Factors Affecting Kimchi Fermentation

Mheen, Tae Ick

Korea Institute of Science and Technology Information
206-9, Cheongryangri-dong, Dongdaemun-ku, Seoul 130-742, Korea

Abstract

Kimchi is a Korean fermented food that is prepared through a series of processes including pretreatment of Chinese cabbage, salting, blending with various spices and other ingredients, and fermentation. The characteristics of kimchi differ depending on the kimchi variety, raw materials, processing methods, and fermentation conditions. Kimchi fermentation is initiated by the various lactic acid bacteria (LAB) present in the raw materials. Sugars in raw materials are converted to lactic acid, acetic acid, carbon dioxide, and ethanol by hetero and homo fermentative LAB during kimchi fermentation, along with other chemical changes. Many physicochemical and biological factors influence kimchi fermentation. This review covers in some detail the factors affecting kimchi fermentation.

Key words: kimchi, fermented vegetable foods, lactic acid bacteria, lactic acid fermentation

I. Introduction

Kimchi is a Korean fermented vegetable food that are salted, blended with various ingredients and fermented for a certain period of time at ambient temperature. The characteristics of kimchi differ depending on the variety of kimchi. The varieties result from the raw materials used, processing methods, season, geographic area and the functional properties of kimchi. More than 200 kinds of kimchi are available in Korea, but kimchi can be classified into two major groups: ordinary and mu/-kimchi (water-kimchi). Ordinary kimchi without added water includes baechu-kimchi (diced Chinese cabbage), tongbaechu-kimchi (whole Chinese cabbage), yeolmoo-kimchi (young oriental radish) and kakdugi (cubed radish kimchi). Wu/-kimchi includes baek-kimchi (baechu kimchi with water), dongchimi (whole radish kimchi with water) and nabak-kimchi (cut radish and Chinese cabbage).

The raw materials used for kimchi preparation are divided into three groups, major, sub-ingredients (spices) and optional ingredients. A recipe for the simplest kimchi may include cabbage 100g, garlic 2g, red pepper powder 2g, green onion 2g, and ginger 0.5g, with an optimum salt content of 2-3%.

The optimum pH for the best taste of kimchi is 4.2-4.5 with an optimum acidity of 0.6-0.8% as lactic acid. The best taste is attained after 2-3 days of fermentation at 20°C with 2-3% salt. Kimchi has a unique sour, sweet, carbonated taste and usually is served cold. Also, kimchi contains large amounts of live lactic acid bacteria (LAB). In this respect, kimchi differs from Western sauerkraut and Japanese asatsuke. The former is only acidic in taste (therefore lacking the complex taste of kimchi) and is served warm, while the latter is not a fermented product and contains few live...
LAB.

The total kimchi production was estimated to be 1,500,000 M/T in 2000 and one fourth of the kimchi consumed was commercially produced. According to a national survey, an adult consumes 50-100g/day of kimchi in summer and 150-200g/day in winter.2

During the past 50 years, many species of bacteria, yeasts, and fungi have been isolated and reported from kimchi samples. The major microorganisms responsible for kimchi fermentation are LAB and yeasts which are known to be responsible for the softening of kimchi texture and the off flavor. The major species of LAB isolated and identified from kimchi are Leuconostoc mesenteroides, Leuconostoc dextranicum, Leuconostoc citreum, Lactobacillus brevis, Lactobacillus fermentum, Lactobacillus plantarum, Pediococcus pentosaceus, and Streptococcus faecalis.1,6

The sugars present in the raw materials are converted to lactic acid, acetic acid, carbon dioxide and ethanol by hetero fermentative LAB during kimchi ripening, and these acids and carbon dioxide are responsible for the fresh and carbonated taste of kimchi. However, after a certain period of time, excessive lactic acids are formed and undesirable flavors develop due to the growth of homo fermentative LAB and yeasts.1,2

In the kimchi fermentation system, the hetero fermentative LAB producing organic acids and carbon dioxide from sugars are major species in the early stage of fermentation, and homo fermentative LAB producing excessive lactic acid are major species in the late stage of fermentation. It has also been shown that low salt concentration and low temperature (eg, 2% and 10°C) favor growth of hetero fermentative LAB, while high salt concentration and high temperature (eg, 3.5% and 30°C) favor growth of homo fermentative LAB. Therefore, salt concentration and temperature are the key factors for controlling kimchi fermentation.6

Besides the above mentioned key factors for controlling kimchi fermentation, many other factors such as the raw materials, processing methods, and natural preservatives and starters which affect kimchi fermentation and preservation have been reported in reviews and books.1,6

In general the factors that affect kimchi fermentation are microorganisms, temperature, salt concentration, fermentable carbohydrates, other nutrients, any inhibitory compounds present in the raw materials, oxygen and pH. In this review, the salts and salting conditions, temperature, raw materials, natural preservatives and selected starter cultures related to kimchi fermentation will be discussed in detail.

II. Factors affect on kimchi fermentation

1. Salts and salting conditions

The concentration of salt is one of the key factors for controlling kimchi fermentation and preservation at various temperatures. There are more than 200 kinds of kimchi available in Korea. However, the salt concentrations of these kimchi all differ depending on the maker. A flow-chart for processing baechu-kimchi is shown in Fig.1.

Prior to kimchi preparation the major raw materials such as Chinese cabbages and radishes may be salted with either a salt solution (brine method) or dry salt (direct addition method) and washed with clean water. This treatment is the most important step for fermentation and maintenance of kimchi quality. It has been reported that the optimum salt concentration for kimchi is about 2.0-3.0%, while appropriate level is determined by individual experience.9 Therefore, it is necessary to optimize the salting condition. Of the two salting methods, the direct addition method is most widely used at the household level, but has the disadvantage of being difficult to control the final salt content of the kimchi. The brine method is preferable for commercial production of kimchi. A satisfactory quality for kimchi can be obtained when the cabbage is salted for 3-6 hours using 15 to 20% salt solution.9

Salting is carried out over a range of time from 3 to 15 hours depending on the salt concentration, temperature, variety, cutting method and size of the cabbage. For baechu-kimchi, the final salt concentration is adjusted to 2.0-3.0% of the overall ingredients, this concentration being best for optimum fermentation. This concentration is
Fig. 1. Flow-chart for production of baechu-kimchi.

Fig. 2. Changes of total acid during kimchi fermentation at different temperatures and salt concentrations.
maintained during fermentation and preservation. If the salt concentration is below the optimum concentration, fermentation proceeds too quickly and can cause excessive acidification and softening. On the other hand, color and flavor are not acceptable when the salt concentration is over 5%. Depending on the salting time, free sugars and amino acids are reduced in raw cabbage and the texture, chemical and physical properties, and total microbial counts change during salting.

Generally, salting reduces the moisture content (10-12%), relative volume, and weight, as well as the internal void space of the cabbage. These changes affect the physical properties of the vegetable, especially the flexibility and firmness of the tissue, which gives a distinctive textural property to the final product. As a result of brining, the total amount of microorganisms, such as aerobic counts, in salted cabbage are reduced (11-87%), and LAB increase (3-4 times). The amount of reducing sugars also decreases. (7-17%) Washing conditions for salted cabbage is also important for quality preservation of the kimchi.

Chinese cabbage treated with a 1000 ppm solution of grapefruit seed extract or citric acid at 10°C shows a retarded increase in titratable acidity and a decrease in pH and reducing sugar concentration. Kimchi made from Chinese cabbage soaked in a heated 10% salt solution at 40°C has improved quality and shelf-life.

Fig.2 shows the effect of salt concentration and temperature on acid production during kimchi fermentation. Total acid was more at lower salt concentration (2.25%) than at any temperature tested for high concentration. At the lower salt concentration, maximum acidity was reached in a shorter period of time. At 30°C and 2.25-3.5% salt concentration, the acidity of kimchi was maintained in the same pattern throughout. An acidity of 1.55% was reached in 5 days and was maintained at 1.6% thereafter, but at 5.0 and 7.0% salt concentration, the acidity reached 1.4 and 1.1% after 5 and 6 days, respectively.

The effect of salt concentration on dongchimi (ponytail Chinese radish kimchi) fermentation was also studied. Diced Chinese radishes were fermented at 4°C with a salt concentration of 1.5-6.3%. The pH level reduced during the fermentation, while the total acid content of dongchimi increased and the salt concentration of the dongchimi liquid decreased. Equilibrium for the salt concentration between the dongchimi liquid and the solid radish was achieved after 15-22 days of fermentation. Vitamin C and the reducing sugar content of the dongchimi liquid and Chinese radish increased until 15-22 days of fermentation, and then decreased. Salt concentration had a significant effect on the sensory properties of dongchimi.

Recently, to examine the quality of mul-kimchi, the temperature (4, 15, and 25°C for 10 days) and salt concentration (0, 0.2, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0%) in water was conducted, and it was found that the pH was the lowest and the acidity the highest in the mul-kimchi containing 1.0% salt. The total vitamin C content in mul-kimchi containing 3.0% salt was higher than in the low-salt samples after the optimum ripening time and the overall palatability of mul-kimchi showed the highest score in the 1.0% salt sample.

2. Temperature

After salt concentration, the most important factor affecting kimchi fermentation is temperature, since the kimchi fermentation occurs mainly by the microorganisms naturally present in the raw materials. Kimchi is now available year-round but the quality of kimchi differs depending on geographical location and season. Ambient temperature is used for making kimchi for personal consumption. Kimchi fermentation and over acidification occurs simultaneously at ambient temperature.

Fig.3 shows the changes of pH and total acids during kimchi fermentation at various temperatures. Ripening time of kimchi depends on the fermentation temperature, therefore differences in pH and acidity were seen. At 20°C, the pH dropped sharply with increasing acidity, but pH and acidity at 10°C changed more slowly than at higher temperatures.

Maximum total acid produced in kimchi at 20°C and 15°C is 1.6%, but never exceeds 1.2% at 10°C. A panel evaluation determined that the pH and
The optimum ripening time and the edible period for kimchi varied depending upon the fermentation temperature and salt concentration as shown in Table 1. At 30°C, the optimum ripening period was 1 day and the edible period was 1-2 days. At lower temperatures, the optimum ripening time and the edible period were longer than at higher temperatures. At 5°C and above 5.0% salt concentration, kimchi ripened very slowly and at 7.0% salt concentration it did not ripen even after 180 days fermentation.

Chemical changes, LAB and yeast counts in kimchi prepared by commercial manufacturers in large scale were monitored at different fermentation temperatures. It was confirmed that the optimum pH of kimchi is around 4.2 which was reached within 2 days at 25°C, 3 days at 15°C, and 23 days at 5°C fermentation, respectively.

Differences in the quality characteristics such as pH, acidity, reducing sugar content, microbial counts and sensory properties between whole Chinese cabbage kimchi (pogi-kimchi) and sliced Chinese cabbage kimchi (mat-kimchi) were examined during fermentation at 20°C for 10 days and 5°C for 50 days. Pogi-kimchi showed a slower ferme-

![Fig.3. Changes of total acid and pH during kimchi fermentation at various temperatures.](image)

### Table 1. Optimum ripening time and edible period of kimchis

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Salt concentration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.25</td>
</tr>
<tr>
<td>30</td>
<td>1-2 (days)</td>
</tr>
<tr>
<td>20</td>
<td>1-3</td>
</tr>
<tr>
<td>14</td>
<td>1-10</td>
</tr>
<tr>
<td>5</td>
<td>35-180</td>
</tr>
</tbody>
</table>
tation, approximately 2 days at 20°C and 10 days at 5°C, than mat-kimchi. Odor, color and flavor scores for the kimchi were higher in the samples fermented at 20°C than those fermented at 5°C, also there were no great differences in the sensory properties of pogi-and mat-kimchi. The gas composition of the packages containing the kimchi fermented at 20°C showed increased CO₂ concentration and decreased O₂ concentration after 3 days for both kimchi varieties.¹⁸

The effect of fermentation temperature on the sensory, physicochemical and microbiological properties of kakdugi (cubed radish kimchi) and on the free sugar, organic acid and volatile compound levels in kakdugi during fermentation were also investigated.²⁰ After initial fermentation for 12, 24 and 36 hr at 20°C, kakdugi was fermented for 57 days at either 4°C, 10°C or 20°C, respectively. The pH was decreased to between 4.1 and 4.3 from the initial pH 5.8, and the total acidity increased 2-4 times that of the initial value (0.2%). The number of LAB remarkably increased in palatable period and gradually decreased thereafter.¹⁸

Free sugar levels decreased at each temperature during fermentation (with the exception of manitol, levels of which increased) although decreases were less marked in samples fermented at 4°C. Of the organic acids tested, lactic acid production was the most pronounced, increasing substantially with time and temperature. In contrast, malic acid, which was the most abundant organic acid initially, decreased in concentration during fermentation, and this decrease was most pronounced at higher temperatures.

Levels of the volatile compound, methyl allyl sulfide, were initially very low, but increased dramatically up to approximately 45 days after which levels decreased. The increase corresponded to increased aroma in the sensory evaluations. These results suggest that fermentation at 4°C, following an initial fermentation at 20°C for 36 hr, is suitable for the production of good quality kakdugi with high free sugar and organic acid contents.²⁰

In order to investigate the fermentation characteristics of kimchi, which was made at 12°C and fermented at 17°C and 4°C, the pH, total acid concentration, total cell counts of microorganisms, LAB, dissolved carbon dioxide content, reducing sugar content and temperature at the center of kimchi jars were measured. The pH and the total acid content of kimchi that was fermented at 17°C for 4 days were almost the same as those of kimchi fermented at 4°C for 48 days. The total cell counts of microorganisms and LAB in kimchi which were fermented at 17°C for 2 days and 4°C for 9 days were 1.5×10⁸ and 6.3×10⁶ cells/ml, and 2.0×10⁷ and 8.7×10⁶ cells/ml, respectively. The results showed that it took 23 and 35 hr, respectively, to reach the temperature of 17°C and 4°C at the centers of a jars during bulk fermentation of kimchi from an initial temperature of 12°C.²⁰

The characteristics of natural lactic acid fermentation using radish juice were investigated at different salt concentrations (0-2%) and temperatures (10-30°C) using low salt kimchi (a kind of water kimchi). It was found that the LAB isolated from radish juice fermented at 2% salt concentration was mainly Leu. mesenteroides, Lac. plantarum and Lac. brevis. Growth rate of LAB increased with increasing temperature at 1% salt concentration and the LAB was still active at 10°C. The time required to reach pH 4.0 during fermentation with juice containing 1% salt was 11-13 days at 10°C and 2-3 days at 30°C.²²

The effects of fermentation temperature (0-15°C) and salt concentration (1.5, 2.75, 4.0%) on the fermentation parameters of kimchi were also analyzed by response surface methodology. The pH decreased and acidity increased with increasing fermentation time; while reductions and incremental rates increased as temperature increased and salt concentration decreased. The optimum pH of 4.2 was achieved within 14-24 days at 5-15°C, but at 5°C, the pH was still >4.2 after 24 days. Maximum edible acidity (0.75%) was reached within 8 days at 15°C, but at 0°C, acidity was only 0.35-0.43% after 24 days of fermentation. Edible periods for kimchi, based on the acidity range 0.4-0.75%, were 4, 10, and 18 days for the fermentation at 15, 10, and 5°C, respectively, at 2.75% salt concentration.²³

3. Raw materials
Kimchi, a fermented vegetable food with various
components (including seasoning and spices), has been the most popular side dish served with cooked rice for hundreds of years in Korea. In total, there are about 200 kinds of kimchi, whose raw materials are mainly Chinese cabbage and radishes. Dried red pepper powder, garlic, green onion and ginger are the widely used seasonings. The types and amounts of seasonings used in kimchi vary greatly between manufacturers and processors. The quality and species of the major ingredients significantly affect fermentation and the product characteristics of kimchi.

The important raw materials of kimchi are divided into three groups: the major raw materials, sub-ingredients (spices) or fermented fishery products, and optional (minor) ingredients.

As seen in Table 2, Chinese cabbage is the most common major raw material for preparing kimchi while radishes are used for kakkugi (cubed radish kimchi) and dongchimi (whole radish kimchi with water) preparation. Cabbage, whole radish, cucumber, mustard leaves, green onion, and leeks which are available in different seasons and localities are the raw materials used for making special kimchi in Korea.

One of the important criteria for making the good taste of kimchi is the selection of good quality raw materials, followed by formulation of kimchi ingredients and seasonings.

Table 3 shows the basic ingredients for making baechu-kimchi, kakkugi, dongchimi, and mulkimchi, but the most simple kimchi recipe includes salted cabbage 100 g, hot pepper powder 2 g, garlic 1.5 g, green onion 2 g, ginger 0.5 g and final salt concentration of 2-3%.14)

Generally softer texture and higher sugar content vegetables are desirable for making good quality and good tasting kimchi. However, hard texture vegetables are more favorable for long-term preservation without softening.51 Among the many kinds of kimchi, baechu-kimchi has been consumed for the longest time as a traditional fermented vegetable food in Korea. The kind and amount of ingredients involved in baechu-kimchi preparation affect the kimchi fermentation rate. Effects of raw materials and ingredients on kimchi fermentation have been extensively studied.35,36,37)

Besides the temperature and salt concentration, the type of kimchi is also a factor in controlling kimchi fermentation. Therefore, the three main types of Chinese cabbage kimchi, baechu-kimchi and tongbaechu-kimchi (semi solid types of the cabbage kimchi prepared with a large amount of hot pepper powder and a small amount of water) and baek-kimchi (a liquid type of kimchi prepared with a small amount of hot pepper powder and a large amount of water), were selected as models to compare the fermentation characteristics of kimchi. The amount of hot pepper powder and water are believed to be the primary (or external) and secondary (or internal) factors, respectively, affecting kimchi fermentation.30

The growth of microorganisms can be controlled by the appropriate addition of raw materials. Among the sub-ingredients, hot pepper powder,29-32 radishes,34 fermented anchovy and shrimp,33-36 starches,35,36 reducing sugar,31 soluble solids,40 and protein sources41 have been probed for their ability to promote kimchi fermentation, but garlic, leaf mustard and leek have been shown a have delaying effects,41-44 while green onion and ginger have controversial effects on kimchi fermentation.45

Garlic is used most frequently as a sub-ingredient (100%) in kimchi. Since ground garlic is used in kimchi making, allin is changed to allicin which has an intensive taste. Allicin takes part in fermentation of kimchi by inhibiting the growth of various unnecessary microorganisms derived from sub-ingredients during the initial fermentation period and slows the fermentation of kimchi. Garlic improves the storage capacity by prolonging the LAB fermentation period and results in less acidification.29,30,34,35 With fermentation of kimchi, the intensive hot taste of garlic slowly changes to a harmonized taste and flavor.40

The composition of pigments in hot pepper consists of 40 different carotenoids, with capsanthin and capsorubin being the most widely found, and carotenes such as provitamin A. The average amount of hot pepper added to kimchi was found to be 2.24% with a frequency of use of 97.3%. In spite of the fact that hot pepper was reported to
Table 2. Raw materials used for kimchi preparation

<table>
<thead>
<tr>
<th>Group</th>
<th>Raw materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major raw materials</td>
<td>baechu (Chinese cabbage), radish, ponytail radish, young oriental radish, cucumber, green onion, Western cabbage, leek, mustard leaves, etc.</td>
</tr>
<tr>
<td>Sub-ingredients</td>
<td>garlic, red pepper, green onion, ginger, radish, etc.</td>
</tr>
<tr>
<td>(Spices)</td>
<td></td>
</tr>
<tr>
<td>Optional-ingredients</td>
<td></td>
</tr>
<tr>
<td>(Seasonings)</td>
<td></td>
</tr>
<tr>
<td>Fermented seafood</td>
<td>anchoy, shrimp, yellow corvina, etc.</td>
</tr>
<tr>
<td>Other vegetables</td>
<td>radish, leek, water cress, carrot, mustard leaves, parsley, etc.</td>
</tr>
<tr>
<td>Fruits and nuts</td>
<td>pear, apple, jujube, chest nut, gingko nut, pine nut, etc.</td>
</tr>
<tr>
<td>Cereals</td>
<td>rice, wheat flour, starch, etc.</td>
</tr>
<tr>
<td>Fish and meats</td>
<td>shrimp, frozen pollack, squid, oyster, beef, pork, etc.</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>mushrooms, sesame seed, monosodium glutamate, corn syrup, sweeteners, etc.</td>
</tr>
</tbody>
</table>

Table 3. Ingredient composition of various kimchi varieties

<table>
<thead>
<tr>
<th>Kimchi (Reference)</th>
<th>baechu - kimchi</th>
<th>kakdugi</th>
<th>mul-kimchi</th>
<th>dongchimi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salted cabbage</td>
<td>80.6 (%)</td>
<td>80 (g)</td>
<td>100 (g)</td>
<td></td>
</tr>
<tr>
<td>Radish</td>
<td>9.4</td>
<td>10</td>
<td>28.6</td>
<td>600 (g)</td>
</tr>
<tr>
<td>Red pepper (powder)</td>
<td>2.6</td>
<td>2</td>
<td>(2.2)</td>
<td>135</td>
</tr>
<tr>
<td>Garlic</td>
<td>1.8</td>
<td>2</td>
<td>1.6</td>
<td>100</td>
</tr>
<tr>
<td>Ginger</td>
<td>0.4</td>
<td>0.5</td>
<td>0.8</td>
<td>35</td>
</tr>
<tr>
<td>Green onion</td>
<td>1.9</td>
<td>2</td>
<td>2.7</td>
<td>165</td>
</tr>
<tr>
<td>Leak</td>
<td>1.3</td>
<td></td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Fermented shrimp</td>
<td>0.5</td>
<td>2</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Fermented anchovy</td>
<td>0.8</td>
<td>1.5</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>Sugar</td>
<td>0.2</td>
<td></td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Salt (Final)</td>
<td>0.1</td>
<td>(3.0)</td>
<td>(2.0-3.0)</td>
<td>140</td>
</tr>
<tr>
<td>MSG</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other ingredients</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.1</td>
</tr>
</tbody>
</table>

Water (ml) 1,650 150
promote the fermentation of kimchi, it did not show any significant increase in sour taste and did not affect sweetness, saltiness, palatability or crispiness.³⁰

Green onion and leek contain various allyl sulfides, carotenes and vitamin C. The frequency of use in common cabbage kimchi was 72.8% for green onion and 32.4% for leek, which both are much lower than the 100% for garlic and 97.3% for hot pepper. The amounts of green onion and leek used for kimchi making are still high, ie, 0.6-0.9% for green onion and 2.0-6.0% for leek. Recently, it has been reported that leek retards the fermentation of kimchi due of its antimicrobial activity.⁴⁶

Ginger contains unique components like citral and linalool, and hot spicy components such as gingerone and shogaol. Ginger causes a delay in fermentation and there were no significant differences in the sourness, sweetness, saltiness, spiciness, palatability, unpleasant and overall tastes, acidic odor and color between the kimchi fermented with and without ginger.⁴⁶

Fermented anchovy and shrimp contain large amounts of proteins and amino acids, and have their own unique taste and flavor. Therefore, these sub-ingredients affect not only the nutritional balance but also the sensory quality of kimchi. These fermented fish products and other protein sources such as skim milk, soy protein isolate, beef extract, and fish protein produced high lactic acid concentrations and promoted the growth of LAB.°

The frequency of addition of starch and sugar in kimchi making was 27% with a concentration of 0.4-3.0%, and sugar was used for sweet and harmonized tastes. However, since starch and sugar are utilized as carbon sources by various microorganisms present in kimchi, they affect kimchi fermentation and sensory quality. In the results, starch and sugar promote the fermentation of kimchi and contribute greatly to the harmony of tastes by reducing the hot and overall tastes, as well as the acidic and garlic odors.³⁰ It was also found that both wheat flour and glutinous rice flour hastened the fermentation of yulmoo-kimchi.³⁰

4. Natural preservatives

The groups of LAB involved in kimchi fermentation continuously produce organic acids after the optimum ripening, and cause changes in the composition of kimchi. These changes are called over ripening or over acidification, and are often observed in summer kimchi and winter kimchi stored for extended periods of time. Over ripening is the most serious problem for storage of kimchi. Since over acidification is mainly due to the activities of lactic acid-producing LAB, the best way to overcome this is to control the growth of LAB without destroying the quality of the kimchi.

Screening of natural preservatives such as medicinal plants, edible plants, herbs and spices, antimicrobial agents and related compounds to inhibit kimchi fermentation have been studied extensively.⁶⁰ Among 42 oriental medicinal plants tested, Baical skullcap barks (Scutellaria baicalensis), and powders of Assam indigo (Baphicacanthus cusia) were very effective for preserving kimchi. Among 32 herbs and spices tested, peppermint leaves (Mentha piperita L.), cinnamon barks (Cinnamomum verum Presl), lemon balm leaves (Melissa officinalis L.), flower buds of clove (Eugenia caryophyllate Thunb.), hop leaves (Humulus lupulus L.), rosemary leaves (Rosmarinus officinalis L.), sage leaves (Salvia officinalis L.), horse radish roots (Moringa oleifera Lam.), and the leaves and flowers of thyme (Thymus vulgaris L.) showed high antimicrobial activity against microorganisms in kimchi. Clove was the most effective microbial inhibitor, when added to fresh kimchi. However, sensory testing was not appropriate for evaluation of the effect of herbs and spices, since their highly specific flavors affect the taste of kimchi. Among 28 fruits, vegetables and related plants tested, the leaves of pine tree (Pinus rigida), persimmon (Diospyros kaki) and oak (Quercus glauca) also demonstrated significant bactericidal effects. In addition, of 21 natural preservatives added individually to fresh kimchi, only nisin and caffeic acid were able to inhibit fermentation.⁵⁰

The changes of pH and acidity of baechu kimchi and mul kimchi were remarkably inhibited
by the addition the tea catechins to a level of 2mg/g fresh baechu, the results suggesting that the tea catechins can be successfully used for extending the shelf-life of kimchi.48)

Studies were carried out to investigate the effects of Lithospermum erythrorhizon and Glycyrrhiza uralensis (LG), both with and without dipping salted Chinese cabbage in 1% chitosan solution (LGDC), on the fermentation of kimchi at 10°C for 25 days. The sour taste of LG and LGDC treated kimchi changed more slowly than that of the control during fermentation. The shelf life of LGDC treated kimchi was extended by more than 10 days compared with the control.48)

By the addition of 1% mixed extract of Lithospermum erythrorhizon and Scutellaria baicalensis and 1% crab shell treated with ozone to kimchi, color, flavor, and sourness were negatively effected to a slight degree, while texture and overall acceptability were found to be the same or slightly improved compared with untreated kimchi.48 It was also found that the kimchi containing 2% ozone treated crab shell powders showed both strong neutralization action for 0-25 days and buffer action after 25 days during fermentation at 10°C.48)

Addition of 500 ppm grape fruit seed extract (GFSE) showed the highest pH during fermentation at 20°C and the lowest titratable acidity compared with the control. The total microbial counts were higher than the LAB counts immediately following the preparation of kimchi, but they were similar after three days. However, sensory evaluation of 3 day old kimchi samples showed a significant difference (P<0.05) between the control and the treated kimchi (100, 300 and 500ppm) when evaluating odor, color and taste. Only the 50 ppm GFSE sample was found not to be significantly different from the control.48)

Recently, the fermentation characteristics of mustard leaf kimchi with added green tea and pumpkin powder have been studied and it was found that the sensory scores for flavor, aroma and overall acceptability were highest in the kimchi with 0.3% pumpkin powder and 0.2% green tea powder.48)

The effect of chitosan (0.5%) on the properties of kimchi was studied during fermentation at 20°C for 8 days. It was found that chitosan reduced the total number of microorganisms and levels of Leuconostoc species and Lac. plantarum in kimchi, and the lower molecular weight chitosan fraction had the greatest effect on the levels of Leuconostoc species. Also, chitosan reduced the intensity of sour and stale flavor in kimchi, and the content of reducing sugar in control kimchi was lower than in the chitosan containing kimchi for the first 6 days of fermentation at 20°C. Malic acid content was lower and lactic and acetic acid content were higher for the control kimchi than for the chitosan containing kimchi for the first 4 days of fermentation. Control kimchi contained more succinic acid than the chitosan containing kimchi for the first 2 days of fermentation.48 Leuconostoc species and Lac. plantarum were higher in the control than in the chitosan containing kimchi dissolved in 0.3% acetic acid and 0.05% sodium benzoate.48 It was also found that addition of chitosan to kimchi influences pectic substance levels and improves their textural properties.48)

Two percent ginseng in kimchi had the best overall preservability and quality, and promoted the growth of Lac. plantarum and Lac. fermentum and inhibited the growth of Leu. mesenteroides and Ped. cerevisiae.48)

Addition of sap from pine needles (Pinus densiflora) delayed kimchi fermentation by slowing down the decrease in pH and inhibiting the growth of Lactobacillus species.48

Water extract of pine needles had stronger inhibitory effects against Lac. plantarum than against Leu. mesenteroides.48

It was found that mustard oil had antimicrobial effects on the major LAB of kimchi such as Lac. plantarum, Lac. brevis, Leu. mesenteroides and Ped. cerevisiae, and mustard powder (0.1%) and mustard oil (200 ppm) extended the shelf-life of kimchi, after 15 days storage at 15°C.48

The extract of bamboo leaves had a wide range of antimicrobial activity against Brettanomyces custersii, Klebsiella oxytoca, Pichia membranaefaciens which cause kimchi softening.48 Recently, the effects of cuttlefish bone (Sepiae os, enoki...
mushroom (*Flammulina velutipes*), Monascus koji, and boiled-dried edible seaweed (*Hizikia fusiforme*) on the fermentation and quality of kimchi have been studied.

5. Starters

The quality of kimchi can be controlled by desirable microorganisms, and various fermentation conditions such as temperature, salt concentration, and nutrients in raw materials. As already mentioned, kimchi fermentation and ripening are carried out by the microorganisms present in the raw materials. Sugars in raw materials are converted to lactic and acetic acid, carbon dioxide, ethanol and mannitol by the LAB growing at 1-3% salt concentration. The total count of kimchi microorganisms reaches its maximum level (1X10^6 cells/ml) at optimum ripening time, after which the number of LAB decreases slowly and maintains what is called the 2nd maximum level (1X10^5 cells/ml).

A hetero fermentative type of LAB, *Leuconostoc mesenteroides*, is a major bacterial component of kimchi from the initial to the middle stage of fermentation. During these stages, hetero fermentative type LAB produce various metabolites such as lactic acid, acetic acid, ethanol, carbon dioxide, mannitol, and dextran which are associated with the taste of kimchi, and the number of LAB reaches its maximum during the optimum ripening period. However, total number of *Leu. mesenteroides* decreases sharply when the pH of kimchi is decreased to 4.0. On the other hand, a homo fermentative type LAB, *Lac. plantarum*, which has a strong pH tolerance under high organic acid concentrations, continuously increases in count during kimchi fermentation to the last stage. It has been reported that the acidification of kimchi is mainly caused by *Lac. plantarum*.

As seen in Table 4, *Lac. plantarum, Lac. brevis, Leu. mesenteroides* and other yeasts have been used as starters in kimchi production.

<table>
<thead>
<tr>
<th>LAB and Yeasts</th>
<th>Characteristics</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Lac. plantarum</em></td>
<td>wild type</td>
<td>66</td>
</tr>
<tr>
<td><em>Lac. brevis</em></td>
<td>single or mixed starter</td>
<td></td>
</tr>
<tr>
<td><em>Ped. cerevisiae</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Leu. mesenteroides</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Leu. mesenteroides subsp.</em></td>
<td>wild type (psychrotrophic)</td>
<td>67,68</td>
</tr>
<tr>
<td><em>mesenteroides AO 2</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Leu. mesenteroides subsp.</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>dextranicum A 18</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Leu. paramesenteroides B 30</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Lac. bavaricus BO 1</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Lac. homohiochii B 2</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Leu. mesenteroides M-10</em></td>
<td>acid tolerant, resistant mutant</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>high CO₂ producer</td>
<td></td>
</tr>
<tr>
<td><em>Saccharomyces sp. YK-17</em></td>
<td>wild type, acid tolerant (psychrotrophic)</td>
<td>70,71</td>
</tr>
<tr>
<td><em>Sacch. fermentati YK-19</em></td>
<td>acid utilize (psychrotrophic)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>growth at 0.3% lactate and 0.6% acetate</td>
<td></td>
</tr>
<tr>
<td><em>Leu. paramesenteroides Pw</em></td>
<td>wild type, acid tolerant</td>
<td>72</td>
</tr>
<tr>
<td><em>Pw-100</em></td>
<td>acid resistant mutant</td>
<td></td>
</tr>
<tr>
<td><em>Leu. mesenteroides M-100</em></td>
<td>acid resistant mutant</td>
<td>73,74</td>
</tr>
<tr>
<td><em>Sacch. fermentati YK-19</em></td>
<td>aroma producer</td>
<td></td>
</tr>
<tr>
<td><em>Leu. mesenteroides</em></td>
<td>adipic acid resistant mutant</td>
<td>75</td>
</tr>
<tr>
<td><em>Leu. paramesenteroides</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
*Lac. bavaricus, Lac. homohiochii, Ped. cerevisiae, Leu. mesenteroides, Leu. dextranicum, Leu. paramesenteroides,* and *Sac. fermentati* were isolated from kimchi and have been used as kimchi starters to improve the quality and shelf-life of kimchi.66-71 The combination of *Leu. mesenteroides, Lac. brevis, Lac. plantarum* and *Ped. cerevisiae,* all strains isolated from kimchi, have been used as starters for kimchi fermentation. These starters increase the fermentation rate, and mixed strains are more effective than single strains in producing better organoleptic quality kimchi.66

Generally, kimchi fermentation has been carried out at relatively low temperatures, and psychrotrophic LAB have been isolated and characterized from kimchi fermented at 5°C.24,67 Therefore, psychrotrophic LAB isolated from kimchi fermented at low temperature were studied as starters for their effect on kimchi fermentation. The results indicate that the fermentation period can be shortened by use of LAB starters isolated from low temperature kimchi. Among the LAB used as kimchi starters, it was shown that *Leuconostoc species* were more effective than any other *Lactobacillus species* tested for kimchi fermentation.66

Because the acid production from the heterofermentative type LAB is lower than that of the homofermentative type LAB, the addition of an acid tolerant mutant strain *Leu. mesenteroides* as a starter for kimchi fermentation may inhibit the rapid pH decrease and lactic acid production during kimchi fermentation. Therefore, the mutant strain *Leu. mesenteroides M-10,* which could grow at low pH (3.0) at 10°C and produced more CO₂ than the wild type, was found to be a superior kimchi starter. With respect to total acceptability, the kimchi prepared using the mutant strain M-10 was better than the other strains, and use of the mutant strain extended the optimum ripening period of kimchi by two fold compared with that of the control. These results show that a mutant strain of *Leu. mesenteroides* which is more stable to growth in acidic conditions was able to extend the edible period of kimchi.66

Psychrotrophic yeast, *Saccharomyces fermentati YK-19,* that showed better growth at 10°C than at 25°C in the medium containing 0.3% lactic acid and 0.6% acetic acid, was isolated from kimchi and used as a kimchi starter in order to prevent over acidification of kimchi.70 The addition of *Sac. fermentati YK-19* prolonged the period of optimum fermentation (at pH 4.2 and 0.6-0.8 acidity) by >63%. The lactic acid content increased rapidly in control samples, followed by the kimchi with *Saccharomyces* sp. YK-17 and *Sac. fermentati YK-19* as starters. The growth of *Lactobacillus species* was inhibited by the addition of yeast starter, particularly by *Sac. fermentati YK-19.* Furthermore, sensory evaluation scores for acidic and moldy flavor were reduced by starter addition, while scores for freshness increased.70

*Leu. paramesenteroides P-100,* a psychrotrophic mutant which grew well at pH 4.0, and 10°C, and in an organic mixture (lactic acid:acetic acid;1:2) was derived from the wild type *Leu. paramesenteroides Pw.* Kimchi with added mutant strain P-100 had better taste than that of control kimchi by the sensory evaluation test and the optimal pH range of kimchi extended up to about 2.2-2.5 times. In the kimchi added with *Leu. paramesenteroides P-100,* the succinic acid content was higher than for that of the others tested, and the total number of *Lac. plantarum* was reduced about 2.5 fold when compared to the control kimchi.70

*Leu. mesenteroides M-100,* an acid tolerant mutant derived from the wild type strain *Leu. mesenteroides Mw,* and *Sac. fermentati YK-19,* an acid utilizing and aromatic flavor producing yeast, were tested for their ability to retard acidification and prolong of the edible period of kimchi.72-76 The addition of *Leu. mesenteroides M-100* to kimchi preparation may induce the prolonged acidification of kimchi because of its low production of lactic acid and increased growth in comparison with *Lac. plantarum.* Also *Sac. fermentati YK-19* may lengthen the edible period of kimchi by reducing the content of lactic acid and acetic acid during the later period of kimchi fermentation, and the superior flavor in the kimchi group treated with starters may be due to the various substances, carbon dioxide, and succinic acid produced by *Leu.
The inoculation with mutant strains of Leu. mesenteroides and Leu. paramesenteroides increased adipic acid resistance compared with the wild type species and its effect on the shelf-life of kimchi were evaluated. The combination of both mutants was more effective than that of any single strain in extending shelf life of kimchi. The optimum inoculation was 0.005% of a 1:10 mixture of Leu. mesenteroides: Leu. paramesenteroides according to the results from acidification tests and sensory analysis.

III. Conclusion

Kimchi has a unique taste characteristics having sour, sweet and carbonated tastes with medium texture. In this respect kimchi differs greatly from sauerkraut that is popular in the West. The optimum acidity, pH and salt concentration of kimchi are 0.6-0.8% (as lactic acid), 4.2-4.5 and 2.0-3.0%, respectively. Kimchi fermented at lower temperatures are superior in quality and taste to those fermented at higher temperatures.

Kimchi fermentation is complex and is due mainly to certain LAB and yeasts naturally present in the raw materials. Several physicochemical and biological factors such as salt and sugar concentration, temperature, raw materials, natural preservatives and starter culture influence the quality of kimchi. Among the many factors affecting kimchi fermentation, salt content and temperature are the most important, followed by the quality of raw materials and microorganisms, typically hetero fermentative LAB and psychrotrophic yeasts.

The salting of the major raw materials of kimchi is a very important step for fermentation and for the quality of the kimchi. The optimum salt concentration of kimchi is around 2.0-3.0%. Under the optimum salt concentration, temperature is the next important factor for controlling kimchi fermentation and preservation.

The optimum temperature for kimchi fermentation is 10-15°C, and storage temperature should be under 5°C. Selection of good raw cabbage is another important factor and addition of garlic, hot pepper, sugars and protein sources are also important for making quality and good tasting kimchi.

Many homo and hetero fermentative LAB, such as genus Lactobacillus, Leuconostoc, Weissella, Lactococcus, Streptococcus and Pediococcus were isolated and identified from various kimchi samples, but genus Leuconostoc, Weissella and other LAB producing organic acids, carbon dioxide and bacteriocins are the most important microorganisms for controlled fermentation of kimchi. Psychrotrophic and acid tolerant LAB, especially wild and mutant strains of the Genus Leuconostoc and yeasts, Genus Saccharomyces, utilizing organic acids and producing aromatic flavors could be applied as starters to control the fermentation and improve the shelf-life of kimchi. However, further studies are needed to understand the mechanism of these LAB and yeasts on kimchi fermentation.

After optimum ripening is reached, kimchi fermentation may continue until the product has an acidic taste and softened texture, which is caused the acid deterioration. Among the natural preservatives tested for preservation and preventing over acidification of kimchi, clove, tea catechin, chitosan, oil of fruits and plant seeds were effective for controlling kimchi microorganisms and improving the shelf-life of kimchi, but high concentrations of natural preservatives may cause an undesirable flavor in kimchi. The storage of kimchi at around 5°C is thought to be the best way to ensure long-term preservation up to 6 months.

Finally, further research is needed to develop the technology necessary for controlled fermentation using starters and for the long-term preservation of commercial kimchi at ambient temperature.

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