.79** | |

| | Moisture (Moist.) | Reducing Sugar (RS) | Crude Protein (CP) | Crude Fat (CF) | Pectin | Cellulose (Cel.) | Vitamin C (VC) | Vitamin E (VE) | Ash | Butenyl isothiocyanate (B-ITC) | Phenylethyl isothiocyanate (P-ITC) | Ca | Mg | Fe | Zn | Na | K | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moist. | Neutral Soil (pH7.6) | | | | | | | | | | | | | | | | | |
| RS | -0.42 | | | | | | | | | | | | | | | | | |
| CP | -0.55* | -0.18 | | | | | | | | | | | | | | | | |
| CF | 0.13 | -0.70** | 0.30 | | | | | | | | | | | | | | | |
| Pectin | -0.30 | 0.53* | 0.08 | -0.74** | | | | | | | | | | | | | | |
| Cel. | -0.73** | 0.75** | 0.42 | -0.35 | 0.40 | | | | | | | | | | | | | |
| VC | 0.16 | 0.52* | -0.26 | -0.37 | 0.05 | 0.41 | | | | | | | | | | | | |
| VE | -0.54* | 0.49* | 0.51* | -0.50* | 0.78** | 0.63** | 0.09 | | | | | | | | | | | |
| Ash | -0.74** | -0.14 | 0.62** | 0.35 | -0.05 | 0.22 | -0.61** | 0.24 | | | | | | | | | | |
| B-ITC | 0.32 | -0.62** | -0.03 | 0.63** | -0.85** | -0.55** | -0.35 | -0.60** | 0.17 | | | | | | | | | |
| P-ITC | -0.06 | -0.54* | 0.52* | 0.60** | -0.67** | -0.15 | -0.32 | -0.20 | 0.43 | 0.82** | | | | | | | | |
| Ca | -0.43 | -0.04 | 0.65** | -0.10 | 0.68** | 0.23 | -0.45* | 0.69** | 0.45* | -0.51* | -0.15 | | | | | | | |
| Mg | -0.43* | -0.02 | 0.57** | -0.13 | 0.69** | 0.18 | -0.54* | 0.67** | 0.48* | -0.47* | -0.17 | 0.99** | | | | | | |
| Fe | -0.55* | 0.18 | 0.44* | -0.17 | 0.71** | 0.29 | -0.54* | 0.66** | 0.53* | -0.51* | -0.28 | 0.90** | 0.95** | | | | | |
| Zn | -0.79** | 0.44* | 0.51* | -0.32 | 0.58** | 0.60** | -0.38 | 0.74** | 0.61** | -0.34 | -0.01 | 0.65** | 0.71** | 0.81** | | | | |
| Na | -0.25 | 0.34 | 0.09 | -0.13 | 0.64** | 0.29 | -0.07 | 0.54* | 0.16 | -0.63** | -0.58** | 0.59** | 0.61** | 0.74** | 0.43 | | | |
| K | -0.46* | -0.02 | 0.15 | 0.23 | -0.15 | 0.19 | -0.28 | -0.28 | 0.38 | -0.14 | -0.09 | 0.11 | 0.10 | 0.18 | 0.13 | -0.07 | | |
| Mn | -0.44* | -0.03 | 0.73** | -0.09 | 0.65** | 0.27 | -0.39 | 0.75** | 0.46* | -0.45* | -0.03 | 0.98** | 0.96** | 0.85** | 0.67** | 0.55** | -0.02 | |

*Significant at the level of $p<0.05$.

**Significant at the level of $p<0.01$.

4. Divisi, D., S. Di Tommaso, S. Salvemini, M. Garramone, and R. Crisci. 2006. Diet and cancer. Acta Biomed. 77 : 118-123.

5. Grubb, C. D. and S. Abel. 2006. Glucosinolate metabolism and its control. Trend. Plant Sci. 11 : 89-100. 6. Hayes, J. D, M. O. Kelleher, and I. M. Eggleston. 2008. The cancer chemopreventive actions of phytochemicals derived from glucosinolates. Eur. J. Nutr. 47 : 73-88.

7. Hong, E. Y. and G. H. Kim. 2006. Changes in vitamin C, amino acid and sugar levels in Chinese cabbages during storage. Kor. J. Food Preserv. 13 : 589-595. 8. Jung, H. S.,

Y. T. Ko, and S. J. Lim. 1985. Effect of sugars on Kimchi fermentation and on the stability of ascorbic acid. Kor. J. Food Nutr. 18 : 36-45.

9. Khokhar, S. and A. C. Kapoor. 1990. Effect of dietary fibres on bioavailability of vitamin A and thiamine. Plant Food. Hum. Nutr. 40 : 259-65.
10. Kim, D. W., O. Bobleter, and G. Bonn. 1986. Enzymatic hydrolysis of cellulose and plant biomass. Kor. Chem. Eng. Res. 24 : 53-62.
11. Lampe, J. W. and S. Peterson. 2002. *Brssica*, biotransformation and cancer risk: genetic polymorphisms alter the preventive effects of cruciferous vegetalbes. J. Nutr. 132 : 2991-2994.
12. Lee, J. E., P. Wang, G. Kim, S. Kim, S, Park, Y. S. Hwang, Y. P. Lim, E. M. Lee, I. K. Ham, M. H. Jo and G. An. 2010. Effects of soil pH on nutritional and functional compounents of Chinese cabbages (*Brassicarapa* spp. *campestris*). Kor. J. Hort. Sci. Technol. accepted
13. Manabe, M. and J. Naohara. 1986. Properties of pectin in Satsuma mandarin fruits (*Citrus unshiu* Marc.) Nippon Shokuhin Kogyo Gakkishi. 33 : 602-608.
14. Miller, G. L. 1959. Use of dinitrosalicylic acid reagent for determination of reducing sugar. Anal. Chem. 31 : 426-428.
15. Nan, H. M., J. W. Park, , Y. J. Song, H. Y. Yun, J. S. Park, T. Hyun, Youn, S. J., Y. D. Kim, , J. W. Kang, and H. Kim. 2005. Kimchi and soybean pastes are risk factors of gastric cancer. World J. Gastroenterol. 11 : 3175-3181.
16. Ryu, C. H., J. H. Jung, C. H. Yang, J. H. Yoo, T. G. Kim, J. D. Kim. 2006. One-to-one company-to-rural town co relationship for fertilizer practice and soil management. Rural Development Administration Department of Rice and Winter Cereal Crop, Suwon, Korea.
17. Schneider, C. 2005. Chemistry and biology of vitamin E. Mol. Nutr. Food Res. 49 : 7-30.
18. Tahvonen, R. 1993. Contents of selected elements in some fruits, berries and vegetables on the Finnish market in 1987-1989. J. Food Compos. Anal. 6 : 75-86.
19. Uniuted States Departement of Agriculture (USDA). 2009. http://www. reeois.usda.gov.
20. Vaskonen, T. 2003. Dietary minerals and modification of cardiovascular risk factors. J. Nutr. Biochem. 14:492-506.
21. Wang, X. H., B. E. Cavell, S. S. Alwi, and G. Packham. 2009. Inhibition of hypoxia inducible factor by phenethyl isothiocyanate. Biochem. Pharmacol. Epub. April 16.
22. Wardlaw, G. M. 1999. Perspectives in nutrition. 4th ed. McGraw-Hill Co., Inc: Boston, MA, USA.
23. White P. J. and M. R. Broadley. 2009. Biofortification of crops with seven mineral elements often lacking in human diets-iron, zinc, copper, calcium, magnesium, selenium and iodine. New Phytol. 182 : 49-84.
24. Zang, Y. X., H. Kim, Y. D. Park, D. H. Kim, and S. B. Hong. 2008. Metabolic engineering of aliphatic glucosinolates in Chinese cabbage plants expressing *Arabidopsis* MAM1, CYP79F1, and CYP83A1. BMB Rep. 41 : 472-478.