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Original Article

Fate and Risk Comparison of Foodborne Pathogens in Raw Chicken, Pork, and Beef Meat at Various Temperatures

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Abstract: The objectives of this study were to investigate the behavior characteristics of pathogenic E. coli, Salmonella Typhimurium, Campylobacter jejuni, and Listeria monocytogenes in various kinds of meat (beef, chicken, and pork) and to compare their risk using FDA-iRISK. The growth of S. Typhimurium in chicken and pathogenic E. coli in pork and beef was well supported and posed a high risk. A similar trend was observed in the risk comparison results using the iRISK. When comparing total disability adjusted life years (DALY) per year based on the kinds of meat, chicken was the highest (88.2), followed by pork (58.5) and beef for "yukhoe" (18.8). When comparing scenarios grouped by bacteria, The highest total DALYs per year was observed with pathogenic E. coli (121), followed by S. Typhimurium (44.8) and L. monocytogenes ($1.67E^{-3}$). These results indicate that the risk of combining meat and foodborne pathogens varies under the same distribution environment. Thus, strict management and supervision are required to store and deliver raw meat to prevent cross-contamination among the raw meats at the processing plant and retail market.

Key words: Potential risk, foodborne pathogens, chicken, pork, beef

I. Introduction

The value of the global meat sector was 945.7 billion U.S. dollars in 2018 and was forecasted to increase to 1142.9 billion U.S. dollars by 2023 (Statista 2020). The total sales volume of meat in Korea was around 2.55 million tons in 2018 and is expected to increase to 2.63 million tons by 2023. Around half of the meat sales volume consisted of pork, followed by poultry, beef, and veal (Statista 2020). According to a report by the Korea Rural Economic Institute (KREI 2019), 44.6% of the respondents had an experience purchasing food online, which increased by 15.5% compared to 2016. Since livestock products are more easily perishable than processed products, strict management and supervision are required to store and deliver livestock products during online distribution.

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Korea has reported the highest number of foodborne outbreaks due to pathogenic Escherichia coli, Salmonella spp. and Campylobacter jejuni over the past 5 years. The largest number of cases and patients of the foodborne outbreak was due to pathogenic E. coli, followed by Salmonella spp., and C. jejuni (MFDS 2020), while no cases of listeriosis were reported in Korea. However, Listeria monocytogenes were detected in various foods, such as smoked salmon, smoked duck, imported raw ham, sausages, and enoki mushrooms (KCA 2015). According to previous studies in Korea (Cho et al. 2012; Hyeon et al. 2011; Hong et al. 2007; Oh et al. 2018), E. coli, Salmonella spp., and L. monocytogenes were isolated from various raw meat samples, including cattle and swine carcass. The highest positive rate of Campylobacter spp. (81.4%) in chicken was reported, followed by E. coli (65.9%) and Salmonella spp. (42.3%). On the other hand, beef and pork were contaminated with E. coli (30.8%, 24.2%), followed by Salmonella spp. (2.0, 8.9%) and Campylobacter spp. (1.2, 1.6%), respectively. L. monocytogenes was isolated from the carcass of swine (14.7%) and cattle (6.6%) in the slaughterhouse (Oh et al.

2018).

Extensive research has been conducted on the growth and survival characteristics of various pathogens on meat products (Ingham et al. 2005; Ingham et al. 2007; Pintar et al. 2007; Sommers et al. 2018). The growth characteristics of E. coli O157:H7, Salmonella serovars, and Staphylococcus aureus were studied during the thawing of a whole chicken and retail ground beef, and growth models were developed using Pathogen Modeling Program 7.0 (Ingham et al. 2005). The growths of E. coli O157:H7, S. serovars, and S. aureus were also predicted in pork, beef, and turkey using an isothermal-based predictive tool (Ingham et al. 2007). The influence of refrigerated storage on pathogen counts in raw chicken was quantified using the most probable number (Pintar et al. 2007). The primary growth model of nonpathogenic E. coli was developed in chickens as a function of temperature (Sommers et al. 2018). However, the growth and survival characteristics of various pathogens are never compared in three major livestock products: beef, pork, and chicken.

FDA-IRISK is a comparative risk assessment tool for probabilistic risk assessments using a Monte Carlo simulation (FDA 2021). IRISK is a web-based system, which is designed to calculate the number of illness cases expected based on the contamination of the food by the hazard in question, the typical consumption pattern, and the dose-response relationship and then translates the number of cases into a public health metric to permit comparison of the public health burden across multiple food-hazard pairs (Chen 2013). The objectives of this study were to investigate the growth and survival characteristics of pathogenic E. coli, S. Typhimurium, C. jejuni, and L. monocytogenes in beef, chicken, and pork and to compare their risk in various kinds of meat products using FDA-iRISK, comparative risk assessment tool.

II. Materials and Methods

1. Bacterial strains

Four different strains of L. monocytogenes (ATCC 19111, 15313 and two strains isolated from slaughterhouse and butcher shop), 3 different types of pathogenic E. coli (ETEC:NCCP 13717, EPEC:NCCP13715, EHEC O157:H7: NCTC 12079), S. Typhimurium (ATCC13311, NCCP 14760, 16207), C. jejuni (ATCC 33291, 33560, NCTC 11168) were used in this study. Stock cultures of each strain were stored in a broth containing 20% glycerol at –80°C, respectively.

To prepare bacterial cultures for inoculation study, 10 μL of each L. monocytogenes, pathogenic E. coli, S. Typhimurium, and C. jejuni was inoculated into 10 mL of sterilized tryptic soy broth (TSB, MB cell, Seoul, Korea) containing 0.6% yeast extract (MB cell, Seoul, Korea), tryptic soy broth, brain heart infusion broth (BHI, MB cell, Seoul, Korea), and brucella broth (BD, Sparks, MD, USA) with 0.16% agar, respectively. L. monocytogenes, pathogenic E. coli, S. Typhimurium were incubated for 24 h at 36°C and 140 rpm using a rotary shaker (VS-8480, Vision, Deajeon, Korea) and C. jejuni was incubated in a microaerophilic chamber (DG250; Don Whitley Scientific, West Yorkshire, UK) with an atmosphere containing 5% hydrogen, 10% carbon dioxide, and 85% nitrogen at 42°C for 24 h. One mL of each strain was mixed to prepare cocktail strains for inoculation. One mL of the prepared cocktail strains of each pathogen was transferred into 9 mL of 0.1% sterilized peptone water (Difco, Becton Dickinson, Sparks, MD, USA), which was serially diluted before inoculation of the sample.

2. Preparation of sample and inoculation

Raw beef, chicken, and pork were purchased from the online market in Korea. Each meat was aseptically sliced into 10 g portions, and the 100 μL of cocktail strains of each pathogen was inoculated into 10 g of each meat sample, respectively. All samples were aerobically packaged, but raw beef for the “yukhoe” dish was vacuum packed (Freshield, Siheung, Korea), reflecting online distribution’s packing status. All inoculated and packaged samples were incubated at 4, 10, 17, and 25°C (Incubator VS-120; Vision Scientific, Daejeon, Korea).

3. Microbiological analysis

The inoculated sample was analyzed based on the storage temperature at a selected sampling time. Each sample was homogenized (Interscience, Paris, France) for 2 min in 90 mL of 0.1% peptone water. One milliliter of the homogenized sample was diluted with 9 mL of 0.1% peptone water, and 200 μL of homogenate samples was dispensed into selective media, polymyxin acriflavin LiCl ceftazidime esculin mannitol agar (PALCAM, MB cell, Seoul, Korea) for L. monocytogenes, eosine methylene blue (EMB) agar for pathogenic E. coli, xylose lysine desoxycholate (XLD, Oxoid, Hampshire, UK) agar for S. Typhimurium, and modified charcoal cefoperazone deoxycholate agar (MCCDA, Oxoid, Hampshire, UK) for C. jejuni using an automatic

spiral plater (Don Whitely Scientific Limited, West Yorkshire, UK) in duplicate. The plates with C. jejuni were incubated in a 42°C chamber under microaerophilic conditions. The other plates were incubated in a 36°C incubator (Vision Scientific, Daejeon, Korea). Each sample's colonies on duplicated plates were counted with an automated colony counter (Scan 1200, Interscience, Saint Nom, France).

4. Growth and survival curves

The growth and survival behaviors of each pathogen in various raw meat were graphed using the modified Gompertz model using a GraphPad Prism V 7.03 (GraphPad Software, San Diego, CA, USA) and Weibull equation (Geeraerd 2005) using a Gina FiT V 1.5 Program, respectively.

Modified Gompertz model:

$$Y=N0+C\times\exp(-\exp((2.718\times SGR/C)\times(LT-X)+1))$$

where N_0 is the initial log number of cells (logCFU/g); C is the difference between initial and final cell numbers; LT is a lag time before growth (h); SGR is a specific growth rate (logCFU/h); X is sampling time (h); Y is log cell number (logCFU/g)

Weibull equation:

$$Log10\ (N)=log10\ (N0)-((t/delta)*p)$$

where N_0 is the initial log number of cells (logCFU/g), delta is time for the first decimal reduction of bacteria population (h); t is time (h); p is the shape of the curve. The Weibull model corresponds to a concave upward survival curve if $p<1$ and concave downward if $p>1$. If $p=1$, the decrease is log-linear.

5. Risk comparison of a pair of meat-pathogen using FDA-iRISK

Since the growth was observed with pathogenic E. coli, S. Typhimurium, and L. monocytogenes in various meat products, FDA-iRisk 4.0 was used to compare the risk of beef, chicken, and pork contaminated with these three foodborne pathogens at 10°C. Since the monitoring of each pathogen in various raw meat was not conducted in the present study, the prevalence data for the previous studies were used (Hong et al. 2007; Hyeon et al. 2011), but the initial contamination level was used as the inoculation data of the present study. The initial unit mass was based on a one-serving size of each meat sample (Park 2016), and the increase of contamination level by growth was obtained from the modified Gompertz model of this study. The dose-response model for each pathogen and DALY values, which represent the degree of burden on health caused by disease, was entered as input values <Table 1>.

6. Statistical analysis

Each experiment was repeated at least twice at different times with replicates per treatment. For each replication, at least 2 to 4 measurement of each parameter was performed. All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC). T-test and one-way variance analysis using Duncan's multiple range tests was used for statistical significance among LT, SGR, and MPD values at $p< 0.05$.

III. Results and Discussion

1. Growth and survival characteristics of foodborne pathogens in various raw types of meat

<Table 2> shows intrinsic conditions, including background microorganisms in various meat samples purchased from the online markets in this work. The lowest pH was observed in raw beef for yukhoe (4.46), followed by pork (5.70) and chicken (5.91). No coliforms were detected in raw beef. Growth of pathogenic E. coli, S. Typhimurium, and L. monocytogenes was not observed in various raw meat at 4°C, while the populations of C. jejuni in pork decreased at 4 and 10°C during 7 days of storage (average shelf life of raw meat) <Figure 1>. Survival characteristic of C. jejuni was observed in pork at 4 and 10°C, and a longer delta value of C. jejuni was observed at 4°C (160.7 h) than at 10°C (106.5 h), indicating that C. jejuni may survive better at 4°C than 10°C. Previous studies also reported a similar trend (Wimpfheimer et al. 1990; Pintar et al. 2007; Sommers et al. 2018). The growth kinetics of L. monocytogenes, pathogenic E. coli, and S. Typhimurium in chicken, pork, and beef at 4, 10, 17, and 25°C are shown in <Tables 3, 4, and 5>, respectively.

<Table 3> shows the growth kinetics of L. monocytogenes, pathogenic E. coli, and S. Typhimurium in aerobically packed, raw chicken at 4, 10, 17, and 25°C. Most pathogenic bacteria cannot grow at 4°C except for L. monocytogenes. However, the growth of L. monocytogenes in various raw meat was not observed at 4°C in this work. It is assumed that the growth was not noticed because the lag time (LT) duration may be continued for 7 days of storage in this study. The bacterium phenotype, physiological state, inoculum size,

Table 1. Input data for the hazard scenarios in various raw meats using FDA-iRISK 4.0

Hazard					
L. monocytogenes			Pathogenic *E. coli*		*S. Typhimurium*
Process model					
Input parameter, iRISK template			Model input		References
		Chicken	**Pork**	**Beef**	
Initial prevalence	LM[1)]	0.06	0.14	0.07	Wu et al. (2016), Oh et al. (2018)
	EC	0.66	0.24	0.31	Cho et al. (2012)
	ST	0.42	0.09	0.02	Hyeon et al. (2011)
Initial unit mass			60 g		Park et al. (2016)
Initial concentration[2)]	LM	Normal (3.44,0.02) logCFU	Normal (3.24, 0.33) log CFU	Normal (3.17, 0.06) log CFU	
	EC	Normal (2.88, 0.01) log CFU	Normal (3.23, 0.05) log CFU	Normal (3.24, 0.02) log CFU	
	ST	Normal (3.62, 0.03) log CFU	Normal (3.10, 0.17) log CFU	Normal (3.52, 0.03) log CFU	
Process stage: storage, increase by growth	LM	Normal (4.32, 0.02) log CFU	Normal (4.37, 0.35) log CFU	Normal (2.1, 0.34) log CFU	
	EC	Normal (3.97, 0.05) log CFU	Normal (3.94, 0.32) log CFU	Normal (2.75, 0.04) log CFU	
	ST	Normal (3.25, 0.22) log CFU	Normal (4.80, 0.16) log CFU	Normal (2.64, 0.03) log CFU	
Consumption model					
		Chicken	**Pork**	**Beef**	
Grams per eating occasion		51.2g	85.5g	32.3g	OECD (2019)
Eating occasion per year		43.28	78.09	33.37	
Dose-response model					
LM	Exponential	$r=1.06E^{-12}$ (Susceptiblepopulation)/$2.37E^{-14}$ (Generalpopulation)			WHO (2004)
EC	Exponential	$r=2.18E^{-4}$			
ST	Beta poisson	$\alpha=0.33$, $\beta=139.9$			Bemrah et al. (2003)
Health effects					
DALYs template	LM	0.12			Havelaar et al. (2015)
	EC	1.68			
	ST	2.23			

[1)]LM, *L. monocytogenes*; EC, Pathogenic *E. coli*; ST, *S.* Typhimurium
[2)]Initial concentration input: mean, a standard deviation at 10°C

Table 2. Physicochemical and microbiological of raw meat samples used in this study

Sample	Beef[1)]	Pork	Chicken
pH	4.46±0.05	5.70±0.02	5.91±0.01
Aw	0.987±0.001	0.955±0.001	0.952±0.004
Total aerobic bacteria	4.70±0.14	4.82±0.14	3.25±0.16
Coliform	Not detected	2.99±0.06	±0.05

[1)]Beef was vacuum packed

and environmental conditions affected LT. At 10 and 17°C, significantly longer LT of L. monocytogenes was observed than that of E. coli and S. Typhimurium in chicken. The difference in LT values between L. monocytogenes and other pathogens (E. coli and S. Typhimurium) in chicken was bigger at 10°C than those at 17 and 25°C. However, higher

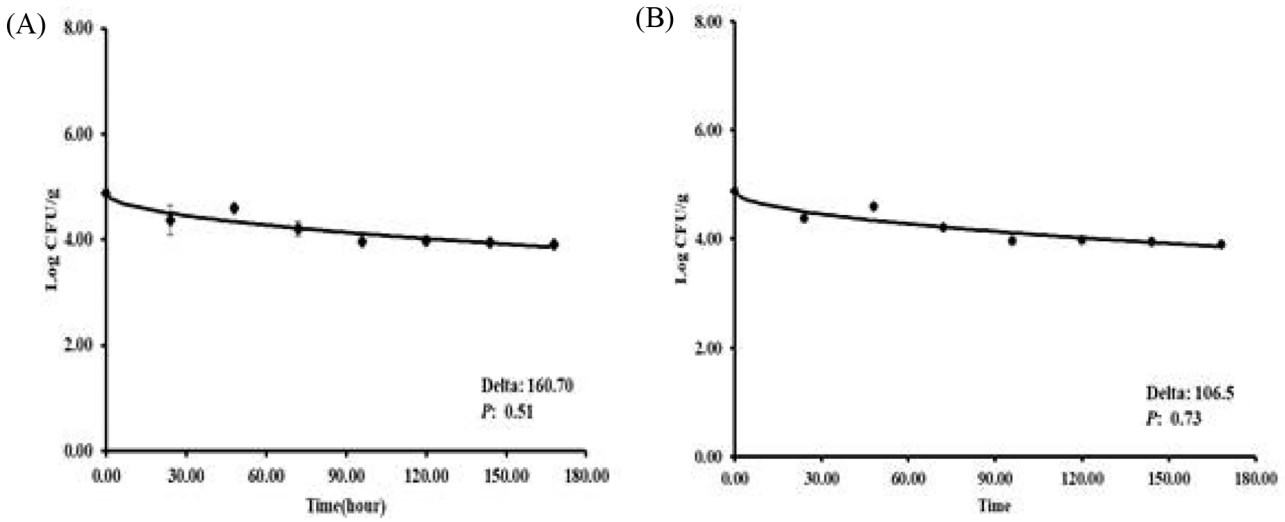

Figure 1. Primary survival model of *C. jejuni* in aerobically packed pork at 4°C (A), 10°C (B)

SGR of L. monocytogenes than those of E. coli and S. Typhimurium was observed at 10 and 17°C. At 17 and 25°C, significantly higher MPD values of S. Typhimurium in chicken (8.85 and 8.37 log CFU/g) than E. coli (7.28 and 8.22, log CFU/g) and L. monocytogenes (7.74 and 7.58, log CFU/g) were noticed, indicating that S. Typhimurium grows well in chicken at ambient temperature. Oscar (2014) compared the growth rate of S. Typhimurium in various parts of chicken meat (white, dark, and skin) at 12 to 19°C. Results show that the growth rate of S. Typhimurium was highest in dark meat, followed by skin and breast meat, indicating that the fate of S. Typhimurium was also affected by the part of the meat. Differences in strain, type of meat, and different packaging conditions of meat samples may affect the behavior of various foodborne pathogens. Thus, samples' intrinsic and extrinsic factors should be considered in each study.

<Table 4> shows the growth kinetics of L. monocytogenes, pathogenic E. coli, and S. Typhimurium in aerobically packed, raw pork at 4, 10, 17, and 25°C. The shortest LT of S. Typhimurium in pork meat was noticed at all temperatures, compared to E. coli and L. monocytogenes. The highest SGR of pathogenic E.coli in pork was observed among three pathogens. Lee et al. (2014) also studied the growth characteristics of L. monocytogenes in raw pork meats at 5, 15, and 25°C. In their work, about 174 h (7.25 days) of LT were also observed at 5°C.

<Table 5> shows the growth kinetics of L. monocytogenes,

Table 3. Comparison of growth kinetics of foodborne pathogen in aerobically packed chicken at various temperatures

Sample	Temperature	Bacteria	LT	SGR	MPD
Chicken	4°C	*L. monocytogenes*		NG	
		E.coli			
		S. Typhimurium			
	10°C	*L. monocytogenes*	32.24^{A}	0.100^{A}	7.754^{A}
		E.coli	10.01^{B}	0.065^{B}	6.855^{B}
		S. Typhimurium	7.67^{B}	0.034^{C}	6.865^{B}
	17°C	*L. monocytogenes*	8.10^{A}	0.133^{A}	7.744^{B}
		E.coli	3.27^{B}	0.078^{B}	7.275^{C}
		S. Typhimurium	4.89^{B}	0.106^{AB}	8.851^{A}
	25°C	*L. monocytogenes*	1.47^{B}	0.207^{B}	7.576^{C}
		E.coli	2.25^{A}	0.389^{A}	8.224^{B}
		S. Typhimurium	2.71^{A}	0.413^{A}	8.371^{A}

LT: lag time (h), SGR: specific growth rate (log CFU/h), MPD: maximum population density (log CFU/g), NG: no growth observed
$^{A-C}$Within the same column in each row, values not followed by the same uppercase letter are significantly different ($p<0.05$)

Table 4. Comparison of growth kinetics of foodborne pathogen in aerobically packed pork at various temperatures

Sample	Temperature	Bacteria	LT	SGR	MPD
Pork	4°C	*L. monocytogenes*			
		E.coli		NG	
		S. Typhimurium			
	10°C	*L. monocytogenes*	14.49^{B}	0.029^{C}	6.514^{B}
		E.coli	20.69^{A}	0.083^{A}	6.775^{B}
		S. Typhimurium	13.90^{B}	0.035^{B}	7.816^{A}
	17°C	*L. monocytogenes*	10.06^{A}	0.101^{B}	6.153^{C}
		E.coli	5.90^{B}	0.129^{A}	9.362^{A}
		S. Typhimurium	5.49^{B}	0.099^{C}	8.582^{B}
	25°C	*L. monocytogenes*	3.25^{A}	0.180^{C}	7.063^{C}
		E.coli	2.92^{B}	0.297^{A}	7.279^{B}
		S. Typhimurium	1.57^{C}	0.254^{B}	9.077^{A}

LT: lag time (h), SGR: specific growth rate (log CFU/h), MPD: maximum population density (log CFU/g), NG: no growth observed
$^{A-C}$Within the same column in each row, values not followed by the same uppercase letter are significantly different ($p<0.05$)

Table 5. Comparison of growth kinetics of foodborne pathogen in aerobically packed beef at various temperatures

Temperature	Bacteria	LT	SGR	MPD
4°C	*L. monocytogenes*			
	E.coli		NG	
	S. Typhimurium			
10°C	*L. monocytogenes*	27.92^{A}	0.019^{C}	5.340^{B}
	E.coli	11.94^{B}	0.025^{B}	6.209^{A}
	S. Typhimurium	7.10^{C}	0.034^{A}	5.907^{A}
17°C	*L. monocytogenes*	11.64^{A}	0.123^{C}	7.238^{C}
	E.coli	9.92^{B}	0.155^{A}	8.441^{A}
	S. Typhimurium	7.74^{C}	0.140^{B}	8.174^{B}
25°C	*L. monocytogenes*	3.02^{A}	0.180^{B}	7.735^{C}
	E.coli	2.36^{B}	0.193^{A}	8.694^{A}
	S. Typhimurium	2.27^{B}	0.181^{B}	8.201^{B}

LT: lag time (h), SGR: specific growth rate (log CFU/h), MPD: maximum population density (log CFU/g)
$^{A-C}$Within the same column in each row, values not followed by the same uppercase letter are significantly different ($p<0.05$)

pathogenic E. coli, and S. Typhimurium in aerobically packed, raw beef at 4, 10, 17, and 25°C. At all temperatures, the longest LT and lowest SGR and MPD were observed with L. monocytogenes, indicating that the growth of L. monocytogenes is slower than that of pathogenic E. coli and S. Typhimurium in aerobically packed beef. E. coli had significantly higher SGR at 17°C (0.155 log CFU/h) and 25°C (0.193 log CFU/h) and MPD (17°C: 8.44 and 25°C: 8.69 log CFU/g) than those of L. monocytogenes and S. Typhimurium in aerobically packed beef, indicating that E. coli is higher risk than L. monocytogenes and S. Typhimurium in aerobically packed beef.

Since most lean beef (for the yukhoe recipe) are vacuum packaged in the online market, the growth kinetics of L. monocytogenes, pathogenic E. coli, and S. Typhimurium were investigated in vacuum-packed, raw beef at 4, 10, 17, and 25°C <Table 6>. A similar trend was observed in vacuum-packed beef except for L. monocytogenes. No growth of L. monocytogenes in vacuum-packaged beef was observed at all temperatures for 7 days of storage at the retail market. Previous studies reported similar results (Gouet et al. 1978; Johnson et al. 1988). Gouet et al. (1978) found that L. monocytogenes did not grow on sterile beef mince during 17 days of storage at 8°C. Neither growth nor death of L. monocytogenes was observed in the lean portion of beef for 14 days at 4°C (Johnson et al. 1988). The growth of L.

Table 6. Comparison of growth kinetics of foodborne pathogen in anaerobically packed beef at various temperatures

Temperature	Bacteria	LT	SGR	MPD
4°C	*L. monocytogenes*			
	E.coli		NG	
	S. Typhimurium			
10°C	*L. monocytogenes*		NG	
	E.coli	**14.29	0.035	4.883
	S. Typhimurium	8.58	0.033	**5.083
17°C	*L. monocytogenes*		NG	
	E.coli	**8.42	0.112	6.029
	S. Typhimurium	6.32	0.166	**5.778
25°C	*L. monocytogenes*		NG	
	E.coli	3.29	0.192	**7.069
	S. Typhimurium	4.33	*0.295	6.336

LT: lag time (h), SGR: specific growth rate (log CFU/h), MPD: maximum population density (log CFU/g), NG: no growth observed
**Significant difference between *E.coli* and *S.* Typhimurium was observed at each parameter ($p<0.05$)
$^{A-C}$Within the same column in each row, values not followed by the same uppercase letter are significantly different ($p<0.05$)

monocytogenes in beef depended on the temperature of storage, the pH of lean, and the type of tissue (fatty and lean), and Listeria maintained higher populations of fat meat than lean meat. Existing microflora, such as low-temperature and lactic acid bacteria, may influence the behavior of L. monocytogenes in beef (Grau & Vanderlinde, 1990). Buchanan et al. (1987) also observed no growth of L. monocytogenes in hamburgers stored at 4°C for 7 days. At 10°C and 17°C, a significantly longer LT of pathogenic E.coli in vacuum-packaged beef was observed than S. Typhimurium ($p<0.05$), but no significant difference in SGR was observed between E. coli and S. Typhimurium <Table 6>. These results indicate that pathogenic E. coli can grow better than S. Typhimurium in beef at the abused temperature, regardless of the packaging method. A higher growth rate was shown in E. coli O157: H7 than in S. serova in ground beef (Ingham et al, 2007). In the present study, longer LT of pathogenic E. coli (14.29 h) and S. Typhimurium (8.58 h) and lower MPD of pathogenic E. coli (4.88 log CFU/g) and S. Typhimurium (5.08 log CFU/g) were observed in vacuum packaged beef <Table 6> than those of aerobic packaged beef at 10°C <Table 5>. These results indicate that vacuum packaging of beef delayed the LT of pathogenic E. coli and S. Typhimurium and lowered the MPD of pathogenic E. coli and S. Typhimurium. In addition, L. monocytogenes grew in aerobically packed beef, while no growth of L. monocytogenes was observed in vacuum-packed beef at 10, 17, and 25°C, which might be due to the low pH (4.46) of raw beef for yukhoe (4.46). L. monocytogenes, E. coli, and S. Typhimurium are all facultative anaerobic bacteria that can grow in both the presence and absence of oxygen. The results of the present study indicate that the anaerobic packaging of meat inhibits the growth of facultative anaerobic microorganisms more effectively than aerobic packaging. This result also confirmed that the growth of L. monocytogenes in beef could be completely controlled by vacuum packaging at even abused temperatures. Thus, vacuum packaging of pork and chicken meat like beef for “yukhoe” must be emphasized in the online market in Korea.

The growth kinetics of foodborne pathogens are compared in chicken <Table 3>, pork <Table 4>, and beef <Table 5> under same aerobic conditions at 10°C. In beef, the longest LT of L. monocytogenes (27.92 h) was observed, followed by pathogenic E. coli (11.94 h) and S. Typhimurium (7.10 h). In addition, the lowest SGR of L. monocytogenes (0.019 log CFU/h) was observed in beef, followed by E. coli (0.025 log CFU/g) and S. Typhimurium (0.034 log CFU/g). These results indicate that S. Typhimurium is the fastest-growing pathogen in beef. Among three pathogens, the longest LT of L. monocytogenes was noticed in chicken (32.24 h), followed by beef (27.92 h) and pork (14.49 h) under same aerobic condition. However, the highest SGR of L. monocytogenes (0.10 log CFU/h) in chicken <Table 3>, pathogenic E.coli (0.083 log CFU/h) in pork <Table 4>, and S. Typhimurium (0.034 log CFU/h) in beef <Table 5> was observed. At 10°C, the MPD values of each pathogen vary according to the type of meat and pathogen. L. monocytogenes in chicken (7.75 log CFU/g), pathogenic E. coli in beef (6.209 log CFU/g),

Table 7. FDA-iRISK risk estimates and scenario ranking report of foodborne pathogens in aerobically packed meats at 10°C

Group	Scenario	Total DALYs per Year		Risk Ranking	
		Group	Scenario	Group	Scenario
Pathogenic *E. coli*	Pork	121	55.4	1	1
	Chicken		48		2
	Beef		17.4		4
S. Typhimurium	Chicken	44.8	40.2	2	3
	Pork		3.11		5
	Beef		1.44		6
L. monocytogenes	Chicken*	$1.67E^{-3}$	$9.22E^{-4}$	3	7
	Pork*		$7.09E^{-4}$		8
	Chicken		$2.06E^{-5}$		9
	Pork		$1.58E^{-5}$		10
	Beef*		$1.47E^{-6}$		11
	Beef		$3.28E^{-8}$		12

*Susceptible population
[1)]DALYs, disability-adjusted life years, the sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability.
ST, *S.* Typhimurium; EC, Pathogenic *E. coli*; LM, *L. monocytogenes*
LM* susceptible population

and S. Typhimurium in pork (7.82 log CFU/g) showed the highest MPD of each pathogen. Capozzi et al. (2009) also showed the differences in MPD due to the background levels of the microflora. They concluded that variable background micro-flora in meat samples might interrupt the growth of foodborne pathogens. The highest SGR and MPD of L. monocytogenes were observed in aerobically packed chicken meat <Table 3>, indicating that the growth of L. monoctyogenes is well supported by chicken meat at 10°C. On the other hand, the longest LT and the highest SGR of pathogenic E. coli were observed in pork. These results and previous studies showed that the growth kinetic values in each pathogen are affected by the type of meat. Thus, the risk in each meat may vary depending on the type, kind, storage, and distribution environments of various types of meats, and pathogen species and strains contaminated in meat products.

2. Risk comparison of pathogens in various types of meat using FDA-iRISK

FDA-iRISK has the advantage of estimating the priority of management by comparing the risk between a combination of food and foodborne pathogens. This study compared the risk of a combination of pathogenic E. coli, S. Typhimurium, and L. monocytogenes in aerobically packed beef, pork, and chicken meats at 10°C <Tables 3, 4, 5>. Since L. monocytogenes can cause serious illness in a susceptible population, such as pregnant women, adults with weakened immune systems, and the elderly, the dose-response model for both the susceptible population and the general population was considered (WHO, 2004).

When the risk of meat was estimated according to the pathogen based on the total disability-adjusted life years (DALYs) per year <Table 7>, pathogenic E. coli (121) was the highest burden, followed by S. Typhimurium (44.8) and L. monocytogenes ($1.67E^{-3}$) for general and susceptible populations. Moreover,pathogenic E. coli was the highest burden in pork (55.4), followed by chicken (48.0) and beef (17.4). S. Typhimurium was the highest burden in chicken (40.2), followed by pork (3.11) and beef (1.44). In L. monocytogenes, chicken for the susceptible population showed the highest burden ($9.22E^{-4}$), followed by pork for the susceptible population ($7.09E^{-4}$), chicken for the general population ($2.06E^{-5}$), pork for the general population ($1.58E^{-5}$), beef for the susceptible population ($1.47E^{-6}$), and beef for the general population ($3.28E^{-8}$). These results indicate that the risk for a combination of food and foodborne pathogens varies under the same distribution environment. Efforts to control the high-risk pathogen in each meat need to prevent foodborne disease outbreaks. In this work, the result of FDA-iRISK and growth kinetics showed a similar tendency.

L. monocytogenes had the least disease burden among the three pathogens in Korea and showed a large gap compared to the disease burden level of other pathogens. This can be

due to the low initial prevalence value of L. monocytogenes (0.06 for chicken, 0.14 for pork, and 0.07 for beef) because the contamination level of L. monocytogenes in raw meat is very low in Korea. Moreover, the longest LT of L. monocytogenes was observed in chicken meat. Additionally, the pork contaminated with pathogenic E. coli showed the highest SGR, and the highest total DALYs per year for pathogenic E. coli was observed in pork. In chicken, no significant difference in LT and MPD between pathogenic E. coli and S. Typhimurium was observed and total DALYs per year of pathogenic E. coli (48.0), and S. Typhimurium (40.2) in chicken showed a small difference. Among the three kinds of meat, the total DALYs per year of beef showed the least disease burden for all pathogens, and the lowest SGR and MPD of all pathogens was observed in beef at 10°C <Tables 5, 6>.

The quantitative microbial risk assessment (QMRA) in poultry meat was reviewed (Khalid et al. 2020). Regardless of region, Salmonella spp. was the first ranked among pathogens most associated with the burden of foodborne diseases in poultry. This is similar to our result that showed the highest total DALYs per year in the chicken group. Previous studies also conducted the probability of illness due to beef consumption using @RISK. The probability of illness of beef was highest in E. coli (1.78×10^{-4}) followed by L. monocytogenes (3.91×10^{-6}) and Salmonella spp. (2.33×10^{-6}) (Smithet al. 2013; Foersteret al. 2015; Abdunaseret al. 2009). Some of the variability of risk assessment results with this work and previous studies may be due to the different scenario settings by different risk assessment programs.

IV. Summary and Conclusion

The fates of foodborne pathogens, including pathogenic *E. coli*, *S.* Typhimurium, *L. monocytogenes, and C. jejuni,* were investigated in beef, chicken, and pork, and their risks in raw meat were compared using an FDA-iRISK, comparative risk assessment tool. The microbial behavior study was conducted for 7 days considering the market shelf life of meat products at 4, 10, 17, and 25°C. At 4°C, no growth of pathogenic *E. coli*, *S.* Typhimurium, and *L. monocytogenes* was observed for 7 days, regardless of meat type. At refrigerated temperatures, the highest SGR of pathogenic *E. coli* and *L. monocytogenes* was observed in pork and chicken, respectively. *C. jejuni* in pork survives better at 4°C than 10°C. No growth of *L. monocytogenes* in vacuum-packed beef was observed at all temperatures for 7 days of storage. The growth kinetic values in each pathogen differ depending on the meat type. Finally, the combined risk of pathogenic *E. coli*, *S.* Typhimurium, and *L. monocytogenes* in aerobically packed beef, pork, and chicken meats were compared at 10°C using FDA-iRISK. Comparing the total DALYs per year by grouping scenarios with the type of meat, the burden was higher in the order of chicken (88.2), pork (58.5), and beef (18.8). When the risk of meat was estimated according to the pathogen, pathogenic *E. coli* (121) was the highest burden, followed by *S.* Typhimurium (44.8) and *L. monocytogenes* ($1.67E^{-3}$) for all populations. The results of FDA-iRISK and growth kinetics showed a similar tendency. *L. monocytogenes* had the least disease burden among the three pathogens in chicken. Among the three types of meat, the total DALYs per year of beef showed the least disease burden for all pathogens. The food industry worker should be aware of the possibility of cross-contamination among the raw meats when they handle different types of raw meats at the processing plant, transport stage, and storage. The effort to control high-risk pathogens in each meat will prevent foodborne disease outbreaks.

Conflict of Interest

No potential conflict of interest relevant this article was reported.

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