Quantitative microbial risk assessment indicates very low risk for *Vibrio parahaemolyticus* foodborne illness from *Jeotgal* in South Korea

Yukyung Choi¹, Joohyun Kang², Yewon Lee², Yeongeun Seo², Sejeong Kim¹, Jimyeong Ha¹, Hyemin Oh¹, Yujin Kim³, Eunyoung Park², Heeyoung Lee³, Soomin Lee¹, Min Suk Rhee⁴, Yohan Yoon¹,²,*

¹ Risk Analysis Research Center, Sookmyung Women’s University, Seoul 04310, Korea
² Department of Food and Nutrition, Sookmyung Women’s University, Seoul 04310, Korea
³ Food Standard Research Center, Korea Food Research Institute, Wanju 55365, Korea
⁴ Department of Biotechnology, College of Life Sciences and Biotechnology, Korea University, Seoul 02841, Korea

Abstract

In this study, a microbial risk assessment was performed for the bacteria *Vibrio parahaemolyticus*, which causes a foodborne illness following the consumption of *Jeotgal*, a fermented seafood in South Korea. The assessment comprised of six stages: product, market, home, consumption, dose-response, and risk. The initial contamination level (IC) was calculated based on the prevalence of *V. parahaemolyticus* in 90 *Jeotgal* samples. The kinetic behavior of *V. parahaemolyticus* was described using predictive models. The data on transportation conditions from manufacturer to market and home were collected through personal communication and from previous studies. Data for the *Jeotgal* consumption status were obtained, and an appropriate probability distribution was established. The simulation models responding to the scenario were analyzed using the @RISK program. The IC of *V. parahaemolyticus* was estimated using beta distribution \([\text{Beta}(1, 91)]\). The cell counts during transportation were estimated using Weibull and polynomial models \([\delta = 1 / (0.0718 - 0.0097 \times T + 0.0005 \times T^2)]\), while the probability distributions for time and temperature were estimated using Pert, Weibull, Uniform, and LogLogistic distributions. Daily average consumption amounts were assessed using the Pareto distribution \([0.60284, 1.32, \text{Risk Truncate}(0, 155)]\). The results indicated that the risk of *V. parahaemolyticus* infection through *Jeotgal* consumption is low in South Korea.

Keywords: Foodborne illness, *Jeotgal*, Risk assessment, Simulation, *Vibrio parahaemolyticus*

Introduction

*Vibrio parahaemolyticus* is a gram-negative, curved, rod-shaped, halophilic bacterium that can be found in marine, coastal, and estuarine environments (Broberg et al., 2011; Nelapati et al., 2012; Tran et al., 2013). It has two types of flagella that it uses...
to swim, swarm, and produce a capsule (Letchumanan et al., 2014; McCarter, 1999). The principal virulence factors of *V. parahaemolyticus* include adhesin, thermostable direct hemolysin (TDH; *tdh*), and TDH-related hemolysin (*trh*), which are involved in its pathogenesis (Letchumanan et al., 2014; Wang et al., 2015). *V. parahaemolyticus* foodborne illness is prevalent globally and evokes symptoms of gastroenteritis in humans (Broberg et al., 2011; Daniels et al., 2000).

*V. parahaemolyticus*-associated foodborne illnesses are mainly caused by the contamination of raw seafood. For example, sardines contaminated with this pathogen were first identified as the cause of seafood borne illnesses in Japan (Levin, 2006). According to the Korean official statistics by the Ministry of Food and Drug Safety (2020), 52 foodborne outbreaks in 873 patients reported between 2015 and 2019 in South Korea were caused by *V. parahaemolyticus*, followed by other pathogens such as *Escherichia coli* (221 outbreaks), *Salmonella* (88 outbreaks), and *Campylobacter jejuni* (64 outbreaks). In South Korea, *V. parahaemolyticus* was detected in raw Korean oysters at retail outlets (Lee et al., 2008); Jun et al. (2012) isolated *V. parahaemolyticus* from corb shells, short neck clams, sea musels, sorb shells, Pacific oysters, and charm abalone purchased in 2009 at fish markets in Seoul, South Korea. In addition, *V. parahaemolyticus*-associated foodborne illnesses caused by cross-contamination from squids were reported in 2018 in South Korea (Jung, 2018).

*Jeotgal* is a Korean, salt-fermented, seasoned seafood that is commonly consumed as a nutritious side dish in South Korea (Koo et al., 2016; Lee, 2013). *Jeotgal* is a raw seafood delicacy prepared using squid, oyster, clam, and octopus (Koo et al., 2016), and therefore, there is a potential food vector for *V. parahaemolyticus* transmission. Microbial quantitative risk assessment of food is a procedure commonly used for identifying health risks, establishing regulations, determining the research needed, and deciding whether the current standards are adequate; the ultimate goal of these assessments is to provide public health services through food safety management (Lammerding, 1997; USDA, FSIS & EPA, 2012). Studies on the risk assessment of *Jeotgal* related to ethyl carbamate (Lee, 2013) have been performed; however, risk assessment for *V. parahaemolyticus* contamination in *Jeotgal* has not been conducted yet. The purpose of this study was to analyze the risk of foodborne illnesses caused by the consumption of *Jeotgal* contaminated with *V. parahaemolyticus*.

### Materials and Methods

#### Prevalence of *Vibrio parahaemolyticus* in *Jeotgal*

Among the various types, squid, clam, and oyster *Jeotgal* were the focus of this study. Ninety *Jeotgal* samples (30 squid, 30 clam, and 30 oyster) were purchased from markets in Seoul and Mokpo, as well as from online markets in South Korea. The *Jeotgal* samples (25 g) were placed in filter bags (3M, St. Paul, MN, USA) along with sterile 0.85% saline (225 mL) and homogenized at 230 rpm for 2 min using a stomacher (Seward, Worthing, UK). Aliquots of the homogenates (1 mL) and diluents (100 μL) were spread onto thiosulfate-citrate-bile salts-sucrose agar (TCBS; BD, Franklin Lakes, NJ, USA) and incubated at 35 °C for 24 h. Colonies on the plates that were predicted to be *V. parahaemolyticus* were analyzed using a compact VITEK2 GN card (BioMérieux, Craponne, France) and PCR targeting the thermostable hemolysin (*thl*) gene. The PCR conditions were as follows: initial denaturation at 94 °C for 3 min; 30 cycles of denaturation at 94 °C for 1 min, elongation at 58 °C for 1 min, extension at 72 °C for 1 min, and final extension at 72 °C for 5 min (Bej et al., 1999).

Based on the number of *V. parahaemolyticus*-positive *Jeotgal* samples, the prevalence was estimated using the beta distribution [RiskBeta (α: number of positive samples + 1, β: total number of samples − number of positive samples + 1)], and the initial contamination level (IC) was estimated as described by Vose (1997).

#### Selection of a model *Jeotgal*

Although there are several types of *Jeotgal*, only one can be used to establish a predictive model for microbial risk assessment. Thus, a predictive model should be developed using model food. The prediction from the model food should be higher than that from the other types of *Jeotgal*. Therefore, five types of *Jeotgal*, prepared using squid, octopus, oyster, pollack roe, and clam, were purchased from supermarkets in Seoul, South Korea. Colonies of *V. parahaemolyticus* ATCC 17802, ATCC 27519, ATCC 33844, and ATCC 43996 strains were inoculated in 10 mL of marine broth (BD) and incubated at 35 °C for 24 h. Aliquots (100 μL) were also inoculated in 10 mL of fresh marine broth and incubated at 35 °C for 24 h. The supernatant was removed following centrifugation at 1,912× for 15 min using centrifuge (Combi R515; Hanil Science, Gimpo, Korea). The washed cell suspensions were then mixed and diluted with phosphate buffered saline (8.0 g of NaCl, 1.5 g of
Na₂HPO₄·7H₂O, 0.2 g of KH₂PO₄, and 0.2 g of KCl in 1 L of distilled water; pH 7.4) to obtain 6.0 Log CFU/mL. Jeotgal samples were inoculated with the prepared solution, to obtain a concentration of 4.0 Log CFU/g. Inoculated samples were stored at 20°C for 96 h, during which alkaline peptone water (20 mL) (APW; BD) was placed in a conical tube (BD) containing 10 g of Jeotgal, that had been homogenized by vortexing for 1 min. The homogenates were decimally diluted in APW, followed by spread-plating on TCBS agar and incubation at 35°C for 24 h. V. parahaemolyticus cell counts obtained in the five types of Jeotgal were compared. The type of Jeotgal that had the highest survival rate of V. parahaemolyticus was selected as the model food for developing predictive models.

**Development of predictive models**

Among the Jeotgal, squid Jeotgal retained the most live bacteria, and thus, squid Jeotgal was selected for predictive models. Ten-gram portions of squid Jeotgal, purchased from a supermarket in Seoul, South Korea, were inoculated with V. parahaemolyticus to obtain a 4.0 Log CFU/g concentration. The inoculated samples were stored at 7°C, 15°C, 25°C, and 35°C, considering the exposable temperature of Jeotgal during distribution and storage. During storage, 10 g of each Jeotgal sample was diluted with 20 mL of APW, and the samples were then homogenized by vortexing for 1 min. Homogenates (0.1 mL) diluted in APW were inoculated onto TCBS agar by spreading. The plates were incubated at 35°C for 24 h, after which V. parahaemolyticus cell counts were confirmed. To describe the kinetic behavior of V. parahaemolyticus in Jeotgal, a primary model was developed by fitting the Weibull model [Log (N) = Log (N₀) – (time/δ)²; N, cell counts; N₀, initial cell counts; δ, treatment time for the first decimal reduction; ρ, curve shape parameter] (Mafart et al., 2002) to the V. parahaemolyticus cell counts. A secondary model was developed by fitting a polynomial model [Y = 1 / (a + b x T + c x T²); a, b, and c, constant; T, storage temperature] with δ values as a function of the storage temperature. This model was used to describe the effect of temperature on the kinetic parameters. To validate the model performance, squid Jeotgal was inoculated with V. parahaemolyticus, and the samples were exposed to the temperatures 10°C and 23°C. V. parahaemolyticus cell counts (observed values) were compared to the values predicted by the developed models. The root-mean-square error (RMSE; Baranyi et al., 1996) was calculated as follows:

$$\text{RMSE} = \sqrt{\frac{\sum (\text{observed value} - \text{predicted value})^2}{n}}$$

**Data collection of distribution condition**

Distribution time and temperature data for the Jeotgal, including transportation, storage, and display at market, were collected via personal communication with an administrator who is in charge of Jeotgal sales at a major market in Korea. Storage time at home was collected via personal communication, and the distribution model for food temperature at home storage was constructed as described by Lee et al. (2015).

**Data collection of consumption condition**

Among the various types, squid Jeotgal is the most commonly consumed Jeotgal in South Korea; hence, the risk in the simulation may be overestimated if the data of consumption for all types of Jeotgal is applied in this scenario. Thus, only the consumption data for squid Jeotgal were collected and analyzed. Data on the daily consumption frequency and amount of squid Jeotgal in South Korea were collected from the 2016 Korea National Health and Nutrition Examination Survey (KNHNES; KCDC, 2018). The appropriate probability distribution from this data was analyzed using the @RISK program (version 7.6, Palisade, Ithaca, NY, USA).

**Hazard characteristics and risk characterization**

The probability of illness/person/day was calculated using a beta-Poisson dose-response model associated with V. parahaemolyticus, which was evaluated as a well-described model and generally used by FAO & WHO (2011) and Iwahori et al. (2010). The full simulation model included data on V. parahaemolyticus prevalence and initial concentration, the predictive models applied to distribution condition, consumption amount and frequency, and the dose-response model. The risk was estimated using a comprehensive simulation in the @RISK program.

**Statistical analysis**

Kinetic parameters (δ and ρ values) from the predictive models which were developed by three repetitions of experiments were established using the general linear model in SAS® (version 9.3, SAS Institute, Cary, NC, USA). The kinetic parameters at different storage temperatures were compared using pairwise t-test with least squared means at α = 0.05.

**Results and Discussion**

**Initial contamination levels of Vibrio parahaemolyticus**

V. parahaemolyticus contamination was not detected in any of...
the 90 Jeotgal samples; thus, the IC was estimated using a beta distribution [BetaRisk(1,91)] model. The average IC estimated was −3.6 Log CFU/g (Fig. 1).

**Predictive model**
In the preliminary experiments, *V. parahaemolyticus* in squid Jeotgal survived for the longest time compared to that in other Jeotgal (data not shown). The pH (6.0) of squid Jeotgal was relatively high compared to that of other types (octopus: 5.73, oyster: 5.45, pollock roe: 5.63, and clam: 5.61). The water activity (Aw) of squid Jeotgal was 0.980, which is similar to the values of other types of Jeotgal (octopus: 0.983, oyster: 0.989, pollock roe: 0.988, and clam: 0.981). The salinity of squid Jeotgal was 4.73%, which was different from those of the other types (octopus: 34.3%, oyster: 3.02%, pollock roe: 4.50%, clam: 7.80%). Considering the overall characteristics, including optimal NaCl concentration (2%–4%), pH (pH 7.6–8.6), and Aw (0.936–0.995), *V. parahaemolyticus* could survive the longest time in squid Jeotgal (Jay et al., 2005; Miles et al., 1997; Parveen et al., 2013).

Squid Jeotgal was ultimately selected to develop a predictive model (Table 1). *V. parahaemolyticus* δ values decreased with increasing temperature: 7°C (δ = 56.77), 15°C (δ = 25.11), 25°C (δ = 7.23), and 35°C (δ = 3.02) as the storage time progressed. The ρ values in the Weibull (primary) model were 0.72 (7°C), 0.56 (15°C), 0.53 (25°C), and 0.66 (35°C). The goodness of fit for the primary model was evaluated with an $R^2$ value of 0.899–0.936 (Table 1), which were close to the $R^2$ values calculated by Ha et al. (2019) that was the range of 0.869–0.967 in the Weibull models. Considering the correlation between the δ values and temperature, the polynomial (secondary) model for δ values was developed as $\delta = 1 / (0.0718 – 0.0097 \times T + 0.0005 \times T^2)$, resulting in an $R^2$ value of 0.860 (Fig. 2). The $R^2$ of the δ values derived from the polynomial (secondary) model developed by Lee et al. (2019) was 0.890, which is similar to the resulting values of this study; however, the ρ values showed no correlation with temperature, eliminating the need for a secondary model. The average ρ value (0.6158) from the primary model was used in the simulation. The predictive model was validated for performance at different temperatures (RMSE: 0.746 for 10°C and 0.470 for 23°C) and in different types of Jeotgal (RMSE: 0.394). Ha et al. (2019) reported that an RMSE of 0.618 indicated appropriate model performance. The RMSE in this study indicates that the model appropriately describes the kinetic behavior of *V. parahaemolyticus* in Jeotgal.

**Probability distributions for storage time and temperature**
The Jeotgal products were transported from manufacturers to markets within 4, 5, or 7 h from manufacturing, which were
collected through personal communication with the person in charge of the products at the market, and thus facilitating the analysis of time using the Pert distribution [RiskPert(4,5,7)]. The data on food temperature during transport, which were collected through personal communication with the person in charge of the products at the market, were fitted with a Weibull distribution [RiskWeibull(1.3219,2.8404, RiskShift(3.1093), RiskTruncate(1,40))]. The Jeotgal products were stored at 0℃−10℃ for 0.17−0.5 h, and the uniform distribution was fitted using the parameters RiskUniform(0,10) and RiskUniform(0.17,0.5), respectively. At the markets, the Jeotgal products were displayed at 2.2281℃−20.272℃ for 0−4,320 h (mean: 720 h); thus, RiskUniform(2.2281,20.272) and RiskPert(0.720,4320) were applicable, respectively to the model. After purchase, the Jeotgal products were stored in refrigerators at home for 0−720 h (shelf life) until consumption. Thus, the data for the storage time at home were fitted to a uniform distribution with the parameter RiskUniform(0,720), and food temperature during home storage was described using the LogLogistic distribution [–29.283,33.227,26.666, RiskTruncate(–5,20)] (Lee et al., 2015; Table 2).

### Jeotgal consumption in South Korea

According to the 2016 KNHNES (KCDC, 2018) dataset, the daily consumption frequency of squid Jeotgal was 80.0%, with an average mass consumption of 13.9 g in South Korea. For the consumption related data, the Pareto distribution [(0.60284,1.32, RiskTruncate(0,155)] was determined to be the optimal probabilistic distribution analyzed by the @RISK program (Table 2 and Fig. 3).

### Vibrio parahaemolyticus dose-response model

The Beta-Poisson dose-response model \[1 – (1 + D/\beta)^{-\alpha}\], \(\alpha = 0.17, \beta = 1.18 \times 10^5\] was selected for \(V. \) parahaemolyticus (FAO & WHO, 2011; Iwahori et al., 2010), where \(D\) is the viable \(V. \) parahaemolyticus cell count consumed and calculated from consumption amount (g) of Jeotgal \(\times\) \(V. \) parahaemolyticus cell counts (CFU/g). Consumption amounts were calculated from the initial concentration to home storage derived from the predictive models, responding to the distribution and storage conditions (time and temperature) (Table 2).

### Risk characterization

The simulation for \(V. \) parahaemolyticus-associated illness following the consumption of contaminated Jeotgal was performed for a scenario consisting of different stages categorized as product, market, home, consumption, dose-response, and risk (Table 2). Specifically, transportation, storage, and display were associated with the market stage, and daily consumption frequency and average daily consumption amount were associated with the consumption stage. The IC calculated from the product stage was applied to the predictive models at the market and home stages, as a response to the environment (time and temperature). In the consumption and dose-response stages, the final contamination level was applied. The probability of illness per person per day was calculated and applied to the scenario described above. The mean probability of illness per person per day was calculated and applied to the scenario described above.

---

### Table 1. Kinetic parameters of Vibrio parahaemolyticus death in Jeotgal during storage at 7℃, 15℃, 25℃, and 35℃, calculated by the Weibull model (primary model)

| Storage temperature (℃) | Kinetic parameters | \(R^2\) |
|-------------------------|-------------------|--------|
| 7                       | 56.77 ± 34.58     | 0.72 ± 0.25      | 0.932 ± 0.027 |
| 15                      | 25.11 ± 16.33     | 0.56 ± 0.15      | 0.899 ± 0.033 |
| 25                      | 7.23 ± 3.68       | 0.53 ± 0.03      | 0.936 ± 0.023 |
| 35                      | 3.02 ± 0.74       | 0.66 ± 0.07      | 0.913 ± 0.054 |

Values are mean ± SD. 

\(A, B\) Values followed by different letters in a row are significantly different. 

\(\delta\), treatment time for the first decimal reduction; \(\rho\), curve shape parameter.
Table 2. @RISK simulation model and scenario for calculation of the risk of *Vibrio parahaemolyticus* foodborne illness by consumption of Jeotgal

| Input model       | Variable      | Formula                                      | Reference                          |
|-------------------|---------------|----------------------------------------------|------------------------------------|
| **Product**       |               |                                              |                                    |
| Pathogen contamination level |               |                                              |                                    |
| *V. parahaemolyticus* prevalence | PR            | = RiskBeta(1,91)                             | This study; Vose, 1997              |
| Concentration (CFU/g) | C             | = –LN (1 – PR) / 25 g                       | Sanaa et al., 2004                 |
| Initial contamination level (Log CFU/g) | IC            | = Log(C)                                    |                                    |
| **Market**       |               |                                              |                                    |
| Transportation time (h) | Mark-time<sub>trans</sub> | = RiskPert(4,5,7)                          | Personal communication¹             |
| Food temperature during transportation (°C) | Mark-Temp<sub>trans</sub> | = RiskWeibull(1.3219,2.8404,RiskShift(3.1093),RiskTruncate(1,40)) | Personal communication              |
| **Death**        |               |                                              |                                    |
| Treatment time for the first decimal reduction | δ             | = 1 / (0.0718 – 0.0097 × Mark-temp<sub>trans</sub> + 0.0005 × Mark-temp<sub>trans</sub>²) | This study                          |
| Curve shape parameter | ρ             | Fixed 0.6158                                 | This study                          |
| *V. parahaemolyticus* survival model | C1            | = IC – (Mark-time<sub>trans</sub> / δ)⁵      | Mafart et al., 2002                 |
| **Market storage** |               |                                              |                                    |
| Storage time (h) | Mark-time<sub>st</sub> | = RiskUniform(0.17,0.5)                     | Personal communication              |
| Food temperature during storage (°C) | Mark-Temp<sub>st</sub> | = RiskUniform(0,10)                         | Personal communication              |
| **Death**        |               |                                              |                                    |
| Treatment time for the first decimal reduction | δ             | = 1 / (0.0718 – 0.0097 × Mark-temp<sub>st</sub> + 0.0005 × Mark-temp<sub>st</sub>²) | This study                          |
| Curve shape parameter | ρ             | Fixed 0.6158                                 | This study                          |
| *V. parahaemolyticus* survival model | C2            | = C1 – (Mark-time<sub>st</sub> / δ)⁵        | Mafart et al., 2002                 |
| **Market display** |               |                                              |                                    |
| Display time (h) | Mark-time<sub>dis</sub> | = RiskPert(0,720,4220)                     | Personal communication              |
| Display temperature in market (°C) | Mark-Temp<sub>dis</sub> | = RiskUniform(2.2281,20.272)                | Personal communication              |
| **Death**        |               |                                              |                                    |
| Treatment time for the first decimal reduction | δ             | = 1 / (0.0718 – 0.0097 × Home-temp<sub>st</sub> + 0.0005 × Home-temp<sub>st</sub>²) | This study                          |
| Curve shape parameter | ρ             | Fixed 0.6158                                 | This study                          |
| *V. parahaemolyticus* survival model | C3            | = C2 – (Home-time<sub>st</sub> / δ)⁵       | Mafart et al., 2002                 |
| **Home**         |               |                                              |                                    |
| Storage time (h) | Home-time<sub>st</sub> | = RiskUniform(0,720)                         | Personal communication              |
| Food temperature during storage (°C) | Home-Temp<sub>st</sub> | = RiskLogLogistic(-29.283,33.227,26.666,RiskTruncate(-5,20)) | Lee et al., 2015                   |
| **Death**        |               |                                              |                                    |
| Treatment time for the first decimal reduction | δ             | = 1 / (0.0718 – 0.0097 × Home-temp<sub>st</sub> + 0.0005 × Home-temp<sub>st</sub>²) | This study                          |
| Curve shape parameter | ρ             | Fixed 0.6158                                 | This study                          |
| *V. parahaemolyticus* survival model | C4            | = C3 – (Home-time<sub>st</sub> / δ)⁵       | Mafart et al., 2002                 |
| **Consumption**  |               |                                              |                                    |
| Daily consumption average amount (g) | Consump | = RiskPareto(0.60284,1.32,RiskTruncate(0.155)) | KCDC, 2018                         |
| Daily consumption frequency (%) | ConFre | Fixed 0.8                                   | KCDC, 2018                         |
| Daily non-consumption frequency (rate) | CF(0)  | = 1 – 0.8 / 100                             | KCDC, 2018                         |
| Daily consumption frequency (rate) | CF(1)  | = 0.8 / 100                                 | KCDC, 2018                         |
day was zero. This low risk was derived from the continuously
decreasing cumulative contamination levels of *V. parahaemolyti-
cus*: –3.61 (IC), –3.94 (market transportation), –4.01 (market
storage), –14.11 (market display), and –23.37 Log CFU/g (home
storage) (Fig. 4).

Table 2. Continued

| Input model                           | Variable  | Formula                                         | Reference                |
|---------------------------------------|-----------|-------------------------------------------------|--------------------------|
| Distribution for consumption frequency| CF        | = RiskDiscrete ((0,1),(CF(0),CF(1)))             | KCDC, 2018               |
| Daily consumption average amount considered frequency | Amount | = IF(CF = 0,0,Consum)                           | KCDC, 2018               |
| Dose-response                         |           |                                                 |                          |
| *V. parahaemolyticus* amount (CFU)    | D         | = $10^4 \times$ Amount                         |                          |
| Parameter                             | α         | Fixed 0.17                                      | FAO & WHO, 2011;         |
| Parameter                             | β         | $1.18 \times 10^5$                              | FAO & WHO, 2011;         |
| Risk                                  |           | Probability of illness/person/day = $1 - (1 + D/\beta)^\alpha$ | Iwahori et al., 2010;    |

1 Personal communication with a person in charge of products at the market.

IC, initial contamination level; C1, market transportation; C2, market storage; C3, market display; C4, home storage.

Fig. 3. Pareto distribution of daily consumption of squid *Jeotgal* without additional heating.

Conclusion

*Jeotgal* containing raw seafoods could be a vector of *V. parahaemolyticus*-associated foodborne illness. In this study, *V. parahaemolyticus* was not detected in all *Jeotgal* and the contamination level was decreased as the distribution carried on in the
QMRA of *V. parahaemolyticus* in Jeotgal

The risk of *V. parahaemolyticus* infection in Jeotgal was very low, as analyzed by quantitative risk assessment, with respect to the distribution in South Korea. The result suggested that the low contamination level and distribution environment could be important factors to decrease the probability of *V. parahaemolyticus*-associated foodborne illnesses.

**Competing interests**

No potential conflict of interest relevant to this article was reported.

**Funding sources**

This research was supported by a grant (17162MFDS035) from Ministry of Food and Drug Safety in 2018.

**Acknowledgements**

Not applicable.

**Availability of data and materials**

Upon reasonable request, the datasets of this study can be available from the corresponding author.

**Ethics approval and consent to participate**

This article does not require IRB/IACUC approval because there are no human and animal participants.

**ORCID**

Yukyung Choi https://orcid.org/0000-0002-7994-9862  
Joohyun Kang https://orcid.org/0000-0002-7341-8526  
Yewon Lee https://orcid.org/0000-0001-8715-1140  
Yeongeun Seo https://orcid.org/0000-0003-4986-9770  
Sejeong Kim https://orcid.org/0000-0001-9741-8056  
Jinyeong Ha https://orcid.org/0000-0001-7973-7926  
Hyemin Oh https://orcid.org/0000-0002-8073-7242  
Yujin Kim https://orcid.org/0000-0002-0903-9871  
Eunyoung Park https://orcid.org/0000-0001-8331-1848  
Heeyoung Lee https://orcid.org/0000-0001-6115-9179  
Soomin Lee https://orcid.org/0000-0003-1811-7365  
Min Suk Rhee https://orcid.org/0000-0003-0412-1910  
Yohan Yoon https://orcid.org/0000-0002-4561-6218

**Fig. 4. Changes in *Vibrio parahaemolyticus* contamination level of Jeotgal during C1, C2, C3, and C4, predicted by distribution models.** IC, initial contamination level; C1, market transportation; C2, market storage; C3, market display; C4, home storage.
References

Baranyi J, Ross T, McMeekin TA, Roberts TA. Effects of parameterization on the performance of empirical models used in ‘predictive microbiology’. Food Microbiol. 1996;13:83-91.

Bej AK, Patterson DP, Brasher CW, Vickery MCL, Jones DD, Kaysner CA. Detection of total and hemolysin-producing *Vibrio parahaemolyticus* in shellfish using multiplex PCR amplification of *tl, tdh* and *trh*. J Microbiol Methods. 1999;36:215-25.

Broberg CA, Calder TJ, Orth K. *Vibrio parahaemolyticus* cell biology and pathogenicity determinants. Microbes Infect. 2011;13:992-1001.

Daniels NA, MacKinnon L, Bishop R, Altekruse S, Ray B, Hammond RM, et al. *Vibrio parahaemolyticus* infections in the United States, 1973-1998. J Infect Dis. 2000;181:1661-6.

Food and Agriculture Organization of the United Nations [FAO], World Health Organization [WHO]. Risk assessment of *Vibrio parahaemolyticus* in seafood: interpretative summary and technical report. Rome: FAO; 2011.

Ha J, Lee J, Lee S, Kim S, Choi Y, Oh H, et al. Mathematical models to describe the kinetic behavior of *Staphylococcus aureus* in jerky. Food Sci Anim Resour. 2019;39:371-8.

Iwahori J, Yamamoto A, Suzuki H, Yamamoto T, Tsutsui T, Motoyama K, et al. Quantitative risk assessment of *Vibrio parahaemolyticus* in finfish: a model of raw horse mackerel consumption in Japan. Risk Anal. 2010;30:1817-32.

Jay JM, Loessner MJ, Golden DA. Foodborne gastroenteritis caused by *Vibrio, Yersinia*, and *Campylobacter* species. In: Jay JM, Loessner MJ, Golden DA, editors. Modern food microbiology. Boston, MA: Springer; 2005. p. 657-78.

Jun JW, Kim JH, Choresca CH Jr, Shin SP, Han JE, Han SY, et al. Isolation, molecular characterization, and antibiotic susceptibility of *Vibrio parahaemolyticus* in Korean seafood. Foodborne Pathog Dis. 2012;9:224-31.

Jung SW. A foodborne outbreak of gastroenteritis caused by *Vibrio parahaemolyticus* associated with cross-contamination from squid in Korea. Epidemiol Health. 2018;40:e2018056.

Koo OK, Lee SJ, Chung KR, Jang DJ, Yang HJ, Kwon DY. Korean traditional fermented fish products: *jeotgal*. J Ethn Foods. 2016;3:107-16.

Korea Centers for Disease Control and Prevention [KCDC]. KNHNES (Korea National Health and Nutrition Examination Survey) [Internet]. KCDC, 2018 [cited 2019 May 12]. https://knhanes.kdca.go.kr/knhanes/sub04/sub04_04_01.do

Lammerding AM. An overview of microbial food safety risk assessment. J Food Prot. 1997;60:1420-5.

Lee H, Kim K, Choi KH, Yoon Y. Quantitative microbial risk assessment for *Staphylococcus aureus* in natural and processed cheese in Korea. J Dairy Sci. 2015;98:5931-45.

Lee J, Lee H, Lee S, Kim S, Ha J, Choi Y, et al. Quantitative microbial risk assessment for *Campylobacter jejuni* in ground meat products in Korea. Food Sci Anim Resour. 2019;39:565-75.

Lee JK, Jung DW, Eom SY, Oh SW, Kim Y, Kwak HS, et al. Occurrence of *Vibrio parahaemolyticus* in oysters from Korean retail outlets. Food Control. 2008;19:990-4.

Lee KG. Analysis and risk assessment of ethyl carbamate in various fermented foods. Eur Food Res Technol. 2013;236:891-8.

Letchumanan V, Chan KG, Lee LH. *Vibrio parahaemolyticus*: a review on the pathogenesis, prevalence, and advance molecular identification techniques. Front Microbiol. 2014;5:705.

Levin RE. *Vibrio parahaemolyticus*, a notably lethal human pathogen derived from seafood: a review of its pathogenicity, characteristics, subspecies characterization, and molecular methods of detection. Food Biotechnol. 2006;20:93-128.

Mafart P, Couvert O, Gaillard S, Leguerinel I. On calculating sterility in thermal preservation methods: application of the Weibull frequency distribution model. Int J Food Microbiol. 2002;72:107-13.

McCarter L. The multiple identities of *Vibrio parahaemolyticus*. J Mol Microbiol Biotechnol. 1999;1:51-7.

Miles DW, Ross T, Olley J, McMeekin TA. Development and evaluation of a predictive model for the effect of temperature and water activity on the growth rate of *Vibrio parahaemolyticus*. Int J Food Microbiol. 1997;38:133-42.

Ministry of Food and Drug Safety [MFDS]. Annual report of foodborne outbreaks [Internet]. MFDS. 2020 [cited 2020 Apr 14]. https://www.foodsafetykorea.go.kr/portal/healthyfoodlife/foodPoisoningStat.do?menu_no=3724&menu.grp=MENU_NEW02

Nelapati S, Nelapati K, Chinnam BK. *Vibrio parahaemolyticus*: an emerging foodborne pathogen-a review. Vet World. 2012;5:48-62.

Parveen S, DaSilva L, DePaola A, Bowers J, White C, Munasinghe KA, et al. Development and validation of a predictive model for the growth of *Vibrio parahaemolyticus* in post-harvest shellstock oysters. Int J Food Microbiol. 2013;161:1-6.

Sanaa M, Coroller L, Cerf O. Risk assessment of listeriosis...
linked to the consumption of two soft cheeses made from raw milk: Camembert of Normandy and Brie of Meaux. Risk Anal. 2004;24:389-99.

Tran L, Nunan L, Redman RM, Mohney LL, Pantoja CR, Fitzsimmons K, et al. Determination of the infectious nature of the agent of acute hepatopancreatic necrosis syndrome affecting penaeid shrimp. Dis Aquat Organ. 2013;105:45-55.

U.S. Department of Agriculture [USDA], Food Safety and Inspection Service [FSIS], U.S. Environmental Protection Agency [EPA]. Microbial risk assessment guideline: pathogenic organisms with focus on food and water. Washington, DC: FSIS; 2012. Report No.: USDA/FSIS/2012-001.

Vose DJ. Risk analysis in relation to the importation and exportation of animal products. Rev Sci Tech. 1997;16:17-29.

Wang R, Zhong Y, Gu X, Yuan J, Saeed AF, Wang S. The pathogenesis, detection, and prevention of *Vibrio parahaemolyticus*. Front Microbiol. 2015;6:144.