

# Safety of Fermented Foods

Assessing risks in fermented food processing practices and advice on how to mitigate them

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- 2 | Starter cultures & fermented food standards

## 3 | Fermented food guidance for:

3.1 Vegetables

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**3.3 Kimchi**

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Additional fermented food guidance can be accessed at: <http://www.bccdc.ca/health-professionals/professional-resources/fermented-foods>

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## Section 3 | Food safety reviews of fermented foods

A national working group of health inspectors, food safety specialists, and industry fermentation experts reviewed this food safety guidance.

Each fermented food review includes:

- background on the food,
- a description of the food preparation,
- a food flow chart,
- a review of the potential issues with the food preparation, and
- food safety control points.

**Figure 1 | Fermented foods described by fermentation agent and complexity**

Complexity	Foods	Fermenting Agent	Section
 <p>high</p> <p>low</p>	Sausage	Added LAB <sup>1</sup> , wild moulds & yeasts	3.13
	Kefir, Kombucha	SCOBY <sup>2</sup> based: <i>Acetobacter</i> , yeast & mould	3.11-3.12
	Koji, Miso	<i>Aspergillus</i> , wild or added yeast & LAB	3.10
	Tempeh	<i>Rhizopus</i>	3.9
	Natto	<i>Bacillus</i>	3.8
	Yogurt, Plant based cheese	Added LAB	3.6-3.7
	Dosa, Idli, Fesikh	Wild LAB and Yeast	3.4-3.5
	Vegetables, Sauerkraut, Kimchi	Wild or added LAB	3.1-3.3

<sup>1</sup>- LAB-lactic acid bacteria; <sup>2</sup>- SCOBY-symbiotic culture of bacteria and yeast

A non-fermented, high alkalinity processed food is also included in this guidance. Pidan century egg (Section 3.14).

### Box 1 | How to use the information in this food safety review


The information presented here lays out best practices for a variety of fermented foods, however, it does not replace or supersede federal and provincial guidance or regulatory requirements for fermented foods. Health inspectors, food safety staff, owner and operators of food processing facilities should follow federal and provincial food safety requirements. This work intends to assist food safety staff (health inspectors) to evaluate the safety of fermented foods and fermentation processes encountered during inspections. Owners and operators of food processing facilities may also find this guidance helpful as it reviews critical control points and measures recommended to produce safe fermented foods. The best available evidence guided this work at the time of publication. The application and use of this document is the responsibility of the user.

This guidance does not include information about good manufacturing practices, labelling practices, or management control programs for cleaning and sanitation, pest control, employee training etc. It is expected that operators will follow approved guidance and seek this information elsewhere.

## 3.2 | Kimchi

Authors: Sung Sik Jang, Lorraine McIntyre | BC Centre for Disease Control

### Overview

<p>Description</p>	<p>Cabbage and other vegetables are salted and fermented with other ingredients such as red pepper powder, garlic, ginger etc.</p> 
<p>Starter culture</p>	<p>Wild fermentation of lactic acid bacteria (LAB) is normal for smaller companies. Large commercial companies use proprietary starter culture not available for purchase (in South Korea, companies make their own). Backslopping is not a practice in this industry.</p>
<p>Key features</p>	<p>Depending on the process chosen</p> <ul style="list-style-type: none"> <li>• Cabbage is typically salted for several hours, the salt is rinsed off, then other ingredients are added, including salt, and the mixture is fermented.</li> <li>• Fresh kimchi, i.e. kimchi prepared for immediate consumption requires continuous refrigeration as pH may be &gt;4.6 allowing pathogens to grow. Fresh kimchi should be used within 3 days.</li> <li>• Fermented kimchi, i.e. kimchi fermented for longer periods, is held refrigerated until pH of &lt;4.6 or lower is achieved (max 7 days), or may be fermented at ambient conditions until a pH of &lt;4.6 or lower is achieved (max 3 days). If pH of 4.6 or less is not achieved within specified time the batch has failed and should be discarded.</li> <li>• Adequately fermented kimchi is held and stored under refrigerated conditions.</li> </ul>
<p>Hazards of concern</p>	<ul style="list-style-type: none"> <li>• <i>E. coli</i>, <i>S. aureus</i>, and <i>Salmonella</i> spp.</li> <li>• Norovirus</li> <li>• Parasites (worms: roundworm, hookworm and others)</li> <li>• Biogenic amine formation</li> </ul>
<p>Important control points</p>	<ul style="list-style-type: none"> <li>• Washing ingredients to remove soil and contamination</li> <li>• Fermentation is recommended at refrigeration temperatures to prevent the growth of acid tolerant pathogens</li> <li>• Brining to prevent the growth of pathogenic bacteria</li> <li>• Fermentation at lower temperature with pH drop to 4.6 or below to remove pathogens and parasites, and a holding time of two weeks prior to distribution.</li> </ul>

## Background

Kimchi originated from Korea 3,000 years ago and refers to various fermented vegetables. The first written record of salted vegetable pickles was found in a Korean compilation book describing the myth of the Goguryeo Dynasty (Dongkukisangkukjip), written in 1241 AD.<sup>1,2</sup> The Codex standard of kimchi was adopted in the 24<sup>th</sup> Codex Alimentarius Commission (2001) and explains the modern description of kimchi products below.<sup>3</sup>

The Codex standard for kimchi is:

- a. prepared from varieties of Chinese cabbage (e.g., Napa) that are free from significant defects, trimmed to remove inedible parts, salted, washed with fresh water, and drained to remove excess water; they may or may not be cut into suitable sized pieces/parts;
- b. processed with seasoning mixture mainly consisting of red pepper powder, garlic, ginger, edible *Allium* varieties other than garlic, and radish. These ingredients may be chopped, sliced and/or broken into pieces; and
- c. fermented before or after being packaged into appropriate containers to ensure the proper ripening and preservation of the product by lactic acid production at low temperatures.

Kimchi may be prepared with a wide variety of ingredients, making it possible to produce over 100 different varieties of kimchi with recipes containing mixtures of vegetable types (over 30 different types, among radishes for example, white, Daikon, ponytail or young Oriental may be chosen),<sup>4</sup> unique flavours and tastes.<sup>5</sup> The main vegetable ingredients of kimchi are cabbage, radish, and cucumber. Salt is an essential ingredient to promote lactic acid bacteria culture. Other flavourings such as red pepper powder, garlic, leek, and ginger are commonly used for seasoning.<sup>6</sup> The most widely consumed kimchi is “Baechu Kimchi”.<sup>5</sup>

Japan, China, and other countries produce and consume localized style kimchi. Japanese kimchi is made without or with a shorter fermentation period and flavoured with amino acids, sorbitol, fruit extract, and sugars. In contrast, Chinese style kimchi is fully fermented and made with stronger, hot flavours.<sup>7</sup>

As a staple food in Korea, kimchi has recently become popular in many countries, including North America. In Korea, kimchi is served daily with every meal, and Korean adults consume an average of 50-200g per day.<sup>8</sup> Kimchi is typically served raw, without heat treatment or pasteurization, and, like many fermented foods, is marketed as containing living probiotic microorganisms with health-promoting functions.<sup>9,10</sup>

Lactic acid bacteria (LAB) present on kimchi ingredients allow a natural, wild fermentation process. LABs will produce various acids and metabolites to prohibit the growth of pathogens originating from raw ingredients. Because kimchi is prepared and served without heat treatment, it can be a source of hazardous microorganisms if the fermentation process is not carefully managed during preparation or if it is not sanitarily handled before consumption.<sup>5,11</sup> Fermentation processes that lower pH are vital to ensure the safety of kimchi.<sup>2</sup>

While most kimchi varieties are consumed after fermentation<sup>12,13</sup> there are types of kimchi prepared with little or no fermentation. Fresh kimchi, named “Baechu-geotjeori”, may be made with a shorter fermentation period, or without any fermentation and is intended for immediate consumption, like a vegetable salad. In Korea, fresh kimchi has been implicated as the vehicle in multiple foodborne outbreaks during summer seasons, where pathogenic *E. coli* was detected.<sup>14,15</sup> Inadequate and minimal fermentation does not allow for development of acidic conditions (pH drop) nor for sufficient holding times, allowing bacteria present on ingredients (from soil or other sources) to persist in the final served product. Thus, in fresh kimchi, the sanitary quality of raw ingredients is important.<sup>15</sup>

A small microbiological survey of kimchi served in restaurants (n=7) in the Toronto area confirmed the presence of total coliform bacteria in 8 out of 12 samples (5 samples <1,000 CFU/g, 3 samples ≥1,000 CFU/g). Fresh kimchi was tested in this study, restaurants reported holding for 1 to 1.5 hrs before service or preparing for immediate service. Overgrowth on some samples suggested *E. coli* may have been present.<sup>16</sup>

## Outbreaks and Recalls

Summarized in Table 1, recalls of kimchi by the CFIA have been linked to labelling issues of undeclared allergens (16 batches of 2 brands in 2011), mould (1 batch of a brand in 2019) in imported kimchi products, and *E. coli* O157:H7 contamination in locally produced kimchi (1 batch in 2022).<sup>17–19</sup> In other countries, kimchi has been recalled for allergens when shellfish ingredients were not declared, for presence of *Listeria monocytogenes* (in U.S.) and for inadequate processing, including insufficient salt added to the product (Australia and New Zealand).

The Canadian recall in 2022 was linked to 14 foodborne illnesses of *E. coli* O157:H7, resulting in a public health notice about the kimchi outbreak.<sup>20</sup>

**Table 1 | Recalls related to kimchi products in Canada and elsewhere**

Country (s)	Year(s)	Hazard Category	Hazard Detail	Number of Recalls	Product Description
Australia, Canada <sup>18,21</sup>	2019, 2011	Allergen	Undeclared fish, shrimp, nuts, sesame	5	Cabbage and Korean Kimchi
Canada <sup>19</sup>	2022	Biological	<i>E. coli</i> O157:H7	2	Kimchi
USA <sup>22</sup>	2021	Biological	<i>Listeria monocytogenes</i>	1	Kimchi – multiple types
Australia <sup>23</sup>	2020	Biological	Insufficient salt content resulting in bacterial growth	1	Kimchi
Canada <sup>17</sup>	2019	Biological	Mould	1	Kimchi
New Zealand <sup>24</sup>	2020	Biological	Lack of process control	1	Kimchi

Table 2 summarizes foodborne illnesses and outbreaks linked to kimchi in Canada and other countries. Reported causes for outbreaks due to kimchi consumption include pathogenic microorganisms such as *E. coli* O169, *E. coli* O6, enteroaggregative *E. coli* (EAEC), enterotoxigenic *E. coli* (ETEC), *E. coli* O157:H7<sup>14,15,20,25</sup> and norovirus.<sup>26</sup> Although not shown in the table, several types of parasites are also reported to be a problem in Korea: *Ascaris lumbricoides* (roundworm), *Ancylostoma duodenale* (hookworm), *Trichostrongylus orientalis*, and *Isoospora belli*.<sup>27</sup> Large-scale outbreaks implicating kimchi occurred from poor quality of raw vegetable ingredients, unsanitary handling, and incomplete fermentation.

**Table 2 | Outbreaks related to kimchi products in Canada and elsewhere**

Country (s)	Date	Pathogen causing illness <sup>1</sup>	No. Ill (no. hospitalized)	Premises where outbreak occurred	Reason
Canada <sup>20</sup>	Jan 2022	<i>E. coli</i> O157:H7	14 (0)	Household	
S. Korea <sup>15</sup>	Jul 2013 May 2014	<i>E. coli</i> O6 (ETEC)	167 1022	Schools (n=1, 2013)	Insufficiently fermented kimchi
S. Korea <sup>26</sup>	Apr 2013	Norovirus	631	School	Non-potable groundwater
S. Korea <sup>25</sup>	Sep 2012	<i>E. coli</i> O120 and O99 (EAEC and ETEC)	1200	Schools (n=7)	
Japan <sup>28</sup>	2001-2002	<i>E. coli</i> O120 and O99 (EAEC and ETEC)	1	Community (Kauto, Japan)	
Japan <sup>29</sup>	June 1991	<i>E. coli</i> O169:H41	3	Household	Kimchi pickles from S. Korea

<sup>1</sup> – EAEC- enteroaggregative *E. coli*, ETEC-enterotoxigenic *E. coli*, EHEC-enterohemorrhagic *E. coli*

### Description of food preparation for kimchi

Kimchi preparation starts with salting the main vegetable ingredients to promote LAB fermentation. Ingredients include Chinese cabbage, white radish, cucumber and other vegetables. A salt brine solution of 10-12% concentration is recommended. The brine is mixed with ingredients for 2 – 10 hrs, and then the ingredients are washed with fresh potable water. Excess water is drained, and vegetables are cut into pieces (usually cabbage is halved into two pieces) depending on the variety of kimchi prepared. Seasonings are added, including red pepper powder, garlic, ginger, and edible *Allium* varieties (e.g., chives, onions). The mixture is further chopped and sliced into sizes suitable for packaging in containers, then fermented at refrigerated (preferred) or room temperature. The initial pH of kimchi is reported to range from 5 to 6, though it can vary according to the ingredient used (note: final pH of fully fermented kimchi should be 4.6 or lower). The typical tastes of kimchi are sour, sweet, and carbonated. These tastes are obtained from salt, and lactic acid fermentation of vegetables with seasonings and seafood. In commercial production, starter cultures may be used to produce a unique taste, but fermentation usually occurs from indigenous LAB on raw ingredients.



Figure 2. Traditional home made kimchi

Traditional kimchi is prepared in November or early December when the temperature decreases to less than 10°C, and storage over winter months is at 0°C and lower.<sup>30</sup> After preparation (washing, brining, and mixing), traditional kimchi is packed in pots and buried under the ground until the fermentation is completed. Texture and taste profiles of the kimchi will continue to change until consumed, usually in March of the next year. Temperature changes during holding in pots and interactions between LAB and composition of LAB species change throughout the fermentation period. Since the 2000's, modern home preparation of kimchi in South Korea occurs in consumer refrigerators with automated temperature settings that can be pre-programmed to ferment kimchi at temperatures of (for example) 15°C or 10°C for 2 to 4 days.<sup>31</sup> Lower temperature fermentations result in less volatile acid production and odour than kimchi fermented at 20°C<sup>32</sup>, however, storage after 24 hours at -1°C or lower resulted in preferred consumer tastes in several studies, consistent with traditional kimchi winter storage temperatures of kimchi pots underground.<sup>30,31,33,34</sup>

Modern kimchi is fermented under refrigeration, for e.g., 10°C and lower, at 4°C. Some processors initiate fermentation at room temperatures of 18°C to 25°C, but lower temperatures are recommended to prohibit the growth of pathogenic bacteria that may be present on raw ingredients and to enhance the growth of psychrotrophic LAB.<sup>2</sup> There is no standard length of time to hold kimchi before fermentation is considered complete, and timing is often based on flavour and texture profiles depending on consumer preference for acidic taste and softness. Consumers often prefer less acid, crunchier kimchi with shorter fermentation times. Commercial companies generally provide best before dates of approximately two months on products. From a food safety perspective, as long as kimchi has been fermented to a pH of 4.6 or lower, pathogens will not multiply in the food product. However, acid tolerant pathogens present on ingredients can be a concern if the kimchi is distributed too soon.



For kimchi sold raw (i.e. sold without heat treatment or pasteurization), operators are recommended to keep and hold product for a minimum of two weeks under refrigeration following fermentation once pH levels drop. This step is to allow sufficient holding time under acidic conditions for more acid-tolerant bacteria to die off before the product goes into distribution and is sold to consumers. Ingredients should be free from contaminants, and clean potable water for rinsing is required. An additional recommended step to remove pathogens in commercial operations with proprietary starter cultures, is to include a sanitizing step for fresh produce ingredients using diluted food grade chlorine bleach (100ppm), followed by rinsing or flushing with water with contact times of less than five minutes.<sup>35</sup> An additional rinse with diluted bleach (50ppm) is included after the brining step. This is not recommended for wild fermentation as bleach will kill native LAB necessary to start the fermentation. Other sanitizers are approved for fresh produce, such as periacetic acid, ozone and others.<sup>36</sup>

**Fresh kimchi concerns:** Pathogenic *E. coli* outbreaks in South Korea during summer months in schools have been linked to fresh kimchi.<sup>25</sup> This raises concern for fresh kimchi products made in restaurants that may be stored over several days before consumption. Guidance for the appropriate shelf-life for fresh kimchi was not found in the literature, however, a maximum of three days of shelf life is recommended. Operators are recommended to store fresh kimchi at refrigeration temperatures to prohibit the growth of unwanted microorganisms. Fresh kimchi should be used within three days, then discarded.

**Aged kimchi:** Traditional aged kimchi (named “Muguenji”) is made by storing kimchi at lower temperatures longer than other typical kimchi. Prolonged fermentation over six months produces higher acidity and a softer texture in this kimchi. It is used as an ingredient for kimchi soup or other Korean cuisines.<sup>4,12,37</sup>

**Fermentation temperature options:** As described, kimchi fermentation may occur at room temperature (defined as between 18°C to 22°C) or in cooler, refrigerated temperatures (defined as 10°C or less). Room temperature fermentation typically occurs in commercial on-premises production, with strict hygienic control of ingredients, to accelerate primary fermentation. However, if primary fermentation is not adequate to eliminate pathogens, any surviving unwanted bacteria could grow during secondary fermentation.

***The following guidance is proposed for kimchi critical limits for time to reach a pH of 4.6 or lower:***

pH decline depends on temperature, time and ingredients. The critical control point (CCP) is achieved when a sufficient drop in pH, i.e. a drop of pH to 4.6 or lower, occurs. This is the first stage of fermentation.

Cautionary note: At lower room temperature (18°C) it may take longer for pH to drop than the critical limits proposed below. Recent temperature modelling by Kim and colleagues (2020) proposed predictive models for acidity development in kimchi.<sup>38</sup> During kimchi fermentation, pH drops to approximately 4.6 or lower in 2 days at 20°C, 6 days at 10°C, 15 days at 5°C and 35 days at 0°C.<sup>38</sup>

*The operator should evaluate the conditions for kimchi manufacture and measure pH drop every 12 hours to establish a normal baseline for the process.<sup>11</sup> Critical limits should be based on those observations, and should be documented for review on request by the food inspector.*

## **CRITICAL LIMITS**

**Option A in kimchi food flow chart:** at room temperature (18°C to 22°C), a pH drop to 4.6 or lower should occur with 2 days (48 hours). If a pH drop to 4.6 or lower is not achieved within a maximum of 3 days (72 hours) the batch should be discarded (2+1 days or discard).

**Option B in kimchi food flow chart:** at cooler, refrigerated temperatures (10°C or lower), a pH drop to 4.6 or lower should occur within 4 days (96 hours). If a pH drop to 4.6 or lower is not achieved within a maximum of 7 days, the batch should be discarded (4+3 days or discard).

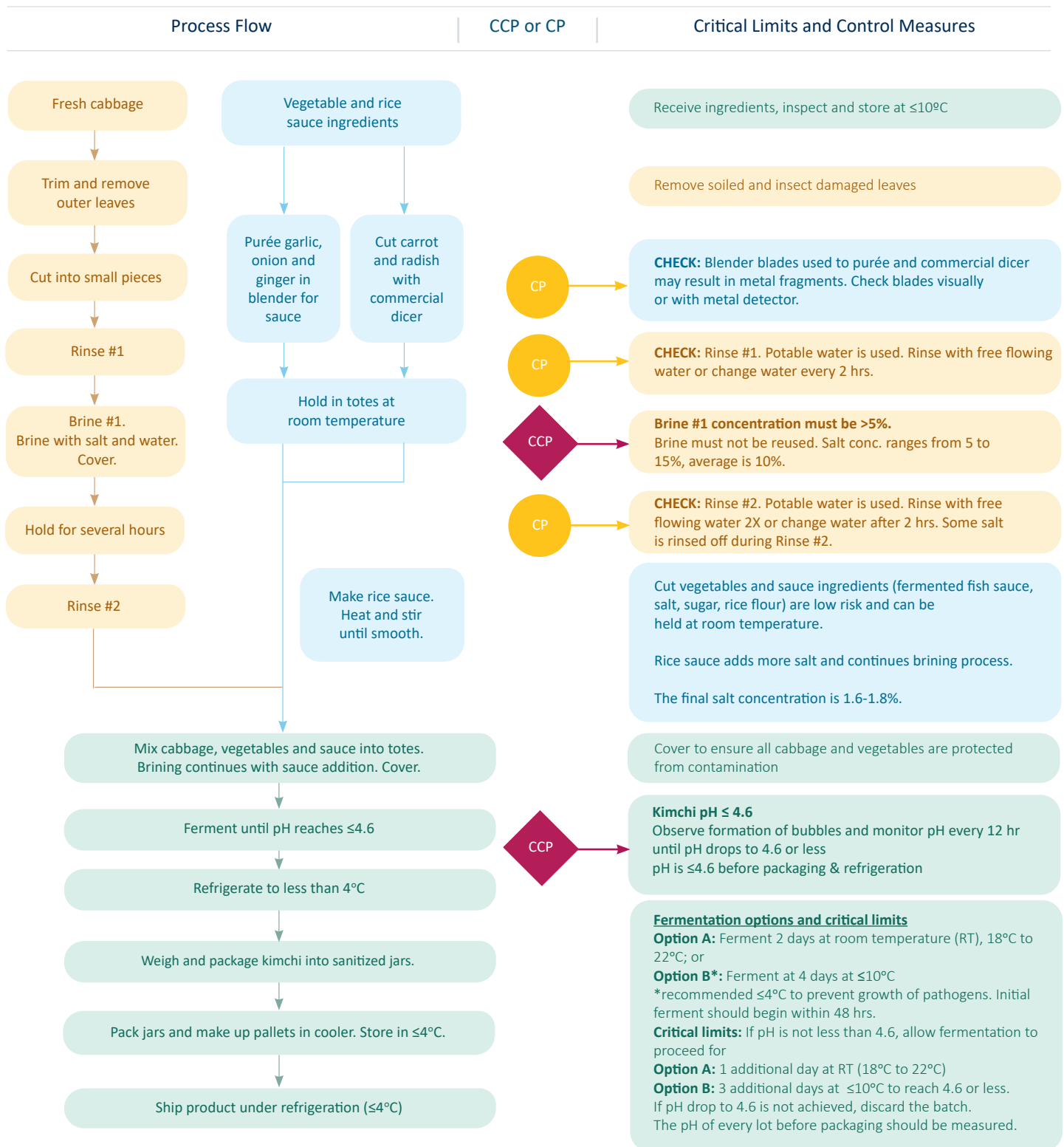
Although in Option A we propose a maximum of 3 days in this guidance at temperatures between 18°C to 22°C, up to 4 days has been reported in the literature.<sup>11</sup> Operators must evaluate conditions for fermentation (i.e., temperature and pH drop) and provide documentation (i.e. records) to justify deviations from guidance proposed here.

## ***Holding time following fermentation***

Illnesses in the most recent Canadian kimchi outbreak appeared to be linked to kimchi that had the shortest holding time before distribution.

One study examining pathogen persistence in acidified (non-fermented) vegetables at a pH of 3.8 noted a time interval of 237 hours for pickled vegetables in citric acid and 282 hours for acetic acid pickled vegetables to achieve a 5-log reduction of *E. coli* O157:H7.<sup>39</sup> For kimchi sold raw without pasteurization, operators are recommended to keep the product refrigerated after the fermentation period and to hold product for a minimum of two weeks once pH levels drop.

# Kimchi food flow chart | Process flow and controls



Based on BioTech kimchi process flow diagram<sup>40</sup> and Ministry of Food and Drug Safety guideline (South Korea).<sup>41</sup> NB: Diagram colours under process flow and controls are matched (green=cabbage process; blue=vegetable process; yellow=both process).

## Potential issues with kimchi food preparation

Issue	Description
<b>Pathogenic microorganisms (in source ingredients and cross-contamination during processing)</b>	Biological hazards include pathogenic microorganisms <i>S. aureus</i> , <i>Salmonella</i> , <i>E. coli</i> , norovirus, and parasites. These can be removed by washing ingredients using potable water during the preparation of raw ingredients and by rapid pH decrease, with final pH $\leq 4.6$ , during fermentation. Salt in the brine inhibits the growth of non-halophilic, putrefactive, and pathogenic bacteria and supports halophilic (2-3%) lactic acid bacteria. Organic acids produced by fermentation and antimicrobial substances such as bacteriocins and carbon dioxide inhibit pathogenic and aerobic bacteria. <sup>2</sup> Parasites in vegetable ingredients can be removed by washing and inactivated with an adequate fermentation process. <sup>2,27</sup> Parasites eggs have been detected in kimchi imported from China: <i>Ascaris lumbricoides</i> (roundworm), <i>Ancylostoma duodenale</i> (hookworm), <i>Trichostrongylus orientalis</i> , and <i>Isospora belli</i> . <sup>27</sup>
<b>Pesticide</b>	Pesticides may be present in raw ingredients. This occurs when pesticides are overused or when produce is harvested too early before pesticide residues dissipate. Washing, salting, and fermentation can remove or reduce pesticides on raw ingredients. One study found washing four times removed up to 43% of pesticide residue; the average half-life of pesticides (e.g., Chlorpyrifos) in this study was 1.8 weeks. <sup>42</sup> Higher fermentation temperatures and longer storage times inactivate pesticides, over 69.4% of the pesticide disappeared after storing kimchi for 24 days at 4°C. <sup>43</sup>
<b>Foreign material (Metal)</b>	Metal fragments can occur when metal blades and utensils are used to chop raw vegetables and other seasonings. Metal detectors should be used to detect iron and stainless steel fragments before packaging. <sup>27</sup>

### Kimchi food safety control points

- The quality of raw ingredients should be checked before the production process. Damaged or contaminated ingredients should be discarded.
- Raw materials should be thoroughly washed and rinsed with potable water to avoid contamination with microbial pathogens, and other foreign materials.
- Rinsing should occur under running water, otherwise, rinse water should be changed every 2 hours.
- Salting using a brine solution plays a vital role in prohibiting pathogenic microorganisms' growth and enhancing the growth of halophilic lactic acid bacteria.<sup>2,11</sup> The recommended brine concentration varies according to the literature (5% to 15%), but a minimum of 5% is recommended.<sup>2,11,44</sup> Brine concentrations should be declared in the SOP, and carefully controlled and consistent between batches.
- Holding and brining steps are recommended at refrigeration temperatures ( $\leq 4^{\circ}\text{C}$  and not more than  $10^{\circ}\text{C}$ ) to limit growth of pathogens that may be present before acid is developed by LAB.
- Brine must not be reused between batches.
- Backslopping is not part of the normal process for kimchi production.
- The final pH of kimchi should be 4.6 or lower. It is recommended to monitor the pH of kimchi every 12 hours to ensure pH drops to 4.6 or lower.
- In addition to a decrease in pH, the length of fermentation and temperature is essential for successful fermentation. A pH of less than 4.6 should be obtained within two days when fermentation occurs at  $18^{\circ}\text{C}$  to  $25^{\circ}\text{C}$  (room temperature) and within four days at  $\leq 10^{\circ}\text{C}$  (refrigerated temperature).<sup>11</sup> Kimchi fermentation is recommended at  $\leq 4^{\circ}\text{C}$  to (1) prevent the growth of acid tolerant pathogens, and (2) support the growth of psychrotrophic lactic acid bacteria growing at low temperatures.<sup>2</sup>
- During initial stages of fermentation, and as a customary practice, some operators will hold kimchi at room temperature for several hours to promote the further growth of microorganisms to obtain more flavours and taste. This practice is not recommended unless the pH has decreased to 4.6 or lower, because storing kimchi  $>4^{\circ}\text{C}$  (e.g., at non-refrigerated temperatures) can induce the proliferation of unwanted pathogenic microorganisms when the primary fermentation process has not been completed.

- Vacuum packing of kimchi prior to fermentation is acceptable because it helps to remove the air and enhance the growth of anaerobic lactic acid bacteria during fermentation.
- Kimchi ingredients should be under brine in food-grade containers resistant to leaching in high-acid environments. Plastic wrap may be placed over the kimchi to prevent mould forming on the top layer.
- The addition of bone or fish broth, raw oysters, or other seafood during fermentation is acceptable as long as the quality of added ingredients is controlled.
- Many varieties (>100) of kimchi in addition to typical cabbage kimchi are produced and consumed. Fresh kimchi made without fermentation or with a very short fermentation should be regarded as a kind of vegetable salad and must be refrigerated and prepared with an acceptable quality of raw ingredients. Ingredients should be free of soil and contamination, and washed before use. Fresh kimchi should be consumed as soon as possible.
- Refrigeration at  $\leq 4^{\circ}\text{C}$  is recommended as a secondary hurdle to prevent multiplication of pathogens in kimchi during fermentation and storage, even when pH is at 4.6 or lower. Refrigerated storage is also recommended for taste to prevent too much acid development.
- Following fermentation, a holding time of a minimum of two weeks is recommended before distribution of the product. This holding time period will allow for acids present in the kimchi to reduce *E.coli* (if present).
- Operators using starter culture may include a produce sanitizer step using a 100 ppm solution of food grade chlorine bleach water (or other approved sanitizer),<sup>36</sup> with contact times of <5 min. Produce (cabbage or other kimchi ingredients) should be rinsed again with potable water before the brining step. Following the brining step, a second rinse with a 50 ppm solution of bleach is recommended, followed by rinsing or continuous rinse with potable water, with contact times of <5 min. Commercial starter culture is added before fermentation. Use of sanitizer is not recommended for wild fermentations as bleach will kill off LAB and slow down acid development in the fermentation liquid.

### Potential health issues with kimchi

Biogenic amines can be produced during kimchi fermentation and are harmful if ingested in high concentrations. Biogenic amines occur primarily from metabolic activity by microorganisms during fermentation in Jeotgal (fermented seafood ) and Aekjeot (fermented fish sauce) products that are commonly used for kimchi production. Jeotgal and Aekjetot were found in one study to contribute to the production of histamine and tyramine in kimchi.<sup>45</sup> The highest levels of histamine reported for kimchi were 947.3 mg/kg (exceeding the illness threshold of 100 mg/kg), of tyramine were 357.9 mg/kg (within reported levels that cause illness between 100 and 800 mg/kg), and phenylethylamine of 23.9 mg/kg (slightly below the illness threshold of 30 mg/kg).<sup>46</sup>

### Box 2 | Biogenic amines in fermented foods

Biogenic amines (BAs) can be produced by microbes in fermented foods, such as fermented soybean products, vegetables, cheeses, sausage, and fish. Normal BA intake does not cause illness as intestinal amine oxidases break down and detoxify the BAs.<sup>17,18</sup> If large amounts of biogenic amines are ingested, or if amine oxidase activity is inhibited, then acute toxic symptoms can occur such as nausea, respiratory distress, hot flushing, sweating, heart palpitations, headache, bright red rash, burning sensations in the mouth, alterations in blood pressure, diarrhea and hypertensive crises.<sup>17,19,20</sup> The toxic effects of BA may vary between individuals as it depends on individual sensitivity and on the consumption of alcohol or drugs that are monoaminooxidase inhibitory.<sup>21,22</sup>

The main BAs are histamine, tyramine,  $\beta$ -phenylethylamine, putrescine, cadaverine and spermidine. Health Canada has set action levels for histamines in anchovies, fermented fish sauces and pastes at 200 mg/kg and for other fish and fish products at 100mg/kg.<sup>23</sup> However, there are no guidelines set for other fermented food products and BAs other than histamines in Canada, or elsewhere in the world. At present, the toxic doses in food are suggested only for three biogenic amines: 100-200 mg/kg for histamines, 100-800 mg/kg for tyramine and 30 mg/kg for phenylethylamine.<sup>18</sup>

Operators manufacturing fermented foods are not required to test for BAs in their products. Operators are recommended to list BAs as a potential chemical hazard in their food safety plan. Operators can address risks of BAs by:

- (1) ensuring preventative measures are in place, the facility is clean and sanitary, handling practices are hygienic to limit bacteriophages and bacteria that interfere with the culture process;
- (2) optimizing the fermentation: regulating time, temperature, moisture content, salt concentrations, and storage conditions; using good quality ingredients;
- (3) purchasing commercial starter culture and/or verifying quality starter culture;
- (4) monitoring that the expected culture activity occurs within correct timeframe; and
- (5) monitoring for expected pH.

If a fermented food is linked to foodborne illness in consumers, inspectors are recommended to consider testing for BAs if symptoms and onset of illness in cases fit suspected BA illness. Further information about BAs and testing is found in Section 2 of this guidance.

Appendix 1. Inspection checklist for kimchi production

This document is to provide checkpoints for manufacturing kimchi in food establishments such as plants or restaurants.<sup>11,42</sup>

<b>Facility name:</b>	<b>Facility address:</b>
<b>Date:</b>	
<b>Site contact name/position:</b>	<b>Phone/email:</b>
<b>Name of auditor:</b>	<b>Main kimchi ingredient</b> e.g., radish kimchi, cabbage kimchi, cucumber kimchi
<b>Notes</b> (e.g., distribution to consumers at home, for restaurants, sale to retail):	

How to use this checklist

**Step 1:** Obtain the SOP and records of temperature and pH from the processing facility for review.

**Step 2:** Guidance for the inspection

- Include worker representatives.
- Inspect processes and equipment through the facility systematically, find out what controls are being performed, and determine the suitability of each process.

General employee and facility hygiene				
Item	Yes	No	N/A	Comments
a. Handwashing facilities are available in processing area and being used.				
b. Production environment is clean and sanitary.				
c. Kimchi is not contacted with bare hands.				
d. An employee hygiene plan is available.				
e. SOP for cleaning and sanitation addresses biofilm formation on the process line to limit cross-contamination				

1. Ingredients receipt & storage				
Item	Yes	No	N/A	Comments
a. All ingredients are clean and sanitary.				
b. Damaged or spoiled ingredients are discarded.				
c. Ingredients are stored in the cooler, off the floor				

2. Prepare & salt cabbage				
Item	Yes	No	N/A	Comments
a. Purpose-built sinks are used.				
b. The brine concentration is minimum >5% and is consistent between batches.				
c. The brine solution is not reused.				
d. All food containers and equipment are washed and sanitized between every use.				
e. Blades and slicers are inspected after slicing to ensure no metal fragments in mixture				

3. Rinse/Drain				
Item	Yes	No	N/A	Comments
a. Rinse water for steps 1 and step 2 is replaced every 2h (every 1h when ambient temp >25°C).				

4. Mixing				
Item	Yes	No	N/A	Comments
a. Storage and production environments are clean and sanitary.				
b. Food-grade vessels are used.				
c. Gloves are worn to prevent bare hand contact during mixing				

5. Fermentation				
Item	Yes	No	N/A	Comments
a. The final pH $\leq 4.6$ should be obtained in 2 days at room temp and 4 days at $\leq 10^{\circ}\text{C}$ .				
b. Brine pH is measured every 12h until pH reaches 4.6.				
c. Batches that do not reach a pH of 4.6 or less within critical limits are discarded (note: critical limits, one extra day at room temp, or 3 extra days at $\leq 10^{\circ}\text{C}$ ).				

6. Refrigerated storage				
Item	Yes	No	N/A	Comments
a. Fermented kimchi is stored at refrigerated temperature.				
b. Shelf-life is recorded/best before date available.				
c. Fermented kimchi is covered tightly in the refrigerator at $\leq 4^{\circ}\text{C}$ .				
d. Food-grade containers are used.				
e. Signs of spoilage such as mould are not detected.				

7. Packaging				
Item	Yes	No	N/A	Comments
a. Food-grade containers are used.				
b. Package and label with batch/lot, allergen information, shelf-life (BBD).				

8. Other recommendations and comments				

## Frequently Asked Questions about kimchi production

**a. What is the acceptable pH of kimchi?**

Before fermentation, the initial pH of kimchi is approximately 5.8, decreasing to 4.6 or lower after several days of fermentation.<sup>43</sup> Also, if the normal microflora of kimchi is successfully maintained during storage, the pH will drop further as residual sugar content is consumed during fermentation. It is a reasonable assumption that if the pH of kimchi is over 4.6, it would mean the fermentation was not adequately performed, and growth of other pathogenic bacteria such as *E. coli* may occur. Therefore, the acceptable maximum pH of kimchi should be maintained at 4.6 or lower to prohibit the growth of pathogenic microorganisms.

**b. What is the appropriate time for pH drop?**

Literature suggests the final pH  $\leq$  4.6 be obtained in two days at room temperature (18°C to 22°C) and four days at refrigeration temperature (10°C or lower).<sup>11</sup> However, time for pH drop is dependent on ingredients as well as temperature, operators are advised to establish critical limits for their process.

**c. Can kimchi be vacuum packed before fermentation?**

Yes. Traditionally, rocks or heavy weights were placed on the top of salted cabbage to remove excess air to enhance the growth of anaerobic lactic acid bacteria during fermentation. Vacuum packing before fermentation is acceptable in the same context. Plastic wrap or weighted glass inserts in jars may also be used to weight down and create a barrier, reducing growth of moulds.

**d. Can bone or fish broth, raw oysters, or other seafood be added to kimchi during fermentation?**

Over 100 varieties of kimchi are being produced, and the various added ingredients decide the characteristics of each type. In particular, raw seafood is commonly used in the preparation of kimchi in Korea. As long as the quality of added ingredients is carefully managed in conjunction with proper fermentation to a pH of 4.6 or lower, the addition of various ingredients would be acceptable.



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Figure 2. Traditional home made kimchi. Dr. JinHee Kim (Public Health Ontario) with permission.