Predictive growth model of the effects of temperature on the growth kinetics of generic *Escherichia coli* in the Korean traditional rice cake product “*Garaetteok*”

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Abstract In this study, a predictive growth model of generic *Escherichia coli* in *Garaetteok* at a range of storage temperatures (T, 10–40 °C) was developed. The primary models of specific growth rate (SGR) and lag time (LT) fit well ($R^2 \geq 0.985$) using a Gompertz equation. Secondary polynomial models were obtained by non-linear regression and calculated as $SGR = -0.01,570 + 0.0183T + 0.00008T^2$; $LT = 43.2064 - 2.4824T + 0.0355T^2$. The appropriateness of the secondary models was verified by mean square error (MSE; 0.0006 for SGR, 0.282 for LT), bias factor (B_f ; 0.948 for SGR, 0.942 for LT), accuracy factor (A_f ; 1.163 for SGR, 1.355 for LT), and coefficient of determination (r^2 ; 0.986 for SGR, 0.996 for LT), and these models were found to be in good agreement with the experimental values used for validation. The secondary models developed in this study may thus be used as practical prediction models for generic *E. coli* growth in *Garaetteok*. These newly developed secondary models of SGR and LT for generic *E. coli* in *Garaetteok* may thus be incorporated into tertiary modeling programs such as the Korea Pathogen Modeling Program, in which they can easily be used to predict the growth kinetics of *E. coli* as a function of storage temperature. Ultimately, model developed in this study may be a vital tool for the reduction of *E. coli* levels in food production, processing, and distribution processes, which in turn will lead to enhanced safety of rice products.

Keywords Generic *Escherichia coli* · Growth · Temperature · Predictive model · *Garaetteok*

Introduction

Rice cake, which includes any kind of processed, shaped food product made from rice flour, is particularly prevalent in Asia. Korean traditional rice cake is usually consumed as a staple and/or snack food for family holidays, ceremonial days, and funeral days, and is produced in four forms: steamed rice cake, pounded rice cake, boiled rice cake, and pan-fried rice cake (Kim and Shin 2004). Among these rice cakes, *Garaetteok* (*Garae* meaning long, cylinder-shaped; *tteok* meaning rice cake) is eaten alone, but is also utilized as the main ingredient in *Tteokguk* (*tteok* soup), made in Korean homes on New Year's day, as well as in *Tteokbokki* (stir-fried and spicy rice cake) commonly sold by street vendors. The consumption of these processed foods as a substitute for staple foods and as a popular snack throughout the year in food service, catering, and home is increasing.

Like some other rice cake types, *Garaetteok* are prone to microbial contamination during storage and distribution in markets and homes because of the high moisture content in these products ($\sim 47\%$) (Hyun et al. 2014) as well as the fact that consumers eat them without heating them. The Korea Food and Drug Administration (KFDA 2011) reported that indigenous aerobic bacteria and coliforms, respectively, were detected in *Garaetteok* at 4.6 and 2.1 log CFU/g in big shopping markets, at 4.7 and 1.7 log CFU/g in franchise stores, and at 3.4 and 0.7 log CFU/g in traditional markets at the time of purchase. After the *Garaetteok* were stored for 9 h at room temperature, the contamination levels of aerobic bacteria and coliforms were found to

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increase by > 2 log CFU/g in *Garaetteok* samples from all sources (KFDA 2011). Storage for more than 9 h may therefore significantly affect the quality of the product. *Escherichia coli* is typically regarded as an indicator organism for fecal contamination in all environments and foods. Moreover, *E. coli* is generally accepted as an indicator of food contamination by enteric pathogens and the growth of *E. coli* in food is indicative of possible increases in most mesophilic, enteric pathogen levels. Therefore, *E. coli* is considered the main target organism in foods, including *Garaetteok*, for the maintenance of hygiene and the control of foodborne illness.

Predictive food microbiology has become an important established microbiological and mathematical approach to ensuring food safety in food manufacturing and distribution (Koseki and Isobe 2005). There has therefore been an increasing interest in the development of mathematical models with which the growth, survival, and inactivation of spoilage and pathogenic microorganisms can be predicted using laboratory media and food matrices under specific diverse environmental conditions in which nutrients, water activity, pH, temperature, oxygen availability, and preservative agents are varied.

Mathematical quantitative models that predict the growth of non-pathogenic *E. coli* as a function of important environmental factors can be used to determine the shelf life and safety of foods (Bernaerts et al. 2000; Gill et al. 1998; Heitzer et al. 1991; Ross et al. 2003; Salter et al. 1998); however, the number of reports of predictive models describing the effects of environmental factors (e.g., nutrients, water activity, pH, temperature, oxygen availability, and preservative agents) on the growth, survival, or inactivation of *E. coli* in both broth and food matrices remains very limited. Specifically, no prediction models for the growth of non-pathogenic generic *E. coli* in *Garaetteok*, a commonly and widely consumed rice product in Korea, have been developed because *E. coli* contamination of this food product has not been reported.

Therefore, the purpose of this study was to investigate the growth characteristics of *E. coli* in *Garaetteok* and to develop predictive growth models as a function of storage temperature by using a polynomial model toward the development of effective control methods for non-pathogenic generic *E. coli*.

Materials and methods

Bacterial culture

Three strains of *Escherichia coli* (ATCC11229, ATCC10536, and ATCC25922) were combined in a cocktail for this study. The cocktail strain was used to

determine the growth characteristics of *E. coli* and to develop predictive mathematical models for its growth in *Garaetteok*. Each strain was maintained at -70 °C in Tryptic Soy Broth (TSB, Difco Laboratories, Detroit, MI, USA) containing 50% glycerol.

Preparation of the bacterial suspension

E. coli was cultured by transferring 10 μ L of the stock culture into 10 mL of TSB at 30 °C for 24 h, harvested by centrifugation at 8000 rpm for 10 min at 4 °C, and washed with 0.1% peptone water (Oxoid, Basingstoke, Hampshire, UK). The bacterial suspension was resuspended in 0.1% peptone water and diluted to 10^2 CFU/mL

Sample preparation and bacterial inoculation

Garaetteok was purchased from a local market on the same day of production in Anseong, Korea. To remove background microorganisms on the *Garaetteok*, 10 g of the samples were washed with sterile, distilled water for 2 min, and then dried for 2 min. The samples were transferred into sterilized, oxygen-impermeable nylon bags (2 mL $O_2/m^2/24$ h at 0 °C, 0.09 mm thickness; Sunkung Co. Ltd., Seoul, Korea) in a clean bench (Vision Scientific Co., LTD., Bucheon, Korea). The packs were sealed and transferred to a refrigerator (4 °C) before irradiation. Packed samples were irradiated in a cobalt-60 gamma irradiator (Point source, ACEL, IR-79, MDS Nordion, Ontario, Canada) at the Korea Atomic Energy Research Institute, Jeongseup, Korea. The source strength was approximately 11.1 PBq, and a dose rate of 10 kGy/h was used. Dosimetry was performed using 5-mm diameter alanine dosimeters (Bruker Instruments, Rheinstetten, Germany), and the free radical signal was measured using a Bruker EMS 104 EPR Analyzer. The dosimeters were calibrated against an international standard provided by the International Atomic Energy Agency (Vienna, Austria). The applied dose in this study was 1.0 kGy. The culture was inoculated on 5–10 spots on the surface of the *Garaedduck* at a concentration of 1.0×10^2 CFU/g. The samples were then stored at 10–40 °C under aerobic conditions.

Growth measurement

The growth of generic *E. coli* in *Garaetteok* was determined as a function of the storage temperature (10, 20, 30, and 40 °C). The samples individually were put into sterile stomaching bags (Nasco Whirl-Pak, Janesville, WI, USA) and stored at 0, 20, 30, or 40 °C of static incubator (Vision Scientific Co., LTD., Bucheon, Korea). A digital thermometer (TE-201, Cas Corporation, Jiashan, China) was

placed in the thermometer to monitor the temperature. The samples were incubated and were diluted appropriately, and were plated in duplicate on 3 M Petrifilm™ *E. coli* (3 M Microbiology Products, St. Paul, MN, USA) and then incubated at 37 °C for 24 h. Colonies presenting a blue colour associated with entrapped gas was considered as *E. coli* and were enumerated. The colonies were reported as colony-forming units (Log CFU/g). This work was compared with the predictive model and observed results for validation.

Primary modeling

Growth curves representing the growth rates and lag times were iteratively generated using a Gompertz equation and fit to a nonlinear regression model (Prism, Version 4.0, GraphPad Software, San Diego, CA, USA) to determine specific growth rates (SGR, h⁻¹) and lag times (LT, h) at each temperature. The Gompertz equation, $Y = N_0 + -C \cdot \exp[\exp\{(2.718 \cdot \text{SGR}/C) \cdot \text{LT} - X\} + 1]$, which was described by Gibson et al. (1988), was used. Y = log cell number, X = incubation time, N_0 = log initial number of cells, C = difference between initial and final cell numbers, LT = lag time before growth, same units as X , SGR = maximum specific growth rate.

Secondary modeling

A polynomial model as a function of the storage temperature was calculated based on the growth on the tested *Garaetteok*. The Gompertz parameters, SGR and LT for the *E. coli* growth data was determined by least squares analysis using PROC GLM of SAS version 8.1 (Statistical Analysis Systems Institute, 2002, Cary, NC, USA). The equations describing these polynomial models contained the following format:

$$Y = b_0 + b_1T + b_2T^2 + \varepsilon$$

where Y is the SGR or LT , b_0 , b_1 , b_2 were the regression coefficients, T was the temperature, and ε was the random error (Gibson et al. 1988).

Evaluation of the model using mathematical/statistical adequacy

The coefficient of determination (r^2) is often used as the overall measure of a prediction (Dalgaard et al. 1994). The r^2 values provided by GraphPad 4.0 are often used as an overall measure of the prediction attained. These values measure the portion of the variation about the mean that can be explained by the model. The equation used to determine the r^2 value was as follows: $r^2 = 1 - \sum e_i^2 / \sum (y_i - \bar{y})^2$, where e_i was the

error of the predictive values, y_i was the predicted values, and $\bar{y}$ was the average of the predicted values (Duffy et al. 1994).

The mean square error (MSE), which is the residual sum of squares divided by the number of degrees of freedom, is a measure of the remaining variability that is not accounted for by deliberate changes in temperature. This value was calculated using the following equation: $\text{MSE} = \sum (\text{observed values} - \text{predicted values})^2 / n$, where n was the number of observations (te Giffel and Zwietering 1999).

The bias factor (B_f) answers the question of whether, on average, the observed values lie above or below the line equivalence and if so, by how much. It also provides the structural deviations of the model. The equation used to calculate the bias factor was as follows: $B_f = 10^{\sum \text{Log}(\text{observed values}/\text{predicted values})/n}$, where n was the number of observations (Khaled et al. 2009). The accuracy factor (A_f) averages the distance between each point and the line of equivalence as a measure of how close, on average, the predictions are to the observed value. The equation used to calculate the accuracy factor was as follows: $A_f = 10^{\sum -\text{Log} |(\text{predicted values}/\text{observed values}) - 1|/n}$, where n was the number of observations (Khaled et al. 2009).

Results and discussion

E. coli growth characteristics in *Garaetteok* stored at 10–40 °C

In Korean homes, *Garaetteok* is commonly stored at room temperature rather than being refrigerated at < 4–5 °C. The reason for this is that refrigeration results in *Garaetteok* becoming dry and hard as the moisture on the surface of the product is prone to evaporation, which is not the case for *Garaetteok* stored at ambient temperatures. For this reason, refrigeration temperatures (4–5 °C) were not included as storage temperatures in the present study.

The pH values of *Garaetteok* stored at 10 °C were not changed during the 10 days of storage (6.58–6.55). Also, there were no changes of visual observation in all 10 °C stored samples during the storage times (data not shown). However, the pH values of *Garaetteok* stored at 20, 30, and 40 °C during the 10 days of storage were reduced to 6.30, 5.62, and 5.61, respectively. Especially, the pH of *Garaetteok* stored at 30 and 40 °C was < 6.0 at 6 days of storage. Furthermore, white, brown, and(or) yellow spots were appeared on the surface of the *Garaetteok* stored at 20 °C from the 6 days of storage and 30 and 40 °C from the 8 days of storage (data not shown).

The growth of generic *E. coli* in *Garaetteok* stored at 10, 20, 30, and 40 °C was examined over the course of 10 days. From the growth curves shown in Fig. 1, it is

evident that the growth of *E. coli* in *Garaetteok* increased with increasing temperature. In the presence of atmospheric oxygen, *E. coli* was even found to grow at low temperatures (10 °C). As temperatures increased, the time required for the generic *E. coli* to reach maximum population in *Garaetteok* decreased: generic *E. coli* in *Garaetteok* stored at 10, 20, 30, and 40 °C were found to reach their population maxima by 192 h (8 days), 84 h (3.5 days), 48 h (2 days), and 24 h (1 days), respectively. The maximum *E. coli* populations reached in *Garaetteok* were, on the other hand, not found to differ markedly among the four storage temperatures (10 °C: 6.1 logCFU/g; 20 °C: 7.1 logCFU/g; 30 °C: 6.9 logCFU/g; and 40 °C: 6.3 logCFU/g). In a study by Gill et al. (1998), 7 °C was the lowest temperature at which *E. coli* growth was observed on pork; and Salter et al. (1998) also noted that non-pathogenic wild type *E. coli* M123 and pathogenic *E. coli* O157:H7 can grow in food and laboratory medium at temperatures of 7.8–46.7 and 1.7–46.1 °C, respectively.

When the effects of temperature (10, 20, 30, and 40 °C) on the specific growth rate (SGR) and lag time (LT) of *E. coli* were assessed in this study, SGR and LT were generally found to increase and decrease, respectively, with increasing temperatures (Table 1). The SGR values increased from $0.037 \pm 0.01 \text{ h}^{-1}$ at 10 °C to $0.5749 \pm 0.06 \text{ h}^{-1}$ at 40 °C and LT decreased from $22.17 \pm 0.02 \text{ h}$ at 10 °C to $0.48 \pm 0.01 \text{ h}$ at 40 °C. Compared to the SGR values reported here, SGR values have been shown to be higher in brain heart infusion (BHI) broth at 15 °C (0.402 h^{-1}) and 35 °C (1.35 h^{-1}) (Bernaerts et al. 2000) as well as in complex medium at 25 °C (0.798 h^{-1}) (Heitzer et al. 1991). The growth of *E. coli* is generally found to be better in liquid rich medium than in *Garaetteok* at similar storage temperatures and we speculate that this difference may be due to the greater

Fig. 1 Observed growth curves of generic *Escherichia coli* in *Garaetteok* at various storage temperatures

Table 1 SGR and LT of generic *Escherichia coli* at various storage temperatures on *Garaetteok* squid, as calculated by the Gompertz equation for the primary modeling

Temperature (°C)	SGR (LogCFU/h)	LT (h)	R ²
10	0.037 ± 0.01	22.17 ± 0.03	0.996
20	0.178 ± 0.02	7.05 ± 0.02	0.999
30	0.431 ± 0.04	1.40 ± 0.01	0.985
40	0.575 ± 0.03	0.48 ± 0.01	0.995

SGR specific growth rate, LT lag time, R² correlation coefficient

availability of nutrients in rich medium such as BHI compared to *Garaetteok*, which consists mainly of carbohydrates.

On the other hand, the SGR values observed for generic *E. coli* in *Garaetteok* in this study are somewhat similar to those reported by Ding et al. (2010): the SGR values of *E. coli* O157:H7 in beef were found to be 0.044 h^{-1} at 10 °C, 0.183 h^{-1} at 20 °C, and 0.377 h^{-1} at 30 °C. The LT values measured in the present study, however, were markedly lower compared to those measured for *E. coli* O157:H7 in beef at the same storage temperatures (62.46 h at 10 °C, 11.3 at 20 °C, and 5.5 h at 30 °C) (Ding et al. 2010). Unfortunately, there is a lack of direct comparisons between generic (non-pathogenic) and pathogenic strains of *E. coli* including *E. coli* O157:H7 in terms of growth kinetics; however, it should be noted that our findings suggest that *E. coli* O157:H7 may be more resistant to certain environments including various storage temperatures than generic *E. coli*.

Predictive model development in *Garaetteok*

The U. S. Department of Agriculture (USDA) typically uses the Gompertz equation to fit bacterial growth curves for the estimating lag times and maximum growth rates (Bhaduri et al. 1994; Buchanan et al. 1993; Buchanan and Phillips 1990; Palumbo et al. 1991). The LT and SGR in *Garaetteok* were calculated from the Gompertz equation used for primary modeling. The values of the LT and SGR obtained at different storage temperatures (10, 20, 30, and 40 °C, Table 1) reveal that SGR increased and the LT decreased with increasing temperature. The values of the SGR and LT had a very high goodness-of-fit, and the curves had high correlation coefficients ($R^2 = 0.985 - 0.999$) at each storage temperature (Table 1).

As mentioned, increasing temperatures resulted in increased SGR and decreased LT values, and polynomial models of the two parameters yielded the following equations:

SGR model for *Garaetteok* : Y

$$= -0.01570 + 0.0183T \\ + 0.000008T^2$$

LT model for *Garaetteok* : Y

$$= 43.2064 - 2.4824T \\ + 0.0355T^2.$$

The four different statistical indices used in the secondary modeling step to predict SGR and LT values of generic *E. coli* in *Garaetteok* are shown in Table 2. The SGR prediction equation was identified as an appropriate secondary SGR model for *Garaetteok* on the basis of a coefficient of determination (r^2) of 0.986, a mean square error (MSE) of 0.0006, a bias factor (B_f) of 0.948, and an accuracy factor (A_f) of 1.163. The fits for the secondary LT model, on the other hand, were not as good as those achieved for the secondary SGR model: the MSE value (0.282) for the LT was somewhat higher than that of the SGR (0.0006). However, the LT prediction equation is still considered an appropriate secondary LT model for *Garaetteok*, since the other three statistical indices used in the secondary modeling step were measured as $r^2 = 0.996$, $B_f = 0.942$, and $A_f = 1.355$.

The r^2 statistical index, which is often used as an overall measure of the fit attained, measures the fraction of the variation around the mean that is explained by the fitted model (Box and Draper 1987). The higher the r^2 value ($0 < r^2 < 1$), the better the prediction of the model (Duffy et al. 1994; Grau and Vanderlinde 1993; Sutherland et al. 1994). The lower the MSE value, the better the adequacy of the model for describing the data (Ross 1999; Sutherland et al. 1994). $B_f < 1$ indicates a ‘fail safe’ model (Nolan et al. 1992), while $B_f > 1$ indicates a ‘fail dangerous’ model (Ross 1999). B_f values in the range of ~ 0.90 – 1.05 are considered good, those in the range of either 0.7 – 0.9 or 1.06 – 1.15 are considered acceptable, and those either < 0.7 or > 1.5 are considered unacceptable (Nolan et al. 1992). In the case of A_f , higher values are indicative of lower accuracy of the average estimate. Salter et al. (1998) reported that acceptable models for the prediction of the effects of temperatures < 40 °C on the growth rate of non-pathogenic *E. coli* M123 are expected to have A_f

values of 1.1 – 1.5 . The USDA Pathogen modeling program that predicts the effects of temperature (10 – 30 °C) on the SGR and LT of *E. coli* O157:H7 in a broth-based system is furthermore expected to have B_f and A_f values of 0.994 and 1.052 , respectively, for SGR; and B_f and A_f values of 1.004 and 1.189 , respectively, for LT (Ding et al. 2010).

The predicted SGR and LT values for generic *E. coli* in *Garaetteok* were determined to be 0.198 h^{-1} and 10.025 h at a storage temperature of 18 °C (Table 3). A marked increase (> 3 -fold) and decrease ($> \text{twofold}$) in the SGR and LT values, respectively, were observed for the *E. coli* in *Garaetteok* in this study compared with a study reported by Kim et al. (2013), who used similar storage temperatures for predictions: the predicted SGR and LT values for *E. coli* O157:H7 were found to be 0.055 h^{-1} and 20.40 h on fresh *Perilla* leaf at a storage temperature of 17 °C. This difference may be due to the different substrates and different strains of *E. coli* used in these studies. The energy, carbohydrate, fat, and protein contents in 100 g of *Garaetteok* are 238 kcal , 52.07 , 0.64 , and 4.52 g , respectively (MFDS, 2016). *Garaetteok* (a carbohydrate-rich food) is likely a better substrate for microbial growth compared with *perilla* leaf due to its higher nutrient content, and generic *E. coli* grows better than *E. coli* O157:H7 in certain environments. This comparison clearly shows that our SGR and LT model for generic *E. coli* growth in *Garaetteok* can be considered a good predictive model.

The predicted LT value for generic *E. coli* growth in *Garaetteok* at a storage temperature of 37 °C was a negative value, which was somewhat different to the observed LT value. LT duration is often generally considered erratic and evaluations of predictive models have shown that LT can be less reliably predicted than generation time (Ross et al. 2000) and growth rate (Davey and Daughtry 1995; Park and Ha 2014; Yoon et al. 2004).

The reliability of secondary models requires mathematical evaluation prior to their practical application. To achieve this, the observed and predicted SGR and LT values of *E. coli* in *Garaetteok* at three randomized incubation temperatures were compared (Table 3). The comparative plots for SGR and LT are shown in Fig. 2a, b, respectively. A scatter plot of observed versus predicted data can be used to assess the success of the model predictions and in this study, most data points were found to be relatively close to the 100% correlation ($y = x$) line, indicating satisfactory performance of the predictive model.

The polynomial model proved reliable in predicting the effects of storage temperature on both the SGR and LT of generic *E. coli* in *Garaetteok*; however, extrapolation of model predictions for the LT in the current study must be done cautiously. Predicting the growth of *E. coli* in *Garaetteok* will assist in reducing the microbial

Table 2 Statistical indices of the secondary modeling for the SGR and LT of generic *Escherichia coli* in *Garaetteok*

Index	r^2	MSE	B_f	A_f
SGR (Log CFU/h)	0.986	0.0006	0.948	1.163
LT(h)	0.996	0.2816	0.942	1.355

r^2 coefficient of determination, MSE mean square error, B_f bias factor, A_f accuracy factor

Table 3 Comparison of the observed and predicted SGR and LT values for generic *Escherichia coli* in *Garaetteok*

Run	Temp (°C)	SGR (Log CFU/h)		LT (h)	
		Observed	Predicted	Observed	Predicted
1	18	0.238 ± 0.02	0.198	9.792 ± 0.03	10.025
2	32	0.494 ± 0.03	0.511	0.344 ± 0.02	0.122
3	37	0.625 ± 0.04	0.630	0.426 ± 0.01	– 0.0429

SGR specific growth rate, LT lag time

Fig. 2 Comparison of the observed and predicted SGR (a) and observed and predicted LT (b) values of generic *Escherichia coli* in *Garaetteok*

quantitative risk associated with the consumption of *Garaetteok*. These predictions will furthermore provide important information concerning the shelf life of *Garaetteok*.

Conclusion

The results of this study verified that generic *E. coli* could be grown in *Garaetteok* at storage temperatures of 10–40 °C. The predictive model developed here is in good agreement with the observed values, which indicates that the model could be used as a practical model with which to predict the growth of generic *E. coli*. There is currently an urgent need for models that can be used to predict the growth, death, and transmission of generic *E. coli* in diverse food matrices and food processing facilities at various temperatures. These newly developed secondary models of SGR and LT for generic *E. coli* in *Garaetteok* may thus be incorporated into tertiary modeling programs such as the Korea Pathogen Modeling Program, in which

they can easily be used to predict the growth kinetics of *E. coli* as a function of storage temperature. Ultimately, model developed in this study may be a vital tool for the reduction of *E. coli* levels in food production, processing, and distribution processes, which in turn will lead to enhanced safety of rice products.

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References

- Bernaerts K, Versyck KJ, Van Impe JF (2000) On the design of optimal dynamic experiments for parameter estimation of a Ratkowsky-type growth kinetics at suboptimal temperatures. *Int J Food Microbiol* 54:27–38
- Bhaduri S, Turner-Jones CO, Buchanan RL, Phillips JG (1994) Response surface models of the effect of pH, sodium chloride and sodium nitrite on growth of *Yersinia enterocolitica* at low temperatures. *Int J Food Microbiol* 23:333–343

- Box GEP, Draper NR (1987) Least squares for response surface work. In: Box GEP, Drapers NR (eds) Empirical model: building and response surfaces. Wiley, New York, pp 34–103
- Buchanan RL, Phillips JG (1990) Response surface models for predicting the effects of temperature, pH, sodium chloride content, sodium nitrite concentration and atmosphere on the growth of *Listeria monocytogenes*. J Food Prot 53:370–376
- Buchanan RL, Bagi LK, Goins RV, Phillips JG (1993) Response surface model for the growth kinetics of *Escherichia coli* O157:H7. Food Microbiol 10:303–315
- Dalgaard P, Ross T, Kamperman L, Neumeyer K, Mcmeekin TA (1994) Estimation of bacterial growth rates from turbidimetric and viable count data. Int J Food Microbiol 23:391–404
- Davey KR, Daughtry BJ (1995) Validation of a model for predicting the combined effect of three environmental factors on both exponential and lag phases of bacterial growth: temperature, salt concentration and pH. Food Res Int 28:223–237
- Ding T, Rahman SME, Purev U, Oh DW (2010) Modelling of *Escherichia coli* O157:H7 growth at various storage temperatures on beef treated with electrolyzed oxidizing water. J Food Eng 97:497–503
- Duffy LL, Vanderlinde PB, Grau FH (1994) Growth of *Listeria monocytogenes* on vacuum-packed cooked meats: Effect of pH, Aw, nitrite and sodium ascorbate. Int J Food Microbiol 23:377–390
- Gibson AM, Bratchell N, Roberts TA (1988) Predicting microbial growth: growth response of *Salmonella* in a laboratory medium as affected by pH, sodium chloride and storage temperature. Int J Food Microbiol 6:155–178
- Gill CO, Greer GG, Dilts BD (1998) Predicting the growth of *Escherichia coli* on displayed pork. Food Microbiol 15:235–242
- Grau FH, Vanderlinde PB (1993) Aerobic growth of *Listeria monocytogenes* on beef lean and fatty tissue: equations describing the effects of temperature and pH. J Food Prot 56:96–101
- Heitzer A, Kohler HE, Reichert P, Hamer G (1991) Utility of phenomenological models for describing temperature dependence of bacterial growth. Appl Environ Microbiol 57:2656–2665
- Hyun YH, Pyun JW, Nam HW (2014) Quality characteristics of *Garaedduck* with *Lentinus edodes* powder. Korean J Food Cook Sci 30:11–21
- Khaled AZ, Oscar TP, Schwarz JG, Hanhem FM, Whiting RC, Yoon KS (2009) Development and validation of a predictive model for *Listeria monocytogenes* scott A as a function of temperature, pH, and commercial mixture of potassium lactate and sodium diacetate. J Microbiol Biotechnol 19:718–726
- Kim OS, Shin MJ (2004) A study on the recognition and preference of Korean traditional rice cake according to age in capital area. Korean J Food Cook Sci 20:444–452
- Kim J, Ro E, Yoon K (2013) Comparison of growth kinetics of various pathogenic *E. coli* on fresh perilla leaf. Foods 2:364–373
- Korea Food and Drug Administration (KFDA) (2011) A report of studies on hazardous microbiological safety assessment of rice cake
- Korea Ministry of Food and Drug Safety (MFDS) (2016) Food nutrition database. <https://www.mfds.go.kr/nutrition.index.do>. Accessed 29 Dec 2016
- Koseki S, Isobe S (2005) Prediction of pathogen growth on iceberg lettuce under real temperature history during distribution from farm to table. Int J Food Microbiol 194:239–248
- Nolan DA, Chanplin DC, Troller JA (1992) Minimal water activity levels for growth and survival of *Listeria monocytogenes* and *Listeria innocua*. Int J Food Microbiol 16:323–335
- Palumbo SA, Williams AC, Buchanan RL, Phillips JG (1991) Model for the aerobic growth of *Aeromonas hydrophila* K144. J Food Prot 54:429–435
- Park SY, Ha SD (2014) Effect of temperature on the growth kinetics and predictive growth model of *Aeromonas hydrophila* on Squid (*Sepioteuthis sepioidea*). Food Sci Biotechnol 23:307–312
- Ross T (1999) Predictive food microbiology models in the meat industry. Meat and Livestock, Sydney
- Ross T, Dalgaard P, Tienungoon S (2000) Predictive modelling of the growth and survival of *Listeria* in fishery products. Int J Food Microbiol 62:231–245
- Ross T, Ratkowsky DA, Mellefont LA, McMeekin TA (2003) Modelling the effects of temperature, water activity, pH, and lactic acid concentration on the growth rate of *Escherichia coli*. Int J Food Microbiol 82:33–43
- Salter MA, Ross T, McMeekin TA (1998) Applicability of a model for non-pathogenic *Escherichia coli* for predicting the growth of pathogenic *Escherichia coli*. J Appl Microbiol 85:357–364
- Sutherland JP, Bay AJ, Roberts TA (1994) Predictive modeling of growth of *Staphylococcus aureus*: the effects of temperature, pH, and sodium chloride. Int J Food Microbiol 21:217–236
- te Giffel MC, Zwietering MH (1999) Validation of predictive models describing the growth of *Listeria monocytogenes*. Int J Food Microbiol 46:135–149
- Yoon KS, Burnette CN, Oscar TP (2004) Development of predictive models for the survival of *Campylobacter jejuni* (ATCC 43051) on cooked chicken breast patties and in broth as a function of temperature. J Food Prot 67:64–70