Food Sci Biotechnol (2021) 30(2):185–194
https://doi.org/10.1007/s10068-020-00864-x

Recent (2011–2017) foodborne outbreak cases in the Republic of Korea compared to the United States: a review

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Received: 24 August 2020 / Revised: 1 December 2020 / Accepted: 11 December 2020 / Published online: 6 February 2021

Abstract This study analyzes and compares foodborne disease outbreaks reported in the Republic of Korea (KR) and the United States (US) during 2011-2017. The foodborne outbreaks data in the KR and the US were collected from the Ministry of Food and Drug Safety and from the Surveillance for Foodborne Disease Outbreaks United States, respectively. The average number of outbreaks and illness population were higher in the US than in the KR, but the KR's illness ratio considering population size was 2.4 times higher than that of the US. When the sites of outbreaks compared, the number of illness was the highest at schools in the KR whereas outbreaks at restaurants were more frequent in the US. In the KR, bacterial infections were the primary cause of outbreaks while bacterial and viral infections accounted for the largest share of outbreaks in the US. Specifically, pathogenic *E. coli* presented a significant risk in the KR whereas *Salmonella* was the most prevalent in the US. These results indicate that the main microbiological targets for detection and control in the KR should differ from the US, which should be considered for developing food safety related policies.

Keywords Foodborne outbreak · Republic of Korea · United States · Hazard analysis · Outbreak place

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Introduction

Foodborne disease outbreaks occur regularly, even in developed countries. In the Republic of Korea (KR) and the United States (US), food science and related technologies are developing rapidly, but still, it remains a challenge to prevent foodborne diseases completely (Kim et al., 2018). The United States Centers for Disease Control and Prevention (CDC) reported that 841 foodborne outbreaks were reported during 2017 resulting in 14,481 hospitalizations (CDC, 2019). Likewise, 363 foodborne disease cases were reported in the KR during 2018, resulting in 11,504 hospitalizations (MFDS, 2019). These statistics indicate that foodborne diseases are a severe public health problem in the KR and the US.

Foodborne outbreaks in the KR and the US should be analyzed by contamination types because it has different aspects corresponding to the type of hazards. Food-safety related hazards are categorized into physical, chemical, and biological hazards. Firstly, physical hazards include metal substances which can be detected with X-ray (van Asselt et al., 2017) and rarely result in foodborne outbreaks. Secondly, chemical hazards are attributed to the chemicals which are residue in food products or accumulated during processing. For example, several chemicals including pesticides and bactericides used in farming, appear as residue in food products, causing acute or chronic diseases (Wu et al., 2018). Meanwhile, toxic chemicals such as polycyclic aromatic hydrocarbons (PAHs) and heterocyclic amines (HCAs) are accumulated during food processing, contaminating food products and causing foodborne diseases (Lu et al., 2017). Finally, biological hazards including pathogenic bacteria, viruses and parasites are directly associated with large foodborne outbreaks. Among the various pathogens, *Escherichia coli* O157:H7, *Salmonella* *enterica* Serovar Typhimurium, *Listeria monocytogenes*, and norovirus are well known contaminants (Kim and Kang, 2017).

Foodborne outbreaks have been reported in the KR and the US, but only a few studies dealt comparatively with foodborne diseases in the KR and the US. Comparison approach of the foodborne outbreaks between the countries is important to identify the significance and characteristic of the outbreaks in each country. For the first step, this review study reflected on foodborne disease outbreaks between 2011 and 2017 in the KR and the US and compared them by outbreak frequency, illness ratio considering population size, outbreak site, and causative agents.

Data collection and analysis

Data on foodborne disease outbreaks in the KR were collected from the Ministry of Food and Drug Safety (MFDS, 2019) and for the US from the Surveillance for Foodborne Disease Outbreaks United States; Annual Report: 2011 to 2017 (CDC, 2014a; 2014b; CDC, 2015; CDC, 2016; CDC, 2017; CDC, 2018; CDC, 2019). The KR's population size is based on the Bureau population estimation of Korea Statistical Information Service (KOSIS, 2020). The population size of the US is based on data from the estimates of the resident population for the US (US Census Bureau, 2020). The number of illness was divided by the number of cases and by total number of people to represent illness/cases ratio (Table 1) and illness ratio (Table 2), respectively.

Frequency of foodborne disease outbreaks in the KR and in the US during 2011–2017

The frequency of foodborne outbreak cases and illness population in KR and in the US was compared (Table 1). In the KR, the average annual outbreaks were 309 and ranged between 235 and 399 from 2011 to 2017. In the US, the average annual frequency was 842, which is 2.72 times higher than the KR. Similarly, in the case of illness population, the average annual numbers were 6340 and 14,237 for the KR and the US, respectively. When the number of illness population was divided by the number of outbreaks, the results indicate that foodborne outbreak impact the KR (ca 20.5 illness people/case) more significantly than the US (ca 16.9 illness people/case). For the next step, the country's total population was considered because the population sizes are different; average (2011–2017) total populations (ten thousands of people) of KR and US are 5070 and 31,838, respectively (KOSIS, 2020; US Census Bureau, 2020). In this regard, the foodborne outbreak ratio was calculated by dividing the illness population into total population (Table 2). From the calculations, the average annual infection ratios in the KR and in the US were 0.012 and 0.005, respectively. These results indicated that foodborne outbreaks in KR are more severe than in the US even though the number of outbreaks and illness are statistically more significant in the US than the KR. Several factors would affect this trend. Firstly, the population density in the KR (527/km^2) is significantly higher than that of the US (36/km^2) (UN, 2020). A higher population density increases the likeliness of foodborne disease outbreaks compared to low population density countries. Secondly, Koreans have a cultural habit of food sharing, which occurs less frequently in the US (Choe et al., 2005). Finally, Koreans prefer raw or rarely heated food. In particular, unprocessed or minimally processed seafood and beef which have high risk of microbiological contamination have been consumed

Table 1 Foodborne outbreak cases and illness reported in Republic of Korea (KR) and in the United States (US) during 2011–2017

		2011	2012	2013	2014	2015	2016	2017	Total	Average
KR	Cases (N)	249	266	235	349	330	399	336	2164	309
	Illness (N)	7105	6058	4958	7466	5981	7162	5649	44,379	6340
	Illness/cases (%)	28.53	22.77	21.10	21.39	18.12	17.95	16.75	20.50	20.51
US	Cases (N)	801	831	818	864	902	839	841	5896	842
	Illness (N)	14,140	14,972	13,360	13,246	15,202	14,259	14,481	99,660	14,237
	Illness/cases (%)	17.65	18.02	16.33	15.33	16.85	17.00	17.22	16.90	16.91

Cases (N): number of outbreaks

Illness (N): number of people suffer from outbreak

Illness/cases ratio was calculated by dividing the number of illness into the number of cases

Table 2 Foodborne outbreak illness ratio reported in Republic of Korea (KR) and the United States (US) during 2011–2017 reflecting total population

		2011	2012	2013	2014	2015	2016	2017	Average
KR	TP (N)	4994	5020	5043	5075	5101	5122	5136	5070
	IR (%)	0.013	0.012	0.010	0.015	0.012	0.014	0.011	0.012
US	TP (N)	31,138	31,387	31,605	31,838	32,074	32,307	32,514	31,838
	IR (%)	0.005	0.005	0.004	0.004	0.005	0.005	0.005	0.005

TP: total number of people (* ten thousands of people)

Illness ratio (IR) was calculated by dividing the number of illness (indicated in the Table 1) into total number of people

in the KR (Park et al., 2013). These differences would increase the risk of disease outbreaks, more in the KR than in the US. More comparative research needs to be conducted to identify the effect of population density and cultural eating habit on foodborne outbreak risk in different countries.

Comparison of the sites related to the foodborne outbreaks reported in the KR and the US during 2011–2017

The sites where foodborne outbreaks occurred were compared in the KR and in the US (Table 3). Outbreak cases were most frequent at restaurants in both the KR and the US, but illness ratio has different trend. The KR's illness ratio was the highest at school whereas that in US was at restaurant. The average annual outbreak case ratios per site (%) in the KR were the highest at restaurant (57.0) followed by schools (12.9), and private homes (2.3). In the US, the average annual outbreak case ratios per site (%) was the highest at restaurant (52.8) followed by private homes (9.6), and schools (1.3). Illness ratio (%) in US has the same trend with the illness ratio at restaurant (35.8), private homes (7.4), and schools (3.2). However, a different trend was observed in illness ratio in the KR. The average annual illness ratio (%) in the KR was the highest at schools (42.4) followed by restaurants (26.0), and private homes (0.5). Even though schools' outbreak ratio was significantly lower than at restaurant, the illness ratio at schools was significantly higher than at restaurant in KR. These results indicate that a foodborne disease outbreak at schools in the KR could result in a more wide-spread infection rate than in the US. Several school related foodborne outbreaks in KR were reported between 2011 and 2017. For example, kimchi contaminated by *E. coli* O169 caused 1642 infections at seven schools in 2012 (Cho et al., 2014a). Furthermore, in 2013, foodborne norovirus infections occurred at a high-school restaurant serving fermented oysters (Cho et al., 2016). Including these typical two outbreaks, other school related outbreaks were also reported in the KR (Park et al., 2014; 2015; Shin et al., 2015). At the same time, significant infections were reported in restaurants in the US (Barkley et al., 2016; Hall et al., 2014, Sarah et al., 2018). Angelo et al. (2017) reported the epidemiology of restaurant-related foodborne outbreaks in the US during 1998–2013 and identified that food handling and preparation practices were the major contributing factors. These results indicate that the KR government should focus on schools to reduce infections, whereas the US should target restaurants.

Comparison of the type of foodborne hazards related to the foodborne outbreaks reported in the KR and the US during 2011–2017

Bacterial hazards were the primary cause of the foodborne infections in the KR, while bacterial and viral infections accounted for the US's largest share between 2011 and 2017 (Table 4). The average annual outbreak case ratio of bacterial infections in the KR was the highest (35.4%) followed by viral (15.8%), parasitic (4.3%), and chemical & toxic hazards (0.6%). As for the illness ratio, bacterial hazard accounted for 63.6% followed by viral (20.0%), parasitic (1.1%), and chemical & toxic hazards (0.2%). This result indicates that an outbreak by microorganisms result in more infections than other hazardous materials. Microorganisms can proliferate in food at favorable conditions, whereas chemical and physical hazards cannot self-replicate. This attribute is the reason for the widespread biological infections (Lynch et al., 2009). Similar trends were observed for the US, but viral infections impacted the US more significantly than the KR. In the US, the average annual outbreak case ratio of viral infections was the highest (35.1%) followed by bacterial (33.9%), chemical & toxic (4.8%), and parasitic (0.8%). The average illness ratio of viral infections was 41.6%, followed by bacterial (40.7%), and chemical & toxic (1.1%). Therefore, biological infections should be the primary target to ensure food safety in both the KR and the US. One of abnormal aspect in the KR's statistics is that unknown data is significantly higher than that of the US. Several factors would affect this aspect, but we suspect that hazard detection method would

Table 3 Statistics of places where foodborne outbreaks were reported in Republic of Korea (KR) and the United States (US) during 2011–2017

			School	Restaurant	Private home	Other location	Unknown	Total
2011	KR	Case (N, %)	30 (12.0)	117 (47.0)	8 (3.2)	43 (17.3)	51 (20.5)	249 (100)
		Illness (N, %)	2061 (29.0)	1753 (24.7)	51 (0.7)	2677 (37.7)	563 (7.9)	7105 (100)
	US	Case (N, %)	3 (0.4)	348 (43.4)	83 (10.4)	203 (25.3)	164 (20.5)	801 (100)
		Illness (N, %)	42 (0.3)	4536 (32.1)	1196 (8.5)	5709 (40.4)	2657 (18.8)	14,140 (100)
2012	KR	Case (N, %)	54 (20.3)	95 (35.7)	14 (5.3)	31 (11.7)	72 (27.0)	266 (100)
		Illness (N, %)	3185 (52.6)	1139 (18.8)	54 (0.9)	1004 (16.6)	676 (11.1)	6058 (100)
	US	Case (N, %)	12 (1.4)	433 (52.1)	90 (10.8)	218 (26.2)	78 (9.4)	831 (100)
		Illness (N, %)	211 (1.4)	5174 (34.6)	1577 (10.5)	6788 (45.3)	1222 (8.2)	14,972 (100)
2013	KR	Case (N, %)	44 (18.7)	134 (57.0)	5 (2.1)	38 (16.2)	14 (6.0)	235 (100)
		Illness (N, %)	2247 (45.3)	1297 (26.2)	22 (0.4)	1110 (22.3)	282 (5.7)	4958 (100)
	US	Case (N, %)	10 (1.2)	433 (52.9)	86 (10.5)	234 (28.6)	55 (6.7)	818 (100)
		Illness (N, %)	362 (2.7)	5585 (41.8)	1078 (8.1)	4936 (36.9)	1399 (10.5)	13,360 (100)
2014	KR	Case (N, %)	51 (14.6)	213 (61.0)	7 (2.0)	65 (18.6)	13 (3.7)	349 (100)
		Illness (N, %)	4135 (55.4)	1761 (23.6)	28 (0.4)	1458 (19.5)	84 (1.1)	7466 (100)
	US	Case (N, %)	9 (1.0)	485 (56.1)	86 (10.0)	220 (25.5)	64 (7.4)	864 (100)
		Illness (N, %)	359 (2.7)	4780 (36.1)	778 (5.9)	6521 (49.2)	808 (6.1)	13,246 (100)
2015	KR	Case (N, %)	38 (11.5)	199 (60.3)	9 (2.7)	80 (24.2)	4 (1.2)	330 (100)
		Illness (N, %)	1980 (33.1)	1506 (25.2)	34 (0.6)	2443 (40.8)	18 (0.3)	5981 (100)
	US	Case (N, %)	16 (1.8)	469 (52.0)	73 (8.1)	277 (30.7)	67 (7.4)	902 (100)
		Illness (N, %)	622 (4.1)	4757 (31.3)	873 (5.7)	7354 (48.4)	1596 (10.5)	15,202 (100)
2016	KR	Case (N, %)	36 (9.0)	251 (62.9)	3 (0.8)	105 (26.3)	4 (1)	399 (100)
		Illness (N, %)	3039 (42.4)	2120 (29.6)	16 (0.2)	1878 (26.2)	109 (1.5)	7162 (100)
	US	Case (N, %)	21 (2.5)	459 (54.7)	76 (9.1)	235 (28)	48 (5.7)	839 (100)
		Illness (N, %)	1377 (9.7)	5353 (37.5)	895 (6.3)	5827 (40.9)	807 (5.6)	14,259 (100)
2017	KR	Case (N, %)	27 (8.0)	222 (66.0)	2 (0.6)	75 (22.3)	10 (3.0)	336 (100)
		Illness (N, %)	2153 (38.1)	1994 (35.3)	6 (0.1)	1202 (21.3)	294 (5.2)	5649(100)
	US	Case (N, %)	8 (1.0)	489 (58.1)	74 (8.8)	237 (28.2)	33 (3.9)	841 (100)
		Illness (N, %)	253 (1.8)	5533 (38.2)	989 (6.8)	6961 (48.1)	745 (5.1)	14,481 (100)
Total	KR	Case (N, %)	280 (12.9)	1231 (56.9)	48 (2.2)	437 (20.2)	168 (7.8)	2164 (100)
		Illness (N, %)	18,800 (42.4)	11,520 (26.0)	211 (0.5)	11,772 (26.5)	2026 (4.6)	44,379 (100)
	US	Case (N, %)	79 (1.3)	3116 (52.8)	568 (9.6)	1624 (27.5)	509 (8.6)	5896 (100)
		Illness (N, %)	3226 (3.2)	35,718 (35.8)	7386 (7.4)	44,096 (44.2)	9234 (9.3)	99,660 (100)
Average	KR	Case (N, %)	40 (12.9)	176 (57.0)	7 (2.3)	62 (20.0)	24 (7.8)	309 (100)
		Illness (N, %)	2686 (42.4)	1646 (26.0)	30 (0.5)	1682 (26.5)	289 (4.6)	6339 (100)
	US	Case (N, %)	11 (1.3)	445 (52.8)	81 (9.6)	232 (27.5)	73 (8.6)	842 (100)
		Illness (N, %)	461 (3.2)	5103 (35.8)	1055 (7.4)	6299 (44.2)	1319 (9.3)	14,237 (100)

Cases (N): number of outbreaks

Illness (N): number of people suffer from outbreak

Ratio (%) was calculated by dividing the number of each place into annual total number

contribute the difference. In KR, conventional counting method is widely used to detect bacterial pathogens, and conventional PCR method is used for virus detection. On the other hand, application of real-time PCR is suggested in the Bacteriological Analytical Manual (BAM) published by the US FDA (US FDA, 2020). It is more difficult to detect virus than bacteria because virus mutates very rapidly. Considering this aspect, the unknown data of the KR could be suspected as viral hazards. In that situation, the significance of the viral infection in KR would compatible to that in US. Therefore, persistent research is needed how to reduce the unknown data in both countries but especially in KR.

Table 4 Type of hazards which related to foodborne outbreaks reported in Republic of Korea (KR) and in the United States (US) during 2011–2017

			Bacterial	Chemical and toxin	Parasitic	Viral	Unknown
2011	KR	Case (N, %)	103 (41.4)	4 (1.6)	0 (0)	34 (13.7)	109 (43.4)
		Illness (N, %)	4401 (61.9)	27 (0.4)	0 (0)	1545 (21.7)	1132 (15.9)
	US	Case (N, %)	240 (30.4)	33 (4.2)	5 (0.6)	224 (28.4)	287 (36.4)
		Illness (N, %)	4989 (36.0)	135 (1.0)	133 (1.0)	5142 (37.1)	3464 (25.0)
2012	KR	Case (N, %)	83 (31.2)	3 (1.1)	0 (0)	34 (13.7)	108 (43.4)
		Illness (N, %)	3268 (53.9)	13 (0.2)	0 (0)	1687 (27.8)	1090 (18.0)
	US	Case (N, %)	243 (29.5)	40 (4.9)	4 (0.5)	292 (35.4)	245 (29.7)
		Illness (N, %)	5791 (39.0)	131 (0.9)	11 (0.1)	6096 (41.0)	2831 (19.1)
2013	KR	Case (N, %)	101 (43.0)	1 (0.4)	0 (0)	44 (18.7)	89 (37.9)
		Illness (N, %)	2741 (55.3)	16 (0.3)	0 (0)	1608 (32.4)	593 (12.0)
	US	Case (N, %)	287 (35.8)	47 (5.9)	7 (0.9)	264 (32.9)	197 (24.6)
		Illness (N, %)	5430 (41.2)	188 (1.4)	240 (1.8)	5278 (40.0)	2049 (15.5)
2014	KR	Case (N, %)	141 (40.4)	1 (0.3)	0 (0)	50 (14.3)	157 (45.0)
		Illness (N, %)	5701 (76.4)	5 (0.1)	0 (0)	841 (11.3)	919 (12.3)
	US	Case (N, %)	317 (37.2)	52 (6.1)	8 (0.9)	288 (33.8)	187 (21.9)
		Illness (N, %)	5858 (45.9)	171 (1.3)	46 (0.4)	5390 (42.2)	1302 (10.2)
2015	KR	Case (N, %)	111 (33.6)	0 (0)	15 (4.5)	60 (18.2)	144 (43.6)
		Illness (N, %)	3777 (63.1)	0 (0)	114 (1.9)	1005 (16.8)	1085 (18.1)
	US	Case (N, %)	316 (35.7)	39 (4.4)	4 (0.5)	316 (35.7)	209 (23.6)
		Illness (N, %)	6497 (44.1)	139 (0.9)	201 (1.4)	5565 (37.8)	2333 (15.8)
2016	KR	Case (N, %)	127 (31.8)	1 (0.3)	39 (9.8)	55 (13.8)	177 (44.4)
		Illness (N, %)	4669 (65.2)	6 (0.1)	212 (3.0)	1187 (1.6)	1088 (15.2)
	US	Case (N, %)	286 (34.8)	27 (3.3)	6 (0.7)	326 (39.7)	177 (21.5)
		Illness (N, %)	5481 (39.7)	150 (1.1)	57 (0.4)	6406 (46.4)	1701 (12.3)
2017	KR	Case (N, %)	100 (29.8)	2 (0.6)	39 (11.6)	48 (14.3)	147 (43.8)
		Illness (N, %)	3668 (64.9)	21 (0.4)	177 (3.1)	1020 (18.1)	763 (13.5)
	US	Case (N, %)	271 (33.3)	40 (4.9)	13 (1.6)	324 (39.8)	167 (20.5)
		Illness (N, %)	5380 (39.5)	156 (1.1)	155 (1.1)	6391 (46.9)	1538 (11.3)
Total	KR	Case (N, %)	766 (35.4)	12 (0.6)	93 (4.3)	342 (15.8)	941 (44)
		Illness (N, %)	28,225 (63.6)	88 (0.2)	503 (1.1)	8893 (20.0)	6670 (15.0)
	US	Case (N, %)	1960 (33.9)	278 (4.8)	47 (0.8)	2034 (35.1)	1469 (25.4)
		Illness (N, %)	39,426 (40.7)	1070 (1.1)	843 (0.9)	40,268 (41.6)	15,218 (15.7)
Average	KR	Case (N, %)	109 (35.4)	2 (0.6)	13 (4.3)	49 (15.8)	136 (43.9)
		Illness (N, %)	4032 (63.6)	13 (0.2)	72 (1.1)	1270 (20.0)	953 (15.0)
	US	Case (N, %)	280 (33.9)	40 (4.8)	7 (0.8)	291 (35.1)	210 (25.4)
		Illness (N, %)	5632 (40.7)	153 (1.1)	120 (0.9)	5753 (41.6)	2174 (15.7)

Cases (N): number of outbreaks

Illness (N): number of people suffer from outbreak

Ratio (%) was calculated by dividing the number of each hazard into annual total number

Table 5 Comparison of the bacterial hazards related to the foodborne outbreaks reported in Republic of Korea (KR) and the United States (US) during 2011–2017

			Pathogenic *E. coli*	*Salmonella*	*Vibrio parahaemolyticus*	*Campylobacter*	*Staphylococcus aureus*	*Clostridium perfringens*	*Bacillus cereus*	Other
2011	KR	Case (N, %)	32 (31.1)	24 (23.3)	9 (8.7)	13 (12.6)	10 (9.7)	7 (6.8)	6 (5.8)	2 (1.9)
		Illness (N, %)	2109 (47.9)	1065 (24.1)	133 (3.0)	329 (7.5)	323 (7.3)	324 (7.4)	98 (2.2)	20 (0.5)
	US	Case (N, %)	27 (11.3)	114 (47.5)	6 (2.5)	30 (12.5)	9 (3.8)	21 (8.8)	9 (3.8)	24 (10.0)
		Illness (N, %)	411 (8.2)	3047 (61.1)	25 (0.5)	291 (5.8)	133 (2.7)	679 (13.6)	100 (2.0)	323 (6.5)
2012	KR	Case (N, %)	31 (37.3)	9 (10.8)	11 (13.3)	8 (9.6)	5 (6.0)	13 (15.6)	6 (7.2)	0 (0)
		Illness (N, %)	1844 (56.4)	147 (4.5)	195 (6.0)	639 (19.6)	35 (1.1)	297 (9.1)	111 (3.4)	0 (0)
	US	Case (N, %)	29 (11.9)	113 (46.4)	11 (4.5)	37 (15.2)	5 (2.1)	25 (10.3)	2 (0.8)	21 (8.6)
		Illness (N, %)	500 (8.6)	3394 (58.6)	66 (1.1)	476 (8.2)	149 (2.6)	1062 (18.3)	24 (0.4)	120 (2.1)
2013	KR	Case (N, %)	31 (30.7)	13 (12.9)	5 (5.0)	6 (5.9)	5 (5.0)	33 (32.7)	8 (7.9)	0 (0)
		Illness (N, %)	1089 (39.7)	690 (25.2)	40 (1.5)	231 (8.4)	63 (2.3)	516 (18.8)	112 (4.1)	0 (0)
	US	Case (N, %)	32 (11.1)	157 (54.7)	13 (4.5)	27 (9.4)	12 (4.2)	27 (9.4)	5 (1.7)	14 (4.9)
		Illness (N, %)	466 (8.6)	3593 (66.2)	80 (1.5)	287 (5.3)	301 (5.5)	601 (11.1)	25 (0.5)	77 (1.4)
2014	KR	Case (N, %)	38 (27.0)	24 (17.0)	7 (5.0)	18 (12.8)	15 (10.6)	28 (19.9)	11 (7.8)	0 (0)
		Illness (N, %)	1784 (31.3)	1416 (24.8)	78 (1.4)	490 (8.6)	195 (3.4)	1689 (29.7)	49 (0.9)	0 (0)
	US	Case (N, %)	25 (7.9)	149 (47.0)	8 (2.5)	31 (9.8)	17 (5.4)	30 (9.5)	15 (4.7)	42 (13.2)
		Illness (N, %)	226 (3.9)	2563 (43.8)	28 (0.5)	353 (6.0)	566 (9.7)	1230 (21.0)	205 (3.5)	687 (11.7)
2015	KR	Case (N, %)	39 (35.1)	13 (11.7)	5 (4.5)	22 (19.8)	11 (9.9)	15 (13.5)	6 (5.4)	0 (0)
		Illness (N, %)	2138 (56.6)	202 (5.3)	25 (0.7)	805 (21.3)	191 (5.1)	394 (10.4)	22 (0.6)	0 (0)
	US	Case (N, %)	35 (11.1)	158 (50.0)	6 (1.9)	33 (10.4)	17 (5.4)	30 (9.5)	15 (4.8)	42 (13.3)
		Illness (N, %)	380 (5.8)	4035 (62.1)	54 (0.8)	258 (4.0)	306 (4.7)	1028 (15.8)	53 (0.8)	383 (5.9)
2016	KR	Case (N, %)	57 (44.9)	21 (16.5)	22 (17.3)	15 (11.8)	1 (0.8)	8 (6.3)	3 (2.4)	0 (0)
		Illness (N, %)	2754 (59.0)	354 (7.6)	251 (5.4)	831 (17.8)	4 (0.1)	449 (9.6)	26 (0.6)	0 (0)
	US	Case (N, %)	29 (10.1)	135 (47.2)	6 (2.1)	25 (8.7)	15 (5.2)	30 (10.5)	19 (6.6)	27 (9.4)
		Illness (N, %)	419 (7.6)	3081 (56.2)	19 (0.3)	187 (3.4)	253 (4.6)	756 (13.8)	641 (11.7)	125 (2.3)

Table 5 continued

			Pathogenic *E. coli*	*Salmonella*	*Vibrio parahaemolyticus*	*Campylobacter*	*Staphylococcus aureus*	*Clostridium perfringens*	*Bacillus cereus*	Other
2017	KR	Case (N, %)	47 (47.0)	20 (20.0)	9 (9.0)	6 (6.0)	0 (0)	7 (7.0)	10 (10.0)	1 (1.0)
		Illness (N, %)	2383 (65.0)	662 (18.0)	354 (9.7)	101 (2.8)	0 (0)	69 (1.9)	73 (2.0)	26 (0.7)
	US	Case (N, %)	22 (8.1)	122 (45.0)	17 (6.3)	23 (8.5)	14 (5.2)	41 (15.1)	11 (4.1)	21 (7.7)
		Illness (N, %)	562 (10.4)	3061 (56.9)	70 (1.3)	147 (2.7)	141 (2.6)	843 (15.7)	341 (6.3)	215 (4.0)
Total	KR	Case (N, %)	275 (35.9)	124 (16.2)	68 (8.9)	88 (11.5)	47 (6.1)	111 (14.5)	50 (6.5)	3 (0.4)
		Illness (N, %)	14,101 (50.0)	4536 (16.1)	1076 (3.8)	3426 (12.1)	811 (2.9)	3738 (13.2)	491 (1.7)	46 (0.2)
	US	Case (N, %)	199 (10.2)	948 (48.4)	67 (3.4)	206 (10.5)	89 (4.5)	212 (10.8)	69 (3.5)	170 (8.7)
		Illness (N, %)	2964 (7.5)	22,774 (57.8)	342 (0.9)	1999 (5.1)	1829 (4.6)	6199 (15.7)	1389 (3.5)	1930 (4.9)
Average	KR	Case (N, %)	39 (35.8)	18 (16.5)	10 (9.2)	13 (11.9)	7 (6.4)	16 (14.7)	7 (6.4)	0 (0)
		Illness (N, %)	2014 (50.0)	648 (16.1)	154 (3.8)	489 (12.1)	116 (2.9)	534 (13.2)	70 (1.7)	7 (0.2)
	US	Case (N, %)	28 (10.0)	135 (48.2)	10 (3.6)	29 (10.4)	13 (4.6)	30 (10.7)	10 (3.6)	24 (8.6)
		Illness (N, %)	423 (7.5)	3253 (57.8)	49 (0.9)	286 (5.1)	261 (4.6)	886 (15.7)	198 (3.5)	276 (4.9)

Cases (N): number of outbreaks

Illness (N): number of people suffer from outbreak

Ratio (%) was calculated by dividing the number of each bacterial hazard into annual total number

Comparison of the type of bacteria related to foodborne outbreaks reported in the KR and the US during 2011–2017

Bacterial infections related to foodborne diseases in the KR were analyzed and compared with in the US (Table 5). Foodborne bacteria were similar in the KR and in the US, but ratios were different for each country. In the KR, pathogenic *E. coli* was more persistent bacterial pathogen, accounting for an average 35.8% of bacterial outbreaks followed by *Salmonella* (16.5%), *Clostridium perfringens* (14.7%), *Campylobacter* (11.9%), *Vibrio parahaemolyticus* (9.2%), *Staphylococcus aureus* (6.4%), and *Bacillus cereus* (6.4%). On the other hand, *Salmonella* was the most persistent bacterial pathogen in the US resulting in 48.2% of bacterial outbreaks, followed by *C. perfringens* (10.7%), *Campylobacter* (10.4%), pathogenic *E. coli* (10.0%), *S. aureus* (4.6%), *B. cereus* (3.6%), and *V. parahaemolyticus* (3.6%). A similar trend was observed for illness ratio. Pathogenic *E. coli* accounted for the majority of bacterial infections (50.0%) in the KR followed by *Salmonella* (16.1%), *C. perfringens* (13.2%), *Campylobacter* (12.1%), *V. parahaemolyticus* (3.8%), *S. aureus* (2.9%), and *B. cereus* (1.7%). In the US, *Salmonella* accounted for 57.8% of bacterial infections followed by *C. perfringens* (15.7%), pathogenic *E. coli* (7.5%) *Campylobacter* (5.1%), *S. aureus* (4.6%), *B. cereus* (3.5%), and *V. parahaemolyticus* (0.9%).

Many researchers investigated the prevalence and risk assessment of bacterial pathogens in both the KR and the US. For example, Lee et al. (2009) investigated the prevalence of *E. coli* in pork, beef, and poultry in the KR, and reported that 39 pathogenic *E. coli* were observed in 273 *E. coli* isolates. Lee et al. (2009)'s study indicates that pathogenic *E. coli* in meat in the KR could be an intermediate for transmission to humans. Cho et al. (2014b) reported that pathogenic *E. coli* contamination in kimchi caused foodborne outbreak in the KR affecting 1200 students and food handlers from 7 schools. Considering that Koreans consume vast quantities of kimchi annually, these kinds of outbreaks would contribute to the high risk of the pathogenic *E. coli*. Moreover, sodium reduce policy in kimchi production is being encouraged by KR government. Even though Song et al. (2019) reported that major foodborne pathogens such as *E. coli* O157:H7, *Salmonella* spp. *L. monocytogenes*, *S. aureus* and *Yersinia enterocolitica* were not detected both in regular and reduced-sodium napa cabbage kimchi, further study is needed to ensure microbiological safety in sodium reduced kimchi. In the US, several *Salmonella* contaminated food results in multistate outbreaks. Jackson et al. (2013) investigated outbreak-associated *Salmonella enterica* serotypes and food from 1998 to 2008 and identified that 80% of outbreaks were

Table 6 Comparison of the viral hazards related to the foodborne outbreaks reported in Republic of Korea (KR) and the United States (US) during 2011–2017

			2011	2012	2013	2014	2015	2016	2017	Total	Average
Cases	KR	Norovirus (N, %)	31 (91.2)	50 (98.0)	43 (97.7)	46 (92.0)	58 (96.7)	55 (100)	46 (95.8)	329 (96.2)	47 (95.9)
		Other virus (N, %)	3 (8.8)	1 (2.0)	1 (2.3)	4 (8.0)	2 (3.3)	0 (0)	2 (4.2)	13 (3.8)	2 (4.1)
	US	Norovirus (N, %)	223 (99.6)	287 (98.3)	257 (97.3)	284 (98.6)	311 (98.4)	322 (98.8)	316 (97.5)	2000 (98.3)	286 (98.3)
		Other virus (N, %)	1 (0.4)	5 (1.7)	7 (2.7)	4 (1.4)	5 (1.6)	4 (1.2)	8 (2.5)	34 (1.7)	5 (1.7)
Illness	KR	Norovirus (N, %)	1524 (98.6)	1665 (98.7)	1606 (98.6)	739 (87.9)	996 (99.1)	1187 (100)	968 (94.9)	8685 (97.4)	1241 (97.4)
		Other virus (N, %)	21 (1.4)	22 (1.3)	22 (22)	102 (12.1)	9 (0.9)	0 (0)	52 (5.1)	228 (2.6)	33 (2.6)
	US	Norovirus (N, %)	5135 (99.9)	6009 (98.6)	4999 (94.7)	5340 (99.1)	5545 (99.6)	5934 (92.6)	6340 (99.2)	39,302 (97.7)	5616 (97.4)
		Other virus (N, %)	7 (0.001)	87 (1.4)	279 (5.3)	50 (0.9)	20 (0.4)	472 (7.4)	51 (0.8)	915 (2.3)	153 (2.6)

Cases (N): number of outbreaks

Illness (N): number of people suffer from outbreak

Ratio (%) was calculated by dividing the number of each viral hazard into annual total number attributed to eggs or poultry followed by plant and other food commodities. Likewise, *Salmonella* contaminated egg or poultry (Schweitzer, 2020) would be major source of multistate outbreaks between 2011 and 2017 and other food commodities such as papaya (Mba-Jonas et al., 2018) and pepper (Hassan et al., 2017) also caused multistate outbreaks in the US. However, it remains a challenge to determine why the pathogenic *E. coli* in the KR and *Salmonella* in the US are more persistent than other bacterial pathogens. Further study is needed to identify the reason for this by analyzing geographic, climatic, and habitual variation.

Comparison of the type of virus related to foodborne outbreaks reported in the KR and the US during 2011–2017

Type of viruses related to foodborne diseases in the KR were analyzed and compared with that in the US (Table 6). Foodborne outbreak cases and illness by norovirus were overwhelming both in the KR and in the US during 2011–2017. The average annual outbreak case ratio of norovirus and other virus infection in the KR was 95.9% and 4.1%, respectively. As for the illness ratio, norovirus and other virus accounted for 97.4% and 2.6%, respectively. Similar trends were observed for the US. The average annual outbreak case ratio of norovirus and other virus infection in the US was 98.3% and 1.7%, respectively. The average annual illness ratio of norovirus and other virus was 97.4% and 2.6%, respectively. Likewise, norovirus is the most notorious pathogenic virus both in the KR and in the US of which detection and control is important. However, it is difficult to cultivate the human norovirus in laboratory even though stem cell based replication method was reported (Ettayebi et al., 2016). Further study is needed to cultivate the human norovirus more easily in laboratory. Foodborne viruses other than norovirus includes adenovirus, astrovirus, rotavirus, and hepatitis A and E. Even though these viruses except norovirus were account for a small proportion of viral outbreaks both in the KR and in the US, detection and control of these viruses were also important because they can be fatal to infants, children, and elderly (Hyeon et al., 2011).

Compliance with ethical standards

Conflict of interest The author declares no conflict of interest.

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