Quantitative Risk Assessment for Korean Style Menu Items: A Case Study on the Exposure Assessment of Saengchae (A Korean Radish Salad)

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Today, Korean style dishes are being globalized, and with such a trend, it should be ensured that they can be safe from foodborne contamination. In this study, QRA, which is a quantitative technique to predict contamination levels and to perform sensitivity and scenario analyses, was performed in order to achieve better safety management for Korean style menu preparations. First, the hygienic conditions of Korean style dishes were surveyed, showing that these foods would not be safe if managed improperly. Saengchae, which was one of the dishes, proved vulnerable to pathogen contamination, and was selected for the case study. As a result, the hazard factor was determined as Staphylococcus aureus, and the hygienic conditions in the restaurant used for the case study were considered safe from food contamination. Through sensitivity analysis, the CCP in the preparation procedure was determined as the storage step. Through scenario analysis, the CL of the resultant CCP was estimated as a storage temperature lower than 15°C, when stored for 3~5 hours. In conclusion, we demonstrated that QRA, known as a versatile solution in quantitative analysis, can be applied successfully to aid conventional HACCP for the safety management of Korean style menu items. Therefore, this study provides an example of a quantitative approach for more extensive cases in the safety management of Korean style dishes.

Key words: quantitative risk assessment, Korean style menu items, exposure assessment, Saengchae (a Korean radish salad)

1. Introduction

Since the 1980s, there have been large changes in Korea in terms of its population, jobs available to women, improvements in economic status, etc. In addition, the foodservice industry has become more competitive, especially since the 1990s [1,2]. In the years 1993, 1999, and 2003, the numbers of restaurants in Korea were 361173, 412166, and 505241, respectively. Korean style restaurants accounted for 60.77% of all restaurants in 1993, and are still rising in number [3–5]. However, most of them are small-scale restaurants, and they are usually managed under poor conditions for various aspects, including food safety. In Korea, HACCP (hazard analysis critical control point) was introduced in 1995 to prevent food poisoning, with food safety laws strictly established. In 2000, HACCP was applied to almost all food items in Korea. In 2003, the mandatory application of HACCP was assigned to several food items, while it was only optional before that time [6,7]. There is ongoing research to expand the application of HACCP in restaurant business [8–11]. At the present time, food safety issues are more popular than in the past, but in restaurants, there is still a need to address food safety concerns. Therefore, a better understanding of food safety in Korean restaurants is required.

Korean style menus, consisting of a few main dishes concomitant with many side dishes, are prepared in several ways. In general, the preparation methods encompass non-heat, heat and post-heat cooking. The main dishes primarily include items prepared by heating methods, but rarely non-heat or post-heat cooking methods. Fortunately, the target dishes for safety management were found to be non-heat or post-heat prepared dishes [13,14]. Since non-heat prepared items do not undergo a heating process, they are more likely to be contaminated. The sources of contamination include already contaminated ingredients, and cross-contamination through cooking
utensils or the kitchen environment, including food handlers. Thus, more safety cautions are required for non-heat prepared items, from handling of the raw ingredients to serving the finished dish. In particular, temperature control was found to be the most critical aspect because kitchens are usually at 5~60°C, which is known as the danger zone for microbial growth [12,15,1].

Several techniques or systems for food safety management have been developed, such as HACCP, SSOP (sanitation standard operating procedure), and GMPs (good manufacturing practices) [7,16-19]. Nonetheless, the incidence of food poisoning has continued to rise [ii]. Currently, HACCP is the most popular system for safety management, but in its practice, the identification of CCPs (critical control points) and estimation of CLs (critical limits) are usually difficult, and these are of great importance in HACCP. The reason for difficulty is that CCP identification and CL estimation are performed in long-term cycles and are based on professional consultation, safety management status at the locations, and surveys of past records of food poisoning occurrences. Therefore, QRA (quantitative risk assessment), a supplementary technique to HACCP, was introduced to quantitatively identify CCPs and estimate CLs [15,20-23]. Moreover, in QRA, actual contamination levels and process conditions with variability and uncertainty can be substituted into mathematical functions through Monte Carlo simulation [24,25].

In this study, QRA was performed to improve the safety management of a Korean style dish. Exposure assessment in QRA was performed to quantitatively identify the CCP and estimate the CL, in which the target dish was chosen as Saengchae (a Korean radish salad). Also, *Staphylococcus aureus* (which was recognized as a hazard) levels of the served dish, were predicted under certain hygienic conditions of the Korean style restaurants used in this case study.

### 2. Materials and Methods

#### 2.1 Hygienic characteristics of Korean style dishes

The hygienic characteristics of Korean style menu items were examined via literature survey, in terms of the handling of raw ingredients, preparation methods, serving, etc.

#### 2.2 Case study for exposure assessment in QRA

Saengchae (a Korean radish salad) was selected for the assessment. According to official food preparation classifications [12], Saengchae falls under non-heat dishes, that are generally more likely to be contaminated. QRA is composed of hazard identification, exposure assessment, dose–response assessment, and risk characterization [15]. In this case study, QRA was limited to hazard identification and exposure assessment. The exposure assessment is a key step to predict the contamination levels for the finished menu items. The routes for contamination, which are the occasions of exposure, were identified, and then the hygienic conditions of each occasion were analyzed in terms of contamination levels and management status.

##### 2.2.1 Identification of occasions of exposure

The contamination routes include the purchased raw ingredients, preparing of the dish, and storing and serving the finished dish (Fig. 1). The preparation methods of three typical Korean restaurants located in Seoul, as well as several technical reports, were surveyed [12,14]. In this case study, the occasions of exposure were limited to cutting, mixing, and storing before serving. Therefore, purchase, inspection, trimming, and washing were not considered in the exposure assessment.

##### 2.2.2 Sampling and microbial assay of *Staphylococcus aureus*

The ingredients at 10~25 g each, were collected with sterile tongs, and put into a sterile vinyl bag with 0.1% buffered peptone water (BPW) in an amount 9-fold greater than the sample weight. Next, the sample was processed by a model PUL 100E Pulsifier (Microgen Bioproducts Ltd, UK). Then, 1 ml of the extract, which was transmitted to a test tube with sterile water, was stepwise diluted 10 times. Also, the cooking utensils such as the knife, cutting board, mixing bowl, and storage container were swabbed with a special 3M™ e. swab, within a surface area of 10×10 cm² (length × width). This sample was subsequently treated in the same manner as the ingredients.

The properly diluted sample solutions of 1 ml were streaked on Baird Parker RPF agar (bioMérieux® sa, France). The *Staphylococcus aureus* colonies were counted 24~48 hr after incubation at 35°C.

##### 2.2.3 Monte Carlo simulation

Monte Carlo simulation is known to be an effective and practical tool to handle data with uncertainty and variability, and it can estimate contamination levels according to exposures. In this study, the exposure occasions included the already existing contamination of the washed ingredients, cross contamination from cutting and mixing, and
quantitative risk assessment for Korean style menu items

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As the first step in the Monte Carlo simulation, the contamination levels as well as working conditions at each step were expressed in appropriate distribution functions. Second, cross contamination levels were added, and microbial growth was calculated according to Gompertz equation [15,27]. Lastly, the Monte Carlo simulation was performed with @RISK 4.0 software (Plisade Inc, 2000) to predict the contamination level of the finished Saengchae.

The calculation procedure first decided the probability functions for the input data of the microbial level as well as the other variables such as temperature and food preparation conditions. Second, as shown in Tables 2, 3, and 4, the variables in the probability functions were inputted to the corresponding equations. The calculation of the equations led to the estimated contamination level of the finally prepared dish.

In addition, sensitivity analysis was performed to determine which of the input variables was critical for affecting the final contamination level [22,28,29]. The resultant variables were equivalent to CCPs. Furthermore, scenario analysis was conducted to analyze how the final contamination level changed according to changes in the conditions of the CCP. If there was an optimum condition other than just a trend, it became a CL for the CCP. The above operations were executed with the options of Latin hypercube sampling and 10000 iterations.

3. Results and Discussion

3.1 Hygienic characteristics of Korean style dishes

The menu items served in restaurants were surveyed, and consisted largely of three styles: Korean, Japanese, and Western, in which Korean style dishes were found to be the most popular. The Korean style dishes were differentiated into three kinds according to the presence/absence of heating in preparation, as shown in Table 1 [30,31]. Post-heat cooking is preheating the ingredients and then treating them with further preparation mainly by non-heat methods.

3.1.1 Non-heat dishes

The non-heat menu items included Saengchae, Hoe, Jeotgal, and Jangajji. First, Saengchae is usually prepared raw to sustain their original color, texture, and flavor and to reduce nutrient losses by heating. Saengchae is largely composed of raw vegetables. Raw vegetables are not clas-

![Flow chart of steps in the preparation procedure of Saengchae (a Korean radish salad). Exposure assessment in this case study covered only the steps from cutting to storing before serving. Dotted rectangle indicates the steps considered in the case study.](image-url)
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...sified as PHFs (potentially hazardous foods), and have not raised much safety concern, yet. However, it was reported that incidences of food poisoning occurred in Korea as a result of microbial growth in raw vegetables, by cross contamination from the environment, suggesting this type of dish is a potential source of food poisoning [13,32,33]. Also, the incidence of raw vegetable-induced food poisoning has been reported in the United States, United Kingdom, and Japan. [32,34,35].

Hoe is very popular, as almost all the nutrients or components are kept thermally intact. It is classified as a PHF due to the high likelihood for pathogen contamination and growth, and therefore, needs intensive safety management [36,37]. Jeotgal is salted fermented fish and shellfish, and Jangajji consists of fermented foods, vegetables, shellfish, and seaweeds with Ganjang (soy sauce), Doenjang (soybean paste), Gochujang, etc., and then fermented.

Table 1  Classifications of Korean style dishes according to presence/absence of heating during preparation and their characteristics.

<table>
<thead>
<tr>
<th>Preparation</th>
<th>Menu</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-heat</td>
<td>Saengchae</td>
<td>Salad to be mixed with seasoning</td>
</tr>
<tr>
<td></td>
<td>Hoe</td>
<td>Cut of raw fish, meat, or shellfish eaten with various seasonings such as Ganjang (soy sauce), Gochujang (Korean hot pepper paste), salt, oil, etc.</td>
</tr>
<tr>
<td></td>
<td>Jeotgal</td>
<td>Fish that is salted and then fermented. It has a unique flavor and taste.</td>
</tr>
<tr>
<td></td>
<td>Jangajji</td>
<td>Combination of vegetables (radish, sesame leaf, etc.), fish (dried yellow croaker), shellfish (abalone), and seaweed (laver, green laver, etc.) that is seasoned with Ganjang, Doenjang (soybean paste), Gochujang, etc., and then fermented.</td>
</tr>
<tr>
<td>Post-heat*</td>
<td>Sukchae</td>
<td>Vegetables that are blanched and then seasoned</td>
</tr>
<tr>
<td>Heat</td>
<td>Gui</td>
<td>Cut of meat or fish broiled in several ways such as by heating on a grill, in a pan, or in an oven</td>
</tr>
<tr>
<td></td>
<td>Twigim</td>
<td>Dishes of meat, fish or vegetables that are deep-fried, battered and coated with flour or egg. For example, Jeon is a pan-fried dish.</td>
</tr>
<tr>
<td></td>
<td>Bokkum</td>
<td>Dishes of meat, fish or vegetables that are cooked by roasting in a small amount of oil (similar to pan-frying).</td>
</tr>
<tr>
<td></td>
<td>Jorim</td>
<td>Dishes of meat, fish or vegetables that are hard boiled in Ganjang for a long time.</td>
</tr>
<tr>
<td></td>
<td>Tang</td>
<td>Soups that are boiled with a combination of ingredients</td>
</tr>
<tr>
<td></td>
<td>Tchigae</td>
<td>Stews that are boiled with a combination of ingredients. It has less water and more pieces as compared to Tang.</td>
</tr>
<tr>
<td></td>
<td>Chim</td>
<td>Dishes of meat, fish, or vegetables that are steamed and seasoned.</td>
</tr>
</tbody>
</table>

*Raw ingredients that are preheated and treated with further preparation mainly by non-heat methods.

Due to the absence of heating in the preparation of non-heat menu items, one should always be aware of the potential incidence of food poisoning. Thus, greater safety care should be given to avoid using already contaminated raw ingredients, and to prevent cross contamination from the kitchen environment of restaurants. In particular, temperature and the length of storage before serving should be strictly regulated.

3.1.2 Post-heat dishes

Sukchae is a typical post-heat menu item. The dishes in this category usually consist of mixing preheated ingredients and seasonings. As a result, the ingredients can be exposed to cross contamination from various sources such as cooking utensils, containers, chef, dishwasher, server, etc. Therefore, post-heat menu items should be managed with the same degree of safety as non-heat items [13,14].

3.1.3 Heated dishes

The menu items in this category, including Gui, Twigim, Bokkum, Jorim, Tang, Tchigae, and Chim, are more vulnerable to deterioration than items in the other categories, due to the denaturation of the components by heating. The preparation steps can be divided into two parts: before heating and after heating. Although there are contaminants that exist prior to heating, these can be con-
trolled to safe or sterile levels by subsequent heating. Likewise, the steps before heating do not need to be considered CCPs [13]. However, this is only true under the assumption that sources of hazard are only limited to microbial factors, which are recognized as the primary hazards in kitchen safety management besides chemical and physical factors [40]. Based on this assumption, the heating step itself or steps after heating are critical in terms of contamination. In most cases, it is the heating step that is determined as the primary CCP, and its CL is suggested as higher than 74°C inside the center of foods [41,ii]. The secondary CCP is usually the holding temperature before serving, and its CL is recommended as higher than 60°C. This is because subsequent deterioration can occur under improper holding conditions after initial heating [8,42,ii].

3.2 Quantitative risk assessment: the case study on Saengchae

As previously mentioned, QRA is composed of four general steps such as hazard identification, exposure assessment, dose–response assessment and risk characterization. This study was limited to exposure assessment and Saengchae was selected as an example, in order to show how the safety of Korean style menu items can be managed by applying QRA. Using simulation models, the contamination levels in the served foods were predicted, and CCP determination and CL estimation were achieved by sensitivity and scenario analyses, respectively.

3.2.1 Hazard identification

Hazard identification is prior to the exposure assessment in QRA. Hazard identification is performed to establish hazard factors by the quantitative likelihood of occurrences. On the other hand, hazard analysis, a counterpart in HACCP, is more inclined to identify hazard factors based on past outbreaks of poisoning [27]. In this study, however, hazard identification was only performed qualitatively, according to data from literature surveys.

*Staphylococcus aureus* was determined as the target pathogen in Saengchae for the following reasons [43,ii]. First, *S. aureus* is a common pathogen found in trash, sewage, excrement, and human skin throughout nature; therefore, it is often the primary source of contamination. Saengchae does not undergo a heating process, so this most commonly occurring pathogen should be the source. Second, humans are usually carriers of *S. aureus*, so poor food handling procedures can cause food poisoning. The food preparation methods in the kitchen must depend on the hygienic conditions of the food handlers more than any other place. Third, *S. aureus* is a cause of foodborne intoxication, so it produces enterotoxins at toxic levels when stored at room temperature; for example, 3 days at 18°C and 5 hours at 25–30°C. Saengchae is usually stored at room temperature around 20°C, 3–5 hours before serving. Lastly, according to statistical data from KFDA (Korea Food & Drug Administration) for sources of contamination, *S. aureus* was shown to be third, after the first and second pathogens, *E. coli* and *Salmonella* in 2007, in terms of the frequency of food poisoning occurrence [ii].

3.2.2 Exposure assessment

3.2.2.1 Identification of occasions of exposure

We analyzed what types of handling the ingredients underwent in preparation. As shown in Fig. 1, the raw ingredients such as the radishes and spring onions, which were inspected, were subjected to trimming, washing, and cutting, in series. Then they were mixed with seasonings such as minced garlic, red pepper powder, vinegar, sugar, and salt with powdered sesame, *etc*. The finished Saengchae is typically kept for a certain period of time, and then served with the main dishes. This is because side dishes such as Saengchae are usually prepared in larger amounts less frequently than main dishes, since main dishes are served in larger amounts than side dishes. The other general occasions for exposure to contamination were not counted as control points, such as the hygienic conditions of the kitchen floor, ceiling, air, water, waste disposal, *etc.*, which were assumed to be strictly regulated as SSOPs (standard sanitation operation procedures) [44].

3.2.2.2 Mathematical modeling of occasions of exposure

The occasions of exposure were classified into three sources: initially existing contamination of the raw ingredients, cross contamination from cooking utensils and human hands, and microbial growth during storage. In this case study, the occasions were simplified by excluding the washing step of the raw ingredients, and therefore, started with contamination in the already washed raw ingredients.

**Already existing contamination in raw ingredients**

The contamination of *S. aureus* in the four ingredients, including radishes, spring onions, minced garlic, and powdered red pepper, was modeled as shown in Table 2. The seasonings used, such as sucrose, salt, and vinegar, were
ignored, as they usually have more extensive shelf-lives. First, the contamination level of each ingredient was calculated as a product of concentration (CFU/g) and prevalence, and then the level for the entire ingredients was calculated as a product of the level of each ingredient and its portion in the whole ingredients (w/w). These three variables, prevalence, concentration and portion, were expressed as probability distribution functions.

The prevalences were expressed as beta distributions. The format in @RISK was RiskBeta(α, β), where α is r+1 and β is n-r+1; n is the number of total data with the presence and absence of detected colonies; and r is the number of data with only colonies present.

The concentrations of *S. aureus* were expressed as cumulative distributions. The format in the @RISK computer program was RiskCumul(min, max, {x₁, x₂, ⋯, xₙ}, {p₁, p₂, ⋯, pₙ}), where the min and max are for the experimental data, xₙ, and pᵦ is the cumulative probability of xᵦ [45]. For example, in a case that *S. aureus* was found in 5 samples out of 11 samples of radish, only the 5 samples were counted for RiskCumul(min, max, {x₁, x₂, ⋯, x₅}, {p₁, p₂, ⋯, p₅}).

The portions for each ingredient in the whole ingredients were expressed as uniform distributions. The format in @RISK was RiskUniform(min, max), where the min and max are for the range of portions.

Cross contamination from cooking utensils and human hands

Cross contamination from the cooking utensils and human hands was modeled as shown in Table 3. The variables under consideration were the contamination levels on the cooking utensils or human hands, and their transfer ratios and contact areas to the ingredients. First, the contamination level of each utensil or hands was calculated as a product of the concentration (CFU/g) and prevalence, and then the level of the cross contaminated ingredients was calculated as a product of the level of each ingredient and its portion in the whole ingredients (w/w). The prevalences, concentrations, and portions, were expressed as probability distribution functions.
Table 3 Mathematical functions of variables for cross contaminations from cooking utensils and human hands, and their operations, based on functions of @RISK for Monte Carlo simulation.

<table>
<thead>
<tr>
<th>Exposure occasion</th>
<th>Distribution function</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cooking utensils &amp; human hands</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knife</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer ratio of <em>S. aureus</em> by knife (Trsk)</td>
<td>RiskUniform (0.17, 0.88)</td>
<td>–</td>
</tr>
<tr>
<td>Prevalence of <em>S. aureus</em> on knife (Psk)</td>
<td>RiskBeta (11, 6)</td>
<td>–</td>
</tr>
<tr>
<td>Concentration of <em>S. aureus</em> on knife (Csk)</td>
<td>RiskCumul (20, 2800, [20, 40, 50, 60, 330, 420, 1240, 2800], (0.182, 0.273, 0.455, 0.546, 0.637, 0.728, 0.819, 0.911))</td>
<td>CFU/100 cm²</td>
</tr>
<tr>
<td>Contact area of knife (Cak)</td>
<td>RiskUniform (0.00143, 0.00167)</td>
<td>100 cm²/g</td>
</tr>
<tr>
<td>Level of <em>S. aureus</em> from knife (Lsk)</td>
<td>Trsk×Psk×Csk×Cak</td>
<td>CFU/g</td>
</tr>
<tr>
<td>Cutting board</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer ratio of <em>S. aureus</em> by cutting board (Trscb)</td>
<td>RiskUniform (0.17, 0.88)</td>
<td>–</td>
</tr>
<tr>
<td>Prevalence of <em>S. aureus</em> on cutting board (Pscb)</td>
<td>RiskBeta (11, 4)</td>
<td>–</td>
</tr>
<tr>
<td>Concentration of <em>S. aureus</em> on cutting board (Cscb)</td>
<td>RiskCumul (20, 700, [20, 30, 40, 50, 80, 100, 440, 700], (0.182, 0.273, 0.364, 0.546, 0.637, 0.728, 0.819, 0.911))</td>
<td>CFU/100 cm²</td>
</tr>
<tr>
<td>Contact area of cutting board (Cacb)</td>
<td>RiskUniform (0.01, 0.0125)</td>
<td>100 cm²/g</td>
</tr>
<tr>
<td>Level of <em>S. aureus</em> from cutting board (Lscb)</td>
<td>Trscb×Pscb×Cscb×Cacb</td>
<td>CFU/g</td>
</tr>
<tr>
<td>Hand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer ratio of <em>S. aureus</em> by human hands (Trsh)</td>
<td>RiskUniform (0.17, 0.88)</td>
<td>–</td>
</tr>
<tr>
<td>Prevalence of <em>S. aureus</em> on hands (Psh)</td>
<td>RiskBeta (9, 6)</td>
<td>–</td>
</tr>
<tr>
<td>Concentration of <em>S. aureus</em> on hands (Csh)</td>
<td>RiskCumul (60, 200, [60, 60, 100, 120, 130, 160, 200, 200], (0.22, 0.33, 0.44, 0.56, 0.67, 0.89))</td>
<td>CFU/100 cm²</td>
</tr>
<tr>
<td>Contact area of hands (Cah)</td>
<td>RiskUniform (0.00167, 0.002)</td>
<td>100 cm²/g</td>
</tr>
<tr>
<td>Level of <em>S. aureus</em> from hands (Lsh)</td>
<td>Trsh×Psh×Csh×Cah</td>
<td>CFU/g</td>
</tr>
<tr>
<td>Mixing bowl</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer ratio of <em>S. aureus</em> by mixing bowl (Trsmc)</td>
<td>RiskUniform (0.17, 0.88)</td>
<td>–</td>
</tr>
<tr>
<td>Prevalence of <em>S. aureus</em> on mixing bowl (Psmc)</td>
<td>RiskBeta (11, 5)</td>
<td>–</td>
</tr>
<tr>
<td>Concentration of <em>S. aureus</em> on mixing bowl (Csmc)</td>
<td>RiskCumul (20, 150, [20, 40, 50, 70, 80, 90, 120, 140, 150], (0.091, 0.273, 0.364, 0.455, 0.546, 0.637, 0.728, 0.819))</td>
<td>CFU/100 cm²</td>
</tr>
<tr>
<td>Contact area of mixing bowl (Camc)</td>
<td>RiskUniform (0.0125, 0.0167)</td>
<td>100 cm²/g</td>
</tr>
<tr>
<td>Level of <em>S. aureus</em> from mixing bowl (Lsmc)</td>
<td>Trsmc×Psmc×Csmc×Camc</td>
<td>CFU/g</td>
</tr>
<tr>
<td>Storage container</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer ratio of <em>S. aureus</em> by storage container (Trsc)</td>
<td>RiskUniform (0.17, 0.88)</td>
<td>–</td>
</tr>
<tr>
<td>Prevalence of <em>S. aureus</em> on storage container (Pskc)</td>
<td>RiskBeta (6, 6)</td>
<td>–</td>
</tr>
<tr>
<td>Concentration of <em>S. aureus</em> on storage container (Cskc)</td>
<td>RiskCumul (10, 80, [10, 20, 40, 80], (0.334, 0.501, 0.668, 0.835))</td>
<td>CFU/100 cm²</td>
</tr>
<tr>
<td>Contact area of storage container (Cakc)</td>
<td>RiskUniform (0.00625, 0.00667)</td>
<td>100 cm²/g</td>
</tr>
<tr>
<td>Level of <em>S. aureus</em> from storage container (Lksc)</td>
<td>Trsc×Pskc×Cskc×Cakc</td>
<td>CFU/g</td>
</tr>
<tr>
<td>Transferred contamination level of <em>S. aureus</em> from cooking utensils and hands (CLse)</td>
<td>Lsk+Lscb+Lsh+Lsmc+Lskc</td>
<td>CFU/g</td>
</tr>
<tr>
<td>Log contamination level of <em>S. aureus</em> in radish salad (LClsrs)</td>
<td>Log (CLsrm+CLse)</td>
<td>Log CFU/g</td>
</tr>
</tbody>
</table>
dients was calculated as a product of the level of each utensil/hands, its transfer ratio, and contact area to the ingredients. These four variables, concentration, prevalence, transfer ratio, and contact area, were expressed as probability distribution functions.

The concentrations and prevalences were expressed as cumulative and beta distributions, respectively, as similar to the previous occasion.

The transfer ratios and contact areas were all expressed as uniform distributions.

Microbial growth during storage

The finished Saengchae is usually stored for a certain period of time before serving, in which any present pathogens can grow. The dish is kept in a storage container at room temperature, so if the temperature is not in the proper range, it can lead to contamination at a toxic level. The microbial growth was described with the Gompertz equation (Eq. (1)).

\[ L = A + C \left\{ \exp\left(-\exp(-B(t-M))\right) \right\} \]

where \( L \) (log CFU/g) is the log count of bacteria at time \( t \) (hr), and \( A \) (log CFU/g) is the initial level of the log count of bacteria. \( C \) (log CFU/g) is the total amount of growth occurring as the bacterial count asymptotically approaches its maximum level. \( M \) (hr) is the time at which the absolute growth rate is maximal, and \( B \) (log CFU/g/hr) is the relative growth rate at \( M \). The variables and parameters in Eq. (1) and Table 4 are given in two forms: conventional deterministic numbers and probability distributions. The variables and parameters with uncertainty, which were \( L, A, C, B, t, M, T \) (storage temperature), and \( C_{NaCl} \) (NaCl concentration of radish salad), were expressed as distributions, and the others as normal deterministic numbers.

3.2.2.3 Prediction of the contamination level of the served dish

Using the mathematical models, the contamination levels of the served Saengchae were estimated by Monte Carlo simulation. The input variables and equation parameters were inserted into the series of equations described in Tables 2, 3, and 4, to calculate the contamination level of the Saengchae served after storage.

In Table 2, the experimental data of \( S. aureus \) concentration and prevalence were substituted in a cumulative function, and each ingredient portion in the whole ingredients in a beta function.

In Table 3, the experimental data of \( S. aureus \) concentration and prevalence were substituted in the same manner as in Table 2. But the concentration (CFU/100cm²) in Table 3 is per unit area swabbed from the sources of cross contamination, whereas the concentration (CFU/g) in Table 2 is per unit mass collected from the ingredients. The unit, CFU/100cm², was converted to the unit, CFU/g, by multiplying the concentration by the contact area with the ingredients. The contact areas were measured by observing the actual area of each utensil or hands in contact with the ingredients of unit mass, when preparing foods in the kitchen. The areas, a range of numbers, were expressed as a uniform distribution. In a previous report,

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Table 4  Mathematical functions of variables for microbial growth during storage and their operations, based on functions of @RISK for Monte Carlo simulation.

<table>
<thead>
<tr>
<th>Exposure occasion</th>
<th>Distribution function</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage temperature (( T ))</td>
<td>RiskUniform (13.1, 22)</td>
<td>°C</td>
</tr>
<tr>
<td>Storage time (( t ))</td>
<td>RiskUniform (3, 5)</td>
<td>hr</td>
</tr>
<tr>
<td>NaCl concentration of radish salad (( C_{NaCl} ))</td>
<td>RiskUniform (2.6, 2.8)</td>
<td>%</td>
</tr>
<tr>
<td>pH of radish salad</td>
<td>Fixed 5</td>
<td>-</td>
</tr>
<tr>
<td>Maximum population density (MPD)</td>
<td>Fixed 7.69</td>
<td>Log CFU/g</td>
</tr>
<tr>
<td>Number of log cycles of growth (( C ))</td>
<td>MPD – LCLSrs</td>
<td>Log CFU/g</td>
</tr>
<tr>
<td>Time at which the absolute growth rate is maximal (( M ))</td>
<td>McCann et al. (2003)</td>
<td>hr</td>
</tr>
<tr>
<td>Relative growth rate at ( M ) (( B ))</td>
<td>McCann et al. (2003)</td>
<td>Log CFU/g</td>
</tr>
</tbody>
</table>

\*\( M \) and \( B \) are calculated by the equations in the reference for the given conditions of \( T, C_{NaCl} \) and pH.
however, this conversion was simply performed by using a universal conversion factor of 100 cm$^2$ per 1 g [15]. So the conversion method in this study was deemed a better method, reflecting the actual working conditions. In addition, the transfer ratios of S. aureus from the contact area of the utensils or hands to the ingredients were considered; because although the contamination level on the contact area is very high, it is hardly transferred to the ingredients, and will not cause serious cross contamination. Marples and Towers [46] reported that the transfer ratio of Staphylococcus saprophyticus was 10% from a wet cloth to hands, and 85% from wet hands to a cloth. Mackintosh and Hoffman [47] reported that the transfer ratios of microorganisms generally range from 17% to 88% from hand to cloth. According to these findings, the transfer ratios from utensils or hands to food ingredients were all assumed as uniform distributions of RiskUniform(0.17, 0.88) in the @RISK program.

In Eq. (1) and Table 4, the equation parameters C, B, and M were calculated by MPD obtained from PMP (Pathogen Modeling Program, ver 7.0. USDA, USA), and by the predictive model of S. aureus growth developed by McCann et al. [48]. The other variables were directly measured from the actual conditions. Only the storage temperature was derived from a report on Saengchae by Heo and Lee [14].

A series of equations from Tables 2, 3, and 4, and Eq. (1), were used in the Monte Carlo simulation to estimate the final contamination level of the served Saengchae. In Table 5, the predicted level of the finished Saengchae is 1.20 log CFU/g, whereas that of the served Saengchae, which was stored 3~5 hours before serving, is 3.26 log CFU/g. It was reported that a contamination level of more than 6 log CFU/g for S. aureus, led to the production of enterotoxin to a level toxic enough to cause food poisoning [43,49,50]. Therefore, the hygienic conditions of the ingredients, preparation, and storage in this case study, were found to be safe, due to a predicted level lower than 6 log CFU/g.

Meanwhile, there can be a margin in this critical level of 6 log CFU/g that is associated with the production of enterotoxin to a toxic level; thus, exactly how much enterotoxin S. aureus of a certain concentration produces at different temperatures, pH, storage times, etc., should be made certain. Therefore, further research on enterotoxin production by S. aureus is needed.

3.2.3 Sensitivity analysis

Sensitivity analysis in QRA provides which processes or control points are most sensitive in changing the predicted contamination level of the products [45]. There are two options in sensitivity analysis, including the sensitivities of stepwise regression and Spearman’s rank correlation. The regression sensitivity was selected for this study, which was appropriate for the identification of the CCP. From the analysis, the storage temperature was found to have the highest sensitivity value of (+) 0.841, and the storage time had the second highest sensitivity value of (+) 0.493. This indicates that storage before serving was the most important step for safety management, which is equivalent to a CCP in HACCP. Therefore, the storage temperature and time should be managed as CCPs according to generic HACCP principles in terms of monitoring, establishing corrective actions, etc [16]. The CL for the CCP can quantitatively be estimated by scenario analysis in QRA, which is discussed in the next section.

3.2.4 Scenario analysis

The first CCP, the storage temperature, was subjected to scenario analysis in the range of 3~25°C (Table 6). Although the predicted levels were found to be lower than 6 log CFU/g, the previously mentioned toxic level, it was difficult to justify this temperature range as a safe zone. This was because the input variables used in the predictions, such as the initial contamination level of ingredients, pH, storage time, etc., were limited to this case study. Thus, the following further analysis was rigorously tried to find a universal CL.

<table>
<thead>
<tr>
<th>Output</th>
<th>Min</th>
<th>Mean</th>
<th>Max</th>
<th>$x_1^*$</th>
<th>$x_2^*$</th>
<th>$p_1$</th>
<th>$p_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log contamination level of S. aureus in radish salad (LCLsr)</td>
<td>0.72</td>
<td>1.20</td>
<td>1.57</td>
<td>1.01</td>
<td>1.40</td>
<td>5%</td>
<td>95%</td>
</tr>
<tr>
<td>Log contamination level of S. aureus in radish salad after storage (LCLsrss)</td>
<td>2.17</td>
<td>3.26</td>
<td>4.48</td>
<td>2.59</td>
<td>4.05</td>
<td>5%</td>
<td>95%</td>
</tr>
</tbody>
</table>

$x_1$ and $x_2$ are the contamination levels at $p_1$ and $p_2$, respectively, which are the cumulative probability.
In the changes of contamination levels according to the storage temperature, 15°C was found to be a boundary between two temperature zones with rapid and gradual changes. In the temperature zone higher than 15°C, if there was even a slight increase in storage time, the levels changed rapidly. However, if the storage temperature was lower than 15°C, any changes went slowly, compensating for any possible prolonged storage period. Consequently, the CL was determined as a storage temperature lower than 15°C. It was reported that *S. aureus* takes 5 hours at 25–29°C, but 7 days at 9°C, to reach a toxic level [43].

### 4. Conclusions

We studied the hygienic characteristics of Korean style menu items, and performed a case study applying QRA to a Korean style dish, Saengchae. Undoubtedly, Korean style dishes were found to be most popular in terms of the menu items served at restaurants in Korea. However, their hygienic characteristics were inferred to have potential for causing food poisoning when managed improperly.

In this case study, QRA was successfully applied to find CCPs and estimate CLs, as a supplementary technique to conventional HACCP. Compared with the decision tree method of HACCP, the exposure assessment in QRA seems more reasonable for identifying CCPs, performed based on quantitative analysis rather than qualitative decisions. By sensitivity analysis in QRA, the CCP was determined as the storage temperature and time before serving the Saengchae. Even the CL could be rigorously estimated by scenario analysis. In addition, an exposure assessment predicted the contamination level of *Staphylococcus aureus* in the served Saengchae, indicating that the restaurant subjected to our case study was safe from food poisoning.

In conclusion, we demonstrated that QRA, which is known as a versatile solution in quantitative analysis, can be successfully applied to aid conventional HACCP for the safety management of Korean style menu items. Therefore, this study is an example of a quantitative approach that can be used in more extensive cases of Korean style dishes, to improve their safety management.

### Acknowledgement

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### References


[33] K. Ryu; Cleaning and sanitation of raw vegetables and fruits.


[45] @Risk Advanced risk analysis for spreadsheets, Palisade Corporation, 31 Decker Rd, Newfield, NY 14867, USA.


**URLs cited**
