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Physicochemical Properties of *Dongchimi* Added with *Gatt (Brassica juncea)*

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Abstract To improve *Dongchimi* (watery radish *kimchi*) quality and preservation, 0, 3, 5, 10, and 15% of *gatt* (*Brassica juncea*; leaf mustard) per radish was added. Chemical characteristics were determined during fermentation at 10°C for 45 days. Total acidity increased slowly by addition of *gatt* during initial fermentation period, and 15% treatment showed lowest total acidity. Total vitamin C content increased initially in all treatments depending on *gatt* content, and decreased thereafter. Period for reaching maximum value was delayed by addition of *gatt*. Highest total vitamin C was found in 15% treatments. In the case of reducing sugar, 5% treatment showed highest contents. Lactic, succinic, and tartaric acid contents consistently increased during fermentation, while those of malic and citric decreased. Turbidity and total solid contents of *Dongchimi* liquid increased in all treatments as fermentation proceeded, although the extent was rather suppressed by addition of *gatt*. Colorimetric lightness values decreased, while the initial increased and then decreased in redness and yellowness. Addition of *gatt* at above 15% weight level per radish accelerated fermentation at the later fermentation stage thus it should be avoided. Most changes in typical characteristics of fermentation were similar depending on treatments. More acceptable *Dongchimi* could be prepared by fermenting at 5% *gatt* concentration under given conditions.

Key words: *Dongchimi*, *gatt* (*Brassica juncea*; leaf mustard), physicochemical characteristics

Introduction

Gatt (*Brassica juncea*) belonging to the cruciferae family is a leaf mustard used as a raw material for *kimchi* (1, 2). It contains a glucosinolate of allyl isothiocyanate called sinigrin, which gives its characteristic spicy flavor, and the active myrosinase leads to the creation of sulfurous substance and other related materials. Of these materials, the lactic acid bacteria and other microorganisms in the *gatt kimchi* have antibacterial effects, which delay the fermentation of *kimchi* and prevents early stage acidification, thus improving preservation and storage (3, 4). In particular, *gatt* contains large quantities of chlorophyll, β-carotene, and ascorbic acid, which have deoxidation characteristics (2, 5) The solid structure of *gatt* prevents softening during long-term storage, and its abundant calcium and potassium makes it an important inorganic supplier. In addition, it has superior color stability during long-term storage as compared to other vegetations (6). As reported in numerous documented studies on the standardization of *kimchi*, over 90% of the *gatt kimchi* constituents consisted of gatt, whereas, in white *kimchi*, *gatt* made up over 50% of the *kimchi* constituents (7). In cubed radish *kimchi* and watery radish *kimchi (Dongchimi)* made for winter, *gatt* comprised over 30% of the constituents, showing that it is used extensively in the preparation of *kimchi*, both as main and supplemental ingredients. The type of *gatt* added in watery radish *kimchi* differs from region to region; in North Korea, red *gatt* is added to the watery radish *kimchi*. Ancient writings and current cookbooks also include gatt in the watery radish *kimchi* *(Dongchimi)*. *Gatt kimchi* has been extensively studied, including its activities of sugars, organic acids, isolated amino acids, nucleic acids, myrosinase, and spicy flavor, alteration in the principal taste and other substances, microorganisms (8, 9), deoxidation characteristics of main color substances, chlorophylls and carotenoids (5), and effects of fermentation temperature on the physiochemical characteristics of *gatt kimchi* (10).

In this study, to determine the optimal amount of red *gatt* necessary for the preparation of watery radish *kimchi*, effects of fermentation and content of *gatt* to the physiochemical characteristics of the watery radish *kimchi* were determined.

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Materials and Methods

Materials The radishes used for watery radish *kimchi* (*Dongchimi* added with gatt), *Raphanus sativus* L., and other ingredients including the Korean native red *gatt*, green onions, garlic, and ginger were purchased from the Garak Wholesale Agriculture and Fisheries Market, Seoul, Korea. After cleaning the red *gatts* of all debris, they were stored at -70°C before use. Main components of the radish include water 95.31%, crude protein 1.5%, crude fat 0.1%, and crude ash 0.5%, and those of the *gatt* include water 92.8%, crude ash 1.9%, crude fat 0.3%, and crude protein 2.5%.

Handling the materials The radishes were washed and dried. After cutting 5 cm off of each end, they were cut into 4 × 1.5 × 1 cm pieces. Ginger and garlic, after being cleaned and thinly diced, were put into a 2-ply gauze bag (15 × 15cm). *Gatts* were washed and cleaned. After selecting only those of similar lengths, they were tied together into bundles of 2-3 and placed in an 8-L clear, glass bottle (18 x 31 cm). Green onions were also tied together into bundles of 2-3 and placed in the bottle.

Preparing the watery radish *kimchi* and conditions for fermentation Table 1 shows list of ingredients used per bottle. The liquid was prepared by mixing salt (93% refined coarse salt, Saempyo, City, Korea) with distilled water at total sodium concentration of 2.5% (w/v). The proportion of the radish to the liquid was 1:1.5 (w/v) (11). *Gatt* at 0, 3, 5, 10, and 15% of radish ratio was placed in each bottle and stored immediately at 10°C for 45 days to measure the physiochemical characteristics.

Physicochemical properties The liquid was used for measurement of pH, total acidity, reducing sugars, turbidity, color, and solid contents in *Dongchimi* added with *gatt*. Total vitamin C and non-volatile organic acid contents were measured using samples blended (Model HMC-150T, Han-il Mixer, Seoul, Korea) and filtered through multi-layered gauze.

pH The pH was measured at room temperature using a pH meter (Model 420A, Orion, Beverly, MA, USA).

Total acidity Liquid (10 mL) was neutralized to pH 7.0 using 0.1 N NaOH solution, and the amount of 0.1 N NaOH used (in mL) was converted into total lactic acid content to determine the acidity (%, w/v).

Total vitamin C Total vitamin C content of the watery radish *kimchi* was determined through the 2,4-dinitro phenyl hydrazine method (12) using the filtrate of 10 g radish and 15 g liquid.

Reducing sugars Liquid was diluted to bring the sugar content within the standard curve, and the amount of reducing sugars was measured using the dinitro salicylic acid (DNS) method (13).

Non-volatile organic acids Table 2 shows results of GC analysis of the non-volatile organic acids of the 20 g radish and 30 g liquid filtrate.

Turbidity Turbidity was measured using a spectrophotometer (Model 340, Sequoia-Turner, Mountian Veiw, CA, USA) at 558 nm.

Color Lightness (L), redness (a), and yellowness (b) of the liquid were measured using a colorimeter (Tri-Stimulus colorimeter, JC-801S, Color Techno System Co., Tokyo, Japan). Each measurement was taken a minimum of five times to yield the average.

Solid contents Filtering the liquid through a 3-ply gauze, 20 mL of the liquid was collected in an aluminum container for a preliminary drying step at 80°C, followed by a 2-hr drying step at 130°C before measurement. Measured solid content was multiplied by the total liquid volume to determine the total solid contents (%).

Statistical analysis The results of the physiochemical characteristic measurements were analyzed using the ANOVA and Duncan's multiple test to determine a 5% significant difference among samples.

Table 1. *Dongchimi* recipe prepared with various levels of *gatt*

Ingredients	Weight (g)	Parts[1)]
Raw Chinese radish	2800	100
Small green onion	28	1
Garic	14	0.5
Ginger	8.4	0.3
Water	4200	150
Gatt[2)]	0	0
	84	3
	140	5
	280	10
	420	15

[1)]Based on raw Chinese radish.
[2)]One of five expressions is chosen for each treatments.

Table 2. Operating conditions of GC for analyzing non-volatile organic acids

Instrument	Varian STAR 3400CX capillary gas chormatograph
Column	Stabilwax-DB (0.25 mm×30 m)
Oven temp.	70°C (hold, 1 min)-5°C rise/min -210°C (hold, 11 min)
Carrier gas	H_2, 12 psi
Injection volumn	0.5 μL
Make-up gas	N_2, 30 mL/min
Detector	Flame ionization detector (FID)
Injector temp.	220°C
Detector temp.	220°C

Results and Discussion

pH Acidities of *Dongchimi* added with various amounts of *gatt* during fermentation were similar regardless of the amount of *gatt* added from Days 2 to 45 of fermentation (Fig. 1).

Between Days 2 to 13, pH increased in the order of 0% >3%>5%>10%>15% treatments, showing that the addition of *gatt* inhibited fermentation during the early to optimal fermentation stages. The control between Days 19 and 45 showed the highest pH. The greater the amount of *gatt*

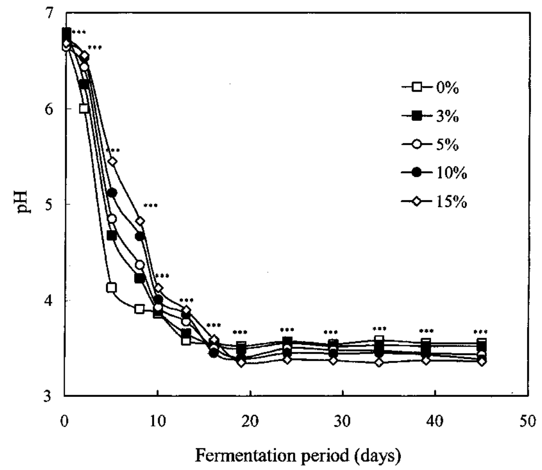

Fig. 1. Changes in pH of *Dongchimi* prepared with various levels of *gatt* during fermentation at 10°C for 45 days. ***p<0.001

added, the lower the pH, which indicates that, after the optimal fermentation period, *gatt* acted to speed up fermentation.

At the optimal fermentation time, pH of the watery radish *kimchi* was 3.9±0.1 (11), and this value was observed on Days 8, 10, and 13 for the control, 3 and 5% treatments, and 10 and 15% treatments, respectively. Furthermore, throughout the total period of *kimchi* fermentation, pH did not drop to below 3.0 as reported elsewhere. (14)

Total acidity Changes in total acidity of liquid are shown in Fig. 2. Immediately after preparation, total acidity did not change much, then began to increase throughout the fermentation process. The acidity of the control was highest at Day 13, and the higher the amount of *gatt* added, the lower the acidity.

These results suggest that *gatt* plays a significant role in fermentation during the early to mid stages. Acidity drastically increased for the control until Day 13, for the 3, 5, and 10% treatments upto Day 16, and for the 15% treatment upto Day 19, and showed stable increases thereafter. From Day 19, acidity decreased as follows: control <3%<5%<10%<15% treatments. Fermentation was initially inhibited by the addition of *gatt* during the early to optimal stages, then increased towards the later stages.

In watery radish *kimchi* added with *Schizandra chinensis (omija)* (15), acidity of the liquid during the early stages of fermentation showed small increases. After optimal fermentation, the acidity increased in the order of control, 0.5%, 1.0%, 1.5%, and 2.0% treatments. The large increases in 1.5 and 2.0% treatments, as compared to the control were similar to our result.

Total vitamin C The changes in total vitamin C contents of radish and liquids are shown in Fig. 3. Total vitamin C content of *gatt* was 25.03 mg%. Immediately after preparation, the order of the vitamin C content was 0%<3%<5%<10%<15% treatments.

With a slight reduction on Day 2, the vitamin C content began to increase on Day 5. Maximum values were observed on Days 8, 10, 13, and 16 for the control, 3 and 5% treatments, 10% treatment, and 15% treatment, respectively, which then began to decrease thereafter. During fermentation, the addition of *gatt* led to increasing vitamin C content, and the order observed during the early stages of fermentation was maintained throughout the fermentation period.

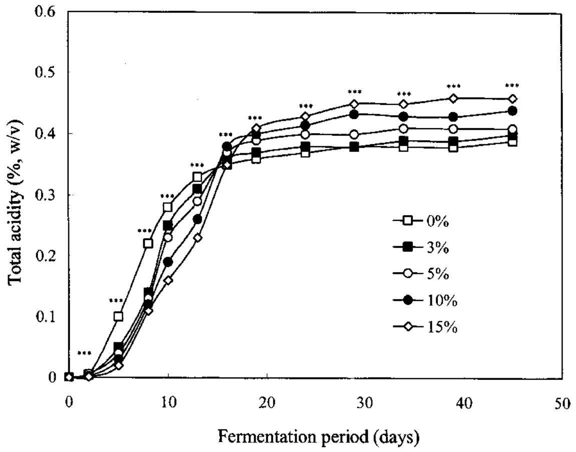

Fig. 2. Changes in total acidity of *Dongchimi* prepared with various levels of *gatt* during fermentation at 10°C for 45 days. ***$p<0.001$

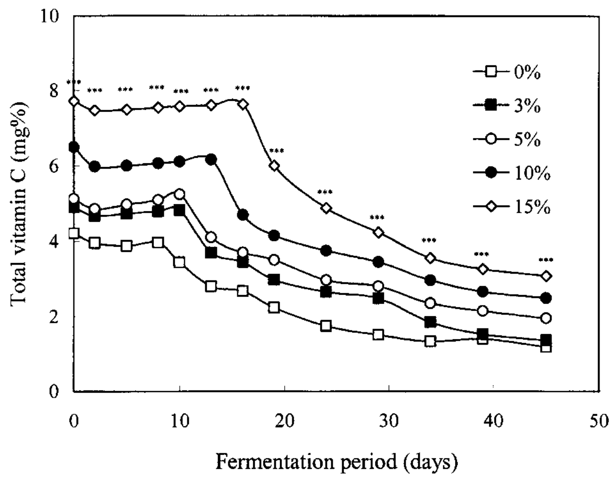

Fig. 3. Changes in total vitamin C of *Dongchimi* prepared with various levels of *gatt* during fermentation at 10°C for 45 days. ***$p<0.001$

This tendency of the vitamin C agreed with those of results, in which maximum vitamin C content occurred during optimum fermentation period, as well as with those showing large increase and then slow decrease of the vitamin C content (16-18).

Reduction in vitamin C content observed during the early stages of fermentation, Day 2, is thought to be due to the activity of ascorbic acid oxidase, in accordance with the results of Park *et al.* (19). In addition, the slight increase in vitamin C content following optimal fermentation observed in all treatments agreed with the findings of Lee and Lee (18), who showed increased vitamin C content during the early stages of fermentation, followed by a reduction as the process entered acidification.

Reducing sugars The changes observed in the level of reducing sugars in liquid during thefermentation of watery radish *kimchi* are shown in Fig. 4. Content of reducing sugars, one of the most important ingredients for determining the taste of watery radish *kimchi*, in *gatt* was 44.75 mg/g.

Although no significant differences were observed immediately after the preparation of watery radish *kimchi*, the levels of reducing sugars began to rise slowly on Day 2 and showed a dramatic increase on Day 8. In the control, 3 and 5%, 10%, and 15% treatments, maximum values were observed on Days 8, 10, 13, and 16, respectively, gradually decreasing thereafter. This result is believed to be due to the effect of *gatt* on delaying fermentation during the early stages. The highest amount of reducing sugars was observed in 5% treatment, and this amount was maintained for the longest period during fermentation. On the other hand, in 15% treatment, despite the high level of reducing sugars, the extracted liquid was observed of low contents, which indicates that a high level of reducing sugars used

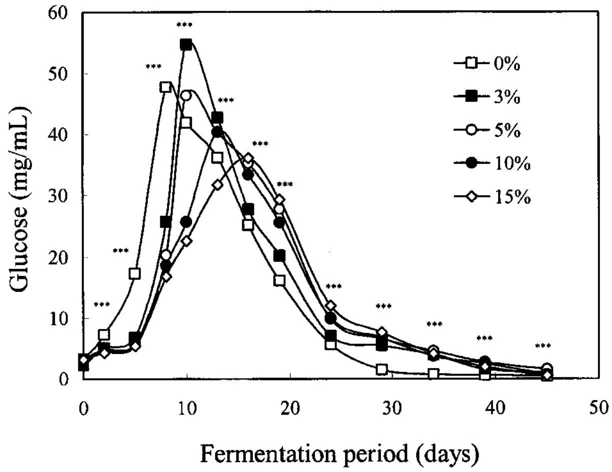

Fig. 4. Changes in reducing sugar contents of *Dongchimi* prepared with various levels of *gatt* during fermentation at 10°C for 45 days. ***p<0.001

as nutrients for the microorganisms remained, resulting in increased fermentation rate during the latter stages. The amounts of reducing sugars were in the order of: 0%< 15%<10%<3%<5% treatments. As the content of the reducing sugars decreased, increases in total acidity and vitamin C content occurred.

According to the studies of Jang and Moon (17) and Kim *et al.* (16), when licorice and onions are added to the watery radish *kimchi*, the contents of the reducing sugars increase, and fermentation results show high acidity. This is in accordance with the study on the content of reducing sugars in radish *kimchi* by Yook *et al.* (20), who showed a continued increase in the reducing sugars content throughout the ripening period of *kimchi*, followed by a reduction thereafter.

Non-volatile organic acids Among the non-volatile organic acids found in the radish, the principle acid was malic acid with minor ones including fumaric, tartaric, and citric acids. In *gatt*, a significant amount of malic acid was detected, followed by, in decreasing order, tartaric, citric, succinic, and lactic acids.

The changes in non-volatile organic acids of radish and liquids are shown in Table 3. A total of five peaks were observed in watery radish *kimchi*. Successfully isolated non-volatile acids included lactic, succinic, malic, tartaric, and citric acids.

In bamboo leaves-added watery radish *kimchi*, lactic, fumaric, succinic, malic, and citric acids were isolated (21), and in a different study on watery radish *kimchi* (11), lactic, fumaric, malic, succinic, and tartaric acids were

Table 3. Changes in non-volatile organic acid of *Dongchimi* prepared with various levels of *gatt* during fermentation at 10°C for 45 days (mg%)

Non-volatile organic acids	Fermentation period (days)	*Gatt* (%)				
		0	3	5	10	15
Lactic acid	0	-[1)]	-	-	-	-
	5	$8.71^{a,2)}$	7.07^{b}	7.25^{c}	6.42^{d}	5.27^{e}
	10	28.91^{a}	21.68^{b}	23.87^{c}	17.16^{d}	16.51^{e}
	24	33.04^{e}	37.34^{d}	38.31^{c}	41.74^{b}	43.22^{a}
	45	38.80^{e}	41.99^{d}	42.91^{c}	54.08^{b}	68.33^{a}
Succinic acid	0	-	-	-	-	-
	5	0.12^{e}	0.23^{d}	0.26^{c}	0.30^{b}	0.39^{a}
	10	0.26^{c}	0.31^{b}	0.30^{b}	0.34^{a}	0.37^{a}
	24	0.27^{c}	0.32^{b}	0.31^{b}	0.44^{a}	0.44^{a}
	45	0.30^{d}	0.36^{c}	0.44^{b}	0.54^{a}	0.56^{a}
Malic acid	0	545.40^{e}	546.52^{d}	549.41^{c}	559.30^{a}	550.01^{b}
	5	449.51^{e}	492.66^{d}	504.80^{b}	500.33^{c}	507.63^{a}
	10	377.31^{e}	382.74^{d}	385.77^{c}	476.23^{b}	481.08^{a}
	24	142.09^{a}	134.88^{b}	122.52^{c}	55.33^{d}	58.72^{e}
	45	71.43^{a}	58.62^{b}	50.82^{c}	45.69^{d}	28.03^{e}
Tartaric acid	0	51.23^{e}	59.87^{d}	60.29^{c}	64.57^{b}	69.08^{a}
	5	67.99^{e}	70.34^{d}	72.17^{c}	72.77^{b}	75.78^{a}
	10	73.20^{e}	74.24^{d}	85.37^{c}	87.98^{b}	90.73^{a}
	24	94.39^{e}	98.42^{d}	100.57^{c}	119.51^{b}	125.67^{a}
	45	98.42^{e}	104.05^{d}	109.58^{c}	129.64^{b}	154.01^{a}
Citric acid	0	13.08^{d}	15.21^{c}	15.36^{b}	15.40^{b}	19.79^{a}
	5	11.69^{e}	11.98^{d}	12.39^{c}	13.36^{b}	14.96^{a}
	10	9.51^{e}	10.00^{d}	10.26^{c}	11.88^{b}	12.23^{a}
	24	9.37^{a}	9.03^{b}	9.00^{b}	8.72^{c}	7.99^{d}
	45	8.60^{a}	8.42^{b}	8.07^{c}	7.47^{d}	5.86^{e}

[1)]Not detected.
[2)]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.

isolated. Furthermore, lactic, malic, oxalic, citric, and succinic acids were the main non-volatile organic acids isolated from *gatt kimchi* (9). Studies on cubed radish *kimchi* (22) revealed nine organic acids, and, in comparison to this study, additional organic acids isolated included oxalic, malonic, levulinic, and pyroglutamic acids. Different organic acids were detected depending on the type of *kimchi* and the analytical method used.

During the fermentation process, levels of lactic and tartaric acids increased, whereas those of malic and citric acids decreased. On Days 5 and 10, lower levels of lactic acid were reported for *kimchi* containing a high amount of *gatt*, whereas, after Day 24, level of lactic acid increased. This shows that *gatt* inhibits fermentation during the early stages, but promotes fermentation during the latter stages.

Succinic acid, a principle ingredient responsible for the savory taste of *kimchi* (23) and shown to have a significant influence on the taste of cubed radish *kimchi* (24), was detected in this study. Levels of succinic acid increased with the addition of *gatt* and slowly increased throughout the fermentation process. According to Kim and Jang (22), level of succinic acid increased slightly during the fermentation process. Results that the level of succinic acid increased along with that of lactic acid were in accordance with this study.

Malic acid, a principle non-volatile organic acid observed in raw radish, significantly decreased throughout the fermentation process. In particular, after Day 24 of fermentation, the malic acid contents of 10 and 15% treatments were lower than those of others.

Level of citric acid, as with malic acid, decreased throughout the fermentation process. Up until Day 10, level of citric acid increased with the addition of *gatt*, whereas decreased after Day 24.

Turbidity The changes in turbidity of liquid during the fermentation of watery radish *kimchi* are shown in Fig. 5. Immediately after the preparation of *kimchi*, turbidity was 8.4~10.4, not significantly different from that of distilled water (0%). During fermentation, turbidity increased in all treatments. Control showed a sudden increase on Day 8. The 3 and 5% treatments showed gradual increases until Day 8, then increased sharply on Days 10 and 13, respectively. The 10 and 15% treatments increased gradually until Day 10 then sharply increased on Days 16 and 19, respectively, evidence to the active fermentation taking place during this time.

The turbidity of the control was highest on Day 19, with lower turbidity observed in treatments with higher amounts of *gatt*, which indicates that, for a fixed time after addition, *gatt* acts to inhibit fermentation. Following Day 24, the turbidities of the 10 and 15% treatments were high. This shows that, although *gatt* exerts inhibitory effects during the early stages, excessive amount (i.e. 15%) rather acts to accelerate the fermentation. In studies of watery radish *kimchi* covered with bamboo leaves (21), turbidity increased as fermentation progressed, then decreased before slowly increasing again to maintain turbidity. This trend was similar to the results of this study.

Color Changes in lightness ("L") of liquid are shown in Fig. 6. Without any significant changes immediately following preparation, lightness slowly decreased on Day 2 and continued to decrease steadily throughout the fermentation process. Upto Day 10, the lightness of the control was lowest, followed by 3%<5%<10%<15% treatments. The clarity of the liquid can be explained by the small delays in fermentation with the addition of more *gatt*. On Day 13, the lightness of the 5% treatment was lower than that of the control. On Days 16 and 19 for the 10 and 15% treatments, respectively, the lightness decreased drastically. From Days 19 to 45, the lightness values were in the order of 15%<10%<5%<3%<0% treatments. This coincides with the results of highest turbidity observed on Day 24 for the 10 and 15% treatments. Immediately following the preparation, the lightness was highest, transparent. This was due to the fact that, as fermentation progresses, the activity of the microorganisms inhibits the transmission of light through the soluble matter of the radish, thus lowering the lightness.

Changes in redness ("a") of liquid are shown in Fig. 7. No differences were observed among the treatments

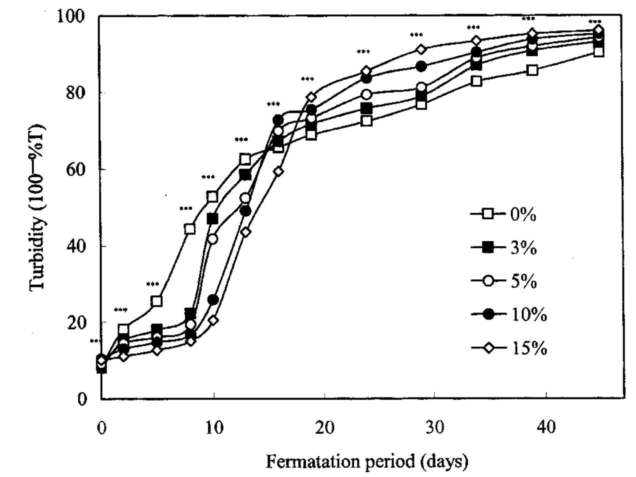

Fig. 5. Changes in turbidity of *Dongchimi* prepared with various levels of *gatt* during fermentation at 10°C for 45 days. ***p<0.001

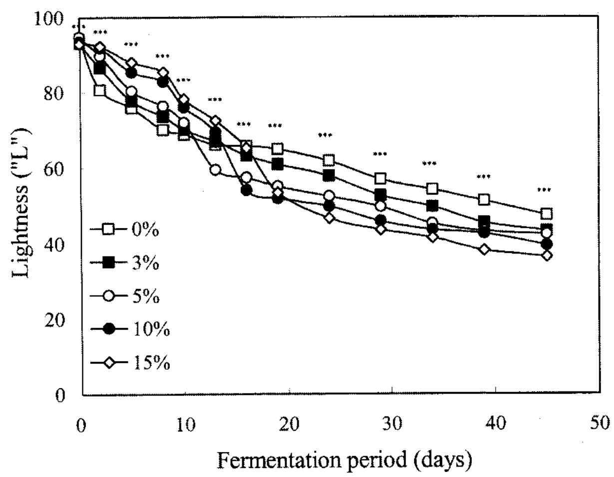

Fig. 6. Changes in lightness (L) values of *Dongchimi* prepared with various levels of *gatt* during fermentation at 10°C for 45 days. ***p<0.001

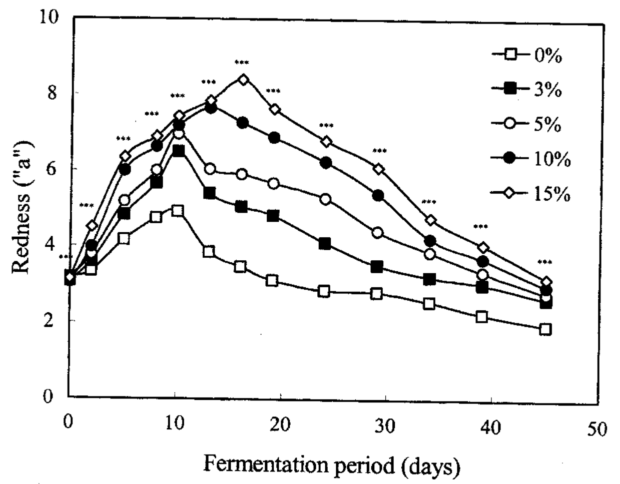

Fig. 7. Changes in redness (a) values of *Dongchimi* prepared with various levels of *gatt* during fermentation at 10°C for 45 days. ***p<0.001

immediately following preparation. However, after Day 2, redness increased with the addition of more *gatt*. This is believed to be due to the characteristic redness of the red *gatt* used. Maximum values were observed for the control, 3 and 5% treatments, 10% treatment, and 15% treatment on Days 8, 10, 13, and 16, respectively, followed by steady increases and then decreases among all treatments. In the analysis of *kimchi* liquid for quality evaluation of low temperature-fermented cabbage *kimchi* by Lee *et al.* (25), maximum red color was observed during the optimal fermentation period, followed by a reduction (26). Although the kind of *kimchi* used in their study was different from that used in this study, both showed the same results.

Changes in yellowness ("b") of liquid are shown in Fig. 8. No differences were observed among the treatments immediately following preparation. In all treatments, after reaching maximum yellowness values at different times, the yellowness decreased. Maximum values were observed for the control, 3 and 5% treatments, 10% treatment, and 15% treatment on Days 8, 10, 13, and 16, respectively, and decreased thereafter. Increasing levels of yellowness were observed from Days 2 to 45 in the following order: 0%<3%<5%<10%<15% treatments.

Solid contents Solid contents of liquids immediately following preparation in all treatments were 1.12~1.37% and increased throughout the fermentation process (Fig. 9). Maximum values were in the order of 15%<10%<5%<3%<0% treatments until Day 10. Significant increases were observed for the control, 3 and 5% treatments, 10% treatment, and 15% treatment upto Days 10, 13, 16, and 19, respectively. Low solid contents were observed upto Day 19 in treatments with high amounts of *gatt*. This is believed to be due to the delay in fermentation caused by *gatt* at the early stages.

After Day 19, the order of solid contents was 0%<3%<5%<10%<15%, and this trend was maintained until Day 45. Towards the end of fermentation, 15% treatment showed higher solid content than the control, whereas little differences were observed between 3 and 5% treatments, and the control. As fermentation progressed, a delay during the early stage of fermentation occurred with the addition of *gatt*; however, following the optimal fermentation period, the fermentation occurred at a faster rate than the control, coinciding with the results of total acidity and turbidity.

In the study on bamboo leaves-added watery radish *kimchi* (21), an increase in solid contents was observed as fermentation progressed. However, with the addition of more bamboo leaves, the solidity decreased. This phenomenon continued throughout the later stages of fermentation and coincides with the trend observed in this study.

These results showed that changes in pH, total acidity, and turbidity followed the same trend up to Day 13 following the addition of *gatt*, which inhibited fermentation; however, excess *gatt* (above 15%) might accelerate fermentation during the latter fermentation stage and should be avoided. More acceptable *Dongchimi* could be prepared by fermenting *kimchi* with 5% *gatt* at the given conditions.

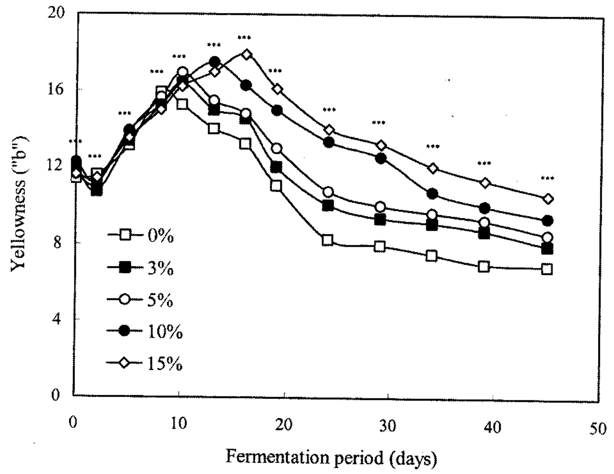

Fig. 8. Changes in yellowness (b) values of *Dongchimi* prepared with various levels of *gatt* during fermentation at 10°C for 45 days. ***p<0.001

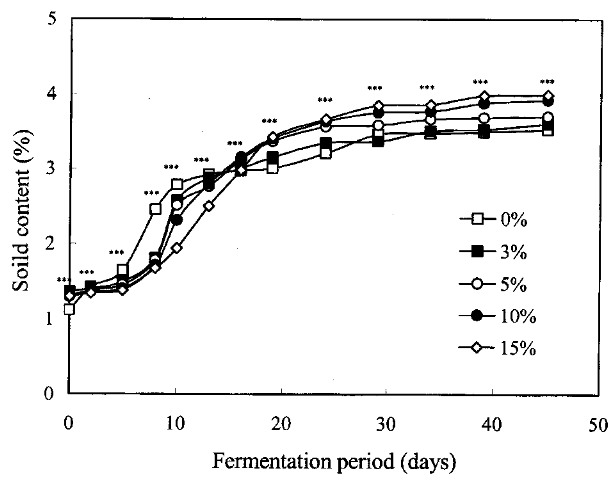

Fig. 9. Changes in total solid contents of *Dongchimi* prepared with various levels of *gatt* during fermentation at 10°C for 45 days. ***p<0.001

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