Modeling the Level of Contamination of *Staphylococcus aureus* in Ready-to-Eat Kimbab in Korea

GYUNG-JIN BAHK,1,2* CHONG-HAE HONG,3 DEOG-HWAN OH,4 SANG-DO HA,5 KI-HWAN PARK,5
AND EWEN C. D. TODD2

1Department of Food Industry Development, Korea Health Industry Development Institute, Seoul, 156-800, Korea; 2National Food Safety & Toxicology Center and the Food Safety Policy Center, Michigan State University, East Lansing, Michigan 48824, USA; 3Department of Veterinary Medicine and 4School of Biotechnology and Bioengineering, Kangwon National University, Chuncheon, Kangwon, 200-701, Korea; and 5Department of Food Science and Technology, Chung-Ang University, Anseong, Gyeonggi, 456-756, Korea

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ABSTRACT

The risk of *Staphylococcus aureus* in ready-to-eat kimbab (rice rolled in laver) sold in Korea was evaluated by a mathematical modeling approach. Four nodes were constructed from preparation at retail to consumption. A predictive microbial growth model and survey data were combined with probabilistic modeling to simulate the level of *S. aureus* in a single kimbab at the time of consumption. We estimated the mean level of *S. aureus* to be 2.92 log CFU/g for a typical kimbab (150 to 200 g each) at the time of consumption. Our model also showed that 29.73% of the kimbabs had ≥100,000 *S. aureus* CFU/g, which poses some risk of illness, since some level of enterotoxin would be expected from toxigenic strains. However, because of the lack of dose-response models for staphylococcal enterotoxin, the final level of *S. aureus* in the kimbabs could not be used to estimate how many people would become ill from eating them. Correlation sensitivity results showed that consumer eating patterns and initial contamination levels at retail stores were the most significant risk factors for illness and that temperature control under 10°C was a critical control point in kimbab retail establishments to prevent the growth of *S. aureus*.

Kimbab, rolled rice and other foodstuffs in laver, is a typical ready-to-eat (RTE) food in Korea and is made from boiled rice; seasoned laver, an edible purplish-red seaweed; and other previously cooked food ingredients. This is an RTE product that is generally offered for sale at room temperature. Recently, there has been a demand for this product, mostly at catering establishments and retail stores. If good hygienic practices are not followed in the actual making and storage practices, then the consumption of kimbab can present a risk of illness from contamination by pathogens such as *Staphylococcus aureus* or *Bacillus cereus*. *S. aureus* ranks second after *Salmonella* in causing foodborne outbreaks in Korea (9). Many outbreaks of foodborne illness in Korea have been attributed to the consumption of RTE food, including kimbab (8), and these outbreaks increased substantially from 6.9% in 1999 to 26.7% in 2003 (9). Although none of these RTE foods was specified, kimbabs were likely included because they are so popular. Recently, Park et al. (17) reported that kimbabs for sale in retail stores were contaminated with *S. aureus* and *B. cereus* (45 and 20% of samples, respectively). Although *B. cereus* has been implicated in a few outbreaks (9), it is not as important a pathogen as *S. aureus* in Korea; therefore, we limited our study to the contamination of kimbabs with *S. aureus*.

A science-based approach to food safety for pathogens is microbial risk assessment (MRA). MRA is increasingly used to evaluate and control public health risks such as contaminated foods. MRA offers a structured approach to assess risks to consumers that are associated with microorganisms in foods and can estimate the probability that a foodborne pathogen will lead to illness (14). This approach is increasingly being used within the area of food safety because it allows some degree of quantification of the risks and their reduction with potential mitigation strategies (10). However, it is not always possible to conduct a full MRA if the input data are limited. This applies particularly to the lack of dose-response data. At present, we do not understand enough about how toxin production is quantitatively linked to *S. aureus* counts to be able to correlate *S. aureus* levels with amounts of toxin produced or to predict how much toxin is required to cause illness. Thus, we limited our modeling to the contamination of a kimbab from retail to the time of consumption, taking into consideration the complexity of the processing, display at retail, and storage factors of this RTE food.

Our first objective was to develop a quantitative exposure assessment model to evaluate the risk associated with kimbab contaminated with *S. aureus*. The second objective was to study the different components of the exposure assessment where the risks might be the greatest.

MATERIALS AND METHODS

Model design. Most kimbabs are prepared at retail locations for sale directly to the public, and our exposure pathway reflects this for a single kimbab from retail to consumption. The model

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*Author for correspondence. Tel: 517-432-3100, Ext 125; Fax: 517-432-2310; E-mail: bahk@msu.edu. Korea address: 57-1 Noryangjin-dong, Dongjak-gu, Korea Health Industry Development Institute, Seoul, 156-800, Korea. Korea E-mail: parkkj@khidi.or.kr.*
TABLE 1. Description of variables and models for exposure assessment of Staphylococcus aureus in kimbab

<table>
<thead>
<tr>
<th>Node</th>
<th>Variables</th>
<th>Definition</th>
<th>Unit</th>
<th>Assumption/formula/distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Retail</td>
<td>Pp</td>
<td>Prevalence of <em>S. aureus</em> in kimbab</td>
<td>Log CFU/g</td>
<td>Beta (10, 10)</td>
</tr>
<tr>
<td></td>
<td>Pn</td>
<td>Prevalence of nondetectable kimbab</td>
<td>Log CFU/g</td>
<td>1 − Pp</td>
</tr>
<tr>
<td></td>
<td>Lp</td>
<td>Level in <em>S. aureus</em>–positive kimbab</td>
<td>Log CFU/g</td>
<td>Cumulative (2.61, 4, {2.61, 2.65, 2.77, 2.84, 3.16, 3.27, 3.47, 3.48, 3.5}, {0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9})</td>
</tr>
<tr>
<td></td>
<td>Ln</td>
<td>Level in nondetectable kimbab</td>
<td>Log CFU/g</td>
<td>Cumulative (-5.7, 2.5, {−5.7, −1.6, 2.5}, {0.01, 0.5, 0.99})</td>
</tr>
<tr>
<td></td>
<td>Cr</td>
<td>Contamination level of <em>S. aureus</em> in kimbab at retail</td>
<td>Log CFU/g</td>
<td>Discrete (Lp:Ln, Pp:Fn)</td>
</tr>
<tr>
<td>2 Display for sale</td>
<td>Ts</td>
<td>Storage time</td>
<td>h</td>
<td>Normal (2.31, 4.63)</td>
</tr>
<tr>
<td></td>
<td>Tms</td>
<td>Storage temperature</td>
<td>°C</td>
<td>Normal (22.5, 3.17)</td>
</tr>
<tr>
<td></td>
<td>G</td>
<td>Growth at selling</td>
<td>Log CFU/g</td>
<td>Equation 2</td>
</tr>
<tr>
<td>3 Holding</td>
<td>ts</td>
<td>Holding time</td>
<td>h</td>
<td>Normal (1.61, 0.78)</td>
</tr>
<tr>
<td></td>
<td>tms</td>
<td>Holding temperature</td>
<td>°C</td>
<td>Normal (22.5, 3.17)</td>
</tr>
<tr>
<td></td>
<td>g</td>
<td>Growth at holding</td>
<td>Log CFU/g</td>
<td>Equation 2</td>
</tr>
<tr>
<td>4 Consumption</td>
<td>Cf</td>
<td>Consumer eating pattern:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amount of consumption of <em>S. aureus</em> by group A</td>
<td>Log CFU/g</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amount of consumption of <em>S. aureus</em> by group B</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Consumption level of <em>S. aureus</em> in kimbab</td>
<td>Log CFU/g</td>
<td>Discrete (G:G, 87.99:12.11)</td>
</tr>
</tbody>
</table>

*a (a, b): a = positive no. + 1, b = total no. − positive no. + 1, based on data in Table 2.

*b Based on data in Table 2.

c The case of those who ate kimbab after keeping it for some time.

d Group A: those who ate kimbab soon after purchase.

e Group B: those who ate kimbab after keeping it for some time.

for exposure assessment for *S. aureus* in kimbab from display for sale at retail stores to consumption was constructed in an Excel (Microsoft, Redmond, Wash.) spreadsheet and was simulated with @RISK (version 4.5, Palisade, New§eld, N.Y.), a spreadsheet add-on program. The retail-to-table pathway (Table 1) was modeled as a series of unit operations and associated changes in pathogen events that included the following: (i) initial contamination level of kimbab at retail (node 1: retail), (ii) growth at retail stores (node 2: display for sale), (iii) growth during storage at home or elsewhere until the time of consumption (node 3: holding), and (iv) contamination level at consumption (node 4: consumption). All of these node values may give rise to a change in *S. aureus* prevalence, level, or both. The model to describe these changes was analyzed by Monte Carlo simulation, with input and output values given in terms of probability distributions reflecting uncertainty or variability (19). The node description, formulas, and input settings used in this model are shown in Table 1.

**Input settings—node 1: retail.** The first node in the model simulated the initial contamination of kimbab with *S. aureus*. Prevalence and concentration data for kimbabs while on display for sale in retail stores were derived from a 2004 survey in Korea (17) (Table 2). The prevalence was modeled as a beta distribution to simulate the uncertainty about the true positives in the survey (Table 1). Concentration was modeled as a cumulative distribution to simulate the uncertainty in pathogen levels (Table 2). This is consistent with the approach of Lindqvist et al. (11). The worst case, i.e., maximum level, was assumed to be 4 log CFU/g on the basis of the results obtained in the survey (Table 2). To estimate nondetectable levels of *S. aureus* in positive kimbab samples, we used the Jarvis equation (6) to calculate the contamination levels from the presence-absence tests, as follows:

\[
M = -(2.303/V) \log(Z/N)
\]  

(1)

where *M* is the true density of organism in the batch, *V* is the quantity of material tested, *Z* is the number of sample units assessed by testing as negative, and *N* is the total number of sample units examined.

Incorporating the data from Table 2 into this equation, we calculated the nondetectable level of *S. aureus* in kimbab at about −1.6 log CFU/g. It was assumed that this level could be represented by a left-hand–tailed cumulative distribution with mean values of −1.6 log CFU/g (50.0%), minimum values of −5.7 log CFU/g (1.0%), and maximum values of 2.5 log CFU/g (99.0%) to model the uncertainty about the true level of nondetectable *S.

TABLE 2. Survey of the prevalence and levels of Staphylococcus aureus in kimbab during 2004 in Korea (17)"
TABLE 3. The results of growth rate, lag time, and total growth amount of *Staphylococcus aureus* in *kimbab* (7)

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>Growth rate (GR) (log CFU/g/h)</th>
<th>Lag time (LT) (h)</th>
<th>Total growth (C) (log CFU/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>0.14</td>
<td>6.30</td>
<td>1.72</td>
</tr>
<tr>
<td>10</td>
<td>0.23</td>
<td>4.30</td>
<td>2.93</td>
</tr>
<tr>
<td>12</td>
<td>0.33</td>
<td>2.64</td>
<td>3.85</td>
</tr>
<tr>
<td>14</td>
<td>0.46</td>
<td>2.48</td>
<td>4.25</td>
</tr>
<tr>
<td>18</td>
<td>0.84</td>
<td>0.98</td>
<td>4.72</td>
</tr>
<tr>
<td>20</td>
<td>1.18</td>
<td>0.85</td>
<td>5.10</td>
</tr>
<tr>
<td>22</td>
<td>1.39</td>
<td>0.81</td>
<td>5.87</td>
</tr>
<tr>
<td>25</td>
<td>1.67</td>
<td>0.65</td>
<td>5.94</td>
</tr>
</tbody>
</table>

*aureus* in *kimbab* (Table 1). Finally, to estimate the level of *S. aureus* in *kimbab* at the time of sale, a discrete distribution was used to simulate the uncertainty in the initial contamination level (Table 1).

**Input settings—node 2: display for sale.** The second node simulated the growth of *S. aureus* in *kimbab* during storage at retail stores. To estimate the growth at this node, it is important that the proper growth model of *S. aureus* is chosen. The model must account for pathogen growth in *kimbab* by considering the storage time and temperature at retail stores. The growth model for *kimbab* was based on the results of growth experiments conducted by Jin et al. (7) (Table 3). We chose the Gompertz equation to generate growth curves from this limited set of experimental data (4):

\[
L(t) = A + C \exp(-\exp(-B(t - M)))
\]  

(2)

where \(L(t)\) is the log count of bacteria as a function of time (log CFU per gram); \(A\) is the starting value of the log count of bacteria—the contamination level of *S. aureus* in *kimbab* at retail, shown as Cr in Table 1 (log CFU per gram); \(C\) is the total amount of growth experienced as the bacteria count asymptotically approaches its maximum value as \(C\) in Table 3 (log CFU per gram); \(M\) is the time at which the bacteria growth rate is maximum (in hours); \(B\) is the growth rate at \(M\) (log CFU per gram per hour); and \(t\) is the storage or holding time, shown as Ts or ts, respectively, in Table 1 (in hours).

The \(B\) and \(M\) values for each temperature were determined by the following equation, with the values obtained from Table 3:

\[
B = \exp(1)\cdot \text{GR} / C
\]

\[
M = \text{LT} + (1/B)
\]

(3)

The response surface regression model for temperature was calculated for \(B\) and \(M\) values, which was created by equation 3 with the SAS (version 8.1, Statistical Analysis Systems Institute, Cary, N.C.) response surface regression procedure. To validate our model, the predicted values and experimental values were compared, and the growth model was tested with relative error and prediction error techniques used by Oscar (16) to estimate the model accuracy. The Triang distribution used for the \(C\) value in equation 2 was based on the total growth amount in Table 3 (e.g., Triang [5,10, 5.87, and 5.94] for temperatures of 20, 22, and 25°C, respectively) and was used to determine the uncertainty in growth depending on temperature.

The storage scenarios at *kimbab* retail stores were based on a Korea Food and Drug Administration survey (15) (Table 4), which reported the times and temperatures of *kimbabs* from production to retail sale. However, a weak point of this survey was that it was conducted only in the summer season, not year-round. Therefore, we decided to consider the temperature values the worst-case situation. The mean and standard deviation were used in a normal distribution to simulate the uncertainty in storage time and temperature at *kimbab* retail stores (Table 1).

**Input settings—node 3: holding until the time of consumption.** The third node simulated the growth of *S. aureus* in *kimbab* after its purchase from retail stores until the time of consumption. At this node, the growth model of *S. aureus* in *kimbab* was based on the survey of storage time and temperature before consumption. The Gompertz growth model was used in the same way as in node 2. The survey conducted by Oh et al. (15) reported the mean holding time to be 1.61 h with a standard deviation of 0.78 h, and this mean and standard deviation were used in a normal distribution to simulate the uncertainty in storage time (Table 1). To our knowledge, there are no data on the storage temperatures for *kimbabs* in homes, offices, or eating places. Therefore, the temperature of *kimbab* for this node was the same as for node 2 (Table 3).

**Input settings—node 4: consumption.** Node 4 simulated the final contamination level of *S. aureus* in *kimbab* at consumption. According to the survey reported by Oh et al. (15), 87.99% of consumers in Korea ate their *kimbab* soon after purchase, and the remainder (12.11%) ate it after keeping the *kimbab* for some time, about 1.6 h, as mentioned in the explanation for node 3. The survey data were used in the form of a discrete distribution to simulate the uncertainty of the time of consumption (Table 1).

**Simulation.** The model defined (Table 1) was simulated with the @RISK settings of Latin Hypercube sampling, 10,000 iterations, and a random number generator seed of one. A safety level for *S. aureus* in *kimbab* was determined by sensitivity and scenario analyses with @RISK. A sensitivity analysis was conducted to identify the model parameters that had the most influence on the final consumption level of *S. aureus*. This was achieved by calculating and ranking the correlation coefficients between each of the input parameters in the model and estimating the final consumption level for a single *kimbab*. A scenario analysis was attempted to identify the impact that different input values can have on the final contamination level.

**RESULTS**

**Initial contamination level.** The prevalence of *S. aureus* in *kimbab* at retail stores was 45.0%. The concentration of this pathogen ranged from 2.61 to 3.50 log CFU/g, with a mean of 3.08 log CFU/g (Table 2) (17). This survey was chosen because it was recent and contained quantitative data. However, this survey may not represent an accurate picture of *kimbab* in Korea because the sampling time, season, and geographic area were not accounted for. Therefore, a probability distribution model was used to account for
FIGURE 1. The predicted growth curves of S. aureus in kimbab at four different temperatures: 8, 12, 18, and 25°C.

FIGURE 2. Predicted versus observed growth values for S. aureus in kimbab. Dotted lines represent ±1 log CFU/g.

FIGURE 3. Cumulative distribution for comparing the increased counts of S. aureus in kimbab from initial contamination (in storage at retail) (A) to growth at retail (display for sale) (B) to storage at home or elsewhere until the time of consumption after purchase (holding) (C). (A) −4.91 log CFU/g (at the 5th percentile) to 3.50 log CFU/g (at the 95th percentile), with a mean of 0.74 log CFU/g; (B) −3.34 log CFU/g (at the 5th percentile) to 7.10 log CFU/g (at the 95th percentile) with a mean of 2.72 log CFU/g; and (C) −1.76 log CFU/g (at the 5th percentile) to 8.74 log CFU/g (at the 95th percentile) with a mean of 4.34 log CFU/g. The dotted line represents the threshold level for toxin production, 5 log CFU/g. The probability of pathogen levels above this level is (A) 0.00, (B) 26.68, and (C) 51.69%.

this total uncertainty and to add weighting in this simulation model. Results of the simulation indicated that the range of contamination levels for S. aureus in kimbab selling at retail stores was −4.91 log CFU/g (5th percentile) to 3.50 log CFU/g (95th percentile), with a mean of 0.74 log CFU/g (Fig. 3 (A)). Since the survey data were based on an analysis of samples after production, these results were assumed to be the initial contamination level of S. aureus in kimbab at retail stores.

**Growth model.** Response surface regression models for the effect of temperature on the $B$ and $M$ values of S. aureus in kimbab are shown by the following equations. Values of exp(1) and log(2) were incorporated into the values of $B$ and $M$ in the regression model. This transformation was used to stabilize model variance. Both values had high $R^2$ values, indicating a high degree of goodness of fit to the data. 

- $B = (0.083869 + 0.004253 \cdot T_m + 0.000966 \cdot T_m^2) / \exp(1)$ ($R^2 = 0.9669$);
- $M = (21.904231 - 1.639779 \cdot T_m + 0.033711 \cdot T_m^2)/\exp(1) \cdot \log(2)$ ($R^2 = 0.9962$), where $T_m$ = temperature.

The predicted growth curves of S. aureus in kimbab at different temperatures are shown in Figure 1. As expected, there were differences in growth kinetics with lag time and growth rate depending on various temperatures (data not shown). Figure 2 shows the comparison of predicted values with observed values. Some predictive values are overestimated with respect to the observed values, but most of the observed points were within ±1 log CFU of the predictions. To evaluate the growth model, we tested the prediction error for each model while varying temperatures. Prediction errors ranged from 5.3 to 34.7%, with the lower temperature showing the lower prediction error. Overall, 14.4% of the prediction errors with the growth models were lower than, or similar to, those of published models (16). Even though there were some overestimated values in this growth model, low prediction errors indicate that this growth model provides a reliable estimate of growth of S. aureus in kimbab at varying times and temperatures.

**Growth during storage at retail and until time of consumption.** For many microbiological hazards, conditions of storage and handling of foods have a major influence on their prevalence and concentration, particularly the latter. In this pathway of this kimbab model, it was assumed that there was no reduction in S. aureus levels, since the preparation of kimbab involved only rolling in laver and no heating step. The growth of any S. aureus present was determined only by time and temperature during display for sale.

The increased counts of S. aureus in kimbab from initial contamination through the temperatures and times found during retail storage (Table 4) and the effect of trans-
FIGURE 4. Relative frequency for the simulated result of a contamination level for S. aureus for consumption of kimbab. The estimated contamination level in log CFU per gram is −3.19 (minimum, 5th percentile), 3.62 (median, 50th percentile), and 7.35 (maximum, 95th percentile) with a mean of 2.92. The dotted line represents the threshold level, 5 log CFU/g, and the probability of toxin production sufficient to cause illness above this level is 29.73%.

port from retail to final consumption can be seen in Figure 3. The increased counts from the initial contamination (A) to storage at retail (B) have a mean of about 1.98 log CFU/g (B, 2.72; A, 0.74). The increased counts from display for sale (B) to consumption after purchase after having been stored for some time (C) have a mean of about 1.62 log CFU/g (C, 4.34; B, 2.72). A little gap between the two was not expected because the holding time from retail to final consumption is 1.61 ± 0.78 h, which is shorter than the time of storage at retail, 2.31 ± 4.63 h, but the ambient temperature would be higher than in a retail store. Clearly, this showed that during display for sale, transport, and subsequent storage, the temperatures might be too high and could allow the growth of S. aureus.

In this study, we assumed that the threshold level for S. aureus enterotoxin production was 5 log CFU/g. This level is generally considered the minimum level of concern for the consumer (18). Figure 3 also shows the probability of kimbab containing S. aureus above this level (10⁸ CFU/g), based on the simulation results being 0.00% at the initial contamination of kimbab in retail stores (A), 26.68% at the time of sale and subsequently consumed soon after purchase (B), and 51.69% upon the consumption of kimbab that has been held for some time after purchase (C).

**Final contamination level.** Figure 4 shows the probability distribution for the simulated results for the contamination level of S. aureus in a single kimbab at the time of consumption. The estimated contamination levels ranged from a minimum of −3.19 log CFU/g (at the 5th percentile) through a median of 3.62 log CFU/g (at the 50th percentile) to a maximum of 7.35 log CFU/g (at the 95th percentile) with a mean of 2.92 log CFU/g. The predicted probability for kimbabs to be above the threshold level of 5 log CFU/g was 29.73%. This percentage is smaller than shown in Figure 3C, 51.69%, because at this node, we considered all consumer eating patterns. Koreans eat kimbabs frequently and typically eat one or two (150 to 200 g each) at a meal. Although we did not do a complete exposure assessment, it is clear that many Koreans are consuming kimbabs containing S. aureus and that some of them would ingest enterotoxins.

**Sensitivity and scenario analyses.** These analyses were identified from the input distributions, which are significant in determining output variable values, e.g., the final contamination levels in kimbab in this study. Table 5 shows the correlation factors used in the sensitivity analysis affecting the final contamination level of S. aureus in kimbab during the retail-to-consumption pathway. The higher value in the sensitivity analysis had the most significant input variables. The consumer eating pattern is the most significant input variable, and the next most significant is the initial contamination level at retail stores. Therefore, according to the simulation results, to prevent foodborne disease by S. aureus through the consumption of kimbab, it is recommended that, in order of importance, consumers eat the kimbab soon after purchasing it and that the retail store keep the initial S. aureus contamination to a minimum through, for example, the use of good hygienic practices.

Since it is not easy to alter consumer eating patterns, the most easily controlled factor is the storage temperature at retail stores. Figure 5 shows the change of distribution of S. aureus during retail storage for the three storage temperature (8, 10, and 12°C) scenarios. The estimated maximum (95%) contamination level at 10°C storage is 5.20 log CFU/g. These results suggest that a temperature of less than 10°C is a critical control point for kimbab retail establishments to prevent the growth of S. aureus sufficient to produce enterotoxins.

**DISCUSSION**

This study illustrates a quantitative model for an exposure assessment of a single kimbab contaminated with S. aureus from production at retail until time of consumption. We could not proceed further to produce a risk characterization at the stage of the MRA because of the lack of a dose-response assessment. The actual harmful agent of S. aureus is not the bacterial cell but, rather, the enterotoxin that it may produce (2). Not all S. aureus strains produce enterotoxin, and there are different types of enterotoxins.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Parameter</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Consumer eating pattern (Cf)</td>
<td>1.000</td>
</tr>
<tr>
<td>2</td>
<td>Initial contamination level at retail stores (Cr)</td>
<td>0.827</td>
</tr>
<tr>
<td>3</td>
<td>Storage time of kimbab at retail stores (Ts)</td>
<td>0.444</td>
</tr>
<tr>
<td>4</td>
<td>Storage temperature of kimbab at retail stores (Tms)</td>
<td>0.034</td>
</tr>
<tr>
<td>5</td>
<td>Holding time of kimbab (t)</td>
<td>0.010</td>
</tr>
<tr>
<td>6</td>
<td>Holding temperature of kimbab (tms)</td>
<td>0.003</td>
</tr>
</tbody>
</table>

* Variables in Table 1.
Enterotoxin production from S. aureus depends on factors such as food type, temperature, water activity, pH, and preservatives (2). In this study, we considered only temperature because kimbabs are made from many ingredients. To date, no dose-response models have, to our knowledge, been attempted for toxigenic microorganisms such as S. aureus because the microbial count data are not sufficient to be correlated to toxin concentrations. According to the U.S. Food and Drug Administration, the minimum infective dose to produce symptoms of staphylococcal intoxication is less than 1.0 μg. This toxin level is reached when S. aureus populations exceed 100,000 per gram (18), but there is likely strain-to-strain variation, and some toxins may be produced at lower concentrations, given the outbreak data. Although the Anuciacao et al. study (1) reported that a substantially higher level (10^6 CFU/g) is required for toxin detection, we decided that the threshold level of concern would be 5 log CFU/g for production of enterotoxins, even though it may not be the threshold for illness (12).

Another problem in MRA has been determining the level of contamination of pathogens in foods when the methodology (sensitivity of the analytical procedure and the sampling plan) is insufficient to detect very low levels. Lindqvist et al. (11) reported that storage of cheeses with apparently no S. aureus led to detectable levels above the threshold and emphasized the importance of assumptions concerning the level of bacteria in samples in which a pathogen is not detected. Some risk-assessment studies assume that products can be recorded with less than 0.04 CFU/g, i.e., 1 in 25 g in negative samples. In our study, we included some low initial counts that would not be typically detected by routine testing since they are below the lower limit of detection. Therefore, to estimate the so-called nondetectable level of S. aureus in positive kimbab samples, we used the Jarvis equation (6). From this, we can infer the contamination level from presence-absence tests by calculating the number of negative samples at a single dilution level to derive the probability of the occurrence of zero defects. The advantage of this equation is that quantitative information from qualitative data is obtained. However, a disadvantage of this approach is that even the lowest estimated value may have a very small degree of risk. Therefore, to minimize this, we used a left-hand-tailed cumulative distribution with the lowest value for modeling set at 1%.

Predictive models describing the growth of S. aureus as a function of temperature, pH, and preservatives are available in both the U.S. Department of Agriculture Pathogen Modeling Program, version 7.0, and Food Micro-Model, but these cannot be linked directly in an iterative process, which is necessary to perform the simulation. Furthermore, these models were constructed from laboratory experimental conditions, e.g., growth in broth. Thus, we added Jin’s (7) S. aureus growth model to the exposure assessment simulation model, since it was constructed using growth in kimbabs, even though the results of this growth model are somewhat overestimated.

We used only storage time and storage temperature as control factors. However, there are many environmental factors that affect the growth of pathogens, such as pH and water activity. Therefore, in the future, these factors should be considered for estimating the pathogen’s growth more exactly. Nauta (12) pointed out that, in general, predictive models produce point estimates. If a confidence interval is given, it is not clear whether this represents variability, uncertainty, or both. In this study, we used the Triang distribution to determine the C value of the Gompertz equation to adjust for growth uncertainty with respect to temperature. Also, Nauta et al. (13) reported that many models neglect the variability between different strains of one species. This variability between strains can be relevant in the risk assessment of all microbial species, and we are aware that there may be good and poor enterotoxin producers present in kimbab, but we did not consider this in this assessment. The simulation model also did not take into account possible cross-contamination occurring during retail and eating places such as home and office, nor did it take into account home refrigeration temperature.

Many consumers may not have refrigerated their kimbabs, whereas others may have refrigerated them for variable times. Most of the attention in exposure assessment is focused on the concentration of a microbial hazard in food if it is present, even though food consumption data and consumer behavior are critical to develop a good estimate of risk (3). However, there are few data on consumer consumption characteristics that take into consideration consumer susceptibility to infection or, in this case, intoxication. All these types of data gaps and the required priority to fill them should be clearly communicated to risk managers (5).

However, despite the above-suggested limitations, a quantitative approach was useful to gain insight into the potential for illness from a very popular RTE food in Korea, to evaluate several factors that influence its potential risk as a pathogen, and to make some suggestions to minimize these risks. The consumption pattern and the control of S. aureus at retail stores appeared to be the most important risk factors to address when attempting to improve
the safety of kimbab and probably other RTE foods, and educational programs should be considered a way of impacting these issues. We plan to continue this study by estimating the amount and frequency of kimbab consumption in Korea and the likelihood of illness arising from Koreans eating kimbab, on the assumption that 100,000 S. aureus cells are sufficient for some enterotoxin production in some pathogen strains, with some degree of validation of the estimate on the basis of known illness data.

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