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Evaluation of the microbiological status of raw pork meat in Korea: modification of the microbial guideline levels for meat

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Abstract This study aimed to evaluate the suitability of total aerobic plate count (APC) guidelines for raw pork ($< 1 \times 10^7$ CFU/g) distributed in Korea. The APC values for raw pork collected from meat packing centers and meat shops in three provinces (Seoul/Gyeonggi, Gangwon, and Chungcheong) were reported to be $\leq 1.5 \times 10^6$ CFU/g. To evaluate practical APC guidelines for pork and meat quality, APC levels and quality traits were determined for pork under cold storage. On day 12, APC for pork was 4.3×10^6 CFU/g, which was below the guideline level, while overall acceptability scores were < 3.0, indicating that the pork was rated as not acceptable by sensory panels. Therefore, to satisfy both the microbiological safety of pork and organoleptic quality for consumer palatability, we suggest that the current APC guideline levels for pork should be lowered to 1×10^6 CFU/g.

Keywords Pork meat · Microbiological guideline · Sensory evaluation · Total aerobic plate counts

Introduction

The microbiological sanitation of foods is crucial for public health concerns. Particularly, meat acts as an optimal medium for microbial growth, and its spoilage imposes an economic loss on the producers as well as health hazards on the consumers due to the possible presence of pathogenic microorganisms [1]. Moreover, due to the opening of markets via the free trade agreement, import of meat has increased and ensuring the safety of meat has become an international issue at every stage of meat distribution [2].

Korea and China have the largest meat consumption per capita in Asia (51.5 and 49.8 kg/capita, respectively) according to a report from the Organization for Economic Cooperation and Development in 2014 [3]. In 2016, annual consumption of pork in Korea was reported as 28.4 kg/capita, and those of beef and poultry were 9.5 and 14.4 kg/capita, respectively [3]. Fresh pork is a highly perishable meat because of its nutritional composition [4], thus its shelf-life is considerably short.

Shelf life indicates the amount of time passing through before meat becomes unacceptable for human consumption due to the growth of spoilage microorganisms [5]. In particular, pork can be contaminated with bacteria during packing, distribution, and retail preparation [6]. Shortening the shelf life of pork leaves the producer with economic losses, and leaves the consumer with questionable meat safety. Therefore, continuous monitoring of bacterial contamination levels in pork, particularly those of pathogens, must be performed.

Meat quality control and freshness have been primarily evaluated by two methods [7]: total aerobic plate count (APC) analysis and sensory evaluation by experts. There are various categories of guidelines or criteria for APCs of meat in each country. Since 1992, the United States has been conducting a nationwide microbiological baseline study for evaluating microbiological contamination levels in meat at the Food Safety and Inspection Service. In the European Union, according to the microbiological criteria for foods (EC No. 2073/2005), APCs of mechanically separated meat are limited to $< 5 \times 10^6$ CFU/g. The Australian APC standard for the hygienic production and

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transportation of meat and meat products for human consumption (AS 4696:2007) is recommended to as < 1×10^6 CFU/g or CFU/cm^2. In Korea, the Ministry of Food and Drug Safety (MFDS, Notice 2014-135) recommends that the APC of distributed meat should be < 1×10^7 CFU/g, which is an order of magnitude higher than those in other countries (1×10^6 CFU/g). Moreover, some studies have reported that APC of 1×10^7 CFU/g adequately represents the beginning of the spoilage process in meat [8–10]. Therefore, consumer confusion is common because the APC level suggested by the microbiological safety guidelines in Korea is similar to the APC at the spoilage level. Practical guidelines for APC of raw pork are needed by evaluating the change in meat quality with changing APC levels during storage.

The objective of this study was to evaluate the microbiological contamination levels of raw pork from MFDS in Korea over a period of five years (2010–2014), and to monitor the present microbiological contamination level of pork in three provinces in Korea. Furthermore, change of pork meat quality during cold storage was determined as a scientific basis to provide the practical APC guideline for raw pork.

Materials and methods

Monitoring microbiological contamination levels for pork in Korea (2010–2014)

Monitoring data for the APC of pork in meat packing centers (n = 3,205) and meat shops (n = 4,315) in Korea (2010–2014) were obtained from MFDS.

Monitoring the microbiological contamination levels for pork in three provinces in Korea

From July to August, 2015, total 21 raw pork loins were collected from one meat packing center (3 samples) and six meat shops (18 samples) in three provinces (Seoul/Gyeonggi, Gangwon, and Chungcheong) in Korea. The meat packing centers and meat shops were randomly selected. For the six meat shops in each province, one was located in a supermarket and was considered a big shop and the others were small-scale butchers' shops across the three provinces. The collected samples were transported to laboratories under refrigerated conditions (3 ± 1 °C) and then used for microbiological analysis within 24 h of arrival.

Microbiological analysis

For APCs and *Escherichia coli* counts, 10 g of pork loin was transferred to a sterile stomacher bag filled with 90 mL of sterile saline solution. The contents were homogenized for 2 min using a stomacher (Bag Mixer 400, Interscience, St. Nom, France). A serial dilution was prepared with the saline solution, and 1 mL of diluent was seeded onto Petrifilms (APC, *E. coli*/Coliform count plate, 3 M Microbiology, St. Paul, MN, USA). APC and *E. coli* counts were performed after incubation at 37 °C for 48 h according to the manufacturer's instructions.

Measurements of quality parameters and microbial levels in pork during cold storage

To evaluate the pH, microbiological, and sensory characteristics of pork loins during storage, we obtained pork loins 24 h postmortem from a local meat packing center in the Gangwon province in Korea. They were transferred to the laboratory in an ice box. The cuts of pork loin were wrapped with low-density polyethylene film. The pork loins were stored in a refrigerator at 3 ± 1 °C for 16 days. During storage, pork loins were removed on days 1, 3, 6, 8, 9, 10, 11, 12, 13, 14, 15, and 16 to analyze the pH, APC, *E. coli*, and sensory characteristics. The pH was measured with homogenized 10 g of pork loins with 90 mL of sterile water using a pH meter (Orion 230A, Thermo Fisher Scientific, Inc., Whaltham, MA, USA). Sensory evaluation was conducted by 15 evaluators; color, aroma, and overall acceptability was expressed using a 9-point hedonic scale, where 9 = like extremely and 1 = dislike extremely. Drip loss also was expressed using a 9-point hedonic scale, where 9 = very much and 1 = very little.

Statistical analysis

All analyses were performed at least thrice, and an analysis of variance was conducted using the general linear model procedure with SAS software (SAS Institute Inc., Cary, NC, USA), followed by Duncan's multiple range test to analyze significance differences among mean values. Data were expressed as mean ± SE. Differences were considered significant at $p < 0.05$.

Results and Discussion

Monitoring microbiological contamination levels for pork in Korea according to the MFDS dataset (2010–2014)

Many countries control microbiological levels of raw meat to ensure meat safety for consumers. When raw pork is distributed through cutting, packing, and selling, hygiene management is incredibly important. Meat from meat packing centers and meat shops are directly provided to consumers. In Korea, the microbiological guidelines for raw meat in meat packing centers and meat shops as recommended by MFDS (Notice 2014-135). APCs and *E. coli* for pork in meat packing centers and meat shops in Korea are recommended to be $< 1 \times 10^7$ CFU/g and $< 1 \times 10^4$ CFU/g, respectively.

The results of APC levels for fresh pork meat from meat packing centers and meat shops in Korea over a five-year period (2010–2014) are shown in Table 1. A total of 3205 raw pork samples from meat packing centers were analyzed for APCs, and the APC levels for 3161 (98.63%) distributed pork products were $< 1 \times 10^6$ CFU/g. A total of 4315 raw pork samples from meat shops were analyzed for APCs over the same five-year period, and 3985 (92.35%) pork products were distributed with APC levels of $< 1 \times 10^6$ CFU/g. Among the APCs evaluated for pork samples from meat packing centers and meat shops, only 1 (0.03%) and 37 (0.86%) cases, respectively, exhibited unacceptable quality by exceeding the microbiological guidelines in Korea.

Monitoring microbiological contamination levels for collected pork loins from three provinces in Korea (2015)

From July to August 2015, we investigated microbiological contamination levels using APCs and *E. coli* levels for pork meat collected from one meat packing center in each of the three provinces (Table 2). The mean values of APCs for pork in the meat packing centers from Seoul/Gyeonggi, Gangwon, and Chungcheong provinces were 8.3×10^1, 1.2×10^4, and 6.5×10^3 CFU/g, respectively. *E. coli* was not detected in any of the pork products from meat centers in any of the provinces. A study by Kim et al. [11] indicated that the APCs levels for pork in meat packing centers ranged from 4.5×10^3 to 9.5×10^4 CFU/g. These values are comparable to APC levels determined in this study from the Gangwon and Chungcheong provinces.

In addition, microbiological monitoring was conducted to investigate microbial contamination levels for pork in six meat shops from each of the three provinces (Table 3). The maximum mean value of APC from meat shops in the three provinces was 1.2×10^6 CFU/g, while the minimum mean value was 2.2×10^3 CFU/g. Kim et al. [11] reported that APC levels for pork in meat shops ranged from 2.8×10^5 to 3.0×10^5 CFU/g, which were similar to our results. *E. coli* in pork samples were detected from only two meat shops, and their levels ranged from 3.0 CFU/g to 4.3×10^1 CFU/g.

Microbiological monitoring of purchased raw pork loins from retail locations can help in providing information regarding consumer exposure to pathogens in raw meat prior to food handling and preparation, as well as the potential for cross contamination in domestic environments [12].

According to MFDS's report, pork hygiene in Korea was managed well during the monitoring period as the percentage of pork samples exceeding APC guidelines was $< 1\%$ (Table 1). Also, our experimental results showed that there were no cases that exceeded the microbiological guidelines for pork in the three provinces in this study (Table 2, 3). Jeon et al. [13] reported that APC levels for pork from butchers' shops were $< 1 \times 10^6$ CFU/g (89.8%) and *E. coli* levels were $< 1 \times 10^3$ CFU/g (99%). Other researchers have confirmed that APCs for pork from meat shops ranged from 4×10^2 to 1.1×10^6 CFU/g [14]. APCs of all pork samples collected from meat shops in Seoul were $< 1 \times 10^6$ CFU/g. APCs of 70.1% of the samples ranged between 1×10^2 and 1×10^5 CFU/g and *E. coli* counts were approximately 10^1 CFU/g [15]. In this study, the status of microbiological contamination in pork loins distributed in August 2015 was similar to those of previous reports. Therefore, we can conclude that hygiene management for pork meat has been well maintained in Korea.

Table 1 Total aerobic plate counts for raw pork loins collected from meat packing centers and meat shops across Korea over a five-year period (2010–2014)

Place	Total aerobic plate count[a]					
	$\leq 10^3$	$10^3 < - \leq 10^4$	$10^4 < - \leq 10^5$	$10^5 < - \leq 10^6$	$10^6 < - \leq 10^7$	$10^7 <$
Meat packing centers	1132[b]	1125	706	198	43	1
(n = 3205)	(35.32)[c]	(35.10)	(22.03)	(6.18)	(1.34)	(0.03)
Meat shops	902	1124	1156	803	293	37
(n = 4315)	(20.90)	(26.05)	(26.79)	(18.61)	(6.79)	(0.86)

Above data was obtained from the Korean Ministry of Food and Drug Safety

[a]CFU/g

[b]Number of samples

[c]Percentage of the total number of samples (%)

Table 2 Total aerobic plate counts and *E. coli* counts in raw pork loins collected from meat packing centers in three provinces of Korea (CFU/g)

Province	Total aerobic plate count			*E. coli*		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Seoul/Gyeonggi	8.3×10^1	6.0×10^1	1.1×10^2	N.D.	N.D.	N.D.
Gangwon	1.2×10^4	6.6×10^3	1.7×10^4	N.D.	N.D.	N.D.
Chungcheong	6.5×10^3	4.9×10^3	8.0×10^3	N.D.	N.D.	N.D.

n = 15

N.D. not detected

Table 3 Total aerobic plate counts and *E. coli* counts for raw pork loins from meat shops in three provinces of Korea (CFU/g)

Province	Markets	Total aerobic plate count			*E. coli*		
		Mean	Minimum	Maximum	Mean	Minimum	Maximum
Seoul/Gyeonggi	A[a]	1.2×10^6	1.0×10^6	1.5×10^6	N.D.	N.D.	N.D.
	B	8.2×10^3	6.0×10^3	9.8×10^3	N.D.	N.D.	N.D.
	C	1.9×10^5	1.8×10^5	1.9×10^5	N.D.	N.D.	N.D.
	D	3.1×10^3	1.7×10^3	4.6×10^3	N.D.	N.D.	N.D.
	E	3.1×10^4	2.2×10^4	3.9×10^4	N.D.	N.D.	N.D.
	F	4.0×10^5	3.7×10^5	4.4×10^5	N.D.	N.D.	N.D.
Gangwon	A	1.8×10^4	1.1×10^4	2.3×10^4	N.D.	N.D.	N.D.
	B	9.3×10^5	7.6×10^5	1.2×10^6	4.3×10^1	2.0×10^1	8.0×10^1
	C	8.8×10^4	6.3×10^4	1.0×10^5	N.D.	N.D.	N.D.
	D	4.2×10^4	2.6×10^4	6.1×10^4	N.D.	N.D.	N.D.
	E	9.4×10^5	7.8×10^5	1.0×10^6	N.D.	N.D.	N.D.
	F	7.1×10^4	6.5×10^4	7.8×10^4	N.D.	N.D.	N.D.
Chungcheong	A	1.8×10^5	1.7×10^5	1.9×10^5	N.D.	N.D.	N.D.
	B	4.3×10^3	3.2×10^3	5.3×10^3	N.D.	N.D.	N.D.
	C	1.9×10^4	1.5×10^4	2.5×10^5	N.D.	N.D.	N.D.
	D	4.2×10^3	3.1×10^3	4.9×10^3	N.D.	N.D.	N.D.
	E	2.2×10^3	1.5×10^3	2.9×10^3	N.D.	N.D.	N.D.
	F	2.2×10^4	2.2×10^4	2.3×10^4	3.0	N.D.	1.0×10^1

n = 18

N.D. not detected

[a]A: supermarket, B–F: local butchers' shops

Hence, on comparing the contamination levels in meat packing centers and meat shops, meat packing centers had consistently lower levels of APCs than those of meat shops. Higher levels of contamination at retail locations could be due to improper cleaning/sanitization of equipment and poor employee hygiene within the shop [6]. Therefore, at the retail level, we suggest that additional efforts be implemented to improve sanitation in meat shops.

Meat quality and microbial levels in pork loins during cold storage

After slaughtering of animals, the main factors limiting the shelf life of fresh meat are temperature, pH, and microbial activities [16]. Therefore, measurement of pork quality during storage at a typical temperature of 4 °C can provide practical data for estimating appropriate microbiological guidelines. The changes in pH, microbiological levels, and sensory quality characteristics for pork loins during storage at 4 °C is shown in Table 4. Previous studies have suggested that initial pH values of fresh pork are typically in the range of 5.4–5.8 [17, 18]. In this study, the initial pH value was 5.56. The pH values for pork loin significantly increased from 5.56 to 6.40 during storage ($p < 0.05$). Higher pH values have been associated with a faster microbial spoilage in meat [19], because increased pH levels are related to proteolytic activity with the formation of peptides, amino acids, and ammonia [20]. MFDS states that meat pH levels in the range of 6.2–6.3 indicate the early spoilage stage. Also, Gil et al. [16] reported that the pH values of pork when stored at 4 °C ranged from 5.60 (day 1) to 6.27 (day 10).

The shelf life and quality of meat greatly depend on initial bacterial levels [10]. In this study, the APCs for pork loin were initially 1.2 × 10^4 CFU/g and then significantly increased over the 16-day storage period ($p < 0.05$). On day 13, APCs for pork loin samples were 2.8 × 10^7 CFU/g (7.45 log CFU/g), exceeding the microbiological guidelines set for pork in Korea. *E. coli* was not detected during this storage period. It was reported that APCs for pork loin samples were initially 5.50 log CFU/cm^2, remaining at this level until day 7 [21]. However, APCs for pork loin samples significantly increased to 7.79 log CFU/cm^2 after 14 days of storage [6], which is similar to our results in the current study. A study by Ko and Yang [22] showed that APCs for pork loin were initially 2.6 × 10^2 CFU/cm^2 and increased slowly until day 7, with increasing up to 2.0 × 10^7 CFU/cm^2 at day 10. In our study, APC levels at day 10 were lower than those in Ko and Yang's study [22], but similar patterns were observed where significant increases occurred from day 8 to 10. Also, Gil et al. [16] reported that microbial growth significantly increased from 3.7 × 10^3 CFU/g on the first day to > 10^9 CFU/g by the end of the study.

For the sensory evaluation, color, aroma, drip loss, and overall acceptability were evaluated. If the color, aroma, and overall acceptability scores for pork loin were < 3, the meat was regarded as losing its market value. Sensory evaluation is a useful indicator for determining the different sensory attributes of meat and can be adapted to aid shelf life predictions [23]. In this study, the color and aroma scores were maintained until day 3, but significantly decreased at day 6 ($p < 0.05$). At day 12, the color and aroma scores were < 3, and the meat was considered to be unacceptable. Sensory deterioration occurs when meat nutrients, such as free amino acids, glucose, and volatile compounds, are metabolized during microbial growth, and this process contributes to the development of off-flavors and off-odors [10]. According to Ye et al. [24], odor and APC both increased rapidly during storage, and the two

Table 4 Changes in pH, microbiological characteristics, and sensory characteristics of pork loins during storage at 4 °C

Traits	Storage days					
	1	3	6	8	9	10
pH	5.56 ± 0.010 ^{g}	5.61 ± 0.007^{gf}	5.61 ± 0.012^{gf}	5.62 ± 0.006^{f}	5.61 ± 0.010^{gf}	5.72 ± 0.039^{e}
Total aerobic plate count (log CFU/g)	4.04 ± 0.122 ^{h}	4.35 ± 0.125^{gh}	4.51 ± 0.090^{gh}	4.95 ± 0.072^{f}	5.21 ± 0.135^{f}	6.23 ± 0.159^{e}
(CFU/g)	1.2 × 10^4	2.4 × 10^4	3.4 × 10^4	9.2 × 10^4	1.8 × 10^5	1.9 × 10^6
E. coli (log CFU/g)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Sensory evaluation						
Color	8.11 ± 0.309^{a}	7.78 ± 0.222^{a}	6.44 ± 0.242^{b}	6.44 ± 0.294^{b}	6.00 ± 0.289^{b}	4.67 ± 0.167^{c}
Aroma	7.67 ± 0.408^{a}	7.33 ± 0.236^{a}	6.56 ± 0.338^{b}	6.22 ± 0.278^{b}	6.11 ± 0.261^{b}	4.67 ± 0.167^{c}
Drip loss	1.83 ± 0.312^{d}	2.33 ± 0.167^{d}	4.78 ± 0.465^{bc}	4.33 ± 0.441^{c}	4.44 ± 0.377^{c}	5.67 ± 0.289^{b}
Overall acceptability	7.89 ± 0.200^{a}	7.56 ± 0.176^{a}	6.11 ± 0.261^{b}	6.11 ± 0.261^{b}	5.78 ± 0.401^{b}	4.56 ± 0.176^{c}
Trait	Storage days					
	11	12	13	14	15	16
pH	5.72 ± 0.015^{e}	5.74 ± 0.013^{e}	6.04 ± 0.012^{d}	6.10 ± 0.012^{c}	6.27 ± 0.009^{b}	6.40 ± 0.023^{a}
Total aerobic plate count (log CFU/g)	6.27 ± 0.068^{e}	6.62 ± 0.035^{d}	7.45 ± 0.012^{c}	7.74 ± 0.055^{bc}	8.09 ± 0.045^{ab}	8.03 ± 0.198^{a}
(CFU/g)	1.9 × 10^6	4.3 × 10^6	2.8 × 10^7	5.6 × 10^7	1.2 × 10^8	1.3 × 10^8
E. coli (log CFU/g)	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Sensory evaluation						
Color	4.22 ± 0.278^{c}	3.00 ± 0.167^{d}	2.56 ± 0.421^{de}	2.00 ± 0.408^{ef}	1.56 ± 0.294^{f}	1.44 ± 0.176^{f}
Aroma	3.00 ± 0.167^{d}	2.11 ± 0.261^{e}	2.00 ± 0.289^{ef}	1.67 ± 0.289^{ef}	1.22 ± 0.222^{f}	1.22 ± 0.147^{f}
Drip loss	5.33 ± 0.471^{bc}	6.89 ± 0.200^{a}	7.56 ± 0.242^{a}	7.67 ± 0.373^{a}	7.89 ± 0.309^{a}	7.67 ± 0.289^{a}
Overall acceptability	3.44 ± 0.294^{d}	2.44 ± 0.294^{e}	2.33 ± 0.289^{ef}	1.67 ± 0.236 ^{fg}	1.22 ± 0.222 ^{g}	1.44 ± 0.176 ^{g}

N.D. not detected

$^{a–h}$Mean ± SE within same row with different letters differ significantly at $p < 0.05$

parameters were significantly correlated ($R^2 = 0.8617$, $p < 0.001$). Therefore, it has been suggested that the increased meat odors may be caused by increasing bacterial cell numbers throughout the storage period. The drip loss score significantly increased until day 12 ($p < 0.05$). The overall acceptability scores were highest at 7.89 and 7.56 on days 1 and 2, respectively ($p < 0.05$). Then, the overall acceptability score decreased with increasing storage duration ($p < 0.05$). Particularly, on day 10, the sensory evaluation score (aroma, color, and overall acceptability) dropped below 5, showing a negative perception of the meat by the evaluation panels. At the same time, APCs were determined at 1.9×10^6 CFU/g. At day 12, the sensory characteristics score (aroma, color, and overall acceptability) dropped below 3, indicating that the meat was no longer acceptable according to the evaluation panels. APCs on day 12 were 4.3×10^6 CFU/g, although bacterial cell levels were below the microbiological guidelines for pork in Korea (1×10^7 CFU/g), sensory panels responded very negatively to the meat. In regards to the relationship between APC levels and sensory evaluations, Tang et al. [10] reported that APCs of 1×10^7 CFU/g were used as an index for evaluating the shelf life of pork and corresponding bacterial load causing spoilage, indicating a correlation when the sensory score was < 3 on a scale of 5.

An evaluation of meat freshness is complicated due to various microbial, physicochemical, and biochemical characteristics [16]. Traditionally, sensory tests controlling organoleptic attributes have provided a reliable method for evaluating meat freshness. Therefore, from our results, we concluded that the current microbiological guideline levels for pork in retail establishments (1×10^7 CFU/g) should be more strict, with a modification to 1×10^6 CFU/g to satisfy both meat safety and sensory palatability.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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