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Research note

Seasonal and Monthly Variations in Microbiological Contamination of Korean Goat Carcasses

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ABSTRACT - This study aimed to evaluate monthly and seasonal variations in microbial contamination of goat carcasses at a slaughterhouse in Korea. A total of 172 carcass samples were collected from the shank region over 12 months and analyzed for total plate count (TPC) and *Escherichia coli* (*E. coli*) levels using standard microbiological methods. TPC showed significant monthly variations, with the highest levels observed in July and August, with the greatest overall levels noted in summer (2.86 log CFU/cm^2) and the lowest in autumn (1.99 log CFU/cm^2). In contrast, *E. coli* counts were higher in winter and late autumn, with the highest seasonal mean recorded in winter (2.32 log CFU/cm^2) and the lowest in summer (1.86 log CFU/cm^2). Season-specific hygiene control is recommended, including enhanced carcass chilling and temperature management during summer, as well as improved evisceration hygiene, ventilation management, and fecal contamination control during winter.

Keywords: Goat carcasses, Microbial contamination, Monthly and seasonal variations

Ensuring the microbiological safety of meat remains a critical challenge in public health and the food industry. During slaughter and dressing, carcasses are inevitably exposed to diverse contamination sources, including hides, gastrointestinal contents, equipment, air, and personnel[1)]. Within the Hazard Analysis and Critical Control Point (HACCP) framework, pathogenic microorganisms are recognized as the most significant hazard associated with meat production[2)]. Once introduced onto carcass surfaces or into deeper tissues, these microorganisms can proliferate even under refrigeration, leading to spoilage and posing serious risks to consumers[3)].

Indicator microorganisms, particularly total plate count (TPC) and *Escherichia coli* (*E. coli*), are widely used to evaluate hygienic conditions during slaughter. TPC reflects the overall microbial load resulting from environmental contamination, equipment sanitation, and personnel hygiene, whereas *E. coli* serves as an indicator of fecal contamination and the potential presence of enteric pathogens[4)]. Numerous studies have demonstrated that inadequate slaughter hygiene, poor infrastructure, and insufficient HACCP implementation are strongly associated with elevated microbial loads exceeding acceptable microbiological criteria[1)].

Seasonal variation is an important factor influencing carcass contamination. Ambient temperature, in particular, plays a key role, as higher temperatures during warmer months promote rapid bacterial growth during pre-chilling stages[5)]. Consequently, microbial loads are typically higher in summer than in cooler seasons. Long-term surveillance studies have consistently reported peak contamination levels during summer or early autumn, with lower levels observed in spring, highlighting the influence of climatic conditions on meat safety[6)].

In Korea, goat meat is traditionally valued for its nutritional and functional properties, and its consumption remains stable. However, systematic microbiological monitoring of goat carcasses is limited, especially regarding seasonal or monthly variations. Existing research on small ruminants has primarily focused on sheep or goats in other countries[7,8)], with little information available on Korean slaughterhouse conditions. Therefore, this study aimed to investigate monthly and seasonal variations in microbial contamination of goat carcasses over a one-year period, providing baseline data to support improved hygiene management and risk assessment in goat meat production.

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Materials and Methods

Study design and sample collection

This study was conducted from June 2025 to May 2026 at a registered goat-exclusive slaughter facility in Korea. A total of 172 Korean goat carcasses were sampled longitudinally to obtain a dataset encompassing all months of the year. TPC analysis was performed for all 172 samples, whereas *E. coli* analysis was completed for 116 samples that yielded valid results during the selective enrichment and confirmation steps. Immediately after slaughter and dressing, carcass surface samples were collected from the shank region. Sampling was performed using a sterile 10× 10 cm template to delineate a 100 cm^2 area, which was swabbed with a pre-moistened sterile sponge-stick (SSL10BPW, Neogen, Lansing, MI, USA) containing 10 mL of buffered peptone water (BPW) as a diluent. The sponge-stick swab method has been widely applied in carcass microbiological surveillance and has demonstrated recovery efficiency comparable to that of excision methods for both aerobic bacteria and coliforms. Samples were transported under refrigeration (2-4°C) to the laboratory and processed within 2 h of collection.

Microbiological analyses

All microbiological analyses were performed in accordance with the Korean Food Standards Codex (Ministry of Food and Drug Safety, General Testing Methods, Section 8-4, Microbiological Testing Methods). Total plate count (TPC) was determined by the standard plate count (aerobic plate count, APC) method and expressed as $\log_{10}$ CFU/cm^2. Appropriate 10-fold serial dilutions of the sample homogenate were prepared in BPW, and 1 mL aliquots were pour-plated in duplicate onto APC Agar (SMA, Difco, Tucker, GA, USA). Plates were incubated at 35±1°C for 48±3 h, after which all visible colonies were counted. Results were expressed as $\log_{10}$ colony-forming units per cm^2 (log CFU/cm^2). *E. coli* was enumerated by the most probable number (MPN) method using a three- or five-tube configuration. Presumptive coliform tubes in brilliant green lactose bile (BGLB) broth exhibiting gas production were transferred to EC-MUG broth and incubated at 44.5±0.2°C for 24 h. Presumptive *E. coli* isolates were confirmed by Gram staining and IMViC biochemical tests (Indole, Methyl Red, Voges-Proskauer, Citrate), and MPN values were calculated from standard MPN tables. MPN-derived counts were converted to $\log_{10}$ MPN values.

Statistical analysis

All microbiological count data were $\log_{10}$-transformed prior to statistical analysis to normalize the distribution and stabilize variance. Monthly mean contamination levels for TPC and *E. coli* were compared by one-way analysis of variance (one-way ANOVA) at a significance level of α=0.05. Prior to ANOVA, normality and homogeneity of variance were assessed using the Shapiro-Wilk test and Levene's test, respectively. One-way ANOVA followed by Tukey's honestly significant difference (HSD) test was subsequently performed. When ANOVA revealed statistically significant differences among monthly means (P<0.05), Tukey's HSD post-hoc test was applied to identify specific month pairs that differed significantly. Additionally, monthly data were aggregated into four meteorological seasons and one-way ANOVA followed by Tukey's HSD was repeated to evaluate seasonal effects on carcass contamination. All statistical procedures were conducted using SPSS, with significance defined at P<0.05 throughout.

Results and Discussion

Monthly microbiological contamination data for 172 Korean goat carcasses are summarized in Table 1. One-way ANOVA revealed statistically significant differences in both TPC and *E. coli* counts across months (P<0.001). TPC was numerically highest in July and August and showed significantly higher values than in autumn and winter, although it did not differ significantly from spring. *E. coli* counts were significantly elevated in January, February, August, and November compared with other months.

TPC followed a clear pattern, reaching its peak during midsummer and declining progressively through autumn and into winter. In contrast, *E. coli* exhibited a divergent, bimodal-like distribution, with elevated counts observed in winter and late autumn (November), and relatively lower counts during the summer months.

Monthly data were aggregated into four meteorological seasons as follows: spring (March-May), summer (June-August), autumn (September-November), and winter (December-February) (Table 2). TPC was numerically highest in summer (2.86 log CFU/cm^2) and lowest in autumn (1.99 log CFU/cm^2) (P<0.05). However, the summer value was not significantly different from the spring value, indicating that TPC was highest in summer numerically, but the seasonal difference between summer and spring was not statistically significant. *E. coli* showed the opposite trend, with the highest mean in winter and the lowest mean in summer.

The present study demonstrated that TPC and *E. coli* contamination on Korean goat carcasses exhibited distinct and divergent seasonal patterns over a one-year surveillance period. The significant elevation of TPC during summer is consistent with the well-established relationship between

Table 1. Monthly microbial contamination of goat carcasses

Month	Number of carcasses	Total plate count (TPC) counts Log CFU/cm^2 (mean±SD)	Number of carcasses	*E. coli* counts Log CFU/cm^2 (mean±SD)
January	18	1.98±0.45^b	13	2.55±0.44^a
February	24	2.24±0.45^b	16	2.37±0.79^a
March	16	2.65±0.59^b	9	1.72±0.28^b
April	13	2.35±0.51^b	13	1.86±0.48^b
May	17	2.61±0.96^b	7	1.34±0.30^c
June	16	2.50±0.84^b	11	1.65±0.43^c
July	13	3.06±0.90^a	7	1.31±0.16^c
August	18	3.03±0.77^a	19	2.19±0.39^a
September	6	2.16±0.24^b	2	1.65±0.49^b
October	9	1.95±0.38^b	4	1.31±0.23^c
November	8	1.91±0.43^b	8	2.35±0.28^a
December	14	2.18±0.48^b	7	1.85±0.49^b

Different superscript letters within the same column indicate statistically significant differences (P<0.001) according to Tukey's HSD test.

Table 2. Seasonal microbial contamination of goat carcasses

Season	Number of carcasses	Total plate count (TPC) counts Log CFU/cm^2 (mean±SD)	Number of carcasses	*E. coli* counts Log CFU/cm^2 (mean±SD)
Spring	46	2.55±0.23^a	90	1.69±0.43^b
Summer	94	2.86±0.35^a	47	1.86±0.11^b
Autumn	46	1.99±0.17^b	23	1.95±0.14^b
Winter	56	2.04±0.16^b	56	2.32±0.19^a

Different superscript letters within the same column indicate statistically significant differences (P<0.05) according to Tukey's HSD test.

ambient temperature, relative humidity, and bacterial proliferation on carcass surfaces. Previous studies on cattle and pig carcasses have consistently reported higher total aerobic counts during warmer months, primarily attributed to the accelerated bacterial multiplication that occurs during the pre-chilling phase when ambient temperatures are elevated[9]. Similarly, TPC and coliform counts in HACCP-implemented Korean meat-processing plants peaked in summer and were lowest in winter[10]. Temperature management during carcass dressing is therefore identified as a critical control point for limiting mesophilic bacterial growth, particularly during summer operations[11].

The seasonal pattern of *E. coli*, however, diverged markedly from that of TPC, with the highest contamination recorded in winter and late autumn. The increased *E. coli* contamination observed during winter may be associated with reduced ventilation, seasonal husbandry conditions, and potential alterations in gut microbiota[12-14]. This study has several limitations. First, samples were collected from a single slaughterhouse, which may limit generalizability. Second, only the shank region was sampled. Third, environmental variables such as temperature, humidity, ventilation rate, and slaughter-line hygiene were not directly measured. Therefore, future multi-site studies incorporating environmental monitoring are warranted.

From a food safety governance perspective, the data indicate that temperature control during the slaughter process is the primary lever for reducing overall bacterial load, and that this control is especially critical during summer. Conversely, enhanced management of fecal contamination during evisceration and improved facility ventilation are of greatest importance during winter. These findings are in line with the principle that HACCP-based hygiene management systems should be dynamic, incorporating seasonal risk profiles rather than applying uniform year-round protocols[9,10].

This one-year surveillance study demonstrated that microbiological contamination of Korean goat carcasses shows significant monthly and seasonal variation, with TPC and *E. coli* exhibiting opposing seasonal patterns. TPC was highest during summer, likely driven by elevated ambient temperature facilitating mesophilic bacterial growth, while *E. coli* was highest in winter, possibly reflecting reduced facility ventilation and altered animal gut microbiota during

cold periods. The divergent behavior of the two indicators confirms that both must be monitored independently for a comprehensive assessment of slaughter hygiene. These findings provide scientifically grounded, season-specific baseline data that can be directly applied to the design and verification of HACCP-based microbial control strategies at Korean goat slaughter facilities. Specifically, enhanced temperature management during summer and stricter evisceration hygiene combined with improved ventilation during winter are recommended as prioritized seasonal interventions. Future research identifying the specific contamination sources responsible for elevated *E. coli* levels will further strengthen the precision of seasonal hygiene management protocols.

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국문요약

본 연구는 국내 염소 도축장에서 12개월 동안 한국흑염소 도체의 월별 및 계절별 미생물 오염 변화를 평가하고자 수행되었다. 총 172개의 도체 시료를 정강이 부위에서 채취하여 일반세균수(TPC)와 *E. coli*를 표준 미생물 분석법으로 측정하였다. TPC는 월별로 유의한 차이를 보였으며, 7-8월에 가장 높았고, 계절별로는 여름(2.86 log CFU/cm^2)에서 가장 높고 가을(1.99 log CFU/cm^2)에서 가장 낮았다. 반면, *E. coli*는 겨울과 늦가을에 높은 값을 나타내어 겨울(2.32 log CFU/cm^2)에서 최대, 여름(1.86 log CFU/cm^2)에서 최소를 보였다. 따라서 계절별 위생관리 전략 수립의 필요성을 제시한다.

Conflict of Interest

The authors declare no potential conflict of interest.

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