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## Microbial risk assessment of staphylococcal food poisoning in Korean kimbab

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### Abstract

The objective of this study was to conduct a preliminary microbial risk assessment for *Staphylococcus aureus* in kimbab, and then propose appropriate guidelines for its preparation and storage. Kimbab is a ready-to-eat product, popular in Korea, made of various foods surrounded by rice and seaweed. Because it is usually prepared by hand and stored at room temperature, it can be contaminated with *S. aureus*. Data on the prevalence, concentration and growth of *S. aureus* in kimbab as well as typical ambient temperatures in Seoul were collected; probability distributions were then selected to describe these data. A Monte Carlo simulation model was created using @risk. When current Korean retail data on *S. aureus* prevalence and concentration were used as inputs, the simulation predicted that the *S. aureus* concentration would be between 4.0 and 4.9 log CFU/g after 1 h of storage at ambient temperature during the warmest part of the year (March through November). Conversely, by assuming a starting concentration of 1 cell/g, the simulation predicted that the *S. aureus* concentration would reach 4.4 log CFU/g after 5 h of ambient storage in May and 3.4 log CFU/g in October. Our results suggest that, given the current prevalence and concentration of *S. aureus* found in kimbab at retail outlets, the product should be consumed within 1 h of purchase. Our results also indicate that if Korean consumers wish to safely store kimbab for 5 h at ambient temperature, *S. aureus* concentration should not exceed 1 CFU/g at the time of preparation.

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**Keywords:** Kimbab; *Staphylococcus aureus*; Quantitative risk assessment; Monte Carlo simulation

### 1. Introduction

Kimbab is the most popular ready-to-eat food in Korea. It is similar to sushi, but does not contain raw fish. It is made of various foods (e.g. ham, eggs, cooked vegetables) surrounded by rice and seaweed. Because kimbab is usually prepared by hand after all the ingredients have been cooked and cut, it can be contaminated with *Staphylococcus aureus*. Recently, Park et al. (2005) tested 32 samples of kimbab from several restaurants and found that 20 were contaminated with *S. aureus*. Kimbab can be eaten promptly after preparation and purchase, but it is typically consumed later. Many Koreans, especially students, enjoy partaking of this product as a picnic lunch, which means it is consumed several hours after preparation. It is considered a

potentially hazardous food (Institute of Food Technologists, 2001) and requires time/temperature control. However, people usually store it at room temperature to avoid retrogradation of the rice starch. This makes the rice hard and is considered organoleptically unacceptable by Korean consumers.

The Korean Food Code stipulates that pathogens should not be detected in kimbab (Korea Food and Drug Administration, 2006). Unfortunately, pathogenic microorganisms often are found in this product and the Korea Food and Drug Administration reports that kimbab has been implicated in many foodborne disease outbreaks. Woo (2005) has determined that, for the year 2004, “lunch box” (an assortment of Korean foods commonly served in a plastic box) and kimbab together are the primary cause of foodborne illness outbreaks in Korea, followed by fishery and then meat products. The Korea Food and Drug Administration reports that *S. aureus* was the third leading causative bacteria of foodborne illness outbreaks in Korea in 2004 (Korea Food and Drug Administration, 2005).

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Some research on *S. aureus* in kimbab has already been conducted. Lee et al. (2004) used a predictive growth model to estimate the maximum edible time of kimbab to be 1.9 h at 30 °C and 17.7 h at 15 °C. Bahk et al. (2005, 2006) developed a quantitative microbial risk assessment (QMRA) model for *S. aureus* in kimbab and suggested that it be stored at less than 10 °C. The latter study was limited, however, by using data from only 20 samples in its exposure assessment. More studies are needed to understand the risk factors associated with kimbab preparation and storage so that *S. aureus* foodborne disease outbreaks associated with this popular Korean food can be reduced.

QMRA is a useful method in the ongoing efforts to ensure food safety. It is traditionally defined as consisting of four components: hazard identification, dose–response assessment, exposure assessment and risk characterization, which together provide numerical expressions of risk (Codex Alimentarius Commission, 1999). Because the estimation of microbial risk inherently contains variability and uncertainty, simulation methods such as Monte Carlo are typically used to conduct QMRA (Schlundt, 2000; FAO/WHO, 2002).

The objective of this study was twofold: (1) to conduct a preliminary microbial risk assessment for *S. aureus* in kimbab using Monte Carlo simulation and (2) to conduct a scenario analysis of various storage times and initial contamination levels to propose appropriate guidelines for the preparation and storage of this food product.

## 2. Materials and methods

### 2.1. Initial prevalence and concentration

Two factors, contamination levels of *S. aureus* in kimbab at time of purchase and the amount of growth before consumption, were considered and a simulation model was constructed to estimate the distribution of the contamination level of kimbab at time of consumption. A description of the parameters used in the simulation model can be found in Table 1.

Table 2

Published prevalence data for *S. aureus* in kimbab

Sample source	Number of samples		Reference
	Tested	Positive	
Restaurant	32	20	Park et al., 2005
Restaurant and store	46	9	Park et al., 2003a
Restaurant and store	214	73	Kang et al., 2002
Store	20	0	Jeon et al., 2004
Store	25	0	Park et al., 2003b
Store	5	0	Consumer Safety Center, 2003
Store	42	1	Kim et al., 2001
Total	384	103	

To estimate the contamination level at time of purchase, data on the prevalence and concentration of *S. aureus* in kimbab at retail establishments were collected from the scientific literature and government publications.

Seven studies (Kim et al., 2001; Kang et al., 2002; Consumer Safety Center, 2003; Park et al., 2003a; Park et al., 2003b; Jeon et al., 2004; Park et al., 2005) contained data on *S. aureus* prevalence in kimbab at the retail level and are summarized in Table 2. The percentage of positive samples varied among the studies but Kang et al. (2002) has shown that there were no seasonal differences. A total of 384 samples were tested in the seven studies cited above and *S. aureus* was detected in 103 of these samples (26.82%).

Some of these studies also estimate *S. aureus* concentration in kimbab. Park et al. (2005) reported that the concentration of *S. aureus* in contaminated retail kimbab was 2.61 to 3.50 log CFU/g in non-chain or 1.48 to 5.29 log CFU/g in chain-type restaurants. Kang et al. (2002) tested 214 samples and determined that 56% of the positive samples were contaminated with less than 200 CFU/g of *S. aureus*. Given the generally poor quality and somewhat contradictory data, we selected the Pert distribution to describe the initial concentration of *S. aureus* in contaminated kimbab where the minimum value selected was

Table 1

Simulation model parameters used to estimate the contamination level of *S. aureus* in kimbab at time of consumption

Unit operation	Distribution	Variables	Description	Unit	Formula
Purchase	Input	$P_K$	Prevalence of <i>S. aureus</i> in kimbab	–	Discrete ([0,1],[73.2,26.8])
	Input	$C_{CK}$	Concentration of <i>S. aureus</i> in contaminated kimbab	log CFU/g	Pert (0, 2, 5.29)
	Output	$C_K$	Contamination level of <i>S. aureus</i> in kimbab	CFU/g	IF ( $P_K=0,0$ , ROUNDDOWN (POWER(10, $C_{CK}$ ), 0))
Consumption	Input	$T$	Temperature	°C	Pert(min, median, Max)
	Input	$t$	Time	H	Fixed, 1–6
	Input	LT	Lag time of <i>S. aureus</i> in kimbab	H	$1/(0.0547 \times T - 0.0604)^2$
	Input	GR	Growth rate of <i>S. aureus</i> in kimbab	log CFU/g/h	$(0.0584 \times T - 0.1329)^2$
	Input	MPD	Maximum population density	log CFU/g	Fixed, 9
	Output	$LC_{KC}$	Log contamination level of <i>S. aureus</i> in kimbab at consumption	log CFU/g	IF ( $P_K=0, 0$ , IF ( $t < LT$ , LOG( $C_K$ ), LOG( $C_K$ )+GR $\times(t-LT)$ ))
Output	$C_{KC}$	Contamination level of <i>S. aureus</i> in kimbab at consumption	CFU/g	IF ( $LC_{KC}=0, 0$ , IF ( $LC_{KC} < MPD$ , ROUNDDOWN(POWER (10, $LC_{KC}$ ), 0), POWER (10, MPD)))	

Table 3  
The growth rate and lag time of *S. aureus* in kimbab from Jin et al. (2004) as reported by Bahk et al. (2005)

Temperature (°C)	Growth rate (log CFU/g/h)	Lag time (h)
6	0.03	21.17
8	0.14	6.30
10	0.23	4.30
12	0.33	2.64
14	0.46	2.48
16	0.53	1.33
18	0.84	0.98
20	1.18	0.85
22	1.39	0.81
25	1.67	0.65

Table 4  
The maximum, median and minimum temperatures of Seoul, Korea in 2004 based on 24 h averages (Korea Meteorological Administration, 2005)

Month	Temperature (°C)		
	Minimum	Median	Maximum
Mar	-3.4	7.8	14.5
Apr	5.6	13.6	19.7
May	14.2	17.4	21.8
Jun	19.2	23.4	26.3
Jul	21.0	24.1	29.9
Aug	21.8	26.0	30.4
Sep	16.5	21.8	25.5
Oct	10.7	15.3	20.2
Nov	4.1	8.9	16.4

0 log CFU/g, the most likely value was 2 log CFU/g and the maximum value was 5.29 log CFU/g. Clearly additional data on *S. aureus* concentration in kimbab at the point of sale would be useful in future risk assessments.

## 2.2. Growth model

Several studies have been conducted to develop predictive growth models for *S. aureus* using liquid broth as the growth medium (Buchanan et al., 1993; Sutherland et al., 1994). However, growth models that have been developed by studying real food systems are more useful when conducting QMRA. Only one study, published as a conference proceeding (Jin et al., 2004) has reported on growth parameters of *S. aureus* in kimbab. We were not able to obtain the original reference, but those findings were reported in Bahk et al. (2005), are shown in Table 3 and were used to develop new predictive models for the growth rate and lag time of *S. aureus* in kimbab. The square root of the published growth rates was plotted vs. temperature and linear regression was used to model the effect of temperature on growth rate (Fig. 1A). The relationship between the square root of inverse lag time (i.e. 1/lag time) versus temperature was determined in a similar manner (Fig. 1B). A maximum theoretical concentration of 9 log CFU/g was assumed, based on the

data of Bahk et al. (2005). The model proposed here includes only temperature, but improved models which take into account the effect of different kimbab formulations or ingredients may be developed in the future.

## 2.3. Temperature in Seoul

The Korea Meteorological Administration maintains records of the 24 h average daily temperatures of various cities throughout Korea. Temperatures in Seoul (Table 4) were used for the simulation because Seoul is Korea's largest city and nearly half of Korea's population resides either in or around it (Korea Meteorological Administration, 2005). The Pert distribution was used to model the distribution of temperature, and the median value of the temperature was used as a most likely value (i.e. mode) of Pert distribution. Since the distributions of temperature values in Seoul are generally symmetrical, the use of the median value in this way is appropriate.

## 2.4. Toxin production concentration of *S. aureus*

Foodborne disease caused by *S. aureus* is caused by the enterotoxins it produces. Several studies have shown that the

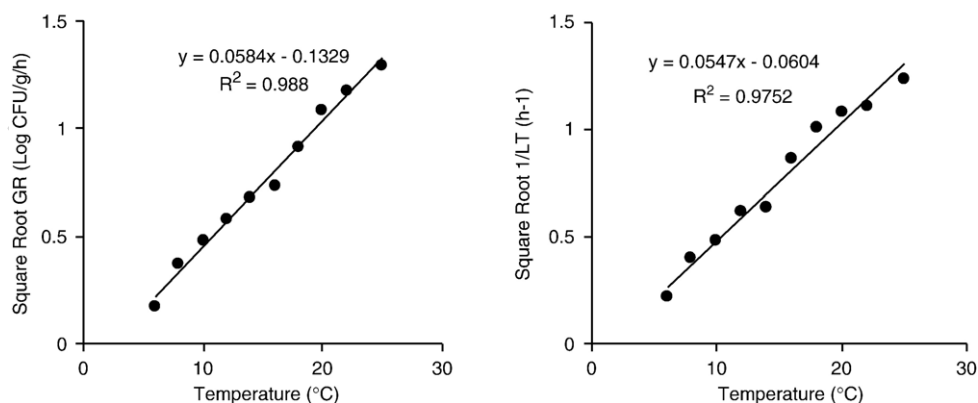


Fig. 1. The square root of growth rate (GR) and 1/lag time (LT) of *S. aureus* in kimbab versus temperature.

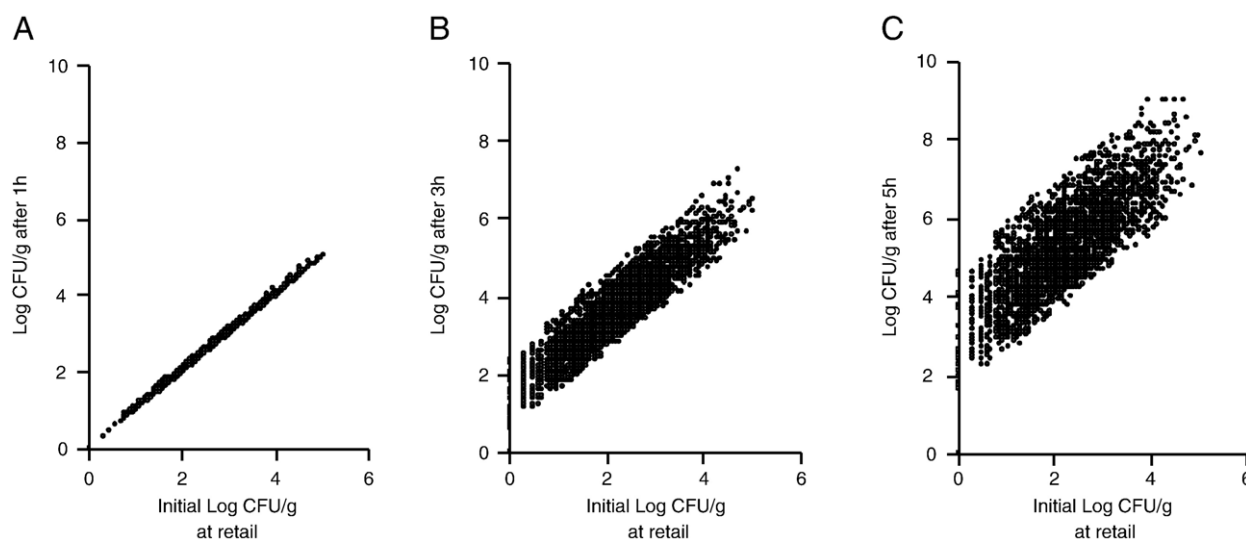


Fig. 2. Scatter plots of *S. aureus* in kimbab after storage versus *S. aureus* in kimbab at retail in May, with uncontaminated samples omitted. A; 1 h after purchase, B; 3 h after purchase, C; 5 h after purchase.

concentration of *S. aureus* needed for detectable toxin production in a variety of foods varies between  $10^6$  and  $4 \times 10^7$  CFU/g (Gockler et al., 1988; Anunciacao et al., 1995; Walls and Scott, 1997; Lee et al., 2004; Fujikawa and Morozumi, 2006). In contrast, Doan and Davidson (1999) reported that toxin could be produced at a *S. aureus* concentration of  $10^5$  CFU/g in French fries at 26.7 °C, and that toxin production was dependent on inoculation level and temperature. According to the U.S. Food and Drug Administration, a toxin dose of less than 1.0 µg in contaminated food will produce symptoms of staphylococcal intoxication and this toxin level is reached when *S. aureus* populations exceed  $10^5$  CFU/g (Food and Drug Administration, 1992). Based on all this information,  $10^5$  CFU/g was used as the minimum concentration of *S. aureus* needed to cause foodborne disease, although further research might refine this value to a greater degree.

### 2.5. Monte Carlo simulation

A Monte Carlo simulation was conducted using @risk (Palisade Corporation, Ithaca, NY) with settings of Latin Hypercube sampling and 10,000 iterations. Error trapping was used to remove certain values like 0 CFU, to avoid taking the log of 0, which is undefined.

## 3. Results

### 3.1. Consumption time after purchasing

The concentration of *S. aureus* in kimbab 1 to 6 h after purchase was estimated for the time period of March through November (Figs. 2–4). To demonstrate how the distribution of the contamination level of *S. aureus* changes over time, the

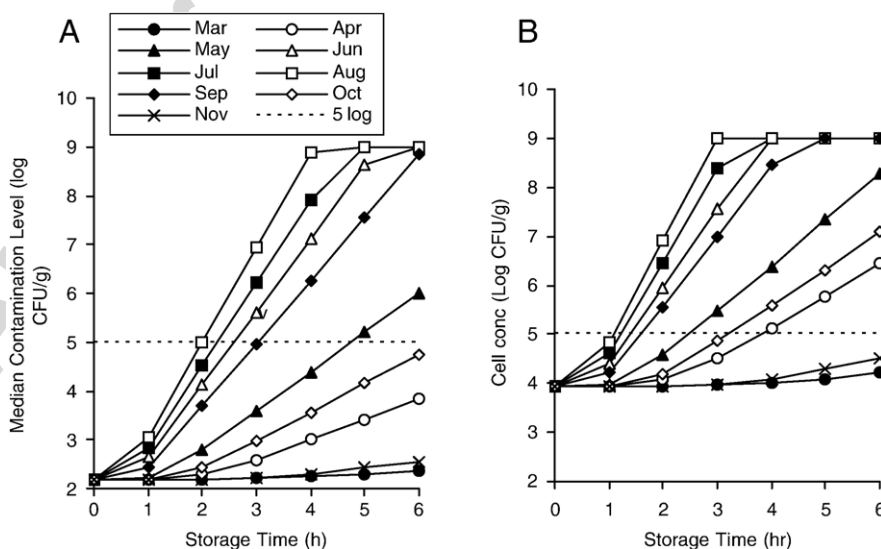


Fig. 3. Estimated median values and 95th percentiles of the contamination level of *S. aureus* in contaminated kimbab after various storage time. The dotted line identifies the concentration level of *S. aureus* considered to be hazardous. A; median values (50th percentiles), B; 95th percentiles.

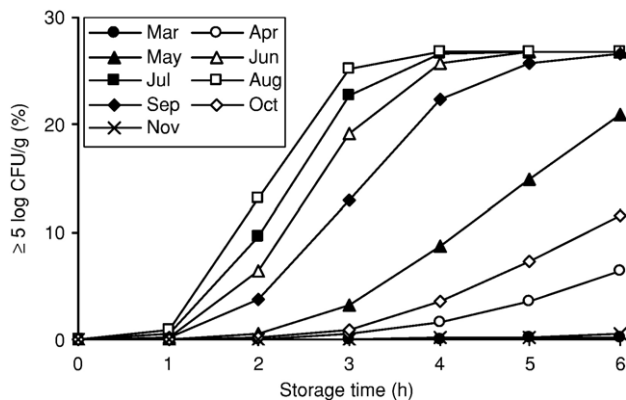


Fig. 4. Percentage of kimbab contaminated by not less than 5 log CFU/g of *S. aureus* in contaminated kimbab at retail after various storage times.

concentration of *S. aureus* in contaminated kimbab after storage was plotted versus the initial concentration of *S. aureus* at retail for the month of May. As seen from Fig. 2, *S. aureus* concentration increases with time, but because storage temperature is variable the amount of increase is also variable. *S. aureus* concentrations reached maximum allowed population density (9 log CFU/g) within 5 h in several of the iterations.

As noted elsewhere (FAO/WHO, 2002), when Monte Carlo simulation is used to conduct QMRA, the output of the simulation will be a distribution and the 95th-percentile of the distribution is often used as the basis for risk management. The choice of the appropriate percentile is one best left to risk managers, but we have used the 95th-percentile here for purposes of illustration. Fig. 3 presents the simulated mean cell concentration and 95th-percentiles of the concentration of *S. aureus* in contaminated kimbab after various storage times at ambient temperature for the time period of March through November. The simulation predicted that the 95th percentiles of the estimated concentration of *S. aureus* would be between 4.0 and 4.9 log CFU/g after only 1 h. The 95th-percentiles of

*S. aureus* concentration in contaminated kimbab were less than 5 log CFU/g after 6 h in March and November, but reached 5 log CFU/g within 2 h from June to September, 3 h in May, and within 4 h in the months of April and October.

The percentage of kimbab contaminated by at least 5 log CFU/g (considered hazardous) was plotted against storage time and these results are shown in Fig. 4. From these data it is evident that less than 1% of kimbab is hazardous after 1 h, generally, except in July (2%) and August (3.5%). In the colder months, the percentage of hazardous kimbab was still less than 1% even after 5 h (November) or 6 h (March). Conversely, in the summer months, a high percentage of the product is hazardous after only 2 h; 23.6% in June, 35.7% in July, 49.3% in August, and 13.6% in September. Finally it should be noted that in July and August, all initially contaminated kimbab had a hazardous concentration of *S. aureus* after 5 h.

### 3.2. Initial contamination level

When the initial concentration was assumed to be 0 log CFU/g (i.e. 1 CFU/g), the 95th-percentile of *S. aureus* concentration in contaminated kimbab was estimated at 4.4 log CFU/g after 5 h of ambient temperature storage in May (Fig. 5A). When the initial concentration was assumed to be 1 log CFU/g, the 95th percentile of *S. aureus* concentration in contaminated kimbab rises proportionally to 5.4 log CFU/g.

Conversely, when these same scenarios were evaluated assuming typical ambient storage conditions in October, the 95th-percentile of the estimated concentration of *S. aureus* rose from 0 log CFU/g to 3.4 log CFU/g after 5 h, and 4.3 log CFU/g after 6 h (Fig. 5B). When the initial concentration was assumed to be 1 log CFU/g, the 95th-percentile of estimated concentration of *S. aureus* was 4.4 log CFU/g after 5 h and 5.3 log CFU/g after 6 h. Finally, when the initial concentration was assumed to be 2 log CFU/g, the 95th-percentile concentration of *S. aureus* was predicted to be 5.4 log CFU/g after 5 h in October.

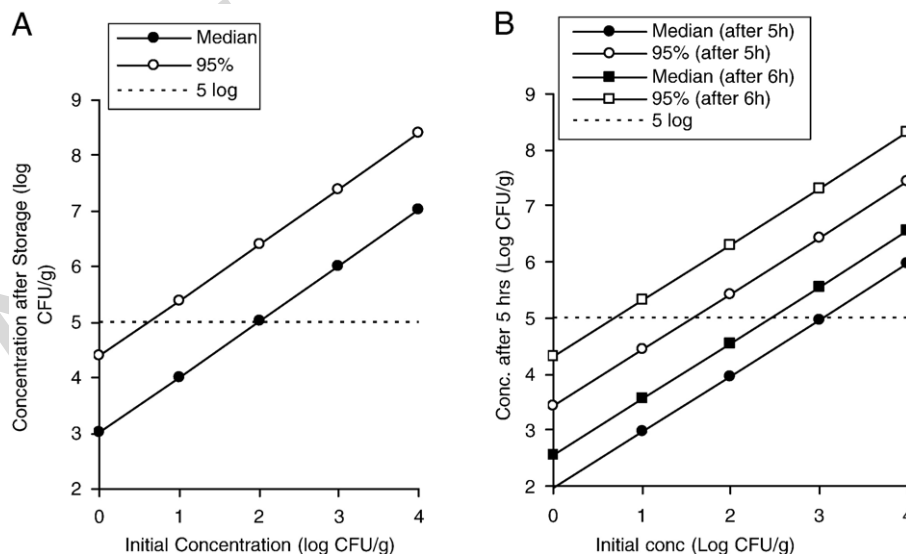


Fig. 5. Estimated concentrations of *S. aureus* in kimbab stored 5 h in May (A) and 5 to 6 h in October (B) for various initial concentrations. Median: median (50th percentile) of the distribution, 95%: 95th percentile of the distribution.

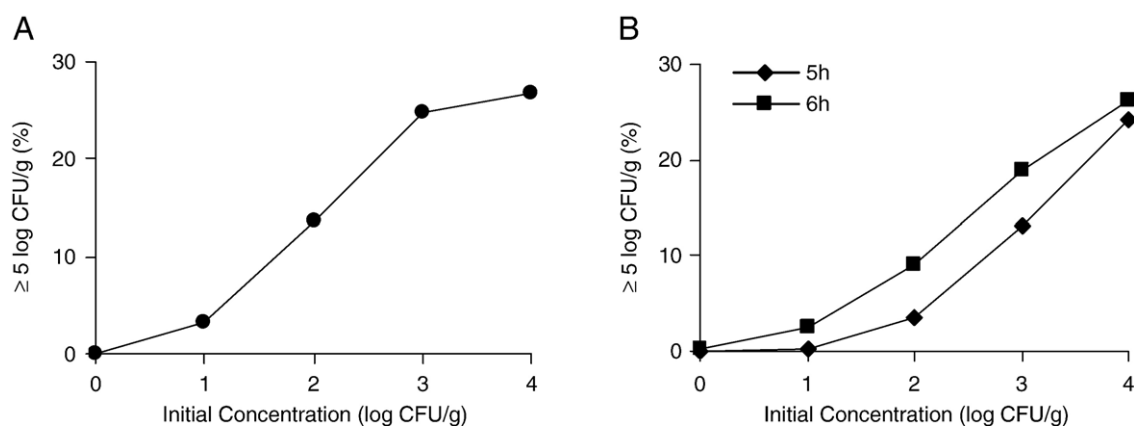


Fig. 6. Percentage of kimbab contaminated by not less than 5 log CFU/g of *S. aureus* in kimbab contaminated by various initial concentrations at preparation. A; stored 5 h in May, B; stored 5 or 6 h in October.

Another method for showing the effect on initial concentration is to plot the relationship between initial concentration and the predicted fraction of samples that exceeds the 5 log CFU/g concentration after a specific time. Fig. 6 shows the percentage of kimbab samples where the *S. aureus* concentration is equal to or greater than 5 log CFU/g for May (Panel A) and October (Panel B). For ambient conditions common in May, a significant fraction (12.4%) of kimbab samples will exceed 5 log CFU/g after 5 h when the initial concentration is 1 log CFU/g, while more than half (50.7%) of samples will exceed 5 CFU/g when the initial concentration is 2 log CFU/g (Fig. 6A). When ambient conditions are typical of those seen in October, virtually all (i.e. 99.5%) samples will contain less than 5 log CFU/g when stored for 6 h when the initial concentration is 0 log CFU/g or for 5 h when the initial concentration is 1 log CFU/g (Fig. 6B).

#### 4. Discussion

QMRA can be a useful tool to estimate the risk of pathogen growth in foods and to make decisions to manage food safety. Unfortunately, a lack of data means that risk estimates are uncertain (Hoonstra and Notermans, 2001; Oscar, 2004). One source of uncertainty in the current risk assessment stems from the lack of a published dose–response model for *S. aureus* toxin. In situations like these, the use of a specific cell concentration to determine if a food is safe may be the best course of action (Lindqvist et al., 2002; Stewart et al., 2003). A concentration of *S. aureus* equal to or exceeding 5 log CFU/g was assumed to be unsafe in the current study, but this assumption is open to interpretation. The incorporation of studies which provide a dose–response assessment of *S. aureus* toxin in food would improve the accuracy of the results presented here.

Bahk et al. (2005) suggest that kimbab be stored at temperatures of less than 10 °C. Since typical Korean consumers don't store kimbab at refrigerated temperatures because of quality losses due to rice starch retrogradation, such a recommendation may not be practical. When doing microbial

risk assessments and making risk management decisions, it is important to consider consumer habits and what consumers may and may not do. In this study, we assumed that the Korean consumer would be unwilling to modify his or her behavior concerning kimbab storage temperature, and thus we offer guidelines for the safe preparation and storage of kimbab.

#### 5. Conclusions

Given the current prevalence and concentration of *S. aureus* in kimbab at the retail level, one risk management option might be to suggest that the product be consumed within 1 h of purchase. If consumers wish to store kimbab for 5 h at ambient temperatures, another risk management option might be to stipulate that the *S. aureus* concentration should not exceed 1 cell per g at the time of purchase. It should be noted that since no data are currently available on kimbab serving sizes and number of servings consumed per day, the specific public health consequences of such management options are unknown.

Kimbab risk management guidelines would be useful for consumers concerned about individual or family food safety. This risk assessment may also be useful to the Korean FDA when considering a quantitative standard for *S. aureus* in kimbab. Finally, this risk assessment points out that additional research on other factors (e.g. product formulation effects, doses of *S. aureus* toxin needed to cause illness, more data on concentration of *S. aureus* in kimbab at the point of sale, data on kimbab serving sizes and number of servings consumed per day) may be useful in improving the safety of this popular Korean food.

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