International Research Journal of Agriculture, Environment and Animal Sciences

Vol 8, Issue 1, pp 1-9, Nov 17, 2026, © International Research Journal Publishers, ISSN 2710-2742 (online) www.irjp.org

Occurrence, Concentrations and Maximum Residue Limit Compliance of Penicillin G and Ciprofloxacin in Pork Meat Sold in Nairobi County, Kenya

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Accepted: 13 November 2026

Abstract

Background: Antibiotic residues in food of animal origin are an important food-safety concern, particularly in livestock production systems where antimicrobial use and compliance with recommended withdrawal periods require effective monitoring. Pork is an important source of animal protein, and monitoring veterinary drug residues is necessary to support consumer protection and food-safety regulation.

Objective: This study investigated the occurrence, concentrations and regulatory compliance of Penicillin G and Ciprofloxacin residues in pork meat sold in Nairobi County, Kenya.

Methods: A cross-sectional analytical study was conducted using pork samples collected from selected retail outlets in Nairobi County. The study examined twelve veterinary antibiotic residues belonging to four antimicrobial classes. Samples were prepared using a modified QuEChERS extraction procedure and analysed using liquid chromatography coupled with electrospray ionisation tandem mass spectrometry (LC-ESI-MS/MS). This article reports the findings for Penicillin G and Ciprofloxacin. Descriptive statistics were used to determine detection frequencies, concentration distributions and the number of samples exceeding the residue benchmark applied in the study.

Results: A total of 108 pork samples were analysed. Penicillin G was detected in 99 samples (91.67%), with a mean concentration of 24.99 ± 43.77 µg/kg and a concentration range of 6.9–381.5 µg/kg. Eight samples exceeded the study-applied benchmark of 50 µg/kg. Ciprofloxacin was detected in 81 samples (75.00%), with a mean concentration of 24.43 ± 23.35 µg/kg and a range of 0.2–158.0 µg/kg. Seven samples exceeded the same benchmark. Compliance was 92.59% for Penicillin G and 93.52% for Ciprofloxacin.

Conclusion: Penicillin G and Ciprofloxacin were frequently detected in the analysed pork samples, although most samples were below the 50 µg/kg benchmark applied in the study. The findings demonstrate the importance of compound-specific residue monitoring and continued surveillance of veterinary antimicrobial residues in retail pork. Regulatory interpretation of the Ciprofloxacin findings requires confirmation against the applicable compound-specific standard.

Keywords: *Antibiotic residues; Penicillin G; Ciprofloxacin; pork meat; Nairobi County; LC-MS/MS; food safety; maximum residue limits*

INTRODUCTION

Veterinary antibiotics are widely used in livestock production for therapeutic and prophylactic purposes. Their application helps prevent and manage bacterial infections, maintain animal health and support livestock productivity. However, the presence of antimicrobial residues in food-producing animals has become an important food-safety concern, particularly when appropriate administration practices and recommended withdrawal periods are not followed (Arsène et al., 2022).

Antibiotic residues may remain in animal tissues following veterinary treatment and subsequently enter the human food chain through the consumption of meat and other animal-derived products. Exposure to certain residues may be associated with allergic reactions, toxicological effects and concerns relating to antimicrobial resistance. These concerns underline the importance of effective monitoring systems that identify the occurrence and concentrations of veterinary drug residues in food products.

The use of antimicrobials in livestock production has increased alongside the expansion and intensification of animal agriculture. Mulchandani et al. (2023) examined global trends in antimicrobial use in food-producing animals and highlighted the importance of understanding antimicrobial consumption patterns within agricultural production systems. The relationship between veterinary antimicrobial use, food safety and public health is also recognised within the One Health framework, which considers the interconnectedness of human, animal and environmental health (Conceição et al., 2023).

Two important veterinary antimicrobial compounds requiring attention are Penicillin G and Ciprofloxacin. Penicillin G, also known as benzylpenicillin, belongs to the β-lactam class of antibiotics. It is used in veterinary medicine to manage infections caused by susceptible bacteria. Its antimicrobial activity is primarily associated with interference with bacterial cell-wall synthesis. The presence of Penicillin G residues in edible animal tissues therefore warrants monitoring to establish whether the concentrations found comply with relevant food-safety standards.

Ciprofloxacin belongs to the fluoroquinolone class of antibiotics. Fluoroquinolones act by inhibiting bacterial enzymes involved in DNA replication, particularly DNA gyrase and topoisomerase IV. Their veterinary use and the possibility of residues remaining in animal-derived foods make them relevant to food-safety surveillance. The detection of fluoroquinolone residues in meat products requires appropriate analytical confirmation and interpretation against relevant regulatory standards.

The accurate determination of antibiotic residues in meat depends on the availability of analytical methods with adequate sensitivity, specificity and reliability. Several approaches have been employed for detecting veterinary drug residues, including immunochemical screening, high-performance liquid chromatography and liquid chromatography-tandem mass spectrometry. Among these techniques, LC-MS/MS is particularly useful for multi-residue analysis because it allows the identification and quantification of different antimicrobial compounds within complex food matrices.

Barros et al. (2023) reviewed multi-residue and multi-class analytical methods for determining antibiotics in food of animal origin. Their review highlighted the importance of appropriate sample preparation, chromatographic separation and mass spectrometric detection in obtaining reliable analytical results. Park et al. (2024) also demonstrated the application of LC-MS/MS in the simultaneous determination of 34 β-lactam antibiotics in livestock and fish samples.

In Kenya, concerns regarding antibiotic residues in pork have been documented by Bor et al. (2023). Their investigation analysed 387 pork samples using a micro-inhibition screening method and reported an overall residue prevalence of 41.26%. The authors recommended routine testing of meat to strengthen consumer protection and improve residue surveillance.

Their findings demonstrate the relevance of monitoring antibiotic residues within Kenya's pork production and marketing systems. Despite this evidence, there remains a need for more detailed quantitative investigations of individual antibiotic compounds in retail pork. Examining specific compounds provides an opportunity to understand their respective detection frequencies, concentration distributions and compliance with applicable residue limits. Of the twelve antibiotic residues examined in the study, Penicillin G and Ciprofloxacin were selected for this article because both were frequently detected and both had samples above the 50 µg/kg benchmark.

Objective

To investigate the occurrence, concentration levels and regulatory compliance of Penicillin G and Ciprofloxacin residues in retail pork meat sold in Nairobi County, Kenya.

MATERIALS AND METHODS

Study design and location

The study employed a cross-sectional analytical research design to investigate veterinary antibiotic residues in pork meat sold in Nairobi County, Kenya. The investigation focused on selected pork retail outlets, including butcheries, supermarkets and open-air markets. Nairobi County was selected because of its established pork retail market and the importance of monitoring food safety in urban meat distribution systems.

Sampling strategy and sample collection

The study employed a stratified random sampling approach to select sampling locations across different administrative and commercial areas of Nairobi County. The sampling frame included selected markets and pork retail outlets. Five portions of pork were collected from each vendor and combined to form a composite sample. Sterile sampling instruments and containers were used during collection. Each sample was assigned a unique identification code, and relevant sampling information was recorded. The collected samples were transported to the laboratory in insulated cooler boxes containing ice packs to maintain the cold chain. Upon arrival, samples were stored under appropriate refrigerated or frozen conditions pending laboratory analysis. The study was conducted in 100 retail outlets, and 108 samples were analysed.

Sample preparation and extraction

The study employed a modified QuEChERS extraction procedure for the preparation of pork samples before chromatographic analysis. QuEChERS is an analytical sample preparation approach used to extract target compounds from complex food matrices while reducing interfering substances. Its application in multi-residue analysis supports the simultaneous determination of different veterinary antimicrobial compounds. This article reports the determination of Penicillin G and Ciprofloxacin from this multi-residue analysis.

Liquid chromatography-tandem mass spectrometry analysis

The study used liquid chromatography coupled with electrospray ionisation tandem mass spectrometry (LC-ESI-MS/MS) for the confirmation and quantification of antibiotic residues. A C18 reversed-phase chromatographic column measuring 150 mm × 2.1 mm, with a particle size of 3.5 µm, was used. The column temperature was maintained at 30 °C, while the mobile phase consisted of aqueous ammonium acetate (10 mM) and acetonitrile. The chromatographic system operated at a flow rate of 0.3 mL/min. Gradient elution was employed, beginning with 95% aqueous mobile phase, followed by increasing proportions of acetonitrile before returning to the initial conditions. The injection volume was 10 µL. The mass spectrometer operated using electrospray ionisation in positive and/or negative ionisation modes, depending on the analytical requirements of the target compounds. Multiple reaction monitoring (MRM) was employed for quantification.

Analytical quality assurance and method validation

The study applied several quality-control procedures intended to ensure the reliability of the analytical findings. These included the use of calibration standards, reagent blanks, duplicate analyses, matrix-matched standards and recovery experiments. The method validation framework included specificity, linearity, accuracy, precision, limits of detection, limits of quantification, recovery and matrix effects. These parameters are important in determining whether the analytical method can reliably detect and quantify antibiotic residues in pork meat.

Data analysis

The study used descriptive statistics from the laboratory analysis of Penicillin G and Ciprofloxacin. The parameters considered included total number of samples analysed, number of positive and negative samples, detection frequency, mean concentration, standard deviation, minimum and maximum concentrations, number of samples exceeding the study-applied benchmark and percentage compliance. Detection frequency (%) = (Number of positive samples / Total number of samples analysed) × 100. Exceedance (%) = (Number of samples above the benchmark / Total number of samples analysed) × 100. Compliance (%) = [(Total samples analysed − Number of samples above the benchmark) / Total number of samples analysed] × 100. Descriptive statistics were used to summarise the occurrence and concentration patterns of the two antibiotic residues.

RESULTS

Occurrence and concentration of Penicillin G

Penicillin G residues were detected in 99 of the 108 pork samples analysed, representing a detection frequency of 91.67%. Nine samples (8.33%) had no detectable Penicillin G residues. The mean concentration was 24.99 ± 43.77 µg/kg, with concentrations ranging from 6.90 to 381.50 µg/kg. When compared with the 50 µg/kg benchmark applied in the study, eight samples exceeded the stated limit. This represented 7.41% of the analysed samples, while the compliance rate was 92.59%. The findings indicate that Penicillin G was frequently detected in the sampled pork. However, the difference between the mean and maximum concentrations demonstrates considerable variation in the measured residue levels.

Table 1. Occurrence and concentration of Penicillin G in pork samples

Parameter	Result
Total samples analysed	108
Positive samples	99
Negative samples	9
Detection frequency (%)	91.67
Mean concentration (µg/kg)	24.99
Standard deviation (µg/kg)	43.77
Minimum concentration (µg/kg)	6.90
Maximum concentration (µg/kg)	381.50
Study-applied benchmark (µg/kg)	50
Samples above benchmark	8
Compliance (%)	92.59

Occurrence and concentration of Ciprofloxacin

Ciprofloxacin residues were detected in 81 of the 108 pork samples, representing a detection frequency of 75.00%. The remaining 27 samples (25.00%) had no detectable Ciprofloxacin residues. The mean concentration was 24.43 ± 23.35 µg/kg, with measured concentrations ranging from 0.20 to 158.00 µg/kg. Seven samples exceeded the 50 µg/kg benchmark applied in the study. This represented 6.48% of the analysed samples, resulting in a compliance percentage of 93.52%. Although the mean concentration was below the applied benchmark, the maximum concentration was substantially higher.

Table 2. Occurrence and concentration of Ciprofloxacin in pork samples

Parameter	Result
Total samples analysed	108
Positive samples	81
Negative samples	27
Detection frequency (%)	75.00
Mean concentration (µg/kg)	24.43
Standard deviation (µg/kg)	23.35
Minimum concentration (µg/kg)	0.20
Maximum concentration (µg/kg)	158.00
Study-applied benchmark (µg/kg)	50
Samples above benchmark	7
Compliance (%)	93.52

Comparative occurrence and concentration patterns

The comparative findings demonstrate differences in the occurrence and concentration patterns of the two antibiotic residues. Penicillin G recorded a higher detection frequency (91.67%) than Ciprofloxacin (75.00%). However, the mean concentrations were relatively similar, at 24.99 µg/kg and 24.43 µg/kg, respectively. Penicillin G also had a higher maximum concentration (381.50 µg/kg) compared with Ciprofloxacin (158.00 µg/kg). Eight Penicillin G samples and seven Ciprofloxacin samples exceeded the benchmark.

Table 3. Comparative occurrence and concentration of Penicillin G and Ciprofloxacin

Indicator	Penicillin G	Ciprofloxacin
Samples analysed	108	108
Positive samples	99	81
Detection frequency (%)	91.67	75.00
Mean concentration (µg/kg)	24.99	24.43
Standard deviation (µg/kg)	43.77	23.35
Minimum concentration (µg/kg)	6.90	0.20
Maximum concentration (µg/kg)	381.50	158.00
Samples above 50 µg/kg	8	7
Compliance (%)	92.59	93.52

Overall, Penicillin G was more frequently detected and had a higher maximum concentration than Ciprofloxacin. Nevertheless, both compounds demonstrated relatively high detection frequencies and instances of concentrations exceeding the benchmark used in the study.

DISCUSSION

Occurrence of Penicillin G in retail pork

The detection of Penicillin G in 91.67% of the analysed pork samples represents an important finding of the present investigation. Its high detection frequency indicates that detectable Penicillin G residues were widespread among the sampled retail pork products. Penicillin G belongs to the β-lactam class of antibiotics, which is widely recognised for its therapeutic applications in veterinary medicine. Its presence in edible animal tissues highlights the importance of monitoring veterinary drug residues and ensuring that appropriate withdrawal periods are observed before slaughter. The findings should be interpreted alongside the Kenyan investigation by Bor et al. (2023), which examined 387 pork samples using the Premi®Test micro-inhibition method and reported an overall antibiotic residue prevalence of 41.26% (95% CI [34.53%, 48.45%]). Although both studies demonstrate the occurrence of antibiotic residues in Kenyan pork, their results are not directly comparable. Bor et al. investigated general antibiotic residue occurrence using a screening approach, whereas the present investigation provides compound-specific quantitative results obtained through LC-MS/MS. The current findings therefore contribute additional information by identifying the occurrence and concentration of Penicillin G specifically. The high detection frequency also makes this compound relevant for targeted monitoring within the Nairobi pork market. The mean concentration of 24.99 µg/kg was accompanied by a relatively large standard deviation of 43.77 µg/kg. This indicates considerable variation in residue concentrations across the positive samples. The maximum concentration of 381.50 µg/kg further demonstrates that some samples contained substantially higher residue levels than the average. Differences in veterinary treatment practices, dosage, animal metabolism and withdrawal-period compliance may contribute to variations in residue concentrations. However, the present investigation did not establish the treatment histories of the animals from which the samples were obtained. Consequently, these factors should be regarded as possible explanations rather than confirmed causes of the observed concentration differences. Uma et al. (2023), in their investigation of antibiotic residues in beef sold in Ethiopia, also demonstrated the importance of compound-specific analysis when examining veterinary drug residues in animal-derived foods. Although their study involved beef rather than pork, it provides relevant regional evidence on the application of LC-MS/MS in residue determination.

Occurrence of Ciprofloxacin in retail pork

Ciprofloxacin was detected in 75.00% of the analysed pork samples, making it another frequently occurring compound in the investigation. Its detection frequency was lower than that of Penicillin G, although the two compounds recorded similar mean concentrations. The mean Ciprofloxacin concentration was 24.43 µg/kg, with a standard deviation of 23.35 µg/kg. The observed range of 0.20–158.00 µg/kg demonstrates variation in the concentrations detected among the sampled pork products. The maximum concentration was more than three times the 50 µg/kg benchmark used in the study. Seven samples exceeded this benchmark, representing 6.48% of the total samples analysed. These findings demonstrate that the presence of detectable residues does not necessarily indicate that a sample exceeds an established residue limit. The distinction between detection frequency and regulatory compliance is therefore important when interpreting antibiotic residue results. The findings are also consistent with the broader analytical concerns discussed by Barros et al. (2023), who emphasised the importance of reliable multi-residue analytical methods for monitoring antibiotics in foods of animal origin. LC-MS/MS provides an appropriate analytical

framework for identifying and quantifying individual compounds, thereby allowing more detailed interpretation than general screening methods alone.

Comparative occurrence and concentration patterns

The comparative findings demonstrate that Penicillin G and Ciprofloxacin exhibited different occurrence patterns despite having relatively similar mean concentrations. Penicillin G recorded a detection frequency of 91.67%, compared with 75.00% for Ciprofloxacin. This represents a difference of 16.67 percentage points. The findings indicate that Penicillin G was more frequently detected within the sampled pork population. The two compounds also differed in their maximum concentrations. Penicillin G reached 381.50 µg/kg, whereas Ciprofloxacin reached 158.00 µg/kg. The higher maximum concentration for Penicillin G suggests that some sampled products contained considerably greater quantities of this compound. However, their mean concentrations were relatively close, indicating that differences in detection frequency did not translate into substantial differences in the reported averages. These observations demonstrate why both occurrence and concentration should be considered when assessing veterinary antibiotic residues. Detection frequency provides information about how widely a compound occurs within the sampled population, whereas concentration measurements indicate the quantities detected in individual samples. The comparative approach is particularly relevant because the two compounds represent different antimicrobial classes. Penicillin G belongs to the β-lactams, while Ciprofloxacin belongs to the fluoroquinolones. Examining both provides a more focused understanding of residue occurrence across two important categories of veterinary antimicrobials.

Regulatory compliance and food-safety implications

The study applied a benchmark of 50 µg/kg to both Penicillin G and Ciprofloxacin. Based on this benchmark, eight Penicillin G samples and seven Ciprofloxacin samples exceeded the stated value. For Penicillin G, the benchmark is consistent with the JECFA maximum residue limit for benzylpenicillin in pig muscle (FAO/WHO, n.d.). This provides a regulatory basis for interpreting the reported Penicillin G exceedances. For Ciprofloxacin, the regulatory interpretation requires further verification. Maximum residue limits are compound-specific and may depend on the veterinary drug, marker residue, animal species and edible tissue. The results highlight the importance of examining individual residue concentrations rather than relying exclusively on average values. The findings also support the recommendations made by Bor et al. (2023), who emphasised the importance of routine testing of pork carcasses for antibiotic residues in Kenya. Regular monitoring can provide information needed to strengthen food-safety assurance and improve oversight of veterinary antimicrobial use.

Implications for food-safety monitoring and antimicrobial stewardship

The occurrence of Penicillin G and Ciprofloxacin residues in retail pork reinforces the importance of responsible veterinary antimicrobial use throughout the livestock production chain. The use of veterinary antibiotics should be supported by appropriate veterinary supervision, accurate treatment records and compliance with recommended withdrawal periods. These practices are important for reducing the likelihood of unacceptable drug residues remaining in edible tissues at slaughter. The One Health approach provides a relevant framework for addressing these concerns because veterinary antimicrobial use, animal health, food safety and human health are interconnected. Monitoring antibiotic residues in pork can therefore contribute to broader food-safety and antimicrobial stewardship objectives. The findings support the need for continued residue surveillance in Nairobi County, particularly for compounds demonstrating comparatively high detection frequencies. Targeted monitoring of Penicillin G and Ciprofloxacin could complement wider multi-residue surveillance programmes.

CONCLUSION

The study established that Penicillin G and Ciprofloxacin residues were present in pork meat sampled from retail outlets in Nairobi County. The findings demonstrate that residues from both β-lactam and fluoroquinolone antimicrobial classes occur in pork available within the study area. Penicillin G was more widely detected than Ciprofloxacin, indicating that its occurrence was more prevalent across the sampled products. Nevertheless, the detection of Ciprofloxacin in a substantial proportion of samples shows that residue monitoring should not be limited to the compound with the highest occurrence.

The concentration findings showed that the two compounds had similar reported mean concentrations, but their concentration distributions were not identical. Penicillin G exhibited greater variability and a higher maximum concentration than Ciprofloxacin, indicating that some pork samples contained substantially elevated levels relative to the overall concentration profile. Ciprofloxacin also showed a wide concentration range, with some samples exceeding the benchmark used in the study. These results demonstrate that average concentration alone does not adequately characterise residue occurrence; the range and upper end of the distribution are also important when identifying samples that may require regulatory attention.

Comparison with the benchmark applied in the study identified samples of both compounds with concentrations above the stated value. This establishes that exceedances occurred in the sampled pork and that high overall compliance percentages do not eliminate the need for targeted follow-up. The benchmark has a recognised basis for Penicillin G in pig muscle, whereas the Ciprofloxacin result should be interpreted as an exceedance of the study-applied comparison value and not automatically as a confirmed breach of an established MRL for that compound in pig muscle. The study therefore distinguishes analytical detection from regulatory non-compliance and underscores the importance of applying compound-, species- and tissue-specific residue standards.

RECOMMENDATIONS

Strengthen compound-specific residue surveillance. Nairobi County food-safety authorities, meat inspectors and relevant national agencies should incorporate both Penicillin G and Ciprofloxacin into routine surveillance of pork sold through butcheries, supermarkets and open-air markets. Penicillin G should receive particular attention because it was detected more frequently and displayed greater concentration variability, while Ciprofloxacin should remain in the monitoring schedule because its occurrence was also widespread. Surveillance should report the number of samples tested, detection frequency, concentration range and benchmark exceedances for each compound separately. This approach would allow authorities to identify both commonly occurring residues and less frequent samples with elevated concentrations.

Improve follow-up of samples with elevated residue concentrations. Regulatory and public-health authorities should ensure that pork samples exceeding applicable residue limits are investigated through established inspection and enforcement procedures. Where Penicillin G exceeds the applicable limit, follow-up should include tracing the product to its supplier or source, reviewing relevant treatment and withdrawal-period records, and taking action in accordance with national food-safety requirements. For Ciprofloxacin, results above the comparison value used in this study should inform surveillance and investigation, while formal enforcement decisions should be based on the legally applicable compound-, species- and tissue-specific standard. This distinction will help ensure that analytical findings are acted upon consistently and on a sound regulatory basis.

Promote prudent veterinary antimicrobial use and observance of withdrawal periods. Veterinary practitioners and pig producers should ensure that Penicillin G, Ciprofloxacin and other veterinary antimicrobials are used only when clinically justified and under appropriate

professional oversight. Producers should follow prescribed dosages and treatment schedules and observe the required withdrawal period before animals are slaughtered for human consumption. Accurate treatment records should be maintained, including the medicine administered, date of treatment, animal identification and withdrawal date. These measures would strengthen traceability and reduce the likelihood that animals carrying unacceptable residues enter the food chain.

Strengthen traceability throughout the pork supply chain. Slaughter facilities, pork traders, retailers and suppliers should source meat from identifiable producers and suppliers who can demonstrate appropriate veterinary treatment and withdrawal-period practices. County meat inspection services should work with relevant veterinary and public-health agencies to improve information sharing and trace-back when residue concerns are identified. Retailers should cooperate with sampling and inspection activities and maintain supplier records that allow affected products to be traced. Residue control requires preventive practices from animal treatment through slaughter, distribution and retail, not laboratory testing alone.

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