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Effects of *Omija* (*Schizandra chinensis* Baillon) Extract on the Physico-Chemical Properties of *Nabakkimchi* during Fermentation

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Abstract In order to improve the quality and preservation of *nabakkimchi*, *omija* was added as an ingredient to determine its effect on the physicochemical characteristics of *kimchi* during fermentation, as well as the optimum level of *omija* extract. *Omija* extract was prepared from *omija* seeds by extraction with water for 9 hr at room temperature in concentrations (w/v) of 0.5, 1.0, 1.5, and 2.0% for use as an ingredient in *nabakkimchi*. The physicochemical characteristics of *nabakkimchi* containing *omija* extract were analyzed during fermentation of the product for up to 25 days. Delayed fermentation was observed, particularly in the early stage of fermentation, and was dependent on the concentration of the *omija* extract, as shown by stabilization of pH decreases and increases in the total acidity. An increased concentration of *omija* extract also raised the initial total vitamin C content and the reducing sugar content, which both then stabilized thereafter. Delayed development of turbidity within the optimum fermentation period of 16 days, increased redness and total color difference, and an electron-donor effect were also promoted by the *omija* extract. However, the *omija* extract also triggered extra tannin production, which leads to an astringent taste, especially at the 1.5 and 2.0% treatment levels.

Key words: *nabakkimchi*, *omija* extract, physicochemical characteristics

Introduction

Kimchi is a traditional fermented vegetable food that is popular in Korea. The natural fermentation pattern of *kimchi* is influenced by the type of *kimchi*, fermentation temperature, raw materials, kinds of condiments, and species of fermentative microorganisms (1). After optimum fermentation, *kimchi* becomes sour, soft in texture, and odorous until it eventually becomes inedible as fermentation progresses (2). Therefore, efforts have been made to extend the shelf life of *kimchi* (3).

In an attempt to maintain the image of *kimchi* as a 'natural food', the use of artificial preservatives is legally prohibited in Korea. As an alternative, diverse methods using natural raw ingredients have been proposed to improve the stability of *kimchi* without adversely affecting the original taste and color of the product (4-6).

Among the many types of *kimchi*, as classified by raw ingredients and preparation methods, *nabakkimchi* (cut Chinese cabbage *kimchi* with added water) and *dongchimi* (whole oriental radish *kimchi* with added water) are both considered to be *mulkimchi* (*kimchi* with added water). The abundance of water with fewer condiments, such as red pepper powder, plays an important role in fermentation by governing the microbiological characteristics, resulting in a less spicy taste with a shorter fermentation time (7). The faster fermentation of *nabakkimchi* in comparison with *dongchimi* is a useful characteristic of this product that can be used to improve the storage life and red color of *nabakkimchi* without inducing a spicy taste.

In oriental medicine, *omija* (*Schizandra chinensis* Baillon) is known as the fruit of the *Max-imowiczia chinensis* tree, which belongs to the Schizandraceae family and is geographically distributed in Eastern Asian countries including South Korea, China, and Taiwan. In South Korea, it is most abundant in the central northern area of the peninsula. The ripe fruit develops characteristic flavors and a sour taste as it matures from August to September with the accumulation of a small percentage of tannin materials. The medicinal effects of the fruits, including liver protection (8), alcohol neutralization effects (9), and an antiglycosuria function (10), are well-documented in traditional oriental medicine. The Schizandra fruit, with their five commingled flavors, are often used for tea or as basic elements for beverages (11).

With an increasing concern for natural antioxidative materials of plant origin, the antioxidant components isolated from Schizandra fruit (12) are of interest to the public. In addition, it is generally known that food materials contain a variety of bio-active natural anti-microbial agents, such as organic acids (including citric, succinic, and lactic acids), essential oils, and coloring pigments. In fact, oil derived from *omija* seeds are also known for bactericidal action, especially against the antibiotic-resistant bacterium *Staphylococcus aureus* (13).

Previous studies on the preservation of fresh *kimchi* have primarily focused on oil-soluble materials, which limit their practical application in ingredient formulations. Another problem with these materials is that they introduce foreign tastes and flavors into the *kimchi*. In contrast, the water-soluble components from *omija* also have antimicrobial properties (13) and are readily available. They can be used to extend the storage life and to improve the appearance and taste of *kimchi*, especially that of *nabakkimchi*. The improvement in the red color of *kimchi* from the anthocyanin pigments (11) in *omija* is an added

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benefit.

The purpose of this study is to evaluate the changes in *nabakkimchi* fermentation following the addition of graduated concentrations of *omija* extract in order to improve the quality of the *kimchi* at an optimum level of *omija* extract. The evaluation is based on the analysis of selected physicochemical characteristics.

Materials and Methods

Materials The *omija* fruit, harvested in the Hongchon district of Gangwon Province, was purchased from a local market in November, 1997 and stored at -70°C until use. A radish (*Raphanus sativus* L.) and a head of the Chinese cabbage (*Brassica campestris* L. spp. *pekinensis*), weighing approximately 2 and 3 kg each, were purchased at the grocery market of the Seoul Agricultural & Marine Products Corporation. Red pepper powder, green onion, garlic, ginger, and fresh red pepper were purchased at the same store on the day of *kimchi* preparation. Partially refined salt (greater than 88% purity) was used in the salting process.

Preparing *nabakkimchi* and conditions for fermentation The preparation of *nabakkimchi* juice was based upon traditional recipes for *omija* honey juice mixed with fruits for punch and *omija* tea (14, 15). In the initial preparation, 5.55 L of *omija* extract was obtained from *omija* seeds soaked in distilled water for 9 hr at room temperature (22.0±0.5°C), followed by filtration through double-layered cheese cloth. This *omija* extract was soaked with water to four concentrations: 0.5, 1.0, 1.5, and 2.0%(w/v). Pure distilled water was used as a control treatment. Twenty-two grams of red pepper powder was completely immersed in 250 mL of *omija* juice at preset concentrations (0.5, 1.0, 1.5, and 2.0%) for an hour before filtering the final *nabakkimchi* juice through double-layered cheese cloth. Washed radish was cut into cubes (3.0×2.5×0.4 cm) and pre-trimmed cabbage was cut into 3×3 cm pieces. Green onion, ginger, and red pepper were shredded into appropriate sizes to be blended and added to *nabakkimchi* juice at a proper ratio according to the recipe (Table 1). Radish and cabbage were initially brined with salt (92.1 g) for 30 min and then blended with a mixture of other ingredients. Salt (52.6 g) was then dissolved in 5.3 L of each concentration of *omija* extract and 200 mL of *nabakkimchi* juice in an 8 L jar. The final weight percentage of salt in the *nabakkimchi* was adjusted to approximately 2.5% (16). The *nabakkimchi* was prepared at room temperature (22.0±0.5°C) and preserved at 10°C for 25 days.

Physicochemical analysis

pH and titratable acidity The pH of the *nabakkimchi* juice was measured. The juice was then titrated with 0.1 N NaOH to a pH value of 8.3 to determine the titratable acidity. The titratable acidity value was converted to lactic acid content (%, w/v) (17).

Total vitamin C The total vitamin C content was measured by HPLC (18) under the conditions listed in Table 2.

Reducing sugars The reducing sugar content was measured by Miller's dinitrosalicylic acid (DNS) method (19) using glucose as a standard.

Tannin The tannin content was quantified according to the method of Motoe and Yamashita (20) using gallic acid as a standard.

Turbidity Turbidity was measured with a spectrophotometer (UV-1601PC; Shimadzu, Tokyo, Japan) at 558 nm (21).

Color Hunter colorimetric values (L, a, b, and ΔE) were obtained using a tri-stimulus colorimeter (JC-801S; Color Techno System Co., Tokyo, Japan).

Electron-donating effect The electron-donating effect was analyzed according to the method of Kang *et al.* (22) by measuring differences in the optical density of *kimchi* juice after treatment with a solution of α-α-diphenyl-β-picryl-hydrazyl (DPPH) dissolved in absolute ethanol.

Statistical analysis The results of the physicochemical characteristic measurements were analyzed using ANOVA and Duncan's multiple test to determine significant differences among samples ($p<0.05$).

Results and Discussion

pH Changes in pH during *nabakkimchi* fermentation with added *omija* extract at various concentrations (0.5, 1.0, 1.5, and 2.0%) and preserved at 10°C for 25 days are shown in Fig. 1. As the concentration of added *omija*

Table 1. Recipe for preparation of *nabakkimchi*

Ingredients	Amount used in a 8 L glass jar	Amount relative to *omija* juice
Omija juice[1)]	5,300 mL	100.00
Raw radish	1,190 g	22.45
Chinese cabbage	700 g	13.21
Large green onion	70 g	1.32
Garlic	45.5 g	0.86
Ginger	24.5 g	0.46
Red pepper powder juice[2)]	200 mL	3.77
Fresh red pepper	14 g	0.26
Salt	144.7 g	2.73

[1)] *Omija* seeds soaked in distilled water for 9 hr at room temp of each to 0.5, 1.0, 1.5, and 2.0%(w/v).
[2)] 22 g of red pepper powder soaked in 250 mL of each of the *omija* juice concentrations for 1 hr at room temp.

Table 2. HPLC operating conditions for analysis of total vitamin C

Instrument	Shiseido SI-1 (HPLC, Tokyo, Japan)
Column	Capcell pak C_{18} UG 80 (4.6×250 mm)
Oven temp.	40°C
Flow rate	1.0 mL/min
Mobile phase	100% H_2O with 5 mM pic B_7
Detector	UV 270 nm
Injection volume	20 μm

increased, the pH value dropped in proportion to the concentration. A control sample (no added *omija* extract) had an initial pH value of 5.87, within the range of most popular *kimchi* varieties. As fermentation progressed, the pH value of the control sample decreased rapidly from pH 5.87 to 3.95 during the first two days. With the 0.5% *omija* extract treatment, the pH value decreased from 4.46 to 4.07 after two days, then decreased further to a minimum of pH 3.78 before slowly increasing thereafter.

However, in contrast to the control and 0.5% *omija* treatment, higher concentrations of *omija* (1.5 and 2.0%) caused an upward shift in pH values on the second day of fermentation. The inherent organic acid in *omija* extract itself as measured pH of 2.82 to 2.98. The initial low pH values as affected by the high acidity of *omija* extract might have been compensated with less acidic exudates soaked out from various subingredients in *nabakkimchi* while progress of the earliest fermentation. After the first two days of fermentation, pH values generally decreased gradually with time, following the typical pattern of *kimchi* fermentation. The presence of *omija* extract in the *kimchi* juice slowed the pH decline, increasing the time required to reach a pH value of consistently less than 4.00 from 2 days for the control (0%) to 4 days for the 0.5% treatment, 7 days for the 1.0% treatment, 7 to 10 days for the 1.5% treatment, and 10 to 13 days for the 2.0% treatment. This retardation of the acidification of the *kimchi* was especially effective during the early period of the fermentation, depending on the concentration of *omija* extract.

Decreases in pH values after 10 to 13 days were identical regardless of *omija* extract treatment. The presence of a weak acid with lower dissociation properties in the *kimchi* might have interrupted further fermentation, as indicated by Kim *et al.* (23) who reported a lower limit of pH 3.0 in their *kimchi* fermentation analysis.

Titratable acidity Changes in the titratable acidity of *nabakkimchi* with various concentrations of *omija* extract are shown in Fig. 2. Upon preparation, *nabakkimchi* titratable acidity values apparently differed due to the various concentrations of *omija* extract. The titratable acidity value increased according to the concentration of *omija* extract, starting from 0.02% for the control sample.

The organic acid inherent to *omija* extract itself had a measured titratable acidity of 0.17%, which corresponds to a pH value of 2.89. Consequently, a 1% *omija* extract resulted in high titratable acidity values in the *nabakkimchi*.

On day 2 of fermentation in the control sample, titratable acidity increased sharply to 0.16% from an almost negligible level on day 0 due to accelerated fermentation during the first 2 days. During the same period, the titratable acidity also doubled in the *kimchi* prepared with 0.5% *omija* extract. However, in contrast, titratable acidity values for the 1.0, 1.5, and 2.0% treatments decreased, possibly due to newly developed equilibria of components extracted from various ingredients while fermentation was suppressed by higher concentrations of *omija* extract.

After day 2, titratable acidity increased gradually until day 4 when each treatment condition resulted in different rates of increase: on day 7, the total acidity values were similar regardless of treatment. In addition, the higher the concentration of the *omija* extract, the lower the titratable acidity of *nabakkimchi* on day 7, again a manifestation of the effectiveness of the *omija* extract during the early to middle fermentation period.

On day 10, after the optimum pH value was attained on day 7, the titratable acidity values increased in the general order of 0 (control) > 0.5 > 1.0 > 1.5 > 2.0% treatment with some exceptions. Titratable acidity values for the 0.5 and 1.0 % treatments were increasing at a slow rate with slight differences between them, while titratable acidity in the 1.5 and 2.0% treatments increased rapidly after day 10. The large increases in titratable acidity values after day 10 were coupled with gentle decreases in pH values after day 10 for these two preparations. During the middle and latter parts of fermentation, weak organic acids with low dissociation properties accumulate in *kimchi*; these weak acids have a limited effect in lowering pH values, although

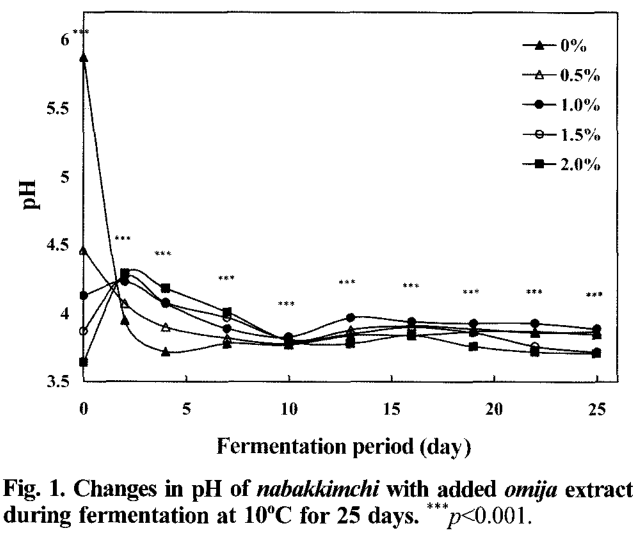

Fig. 1. Changes in pH of *nabakkimchi* with added *omija* extract during fermentation at 10°C for 25 days. $^{***}p<0.001$.

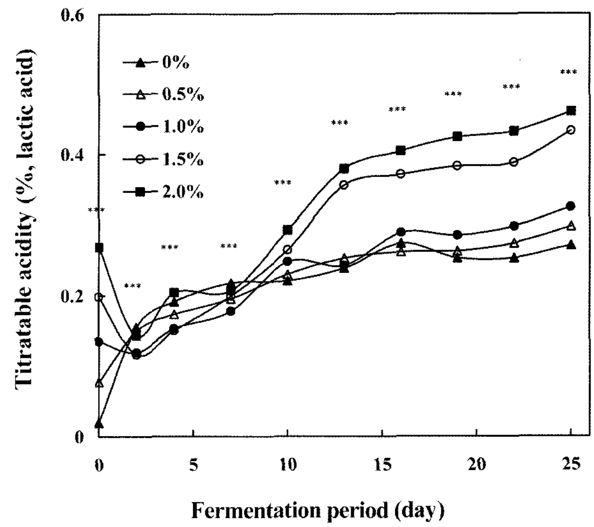

Fig. 2. Changes in titratable acidity of *nabakkimchi* with added *omija* extract during fermentation at 10°C for 25 days. $^{***}p<0.001$.

the large accumulation leads to increasingly high titratable acidity values. Accordingly, the degree of sour taste in *kimchi* depends on the level of titratable acidity rather than on the pH value (24).

Kim and Rhee (25) related taste to the contribution of organic acids to the titratable acidity of *kimchi*. According to Ku *et al.* (26), pH and titratable acidity values, both important quality indicators of *kimchi*, were governed by organic acids that accumulated from the various activities of enzymes and microorganisms that originate from the breakdown of radish and Chinese cabbage and reassembling of components. The fresh taste, as well as the fluctuations of pH and titratable acidity values, of *kimchi* during fermentation can be attributed to the organic acids thus produced.

In the *mulkimchi* (*dongchimi*) model, the reported value of 0.3 to 0.4 % (27) titratable acidity for optimum fermentation differed greatly from our results, which ranged from 0.1 to 0.3 % titratable acidity during the fermentation period.

Total vitamin C Changes in total vitamin C content during *nabakkimchi* fermentation are shown in Fig. 3. The rank order of the amount of total vitamin C immediately after preparation was, in increasing order, 0 (control) < 0.5 < 1.0 < 1.5 < 2.0%. The control sample showed a peak amount of 0.37 mg% on day 7, which was maintained thereafter.

The accumulation of total vitamin C during *kimchi* fermentation due to biosynthesis of natural enzymes was documented by Lee and Lee (28). The *omija* extract also affected the total vitamin C content in a concentration-dependent manner, with values increasing initially then gradually decreasing with time. The highest residual amount of total vitamin C, 3.45 mg%, was recorded on day 25 of fermentation with the 2.0% treatment. The initial higher amounts of total vitamin C found with higher concentrations of *omija* extract were maintained throughout fermentation. The results of other studies partially agree with our results. The patterns identified in previous studies can be described as a small initial increase and decrease, followed by a second sharp increase and a gradual decrease in total vitamin C content (29, 30), or an initial decrease followed by a marked but temporary increase of total vitamin C content on the optimum fermentation day (28). However, another study with results showing an initial increase followed by a decrease in total vitamin C after excessive fermentation (31) was most similar to our result.

The highest initial amount of total vitamin C obtained in the 2.0% treatment was most likely better maintained during the entire fermentation period due to the highly acidic conditions resulting from a high *omija* extract concentration.

The abundance of glucose, which is reportedly involved in the biosynthesis of L-ascorbic acid (28), also contributes to the high total vitamin C content found with high concentrations of *omija* extract.

We attribute the initial loss of total vitamin C content prior to day 2 to the activity of ascorbic acid oxidase, as Park *et al.* (32) have reported previously.

Reducing sugars The reducing sugar content decreased with time for all treatments, differing in rate and extent for each treatment condition (Fig. 4). The most rapid loss occurred in the control sample, which fell from an initial value of 6.27 to 2.20 mg/mL by day 2. This reduction continued before stabilizing at 0.29 mg/mL on day 7.

The reducing sugar content in *kimchi* prepared with *omija* extracts differed according to concentration with 0.34, 0.65, 1.01, and 1.31 mg/mL for the 0.5, 1.0, 1.5, and 2.0% treatments, respectively. These values were direct indicators of the reducing sugar content in the *nabakkimchi*.

The stationary period, during which no notable loss of reducing sugars occurred, was different for each extract concentration. Reducing sugar content was stable after day 22 for the 0.5% treatment, while the 1.0, 1.5, and 2.0% treatments were stabilized by day 25.

Because the reducing sugar content in *nabakkimchi* is

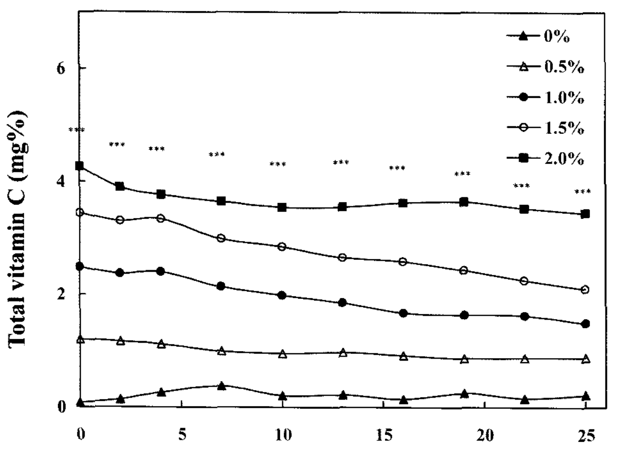

Fig. 3. Changes in total vitamin C content of *nabakkimchi* with added *omija* extract during fermentation at 10°C for 25 days. $^{***}p<0.001$.

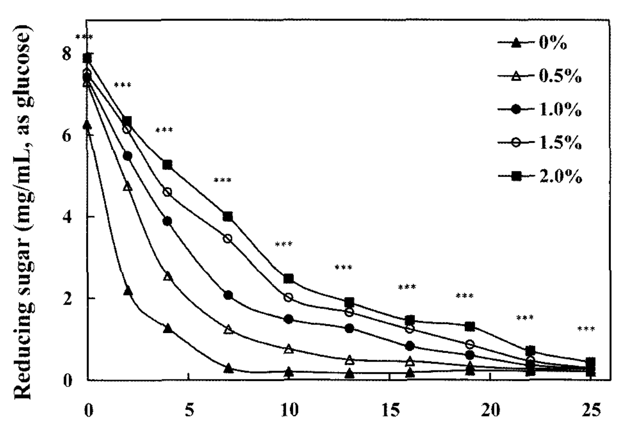

Fig. 4. Changes in reducing sugar content of *nabakkimchi* with added *omija* extract during fermentation at 10°C for 25 days. $^{***}p<0.001$.

closely associated with sensory taste and related to the fermentation rate (which is controlled by the available nutrient source and biosynthesis of L-ascorbic acid), supplementing the *kimchi* with reducing sugars inherent to the *omija* extract might contribute to the speed of the initial *kimchi* fermentation and the nutritional quality of the product.

The decrease in the reducing sugar content was weakly inversely related to the amounts of titratable acidity and total vitamin C. The increased values of titratable acidity from 0.19 to 0.22% and of total vitamin C content from 0.26 to 0.37mg% coincided with a loss of reducing sugar from 1.20 to 0.27 mg/mL from days 4 to 7 for the 0% treatment (control). Similar phenomena were also reported by Jang and Moon (30) and Kim *et al.* (29) for licorice root and onion.

Tannin The changes in tannin content during *nabakkimchi* fermentation are shown in Fig. 5. Similar to the initial reducing sugar content, the amount of tannin also increased as the concentration of *omija* extract increased. The amount of tannin in the *omija* extract was 7.38, 12.95, 21.44, and 27.96 μg/mL for the 0.5, 1.0, 1.5, and 2.0% *omija* extract treatments, respectively.

However, the amount of tannin steadily increased with time following a sharp increase during the first two days, similar to that reported by Moon and Jang (33). The control (0% treatment) and 0.5% treatment samples maintained this higher level until day 16 when a slight increase occurred for the 0.5% treatment. Both the 1.5 and 2.0% treatments also had similar periods of induction before a continuous increase began on day 16.

An increase started at day 13 for the 1.0% treatment. Large amounts of tannin in *nabakkimchi* were related to low acceptability scores in our previous report (33).

Turbidity No noticeable difference in turbidity was found immediately after preparation of *nabakkimchi.* Values ranged from 0.52-0.56 (Fig. 6). No apparent trend in turbidity was observed until day 19 when turbidity stabilized somewhat and could be ranked in increasing order according to the concentration of the *omija* extract.

Up to day 13, the 1.0% treatment showed the lowest turbidity value, probably related to the combined actions of suppressed fermentation and the inherent low original turbidity value. However, after day 16, higher turbidity developed due to accelerated fermentation, especially for the 1.5 and 2.0% treatments.

Kang *et al.* (21) reported that turbidity values during the fermentation of *dongchimi* were stabilized during the initial and middle periods of fermentation, then increased rapidly in the final fermentation period, then stabilized again. Fermentation of *dongchimi* covered with bamboo leaves (34) showed fluctuating turbidity values accompanied by a sequential increase and decrease, followed by a gradual increase to higher values, then a final stagnation; this result was similar to our results.

The 0% treatment (control) showed the highest turbidity up to day 13, while the lowest fluctuation of turbidity values was produced by the 0.5 and 1.0 % treatment. Especially, the 1.0% treatment showed the lowest overall turbidity.

Color Color changes during *nabakkimchi* fermentation are shown in Table 3. With preservation, the lightness of the *kimchi* gradually decreased, and then increased before decreasing again in all samples, regardless of the treatment. The sudden increase in the lightness value was noteworthy, especially in the 2.0% treatment.

The inherent lightness of *omija* extract itself was measured as 94.7(0.5%), 93.1(1.0%), 90.8(1.5%), and 88.9 (2.0%), indicating that lightness decreased as the concentration of *omija* extract increased. The highest lightness values were observed on day 19 for the 1.5 and 2.0% treatments and on day 22 for both the 0.5 and 1.0% treatments, although some of these values were lower than the initial values. The lowest values, 36.8-48.3, appeared on day 16 for all samples except for 1.5% treatment; this was probably related to maximum extraction of soluble materials from the juice as a result of microbial

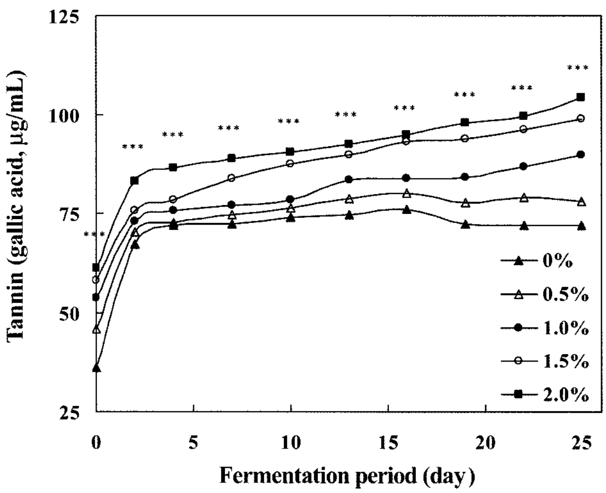

Fig. 5. Changes in tannin content of *nabakkimchi* with added *omija* extract during fermentation at 10°C for 25 days. $^{***}p<0.001$.

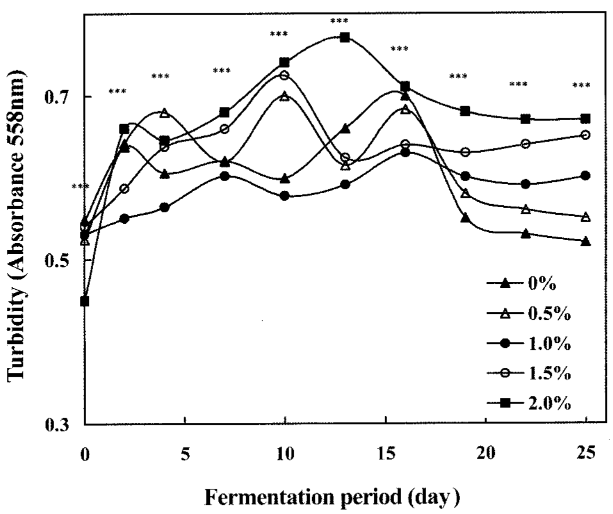

Fig. 6. Changes in turbidity of *nabakkimchi* with added *omija* extract during fermentation at 10°C for 25 days. $^{***}p<0.001$.

Table 3. Changes in color characteristics of *nabakkimchi* with added *omija* extract during fermentation at 10°C for 25 days

Color value[2)]	Days	*Omija* extract content (%)				
		0	0.5	1.0	1.5	2.0
	0	76.5^{a}[1)]	67.2^{p}	62.2^{d}	65.1^{c}	65.7^{bc}
	2	55.1^{d}	58.0^{c}	62.6^{a}	51.0^{e}	58.9^{b}
	4	25.7^{e}	51.3^{c}	53.8^{b}	49.8^{d}	57.9^{a}
	7	57.7^{a}	53.0^{d}	51.7^{e}	54.3^{c}	56.4^{b}
'L' (Lightness)	10	58.4^{a}	54.0^{b}	58.6^{a}	48.2^{d}	50.2^{c}
	13	48.0^{d}	58.3^{b}	65.1^{a}	54.3^{c}	40.9^{e}
	16	45.1^{b}	44.3^{c}	42.4^{d}	48.3^{a}	36.8^{e}
	19	60.9^{a}	57.0^{b}	63.4^{ab}	61.0^{ab}	62.0^{a}
	22	66.1^{b}	62.4^{c}	67.8^{a}	56.9^{e}	58.9^{d}
	25	62.9^{a}	60.3^{b}	58.6^{c}	56.8^{d}	55.5^{e}
	0	4.2^{e}	6.9^{d}	7.5^{c}	8.0^{b}	9.9^{a}
	2	5.4^{e}	5.8^{d}	6.1^{c}	6.9^{a}	6.7^{b}
	4	5.5^{d}	6.7^{d}	6.6^{b}	5.7^{c}	5.7^{c}
	7	5.9^{e}	6.2^{d}	6.6^{c}	7.0^{b}	7.2^{a}
'a' (Redness)	10	5.1^{e}	5.8^{c}	6.0^{b}	5.6^{d}	6.9^{a}
	13	5.3^{e}	5.4^{d}	5.9^{c}	6.4^{b}	7.2^{a}
	16	5.5^{e}	6.4^{c}	6.8^{d}	6.5^{b}	7.3^{a}
	19	5.3^{e}	6.3^{c}	5.7^{d}	6.6^{a}	6.8^{b}
	22	4.9^{e}	6.0^{d}	5.3^{c}	7.0^{b}	6.6^{a}
	25	4.7^{e}	5.5^{c}	5.6^{d}	6.4^{a}	7.0^{b}
	0	15.5^{bc}	15.6^{b}	15.5^{bc}	15.3^{c}	17.1^{a}
	2	15.3^{c}	15.8^{a}	15.8^{a}	15.4^{b}	15.4^{b}
	4	10.6^{c}	15.6^{b}	16.0^{a}	15.7^{b}	15.6^{b}
	7	15.7^{d}	16.0^{c}	16.0^{c}	16.9^{b}	17.1^{a}
'b' (Yellowness)	10	16.2^{b}	15.8^{c}	15.7^{c}	14.6^{d}	16.7^{a}
	13	14.9^{d}	15.4^{c}	15.7^{b}	16.6^{a}	15.3^{c}
	16	14.8^{b}	14.3^{d}	14.7^{c}	15.3^{a}	14.4^{d}
	19	16.4^{b}	16.3^{c}	15.4^{e}	17.0^{a}	16.2^{d}
	22	16.7^{b}	16.5^{c}	15.8^{e}	16.8^{a}	16.5^{d}
	25	15.8^{c}	15.8^{d}	15.0^{e}	16.3^{b}	16.7^{a}
	0	20.2^{d}	29.6^{c}	34.5^{a}	31.7^{b}	31.8^{b}
	2	41.4^{b}	38.5^{c}	34.0^{e}	45.5^{a}	37.7^{d}
	4	70.5^{a}	45.5^{c}	42.8^{d}	46.7^{b}	38.6^{e}
	7	38.9^{e}	43.6^{b}	44.9^{a}	42.4^{c}	40.4^{d}
'ΔE' (Total color difference)	10	38.2^{d}	42.6^{c}	38.0^{d}	48.9^{a}	46.5^{b}
	13	48.4^{b}	38.3^{d}	31.6^{e}	42.4^{c}	55.6^{a}
	16	51.2^{d}	52.1^{c}	54.1^{b}	48.2^{e}	59.6^{a}
	19	35.7^{c}	39.6^{a}	33.1^{e}	35.9^{b}	34.8^{d}
	22	30.7^{d}	34.4^{c}	28.8^{e}	39.9^{a}	37.8^{b}
	25	33.7^{e}	36.2^{d}	37.8^{c}	39.8^{b}	41.2^{a}

[1)]Means with different letters within a row are significantly different from each other at α=0.05 as determined by Duncan's multiple range test.
[2)]L : Lightness, a : Redness, b : Yellowness, $\Delta E = \sqrt{L^2 + a^2 + b^2}$.

fermentations. Generally, the 1.0% treatment maintained the highest lightness values, corresponding to the clearest juice. Its highest value was 67.8 on day 22.

The suppression of vitamin C and reducing sugar content due to retarded fermentation by the *omija* extract as described above was similar to changes in the 'L' value of the color characteristics. Contrary to Kang *et al.* (21), who reported an initial decrease followed by an increase in the lightness value during *dongchimi* fermentation, no continuous increase of lightness was observed. We did confirm a decrease during the early period of fermentation. The continued decrease in lightness values was thought to be caused by accelerated extraction of turbid components from the *kimchi* juice caused by softening of tissue cells through microbial fermentation.

The redness, 'a', value probably originated from the *omija* and red pepper extracts, with values of 5.55 to 14.99 depending upon the concentration of the *omija* extracts. The red tint of the *omija* extract more than doubled the redness of the *nabakkimchi*, raising the value from 4.2 (control) to 9.9 (2.0% treatment). With fermentation, the redness decreased gradually. An increase, followed by a decrease that terminated in a value slightly higher than that of day 0 value was observed in the control sample. This same phenomenon was also documented for *yulmoo-mulkimchi* fermentation (35). However, our samples that contained *omija* extracts generally followed the decreasing pattern of redness in *dongchimi* that was reported by Kang *et al.* (21). A report by No *et al.* (36) on color measurements for the quality evaluation of *baechukimchi* (a different *kimchi* variety) also described a pattern similar to ourst, with redness reaching a maximum at the optimum fermentation time and then decreasing.

The yellowness values of *nabakkimchi* were much the same, with values ranging from 15.3 to 17.1 and the highest value for the 2.0% treatment. The natural yellowness of the *omija* extract, which varied from 11.61 (control) to 14.04 (2.0% treatment), was also a determining factor for differences in yellowness of the product. Changes in yellowness were limited, with overall decreases until day 16 and equilibration thereafter. On day 16, it was noteworthy that all physicochemical criteria of *nabakkimchi* simultaneously peaked as a result of reaching the optimum fermentation conditions. As the highest acidity occurring during this same period, this may have contributed to the appearance of the anthocyanin redness, which is more stable under acidic conditions.

The total color difference (ΔE), as calculated from each colorimetric parameter 'a', 'b', and 'L', initially ranged from 20.2 to 34.5 before increasing to maximum values ranging from 48.2 to 59.6 on day 16, except for the 1.5% treatment, which peaked on day 10; all values then dropped from their respective maximums to range from 36.1 to 48.7 on day 25.

Electron-donor Effect In contrast to the total absence of electron-donating capacity in the control sample on day 0, the samples treated with *omija* extract exhibited an increase in this capacity in proportion to the concentration of the *omija* extract with values of 0.49, 1.45, 2.36, and 3.65% for the 0.5, 1.0, 1.5, and 2.0% treatments, respectively (Fig. 7). The electron-donor effect of the

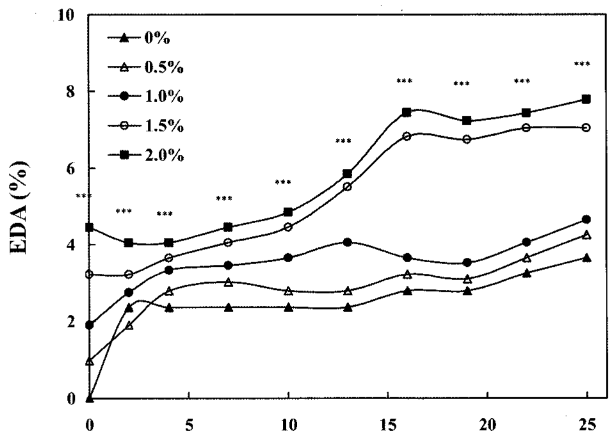

Fig. 7. Changes in electron-donating ability (EDA) of *nabakkimchi* with added *omija* extract during fermentation at 10°C for 25 days. ***p<0.001.

product was probably related to the *omija* extract.

The antioxidative effect, which is related to the electron-donating capacity, increased as fermentation progressed according to the concentration of the soluble extract and the *omija* extract in *nabakkimchi* juice.

In the early stages of fermentation, the control sample exhibited electron-donor effects, reaching its highest effects as organic acids were formed by rapid microbial fermentation as early as day 4. This value was maintained through day 25 of the preservation. The 1.0% treatment exhibited a sudden increase in electron-donating capacity on day 4 and then stabilized until a second sudden rise on day 13 followed by a decrease. In comparison, the 1.5 and 2.0% treatments exhibited a sudden increase on day 16, and then fluctuated until day 25. In general, the electron-donating effect in *nabakkimchi* increased as fermentation progessed until it eventually returned to the upper limits of the original value in the latter stages of the preservation.

The results obtained show that *omija* extract is remarkable in improving eating quality and extend the storage life of *nabakkimchi*. Acceptable *nabakkimchi* could be prepared with 1.0% *omija* extract at the given conditions. Therefore, the application of *omija* extract could be applied industrially, as well as domestically for preservation and taste prepared *nabakkimchi*.

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