EISSN: 2455-8931 doi: 10.14202/IJOH.2025.1-12 OPEN ACCESS

International Journal of One Health

RESEARCH ARTICLE

Assessing antibiotic use practices on central Burkina Faso cattle farms and the associated risks to environmental and human health contamination: A pilot study

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ABSTRACT

Background and Aim: Antimicrobial resistance (AMR) poses a significant threat to global health, driven largely by antibiotic misuse in livestock farming. This pilot study explores cattle farmers' antibiotic use practices and their implications for environmental and human health in peri-urban area of Ouagadougou. This study aimed to identify risky antibiotic use behaviors among cattle farmers and evaluate their contribution to environmental contamination and AMR dissemination.

Materials and Methods: In April 2023, a survey was conducted among 50 cattle farm owners and managers across four peri-urban area of Ouagadougou, Burkina Faso. Data were collected using structured questionnaires through Kobo Toolbox. Farmers' practices were categorized as "good" or "poor" based on cumulative scores derived from binary-coded responses. Logistic regression was used to identify associations between practices and AMR risk factors.

Results: Among participants, 98% (n = 49) were male, 76% (n = 38) had no formal animal health training, and 96% (n = 48) used antibiotics, primarily tetracyclines. Practices associated with increased AMR risk included reliance on non-veterinary personnel for antibiotic administration and inadequate waste management. Multivariate analysis revealed that traditional farming methods significantly reduced contamination risks ($p < 0.05$). However, ownership of farms and using antibiotics solely for treatment were linked to higher odds of environmental contamination. Awareness of the implications of antibiotic residues in manure was low, with 82% of farmers uninformed about potential health risks.

Conclusion: The study highlights prevalent antibiotic misuse and inadequate biosecurity measures among cattle farmers in Burkina Faso. These practices exacerbate AMR risks, necessitating urgent interventions. Strategies should include farmer education on biosecurity, stricter regulation of antibiotic use, and the promotion of sustainable farming practices. A One Health approach integrating human, animal, and environmental health is critical to addressing AMR challenges.

Keywords: antibiotic use, antimicrobial resistance, burkina Faso, cattle farming, environmental contamination, one health.

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Received: 28-10-2024, **Accepted:** 13-01-2025, **Published online:** 09-02-2025

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How to cite: Soma D, Diarra FBJ, Bonkoungou IJO, Somda NS, Bako E, Nikiema MEM, Sore S, Sawadogo N, Barro N, and Kassié D (2025) Assessing antibiotic use practices on central Burkina Faso cattle farms and the associated risks to environmental and human health contamination: A pilot study, Int. J. One Health, 11(1): 1–12.

INTRODUCTION

Livestock plays a pivotal role in the global economy, with the African livestock sector contributing approximately 30%–80% of the continent's agricultural gross domestic product [1]. In Burkina Faso, cattle farming supports the livelihoods of approximately one million producers and households, contributing an estimated $71–$115 million to the national economy [2]. Antibiotics have been employed in animal production for over 50 years as therapeutic agents, metaphylactic agents (administered to a group of animals after the detection of disease in a few individuals), prophylactic agents (administered to prevent disease), and, notably, as growth promoters [3]. In 2013, approximately 131,109 tons of antimicrobials were used globally in food animals, and this figure is projected to increase to 200,235 tons by 2030 [4]. The widespread benefits in terms of efficiency, accessibility, and productivity improvements have resulted in the indiscriminate use of these compounds [5]. However, antibiotic use in animal models can promote the development of antibiotic-resistant bacteria [6]. In Burkina Faso, 74.60% of farmers use self-medication, and 93.65% use it as a growth promoter. Furthermore, the sale and use of veterinary medicines are not monitored or controlled [1].

Human exposure to antibiotic-resistant bacteria from livestock can occur through direct contact with animals, environmental exposure to animal feces, and consumption of animal products [7]. These transmission pathways are among the most significant public health risks to humanity. In addition, antibiotics in soil can adversely affect soil health by altering microbial communities. Müller *et al*. [8] have demonstrated that antibiotics can significantly affect the populations of soil microorganisms. The residues of antibiotics have also been found in manure, posing a risk of environmental contamination [9, 10]. These residues can be absorbed by plants, crops, and soil-dwelling organisms and may enter groundwater through rainfall, irrigation, and other human activities [11]. Certain families of antibiotics, such as tetracyclines and macrolides, are not fully metabolized by the animal's body [12]. As a result, large quantities of these antibiotics are excreted in water and soil through organic waste such as animal urine and manure [13]. This waste is often applied untreated to farmland as fertilizer, contributing significantly to the selection of multi-resistant bacteria and the spread of antibiotic resistance in the environment through air, rodents, or other vectors [14, 15].

Research has shown that small rodents trapped in or near pig farms harbor more resistance genes than those trapped in other areas, further confirming the role of rodents in spreading antibiotic resistance [16, 17]. While foraging at animal production sites, these animals come into contact with animal waste and can disseminate it throughout the environment. Antibiotics can also affect soil microorganisms by affecting their abundance, overall activity, enzymatic functions, carbon mineralization, and nitrogen cycling. The effects of antibiotics on the functional, structural, and genetic diversity of soil microorganisms have been extensively documented [17, 18]. The presence of antibiotic residues and multidrug-resistant bacteria in the environment poses significant ecological risks and health threats to humans [19]. Although livestock farms are major consumers of antibiotics, limited information is available on the extent of their use, the factors influencing this use, and the risky practices of farmers that contribute to the spread of antibiotic resistance within the ecosystems and human populations of Burkina Faso. Despite the recognized issue of antimicrobial resistance (AMR) on farms, data on the specific situation in Burkina Faso are limited. While some reports have focused on antibiotic use in poultry [20] and cattle [21], none have thoroughly investigated farmers' knowledge of the risks associated with the spread of AMR to humans and the environment.

This study aimed to assess antibiotic use practices among cattle farmers in peri-urban area of Ouagadougou, Burkina Faso, and evaluate their contribution to the dissemination of AMR within the environment and human populations. By examining sociodemographic and farm-level factors influencing these practices, the study seeks to identify specific behaviors and conditions that elevate AMR risks. The findings aim to inform targeted interventions and policy recommendations for improving antibiotic stewardship and mitigating the public health threats associated with AMR through a One Health approach.

MATERIALS AND METHODS

Ethical approval and Informed consent

This study was approved by the Burkina Faso Health Research Ethics Committee (CERS) (N°2023-06-132). Before data collection, each participant was fully informed about the study and oral consent was obtained. Before conducting the interviews, the purpose of the study was explained to the farmers to secure their consent. For participants who spoke a local language (mooré), the consent form was translated and explained before the questionnaire was administered. Participants were informed of their right to withdraw from the study at any time by halting the interview.

Study period and location

In April 2023, we conducted structured questionnaire interviews at four peri-urban areas in Ouagadougou: Saaba (14 farms), Koubri (11 farms), Loumbila (14 farms), and Saponé (11 farms) (Figure 1).

Determination of sample size

The sample size was estimated based on the calculation of a proportion.

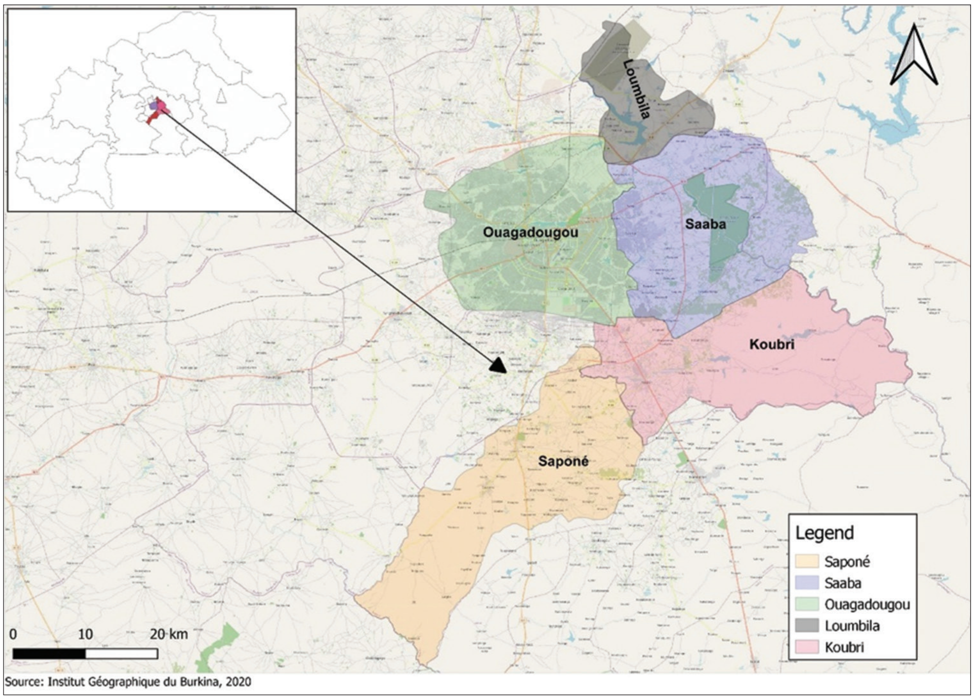

Figure 1: Map of surveyed areas in Burkina Faso [Source: Institut Géographique du Burkina Faso, 2020].

$$n = \frac{t^2 * p(1-p)}{e^2}$$

n: Expected sample size

t: Confidence level (1.96 for a 95% confidence interval)

p: Expected proportion of the farming population with insufficient knowledge regarding the rational use of antibiotics (p = 85%) [20]

e: Margin of error set at 10%.

By applying this formula, the minimum sample size required to achieve an expected proportion of 85%, with a 10% margin of error at a 95% confidence level, was approximately 49 participants.

Study design

Of 54 potential participants, 50 farm owners or managers consented to participate in the study. The inclusion criterion required that the farms be those where samples were collected to assess antibiotic resistance. Indeed, we conducted a previous study on these farms to estimate the prevalence of *Escherichia coli* and *Klebsiella* spp. producing extended-spectrum beta-lactamase [22]. The inclusion criterion required that the farms be those where samples were collected to assess antibiotic resistance. Samples were collected from cattle feces, farm soil, workers' feces, and drinking water. The farms where no samples were obtained were excluded from the study. The study was conducted across four peri-urban areas of Ouagadougou: Saaba (14 farms), Koubri (11 farms), Loumbila (14 farms), and Saponé (11 farms) (Figure 1). These areas were chosen because they are located on the outskirts of the city, where livestock farming is widespread. In addition, these areas have large areas of land available for livestock farming. The farmers were selected according to the guidelines of the Zones of Technical Support in Livestock), which are the subdivisions of the Burkina Faso Ministry of Animal and Fisheries Resources at the departmental level. The study included 29 semi-intensive farms and 21 traditional farms.

In semi-intensive farms, livestock graze during the day and receive supplemental feed in the evening. These farms also routinely perform deworming and medical treatment, and animal health is systematically monitored. In contrast, traditional farms follow a herding system in which animals are constantly moved by a shepherd in search of better grazing pastures. Treatment on traditional farms is typically administered only in cases of illness or during vaccination campaigns.

Data collection

The structured questionnaire was designed in French using the online KoboToolbox software (Kobo Inc., Cambridge, MA 02138) and administered face-to-face using KoboCollect (Kobo Inc., Cambridge, v2023.1.2). The questionnaire was organized into four sections: the first section addressed the sociodemographic characteristics of the participants; the second section focused on patterns of antibiotic use; the third section examined practices that could contribute to the spread of antibiotic resistance in the environment; and the fourth section assessed practices that could increase the risk of spreading antibiotic resistance among farm workers.

Statistical analysis

Data collected through the Kobo Toolbox application were exported to Microsoft Excel 2016 (Microsoft Office, Washington, USA) for analysis. This study employed a methodological framework to investigate how risky antibiotic use practices in cattle farming, influenced by sociodemographic and farm-level factors, contribute to environmental contamination and public health risks.

Livestock farmers' practices were evaluated in three dimensions: Appropriate antibiotic use practices, practices aimed at limiting environmental dissemination of antibiotics, and practices to prevent the transmission of antibiotic resistance to humans. Each dimension was categorized as "good" or "poor." Categories were determined based on binary-coded variables (0 or 1). For each participant, a total score was calculated by summing these variables. Scores ranged from 0 (none of the variables met the criteria) to the total number of variables assessed [23]. The average score across all participants was then computed, and participants were classified as follows: Those with a total score above the group average were categorized as having "good" practices, while those with a score equal to or below the average were categorized as having "poor" practices.

The analysis examined the influence of sociodemographic variables, such as age, gender, and education, and livestock-related factors, including herd size, livestock type, and access to veterinary services, on antibiotic misuse practices. Antibiotic usage practices were also assessed to identify factors contributing to environmental dissemination of antibiotics. In addition, environmental variables such as animal waste management, handling of deceased animals, and disposal of medication packaging were analyzed to evaluate the risk of human contamination.

Descriptive statistics, including frequencies, means, proportions, and 95% confidence intervals, were calculated. Logistic regression analyses were conducted using stepwise downward selection in the Pasteur Institute of Madagascar (IPM), Epidemiology and Clinical Research Unit (https://cran.r-project.org/web/packages/MASS/index.html). Variable selection for the final model was guided by the Akaike Information Criterion (AIC). Starting with a full model, variables were iteratively removed if their exclusion reduced the AIC. This process continued until the final model achieved an optimal balance of simplicity and fit.

RESULTS

Famers' characteristics

Of the 54 farms approached, 50 (92.6%) consented to participate in the study. Among the participants, 98% (n = 49) were male and 2% (n = 1) were female. Of those surveyed, 62% (n = 31) had no formal education and 76% (n = 38) had not received any training in animal health. Nonetheless, 80% (n = 40) reported having access to veterinary services, and 62% (n = 31) had more than 6 months of experience in general animal husbandry (Table 1).

Description of farmers' antibiotic use practices

The farmers' attitudes toward antibiotic use were assessed in this survey based on four statements (Table 2). Among the 50 surveyed farmers, 96% (n = 48) reported administering antibiotics to their animals, primarily to treat infections (70%, n = 35). Most antibiotics (66%, n = 33) were administered by veterinary staff, whereas 24% (n = 12) of farm workers administered antibiotics based on their own experience. Among the antibiotics used, those from the cyclin class were the most prevalent, with tetracycline accounting for 52% (n = 26) and oxytetracycline accounting for 26% (n = 13). Amoxicillin was the least commonly used antibiotic, reported by only 6% (n = 3) of farmers. In addition, 92% (n = 46) of the farm workers indicated that antibiotics were easily accessible through veterinary

Table 1: Sociodemographic characteristics of the surveyed farmers.

Questions/Variables	Modalities	Number of farmers (N)	Percentage	95% CI
Gender	Female	1	2	(0.72–1.27)
	Male	49	98	(47.06–50.94)
Age	Under 37	25	50	(23.61–26.38)
	37 and Over	25	50	(23.61–26.38)
How long have you been farming (in months)?	0–5	19	38	(17.79–20.21)
	6 and more	31	62	(29.46–32.54)
What is your education level?	Uneducated	31	62	(29.46–32.54)
	Educated	19	38	(17.79–20.21)
What type of farming do you have?	Semi–intensive	29	58	(27.51–30.49)
	Traditional	21	42	(19.73–22.27)
What is your role in the farm?	Worker	26	52	(24.59–27.41)
	Owner	24	48	(22.64–25.36)
How many animals do you have in total?	(5–25)	13	26	(12.00–14.00)
	(26–50)	27	54	(25.56–28.44)
	51 and more	10	20	(9.12–10.87)
Have you ever attended animal health training?	No	38	76	(36.29–39.70)
	Yes	12	24	(11.04–12.96)
Do you have access to veterinary services?	No	10	20	(9.12–10.87)
	Yes	40	80	(38.24–41.75)

Table 2: Variables used to calculate antibiotic usage scores by farmers (output for level 1).

Questions	Modalities	Number of farmers (N)	Percentage	95% CI	Score
Antibiotics usually administered	Amoxicillin	3	6	(1.25–16.55)	
	Cotrimoxazole	8	16	(7.17–29.11)	
	Tetracycline	26	52	(37.42–66.34)	
	Oxytetracycline	13	26	(14.63–40.34)	
How often do you use veterinary services?	1–2 times per year	30	60	(28.48–31.51)	
	3 times or more per year	20	40	(18.76–21.24)	
Do you think that the frequent use of antibiotics in animals can have long-term consequences?	No or do not know	41	82	(39.22–42.77)	
	Yes	9	18	(8.17–9.83)	
In your opinion, can antibiotics administered to animals be found in manure?	No or do not know	41	82	(39.22–42.77)	
	Yes	9	18	(8.17–9.83)	
*Who administers antibiotics to your animals?	Other people	17	34	(15.86–18.14)	0
	Veterinarian	33	66	(31.41–34.59)	1
*On what basis do you administer antibiotics?	Dose recommended by veterinarians	40	80	(38.25–41.75)	1
	On another basis	10	20	(9.12–10.87)	0
*For what reason do you use antibiotics?	Other reasons	15	30	(13.93–16.07)	0
	Treat infections only	35	70	(33.36–36.64)	1
*How do you obtain antibiotics and medications for animals?	From the veterinarian	21	42	(19.73–22.27)	1
	From the pharmacy with a veterinary prescription	29	58	(27.51–30.49)	1
After administering an antibiotic to an animal, how many days do you wait before selling or slaughtering the animal?	Less than 2 weeks	30	60	(28.48–31.52)	1
	More than 2 weeks	20	40	(18.76–21.24)	0

*Mean statement used to evaluate farmers' attitudes toward antibiotic use
CI=Confidence interval

agents. Furthermore, 82% (n = 41) of the farmers were unaware that the frequent use of antibiotics could have long-term consequences for animal health, nor did they recognize that the antibiotics administered to animals could be present in manure.

Factors contributing to poor scores or misuse of antibiotics by farmers (Level 1 analysis)

Five questions were used to calculate the antibiotic usage practice scores of the farmers (Table 2). The practice scores for all participants ranged from 1 to 5 points, with an average score of 3.56 points. Of the farmers surveyed, 40% (n = 20) exhibited poor antibiotic usage practices, whereas 60% demonstrated good antibiotic usage practices.

Explanatory factors of antibiotic misuse by farmers

Several sociodemographic variables were included in the Level 1 logistic regression analysis (Table 3). Access to veterinary services was significantly associated with the misuse of antibiotics in livestock ($p < 0.05$). In the multivariate analysis, multiple factors were associated with antibiotic misuse (Table 3).

If cattle had been raised for 6 months or more, the odds of antibiotic use were 4.37 times higher compared with cattle raised for <6 months, holding all other factors constant (odds = 4.37). These findings suggest a positive association between the duration of cattle rearing and antibiotic use.

In farms employing traditional livestock farming methods, the odds of antibiotic use are 0.12 times lower (or 88% reduction) than those using non-traditional methods when controlling for other variables. This indicates that traditional farming practices are significantly associated with lower antibiotic use.

Farmers who received training in animal health exhibit odds of antibiotic use, which are 0.16 times lower (or 84% reduction) than those without such training. This suggests that animal health training is effective in reducing the likelihood of antibiotic use in our study area.

Moreover, if farmers have access to veterinary services, the odds of antibiotic use are only 0.04 times lower (or 96% reduction) than those without access when controlling for other factors. This indicates a strong negative association, suggesting that farmers with access to veterinary services are significantly less likely to misuse antibiotics.

Factors contributing to the spread of antibiotic resistance in farm environment (Level 2 analysis)

Four questions were used to calculate the risk score for the spread of antibiotics in the environment (Table 4). The practice scores for all participants ranged from 1 to 4 points, with an average score of 1 point. Sixty-six percent (66%; n = 33) of farmers had poor

doi: 10.14202/IJOH.2025.1-12

Table 3: Variables used to calculate antibiotic usage scores by farmers.

Variables	Estimate	Standard error	z-value	p-value	Adjusted OR	95% CI
(Intercept)	2.4296	1.13	2.13	0.03	11.35	(1.54–151.19)
More than 6 months of breeding	1.4749	0.87	1.67	0.09	4.37	(0.86–28.86)
Traditional breeding system	−2.0951	0.92	−2.25	0.02	0.12	(0.01–0.66)
Received animal health training	−1.8065	1.01	−1.77	0.07	0.16	(0.01–1.04)
Have access to veterinary services	−3.1439	1.08	−2.90	0.01	0.04	(0.03–0.28)

OR=Odds ratio, CI=Confidence interval

Table 4: Variables used for calculating practices related to environmental pollution scores by farmers (output for level 2)

Questions	Modalities	Frequencies (N)	Percentage	Score
Do you have an animal waste management system?	No	35	70	0
	Yes	15	30	1
How do you manage animal waste?	Other types of management	40	80	0
	Septic tank	10	20	1
What do you do with animals that die during treatment?	Incineration	4	8	1
	Other uses	46	92	0
How do you dispose of or reuse the primary containers and packaging of the medications?	Other uses	23	46	0
	Incineration or veterinary disposal	27	54	1

practices related to environmental contamination by antibiotic resistance (Figure 2), while 34% had good practices.

In the multivariate regression analysis, the role of the respondent in the operation (owner vs. other workers) was found to be statistically significant ($p < 0.05$), as were the reasons for using antibiotics ($p < 0.1$) in relation to the risk of environmental contamination.

An odds ratio of 1.62 indicates that farmers who are owners of the surveyed farms have approximately 62% higher odds of contributing to antibiotic risk in the environment compared to those who are not owners ($p < 0.05$). This result is statistically significant, suggesting a reliable association between ownership status and the risk of spreading antibiotics in the environment.

Regarding the reasons for using antibiotics, the odds ratio of 2.05 suggests that farmers who use antibiotics exclusively for the treatment of infections have about twice the odds of contributing to antibiotic risk in the environment compared with those who do not use antibiotics solely for this purpose. Although the p-value of 0.06 indicates that this result is not statistically significant at the conventional 0.05 threshold, it is close and could be considered marginally significant. This implies that there is some evidence that this behavior (using antibiotics solely for treating infections) may influence the risk of spreading antibiotics, warranting caution when drawing definitive conclusions.

Figure 2: Untreated animal waste discharged directly into the environment.

Factors contributing to the spread of antibiotic resistance among farmers (Level 3 analysis)

Six questions were used to calculate risk scores for farmers' exposure to antibiotic resistance (Table 5). Best practices scored between 1 and 6 points, with an average score of 3.74 points. A total of 35 farmers (70%) had good practices, indicating a low risk of contamination, while 30% had poor practices, suggesting a high risk of contamination within the farming environment (Table 6).

Several sociodemographic variables, along with practices associated with the misuse of antibiotics and the spread of antibiotic resistance in the environment, were included in the Level 3 logistic regression analysis. A total of 21 variables were examined. Among these variables, none were statistically associated with farmers' antibiotic contamination in their environment ($p > 0.05$). This finding suggests insufficient evidence to reject the null hypothesis (i.e., no association between human contamination and the set of variables used) at a 95% confidence level. However, this does not imply that the results lack meaning or value. In the context of this study, it is possible that an effect exists, but the sample size may be too small or the variability in the data too

doi: 10.14202/IJOH.2025.1-12

Table 5: Variables used for calculating scores of practices related to human contamination by antibiotic resistance (output of lvel 3).

Questions	Modalities	Frequencies (N)	Percentage	Score
Do you wash your hands before eating?	Other washing frequencies	2	4	0
	Always	48	96	1
Do you wash your hands after eating?	Other washing frequencies	0	0	0
	Always	50	100	1
Do you ever eat or drink while in the animal facility?	Other frequencies	11	22	0
	Never	39	78	1
While working on this farm, have you ever come into direct contact with urine or feces?	Urine	1	2	0
	Excrement	49	98	0
Do you have specific clothing dedicated to your work?	No	42	84	0
	Yes	8	16	1
Do you take a shower after your workday?	No	8	16	0
	Yes	42	84	1

Table 6: Variables that could influence the risk of spreading antibiotic resistance in humans.

Variables	(Intercept)	Estimate	Standard error	Z-value	p-value	Adjusted OR
		−90.51	**41356.8**	**−0.002**	**0.998**	
Age	Under 37	−120.64	35018.8	−0.003	0.997	4.035980e-53
Experience in months	6 months or more	−261.88	66301.5	−0.004	0.997	1.849682e-114
Level of education	Schooled	−637.94	136619.4	−0.005	0.996	8.867740e-278
The type of livestock farming	Traditional	−403.52	85088.2	−0.005	0.996	5.689735e-176
Role in farm operation	Owner	120.52	34812.3	0.003	0.997	2.204529e+52
Total number of animals	5–25	−18.55	11204.0	−0.002	0.999	8.792725e-09
	51 years or More	776.96	163508.8	0.005	0.996	Inf
Frequency of veterinary service consultations	3 or more times per year	−251.69	54247.8	−0.005	0.996	4.900623e-110
Awareness of the long-term health consequences of antibiotic use	Yes	1051.41	218439.7	0.005	0.996	Inf.
Awareness of the potential presence of antibiotics in manure	Yes	−896.81	181139.0	−0.005	0.996	0.000000e+00
Person administering antibiotics to the animals	Veterinarian	−101.87	32701.2	−0.003	0.998	5.739550e-45
Reason for using antibiotics in livestock farming	Treat infections only	736.15	152520.9	0.005	0.996	Inf.
Sources of antibiotic supply	Pharmacy with veterinary prescription	−191.75	41895.6	−0.005	0.996	5.321340e-84
Animal management system on the farm	Yes	−851.40	185627.7	−0.005	0.996	0.000000e+00
Use of animals that died during antibiotic treatment	Incineration	−544.14	115655.0	−0.005	0.996	4.825015e-237
Disposal or use of medication bottles and packaging	Incineration or taken by veterinarian	231.33	46630.6	0.005	0.996	2.931038e+100

OR=Odds ratio

high to detect it with sufficient confidence. Therefore, considering these results may still be beneficial for decision-making and interventions aimed at mitigating the risks of farmers' contamination, even if the effect is not statistically significant.

Regarding practical implications, 16 variables emerged in the final model as potentially important factors in the fight against antibiotic resistance in the context of our study (Table 6).

Farmers younger than 37 years of age exhibit significantly lower odds of self-contamination compared to those older than 37. Similarly, farmers who have been raising cattle for 6 months or more have markedly reduced odds of contamination compared to those with less farming experience. Farmers with some level of education also show significantly lower odds of self-contamination compared to those without formal schooling.

Traditional livestock farming methods are associated with much lower odds of contamination than modern or alternative farming practices. Farm owners present extremely high odds of self-contamination compared to non-owners (e.g., employees). Farmers managing between 5 and 25 animals have lower odds of contamination than those managing between 26 and 50 animals. In contrast, farmers with more than 51 animals exhibit infinite odds of contamination, indicating a strong positive association with the risk of self-contamination, likely due to increased contact with the farm environment.

Farmers using veterinary services three or more times per year have significantly lower odds of self-contamination than those who use these services less frequently. Those aware of the long-term consequences of antibiotic use in animals demonstrate infinitely higher odds of contamination. Awareness of the presence of antibiotics in manure substantially reduces the risk of contamination, suggesting a potential protective factor and prompting informed farmers to take additional precautions.

When antibiotics are administered by veterinarians, the risk of self-contamination is significantly lower than that of other administration methods. Farmers who use antibiotics exclusively for treating infections exhibit infinite odds of contamination, likely reflecting the intensive handling of these substances. Farmers acquiring antibiotics from a pharmacy with a prescription have much lower odds of contamination than those obtaining them from other sources.

Proper waste management systems for animal by-products are associated with zero odds of contamination, indicating the implementation of strong preventive measures. Incinerating deceased animals significantly reduce the risk of contamination, suggesting that this practice is a best practice for biosecurity. Conversely, when antibiotic flasks and packaging are either incinerated or collected by veterinarians, the odds of contamination dramatically increase, which may indicate inadequate management or increased exposure during these processes.

DISCUSSION

In this pilot study, the first of its kind in Burkina Faso, we described livestock farmers' antibiotic use and the risky practices associated with the spread of AMR in both humans and the environment. This study highlights the intricate relationships among these domains, particularly concerning the use of antibiotics and the emergence of AMR among livestock farmers. The sex distribution of farmers in this study revealed that the majority (98%) were male. This finding is consistent with studies from Burkina Faso [21] and Benin [24] on small ruminants. In addition, 62% of the farmers had no formal education, and 76% had not received prior training in animal production before being employed, with recruitment largely based on livestock experience. This education level contrasts with studies on poultry farms in Nigeria, where 70% of farmers had formal education [25]. Cattle farming, unlike poultry farming, typically does not require a high level of technical knowledge because it involves less processing.

The findings reveal that most farmers in Burkina Faso administer antibiotics primarily for treating infections, with a significant reliance on specific antibiotics such as tetracyclines and oxytetracyclines. However, the lack of knowledge regarding appropriate antibiotic use and potential consequences on animal and human health is alarming. The overuse and misuse of antibiotics in livestock not only promote the development of resistant strains but also increase the risk of these pathogens being transferred to humans, thereby posing a direct threat to public health. These findings align with earlier studies conducted in Burkina Faso [20] and the neighboring country, Togo [26]. The intensification of animal production in recent decades has heavily relied on veterinary medicines [27], which are employed for curative treatments, preventive care, or to compensate for poor farm hygiene [26, 27]. Antimicrobials are also widely used as growth promoters [28]. However, most farmers in this study were unfamiliar with antibiotics and sought veterinary staff for treatment. Some administered antibiotics based on personal experience or consultation with more knowledgeable individuals. The limited use of veterinarians may be attributed to the remoteness of farms, challenges in accessing veterinary services, the availability of unqualified services from feed and medicine sellers, or the exchange of ideas with neighboring farmers. In addition, the ease of purchasing antibiotics without a prescription contributes to this trend [29, 30]. Most participants reported that antibiotics were easy to obtain, with tetracycline and oxytetracycline being the most commonly used drugs. A previous study in Burkina Faso has found that tetracycline is the most widely used antibiotic (90.9%) in cattle farms [31]. Similar studies in Benin [32] and Kenya [33] have reported high tetracycline use in cattle farming. However, research in Nigeria found that gentamicin, sulfonamides, and quinolones were more frequently used on poultry farms [34]. Across five African countries, tetracycline was identified as the most commonly used antibiotic [35].

Analyzing the explanatory factors of antibiotic misuse by farmers, the demographic characteristics of the farmers surveyed indicate that a large portion of the farmers lack formal education and training in animal health, which can exacerbate the risks associated with antibiotic misuse. Access to veterinary services emerged as a critical factor influencing antibiotic use ($p < 0.05$). Indeed, farmers who frequently utilize veterinary services are less likely to misuse antibiotics, highlighting the need for improved access to qualified veterinary care. Strengthening veterinary services and ensuring that farmers have access to knowledgeable professionals can facilitate better decision-making regarding antibiotic use and reduce AMR. A study conducted in Rwanda found that the multivariate analysis of the level of knowledge regarding antibiotics and antibiotic resistance was significantly linked to inappropriate antibiotic use, with animal health professionals possessing insufficient knowledge being three times more likely to misuse antibiotics [36]. Our results contrast those of another study conducted in South Africa, which identified the cost of antibiotics as the primary factor influencing decisions related to antibiotic use [37]. Awareness and understanding of the implications of antibiotic resistance are crucial for the implementation of effective strategies to address this issue. Tailoring educational interventions that consider the sociodemographic context of farmers is essential to enhance their knowledge of antibiotic stewardship and biosecurity practices.

This study underscores the environmental implications of antibiotic use, as poor practices related to waste management and inadequate biosecurity measures contribute to the spread of resistant bacteria. The presence of antibiotics in manure and their subsequent impact on soil and water systems exemplifies the environmental aspects of One Health. Contaminated environments can serve as reservoirs for resistant bacteria, further complicating the control of AMR and increasing the risk of exposure to humans through food and water sources. Regarding factors contributing to the spread of antibiotics in farm environments, farmers who owned the surveyed farms had approximately 62% higher odds of spreading antibiotic risk in the environment compared to non-owners ($p < 0.05$). This result is statistically significant, suggesting that ownership status has a considerable impact on the risk of spreading antibiotics in the environment. In Nigeria, slaughterhouse workers were colonized by multidrug-resistant bacteria, with over 38% of them failing to collect slaughterhouse waste [38]. In Ghana, a study revealed that none of the farmers screened their manure for antibiotic residues [24]. Hou *et al*. [9], Aworh *et al*. [38], and Takanoğlu *et al.* [39] have reported significant quantities of antibiotics in manure, posing environmental risks. Our findings differ from those of studies in Italy, the United States, and Germany, where participants generally perceived risks associated with antibiotic use in livestock farming, particularly regarding soil, water, and feed contamination [40]. The two main cattle-rearing systems in Burkina Faso, traditional (87.87%) and semi-intensive (12.12%), pay little attention to biosecurity, consistent with findings from another study conducted in Burkina Faso [30]. A U.S. study found that organic farmers were more likely than conventional farmers to acknowledge the presence of antibiotics in manure [41]. Some antibiotics used in livestock farming are indeed found in livestock waste. The level of antibiotic metabolism in an animal's body varies between 10% and 90% of the ingested dose [42], depending on the age and species of the animal. Consequently, animal waste can contain not only antibiotic residues but also the products of their metabolism. Solid waste from farms contained 241 mg/kg of ciprofloxacin and approximately 12 mg/kg of doxycycline in a study conducted by Bengtsson-Palme *et al.* [43], in France. Likewise, their study reported that the concentrations in liquid waste were 0.006 mg/L and 0.505 mg/L for ciprofloxacin and doxycycline, respectively. The concentrations of ciprofloxacin and doxycycline likely to cause the selection of resistant bacteria were 0.064 μg/L and 2 μg/L, respectively [43]. Therefore, it can be concluded that this waste constitutes a significant threat to antibiotic resistance in the microflora. The majority of cattle farming environments in Burkina Faso are poorly managed and have inadequate sanitary conditions, thereby promoting the spread of resistant pathogens.

In addition to examining environmental risks, we investigated practices that may contribute to the spread of antibiotic resistance among humans. Among the variables analyzed, none were statistically associated with farmers' antibiotic contamination in their environment, with all p-values exceeding 0.05. A study conducted in South Africa demonstrated that factors such as the age of workers, raising animals at home, eating in the abattoir during work, collecting abattoir waste, and washing hands with soap were significantly associated with the presence of multidrug-resistant *E. coli* in stool samples from slaughterhouse workers [37]. A study in Germany reported the transfer of extended-spectrum beta-lactamases (ESBL)-producing *E. coli* from cattle to farm workers [44]. Another study in Nigeria demonstrated the horizontal transfer of ESBL genes from cattle to slaughterhouse workers [45]. The spread of antibiotic resistance to humans on farms can occur either through direct contact with resistant bacteria present in animals or their biological products (such as urine, excrement, blood, and saliva) or through indirect contact with the environment. These two factors also facilitate the transmission of zoonotic diseases. Veterinarians, farmers, slaughterhouse workers, food handlers, and others who come into contact with them are at higher risk of colonization or infection by resistant strains [3]. The transmission of resistant bacteria from livestock to humans underscores the importance of a coordinated One Health approach to AMR. Effective public health policies must incorporate strategies involving the agricultural sector, healthcare systems, and environmental management. Initiatives are vital to raise public awareness about the risks associated with antibiotic misuse and promote responsible use of antimicrobials. Moreover, implementing training programs for farmers on biosecurity measures and responsible antibiotic use can mitigate the spread of resistance and safeguard both human and animal health.

CONCLUSION

This study provides valuable insights into antibiotic use practices among cattle farmers in peri-urban areas of Ouagadougou and their implications for the spread of AMR in humans and the environment. The findings revealed that while antibiotics are predominantly used for treating infections, the lack of formal education and training among farmers significantly contributes to risky practices. The widespread use of tetracyclines and the frequent administration of antibiotics without veterinary guidance underscore the need for more stringent regulations and farmer education.

A significant strength of this study lies in its focus on the interconnectedness of human, animal, and environmental health, embodying the One Health approach. Using a structured methodology to quantify risk factors, the research successfully identified critical gaps in knowledge, waste management practices, and biosecurity measures. These findings establish a baseline for designing targeted interventions.

However, the study is not without limitations. The small sample size and the focus on area limit the generalizability of the findings to the broader population of cattle farmers in Burkina Faso, especially those in rural regions with potentially different farming practices. In addition, the reliance on self-reported data introduces potential biases such as recall errors and social desirability.

Future research should aim to expand the geographical scope and sample size to include rural farming communities. Observational studies or longitudinal research could provide more reliable data and track changes in antibiotic use practices over time. Furthermore, there is a critical need for interventions to enhance farmers' knowledge of antibiotic stewardship, biosecurity, and waste management practices. Strengthening veterinary services and enforcing regulations on the sale and use of antibiotics are vital steps toward mitigating the spread of AMR.

This study underscores the urgent need for a multi-sectoral One Health strategy to address AMR. By fostering collaboration among policymakers, researchers, and farming communities, we can safeguard public health, preserve the effectiveness of antibiotics, and promote sustainable livestock farming practices.

AUTHORS' CONTRIBUTIONS

DS, FBJD, IJOB, DK: Conceptualization of the study, formal analysis, and writing of the original manuscript. EB, SS, MEMN, NB, NSS, NS, IJOB, and DK: Conceptualization and supervised the study and writing, review, and editing of the manuscript. All authors have read and approved the final manuscript.

ACKNOWLEDGMENTS

The authors are grateful to the Africa Center of Excellence in Social Risk Management (CEA-CEFORGRIS) at the University Joseph KI-ZERBO, Burkina Faso, for providing a doctoral research grant that supported this study (CEFORGRIS-13-01-2025). We thank the managers of the Livestock Technical Support Zones (ZATE) and the farmers involved in the study for their participation and assistance in the areas and for facilitating data collection.

COMPETING INTERESTS

The authors declare that they have no competing interests.

PUBLISHER'S NOTE

Veterinary World (Publisher of the International Journal of One Health) remains neutral with regard to jurisdictional claims in published institutional affiliation.

REFERENCES

1. Erdaw, M. (2023) Contribution, prospects and trends of livestock production in sub-Saharan Africa: A review. *Int. J. Agric. Sustain.*, 21(1): 2247776.
2. FAO. (2019). Le Devenir de l'élevage au Burkina Faso. Défis et Opportunités Face Aux Incertitudes. FAO, Rome, p56.
3. Abreu, R., Semedo-Lemsaddek, T., Cunha, E., Tavares, L. and Oliveira, M. (2023) Antimicrobial drug resistance in poultry production: Current status and innovative strategies for bacterial control. *Microorganisms.*, 11(4): 953.
4. Van Boeckel, T.P., Glennon, E.E., Chen, D., Gilbert, M., Robinson, T.P., Grenfell, B.T., Levin, S.A., Bonhoeffer, S. and Laxminarayan, R. (2017) Reducing antimicrobial use in food animals. *Science*, 357(6358): 1350–1352.
5. Joerger, R.D. (2003) Alternatives to antibiotics: Bacteriocins, antimicrobial peptides and bacteriophages. *Poult. Sci*., 82(4): 640–647.
6. Del Collo, L.P., Karns, J.S., Biswas, D., Lombard, J.E., Haley, B.J., Kristensen, R.C., Kopral, C.A., Fossler, C.P. and Van Kessel, J.A.S. (2017) Prevalence, antimicrobial resistance, and molecular characterization of *Campylobacter* spp. in bulk tank milk and milk filters from US dairies. *J. Dairy Sci.*, 100(5): 3470–3479.
7. Ngaiganam, E.P., Pagnier, I., Chaalal, W., Leangapichart, T., Chabou, S., Rolain, J.M. and Diene, S.M. (2019) Investigation of urban birds as source of β-lactamase-producing Gram-negative bacteria in Marseille city, France. *Acta Vet. Scand.*, 61(1): 51.
8. Müller, A., Stephan, R. and Nüesch-Inderbinen, M. (2016) Distribution of virulence factors in ESBL-producing *Escherichia coli* isolated from the environment, livestock, food and human. *Sci. Total Environ.*, 541: 667–672.
9. Hou, J., Wan, W., Mao, D., Wang, C., Mu, Q., Qin, S. and Luo, Y. (2015) Occurrence and distribution of sulfonamides, tetracyclines, quinolones, macrolides, and nitrofurans in livestock manure and amended soils of Northern China. *Environ. Sci. Pollut. Res*., 22(6): 4545–4554.
10. DeVries, S.L. and Zhang, P. (2016) Antibiotics and the terrestrial nitrogen cycle: A review. *Curr. Pollut. Rep*., 2(1): 51–67.
11. Hamscher, G., Sczesny, S., Höper, H. and Nau, H. (2002) Determination of persistent tetracycline residues in soil fertilized with liquid manure by high-performance liquid chromatography with electrospray ionization tandem mass spectrometry. *Anal. Chem.*, 74(7): 1509–1518.

12. Sarmah, A.K., Meyer, M.T. and Boxall, A.B.A. (2006) A global perspective on the use, sales, exposure pathways, occurrence, fate and effects of veterinary antibiotics (VAs) in the environment. *Chemosphere*, 65(5): 725–759.
13. Bouki, C., Venieri, D. and Diamadopoulos, E. (2013) Detection and fate of antibiotic-resistant bacteria in wastewater treatment plants: A review. *Ecotoxicol. Environ. Saf.*, 91: 1–9.
14. Wu, X.L., Xiang, L., Yan, Q.Y., Jiang, Y.N., Li, Y.W., Huang, X.P., Li, H., Cai, Q.Y. and Mo, C.H. (2014) Distribution and risk assessment of quinolone antibiotics in the soils from organic vegetable farms of a subtropical city, Southern China. *Sci. Total Environ.*, 487: 399–406.
15. Livermore, D.M. (1995) Beta-lactamases in laboratory and clinical resistance. *Clin. Microbiol. Rev.*, 8(4): 557–584.
16. Kraemer, S.A., Ramachandran, A. and Perron, G.G. (2019) Antibiotic pollution in the environment: From microbial ecology to public policy. *Microorganisms.*, 7(6): 180.
17. Cycoń, M., Mrozik, A. and Piotrowska-Seget, Z. (2019) Antibiotics in the soil environment-degradation and their impact on microbial activity and diversity. *Front. Microbiol.*, 10: 338.
18. Rosendahl, I., Siemens, J., Kindler, R., Groeneweg, J., Zimmermann, J., Czerwinski, S., Lamshöft, M., Laabs, V., Wilke, B.M., Vereecken, H. and Amelung, W. (2012) Persistence of the fluoroquinolone antibiotic difloxacin in soil and lacking effects on nitrogen turnover. *J. Environ. Qual.*, 41(4): 1275–1283.
19. Kotzerke, A., Sharma, S., Schauss, K., Heuer, H., Thiele-Bruhn, S., Smalla, K., Wilke, B.M. and Schloter, M. (2008) Alterations in soil microbial activity and N-transformation processes due to sulfadiazine loads in pig-manure. *Environ. Pollut*., 153(2): 315–322.
20. Sawadogo, A., Kagambèga, A., Moodley, A., Ouedraogo, A.A., Barro, N. and Dione, M. (2023) Knowledge, attitudes, and practices related to antibiotic use and antibiotic resistance among poultry farmers in urban and peri-urban areas of Ouagadougou, Burkina Faso. *Antibiotics*, 12(1): 133.
21. Samandoulougou, S., Ilboudo, A.J., Sanon, G., Tindano, K., Compaore, H., Ouedraogo, A., Savadogo, A., Traore, A.S. (2016). Use of veterinary medicines in cattle and poultry production and animal food safety in Burkina Faso. [Qualité sanitaire et nutritionnelle des gésiers de poulets consommés à Ouagadougou au Burkina Faso] *Int. J. Multi-Discip, Sci*. 1 (2016): 50–79.
22. Soma, D., Bonkoungou, I.J.O., Garba, Z., Diarra, F.B.J., Somda, N.S., Nikiema, M.E.M., Bako, E., Sore, S., Sawadogo, N., Barro, N. and Haukka, K. (2024) Extended-spectrum beta-lactamase-producing and multidrug-resistant *Escherichia coli* and *Klebsiella* spp. from the human-animal-environment interface on cattle farms in Burkina Faso. *Microbiol. Res.*, 15(4): 2286–2297.
23. Faizal, A. and Kwasi, O.Y. (2015) Determinants of small ruminant farmers decision to participate in veterinary services in Northern Ghana. *J. Vet. Med. Anim. Health*, 7(5): 193–204.
24. Aguidissou, O.N.C., Boko, C.K., Adoligbe, C.M., Dete, C.H., Capo-Chichi, P.T., Akpo, Y., Koutinhouin, B.G. and Farougou, S. (2020). Inventory of biosecurity measures and antibiotics therapy practices on laying hen farms in Benin. *Vet. World*, 13(12): 2681–2690.
25. Bedekelabou, A.P., Talaki, E., Dzogbema, K.F., Dolou, M., Savadogo, M., Seko, M.O. and Alambedji, R.B. (2022) Assessing farm biosecurity and farmers' knowledge and practices concerning antibiotics and antibiotic resistance in poultry and pig farms in Southern Togo. *Vet. World*, 15(7): 1727–1737.
26. Paul, A., Gnamien, S.T., Haziz, S., Lamine, B.M. and Rose, K.N. (2016) Antimicrobial resistance of potential pathogenic strains isolated from eggs produced by informal farms and sold in Abidjan, Ivory Coast. *Afr. J. Microbiol. Res.*, 10(16): 542–551.
27. Sanders, P. (2005) Antibiotic resistance in veterinary medicine: Public health and animal health [L'antibiorésistance en médecine vétérinaire: Enjeux de santé publique et de santé animale]. *Bull. Acad. Vét. Fr.,* 158(2): 137–143.
28. Butcher, A., Cañada, J.A. and Sariola, S. (2021) How to make noncoherent problems more productive: Towards an AMR management plan for low resource livestock sectors. *Humanit. Soc. Sci. Commun*., 8(1): 287.
29. Dibner, J.J. and Richards, J.D. (2005) Antibiotic growth promoters in agriculture: History and mode of action. *Poult. Sci.*, 84(4): 634–643.
30. Imam, T., Gibson, J.S., Foysal, M., Das, S.B., Gupta, S.D., Fournié, G., Hoque, M.A. and Henning, J. (2020). A cross-sectional study of antimicrobial usage on commercial broiler and layer chicken farms in Bangladesh. *Front. Vet. Sci.*, 7: 576113.
31. Samandoulougou, S., Compaore, H., Tapsoba, F.W., Kinda, R.P., Ilboudo, A.J. and Sawadogo-Lingani, H. (2022) Sanitary and nutritional quality of chicken gizzards consumed in Ouagadougou in Burkina Faso [Qualité sanitaire et nutritionnelle des gésiers de poulets consommés à Ouagadougou au Burkina Faso]. *J. Appl. Biosci*., 167(1): 17335–17347.
32. Mensah, S., Philippe, S., Christie, N., Adjahoutonon, K.Y.K.B., Olivier, L. and Farougou, S. (2019) Antibiotic use in sedentary dairy cattle farms in north-west Benin [Mode d'utilisation des antibiotiques dans les élevages de bovin laitier sédentaires au nord-ouest du Bénin]. *J. Anim. Plant Sci*., 42(2): 7198–7206.
33. Kariuki, J.W., Jacobs, J., Ngogang, M.P. and Howland, O. (2023) Antibiotic use by poultry farmers in Kiambu County, Kenya: Exploring practices and drivers of potential overuse. *Antimicrob. Resist. Infect. Control*, 12(1): 3.
34. Al-Mustapha, A.I., Adetunji, V.O. and Heikinheimo, A. (2020) Risk perceptions of antibiotic usage and resistance: A cross-sectional survey of poultry farmers in Kwara State, Nigeria. *Antibiotics*, 9(7): 378.

35. Caudell, M.A., Dorado-Garcia, A., Eckford, S., Creese, C., Byarugaba, D.K., Afakye, K., Chansa-Kabali, T., Fasina, F.O., Kabali, E., Kiambi, S., Kimani, T., Mainda, G., Mangesho, P.E., Chimpangu, F., Dube, K., Kikimoto, B.B., Koka, E., Mugara, T., Rubegwa, B. and Swiswa, S. (2020) Towards a bottom-up understanding of antimicrobial use and resistance on the farm: A knowledge, attitudes, and practices survey across livestock systems in five African countries. *PLoS One*, 15(1): e0220274.
36. Mugwaneza, D., Rwagasore, E., El-Khatib, Z., Dukuziyaturemye, P., Omolo, J., Nsekuye, O., Rwunganira, S. and Manzi, M. (2024) Factors associated with inappropriate use of antibiotics among animal health professionals in selected districts of Rwanda, 2021. *J. Epidemiol. Glob. Health*, 14(2): 265–273.
37. Samuels, R., Qekwana, D.N., Oguttu, J.W. and Odoi, A. (2021) Antibiotic prescription practices and attitudes towards the use of antimicrobials among veterinarians in the City of Tshwane, South Africa. *PeerJ*, 9: e10144.
38. Aworh, M.K., Abiodun-Adewusi, O., Mba, N., Helwigh, B. and Hendriksen, R.S. (2021) Prevalence and risk factors for faecal carriage of multidrug resistant *Escherichia coli* among slaughterhouse workers. *Sci. Rep.*, 11(1): 13362.
39. Takanoğlu, B.D., Kuran, Ö. and Koluman, A. (2024). Antibiotics: environmental impact and degradation techniques. *J. Innovative Eng. Nat. Sci.,* 4(2): 684–698.
40. Busch, G., Kassas, B., Palma, M. and Risius, A. (2020) Perceptions of antibiotic use in livestock farming in Germany, Italy and the United States. *Livest. Sci*., 241(3): 104251.
41. Georgakakos, C.B., Hicks, B.J. and Walter, M.T. (2021) Farmer perceptions of dairy farm antibiotic use and transport pathways as determinants of contaminant loads to the environment. *J. Environ. Manage*., 281: 111880.
42. Borrajo, P., Karwowska, M. and Lorenzo, J.M. (2022) The effect of *Salvia hispanica* and *Nigella sativa* seed on the volatile profile and sensory parameters related to volatile compounds of dry fermented sausage. *Molecules*, 27(3): 652.
43. Bengtsson-Palme, J. and Larsson, D.G. (2016) Concentrations of antibiotics predicted to select for resistant bacteria: Proposed limits for environmental regulation. *Environ. Int.*, 86: 140–149.
44. Dahms, C., Hübner, N.O., Kossow, A., Mellmann, A., Dittmann, K. and Kramer, A. (2015) Occurrence of ESBL-producing *Escherichia coli* in livestock and farm workers in Mecklenburg-Western Pomerania, Germany. *PLoS One*, 10(11): e0143326.
45. Aworh, M.K., Ekeng, E., Nilsson, P., Egyir, B., Owusu-Nyantakyi, C. and Hendriksen, R.S. (2022). Extended-spectrum ß-lactamase-producing *Escherichia coli* among humans, beef cattle, and abattoir environments in Nigeria. *Front. Cell Infect. Microbiol*., 12: 869314.

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