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ORIGINAL ARTICLE

Antibiotic use among beef cattle farmers in feedlots in Querétaro, Mexico

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Abstract The appropriate and rational use of antibiotics for the treatment and prevention of infectious diseases in animal, human, and environmental health contributes to reducing antimicrobial resistance within the framework of the ''One Health'' approach. Our aim was to identify the practices involved in the use and management of antibiotics on beef cattle farms in Querétaro, Mexico. A cross-sectional study involving 21 beef cattle farmers in feedlots surveyed in the municipality of Ezequiel Montes, Querétaro, was conducted between April and May 2025. Farmers were selected using respondent-driven sampling (RDS). The first participants of the target population were recruited on a convenience basis. A face-to-face survey was implemented, structured into five sections: (i) beef cattle farmers' profile, (ii) characteristics of the feedlot systems, (iii) antibiotic use, (iv) antibiotic prescription, and (v) inventory of stored antibiotic vials. The collected data were processed by performing a descriptive analysis of the variables. All surveyed beef cattle farmers were male, with an age range of 23–63 years (median 40; IQR 33–51.5). Forty-three percent of the beef cattle farmers had only a basic level of schooling. The animal census consisted of 30 574 animals. In 19 of the 21 feedlot systems the veterinarian decided which antibiotics to buy, although all of them reported purchasing antibiotics without a prescription. Farmers recognized that pneumonia is the leading cause of morbidity and mortality in feedlot cattle. A total of 335 stored antibacterial products from 20 antibiotic classes

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were recorded: enrofloxacin (20.3%), penicillin (13.7%), florfenicol (11.0%), oxytetracycline (10.7%), tilmicosin (9.6%), tulathromycin (8.7%), and gentamicin (7.5%). Approximately 11% of the stored antibiotics have a ''Watch'' classification in the World Health Organization (WHO) AWaRe tool. However, in the World Organization for Animal Health (WOAH) classification, all registered antibiotics were in the ''critically important antibiotic'' category. Antibiotics used in intensive animal production systems can exert selective pressure, leading to the development of resistant strains of commensal or pathogenic microorganisms that affect both animal and human health. Research and communication on the rational use of antibiotics between human and veterinary medicine are essential to reducing antimicrobial resistance within the framework of the ''One Health'' approach.

PALABRAS CLAVE
Antibióticos;
Resistencia antimicrobiana;
Bovinos carne;
Ganado;
Una Salud

Uso de antibióticos entre ganaderos de bovinos de carne en corral de engorda en Querétaro, México

Resumen El uso adecuado y racional de los antibióticos para el tratamiento y la prevención de enfermedades infecciosas en la salud animal, humana y ambiental contribuye a contener la resistencia a los antimicrobianos en el marco de Una Salud. Nuestro objetivo fue identificar las prácticas de uso y gestión de antibióticos en los sistemas de producción de ganado de carne en Querétaro, México. Estudio transversal con 21 ganaderos de ganado de carne en corrales de engorde encuestados en el municipio de Ezequiel Montes, Querétaro, entre abril-mayo de 2025. Los ganaderos fueron seleccionados mediante un muestreo impulsado por los encuestados (RDS). Los primeros miembros de la población objetivo fueron reclutados a conveniencia. Se aplicó una encuesta presencial, estructurada en cinco secciones: i) perfil de los ganaderos, ii) características de los sistemas animales, iii) uso de antibióticos, iv) prescripción de antibióticos y v) inventario de viales de antibióticos almacenados. Los datos recopilados se procesaron mediante un análisis descriptivo de las variables. Todos los encuestados fueron hombres, con rango de edad 23-63 años (mediana 40; IQR 33-51,5). El 43% de los ganaderos tenía un nivel de escolarización básico. El censo ganadero ascendía a 30,574 animales. En 19/21 sistemas el veterinario decide qué antibióticos comprar, aunque todos afirman comprar antibióticos sin receta. Los ganaderos reconocen que la neumonía es la principal causa de morbilidad y mortalidad en el ganado. Se registraron un total de 335 productos antibióticos almacenados de 20 clases: enrofloxacina (20,3%), penicilina (13,7%), florfenicol (11,0%), oxitetraciclina (10,7%), tilmicosina (9,6%), tulatromicina (8,7%) y gentamicina (7,5%). Aproximadamente el 11% de los antibióticos almacenados tuvieron una clasificación de «vigilancia» en la herramienta AWaRe de la Organización Mundial de Salud (OMS). Sin embargo, en la clasificación de la Organización Mundial de Sanidad Animal (OMSA), todos los antibióticos registrados se encontraban en la categoría de «antibióticos de importancia crítica». Los antibióticos utilizados en los sistemas de producción animal pueden ejercer una presión selectiva y conducir al desarrollo de cepas resistentes que afectan la salud animal y humana. La investigación y la comunicación sobre el uso racional de los antibióticos son esenciales para contener la resistencia a los antimicrobianos en el marco de Una Salud.

Introduction

Antimicrobial resistance (AMR) is a complex and critical issue for global public health. This phenomenon occurs naturally. However, the use of antibiotics exerts selective pressure, increasing the emergence of resistance[14,37,41]. The use of antibiotics in animals, humans, and the environment constitutes a pivotal element in the proliferation of resistant microorganisms, which in turn can cause infections that are difficult to treat. The integration of diverse sectors and disciplines under the ''One Health'' approach is proposed as a vital solution to address the complex public health challenges facing our society, including antimicrobial resistance. To prevent, detect, and respond to new health challenges, it is essential that all involved sectors collaborate to achieve what no single sector can accomplish e alone. This collaboration should lead to the establishment of new methods for the surveillance and control of infectious diseases[36,38].

The World Health Organization (WHO), the World Organization for Animal Health (WOAH), the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Environment Program (UNEP) are collaborating on strategies to address this issue[13,26,27]. These strategies include the regulation of antibiotic use and the surveillance of bacteria in human, animal, and environmental health. As part of its strategic initiatives, the WOAH has developed a comprehensive list of antimicrobial agents considered essential for veterinary medicine[42]. This endeavor has involved a meticulous evaluation of the diverse classes of antibiotics utilized in food-producing animals, encompassing categories such as: *Critically Important Antimicrobial Agents (VCIA), Highly Important Antimicrobial Agents (VHIA)* and *Important Antimicrobial Agents (VIA)*[42]. In the field of human health, the WHO Advisory Group on Integrated Surveillance of Antimicrobial Resistance (AGISAR) is responsible for periodically reviewing and updating the WHO list of antimicrobials of critical importance to human medicine[40]. The development of the AWaRe (Access, Watch, and Reserve) classification was initiated with the objective of monitoring antibiotic consumption, establishing targets, and assessing the impact of management policies aimed at optimizing antibiotic use and containing antimicrobial resistance at the local, national, and global levels[39].

It has been documented that the use of antibiotics in intensive animal production systems exerts selective pressure, promoting the emergence of resistant strains of both commensal and pathogenic microorganisms, thereby posing a significant threat to animal and human health[23]. Different studies have demonstrated that antibiotic consumption is higher in animal production than in human medicine, with most evidence derived from broiler chicken, pig, and cattle production systems[22,34,35]. In 2024, the WOAH published specific data on global antibiotic use adjusted for animal biomass, estimating that the total amount of antibiotics intended for use in animals ranged from 81 084 to 88 927 tons. Among these, tetracycline and penicillin were identified as the most widely used antibiotics in animal health worldwide[28].

The predominant animal species used for food production as sources of animal protein include cattle, pigs, poultry, and fish. Notably, cattle constitute the primary population in which antibiotics are administered for prophylaxis, treatment, or as growth promoters, practices that contribute to the rise and spread of antimicrobial resistance[1,9,28]. In 2020, the state of Querétaro reported an inventory of 229 248 feeder cattle, with a production of 34 426 tons of beef. In the same year, the municipality of Ezequiel Montes reported an inventory of 85 262 cattle for fattening, representing approximately 35% of the state's total inventory[20]. Although the use of antibiotics in food-producing animals has clear implications for human health, its full scope and impact remain inadequately characterized. This is mainly due to conflicting concerns among the parties involved and the scarcity of research conducted to date. In this sense, this study aimed to identify the practices involved in the use and management of antibiotics in beef cattle farms in Querétaro, Mexico.

Material and methods

A cross-sectional study was conducted between April and May, 2025, with 21 beef cattle farmers from feedlots located in the municipality of Ezequiel Montes, Querétaro (Fig. 1). Farmers were selected using respondent-driven sampling (RDS). First, we recruited a few members of the target population (those involved in beef cattle production) on a convenience basis. The underlying principle of RDS is that each respondent recommends new subjects for inclusion in the sample[29]. Data were collected through face-to-face surveys to obtain pertinent information.

The survey was structured into five sections: (1) beef cattle farmers' profile, (2) characteristics of the feedlots systems, (3) antibiotic use, (4) antibiotic prescription, and (5) inventory of stored antibiotic vials. Furthermore, the survey encompassed a range of characteristics relevant to the animals in production, including the total herd size, sex distribution, and breed composition. The questionnaire was derived from previously validated studies by Galarde et al.[16], which were modified and piloted to fit the objectives of the present study.

Data analysis

A descriptive analysis of the variables of interest was performed using the median and interquartile range (IQR), as well as the standard error of proportion and 95% confidence intervals (95% CI). The data analysis was conducted using the statistical software program STATA (v.15, StataCorp, College Station, TX)[33].

The ''free list technique'' was employed to analyze the open-ended questions. This technique facilitates the identification, specification, and prioritization of the pertinent elements in the conceptualization of specific cultural domains. It calculates the frequency with which an item appears and the relative position in which it is remembered. Additionally, it utilizes Smith's salience index (*S*) using the Visual Anthropac (v. 1.0.1.36) software[2].

Results

A total of 21 surveys were obtained from beef cattle farmers, all of whom were male. Farmers' ages ranged from 23 to 66 years (median 40; interquartile range [IQR] 33–51.5). Forty-two percent of the farmers had a basic education, which included primary and secondary school, as their highest level of formal education. The main sales destinations for these animals were national markets, accounting for 95.2% of total sales. Ninety-five percent (n = 20/21) of farmers sell their animals outside the state. It is advisable for all beef cattle farmers to utilize the services of a veterinarian. Worm control activities are a standard practice in all feedlots, yet 80% of these facilities did not implement good livestock practices or the implementation of animal welfare programs (Table 1). The animal census included 30 574 beef cattle (median 1456, range 74–5000), of which 78.4% were bulls. Most of the animals (94%) were crossbred.

Ninety percent of the beef cattle farmers reported that veterinarians were responsible for deciding which antibi-

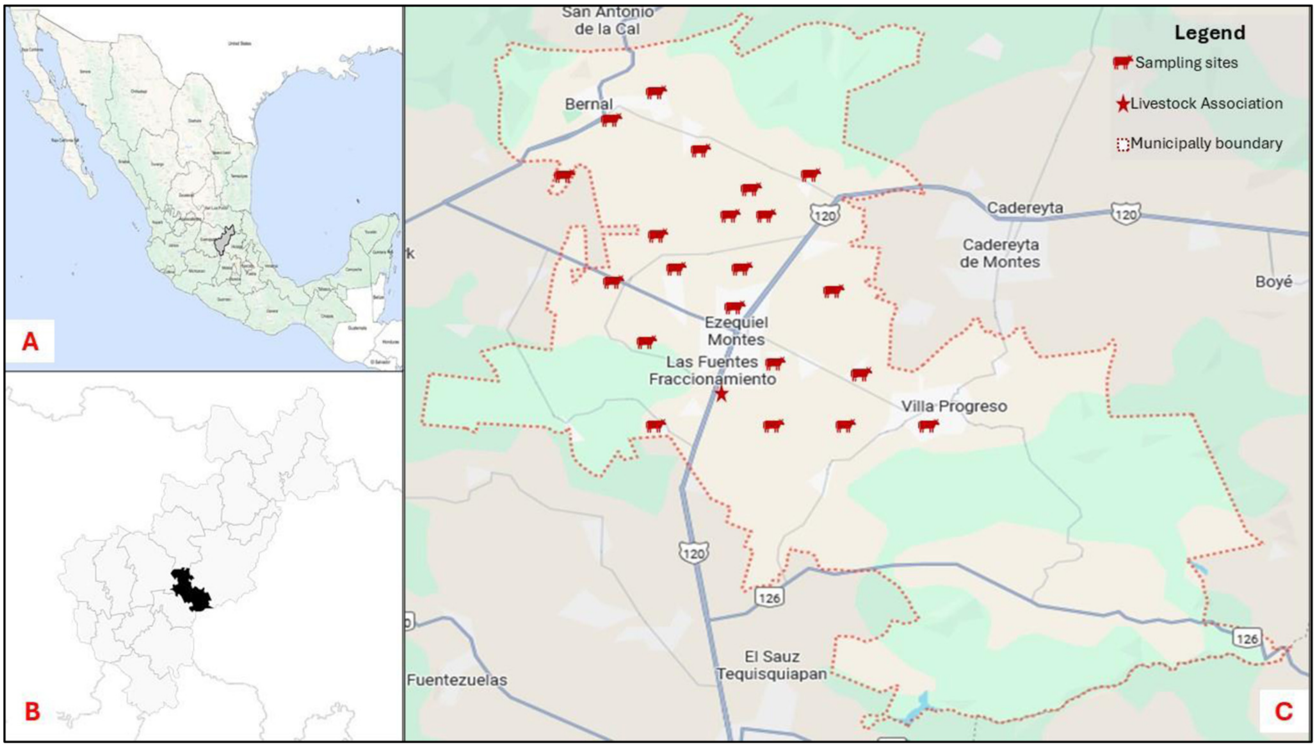

Figure 1 Geographical location of the study site. (A) Mexico, (B) Querétaro State, and (C) municipality of Ezequiel Montes.

otics to purchase. Sixty-two percent of the participants stated that a broad spectrum profile was a defining characteristic in selecting and purchasing antibiotics. The local livestock association in Ezequiel Montes was the main site for buying antibiotics for 66% of the farmers. All the participants reported that intramuscular injection was the main route of antibiotic administration. Consistent with statements about antibiotic use, 85.7% of beef cattle farmers said that ''saving and prolonging the lives of animals'' was the main reason for using antibiotics (Table 2).

All the beef cattle farmers mentioned that they purchased antibiotics without a prescription. Twenty-eight percent said that they could still buy antibiotics even if veterinary prescriptions were mandatory. Forty-three percent of the beef cattle farmers reported that a veterinarian administered antibiotics to livestock, while 57% reported that another person trained by a veterinarian administers them. Seventy-one percent of the beef cattle farmers did not administer antibiotics in feed. Conversely, 28% of the beef cattle farmers reported not administering antibiotics in the water. All the beef cattle farmers indicated that the withdrawal period was longer than 14 days after administration of the antibiotics. Additionally, 66.6% of the beef cattle farmers disposed of empty antibiotic vials in the trash. Only 19% reported having a protocol for antibiotic use, 42% mentioned having an antibiotic inventory and 80% reported using records. All the beef cattle farmers estimated the animals' body weights based on their experience, chose antibiotic dosages according to the antibiotics' labels, did not request laboratory tests, and believed that ''*diseases would increase*'' if antibiotics were no longer used. Eighty-five percent of the beef cattle farmers stated that a veterinarian determined the duration of the antibiotic treatment and did not perform necropsies on the animals to determine the cause of death (Table 2).

Based on the cultural domains of livestock farmers concerning the causes of morbidity and mortality in beef cattle, ten causes of morbidity and four causes of mortality were identified (Table 3). In both cases, pneumonia ($S = 0.9$) was identified as the primary cause of morbidity and mortality in animal production systems.

Regarding the main antibiotics reported to be used for the treatment of digestive and respiratory infections, eight and seven antibiotics were identified, respectively, as shown in Table 3. Penicillin and gentamicin ($S = 0.8$) were recognized as the most representative antibiotics for treating digestive infections. Enrofloxacin ($S = 0.6$), on the other hand, was recognized as the main antibiotic for treating respiratory infections in animal production systems.

Of the beef cattle farmers surveyed, 20 reported having at least one sick animal, whose medical records could be reviewed. Upon reviewing the animals' clinical records, it was observed that 18 of the 20 records reported respiratory infections as the reason for antibiotic use. However, no presumptive diagnosis of disease was described for 15 of the animals. Ninety percent of the treatments were administered by a veterinarian. Additionally, all prescribed treatments included the start and final date of treatment, the active substance of the antibiotics, the dosage in milligrams per kilogram, and their route of administration (intramuscular). However, no animals were selected for an antibiogram (Table 4).

When conducting the survey, the interviewer made an inventory of the antibiotics, counting a total of 335 vials across the 21 beef cattle production systems, and 18 different active antibiotic substances were identified. The most

Table 1 Characteristics of beef cattle farmers in feedlots.

Variables	Beef cattle farmers n = 21 (%)	±SE*	95% CI**
Sex			
Female	0 (0.0)	–	–
Male	21 (100.0)	0.0	–
Age (years)			
Median (IQR)	40 (33–51.5)	2.5	36.4–46.9
Highest level of education completed			
Primary education	5 (23.8)	9.5	9.4–48.3
Secondary education	4 (19.0)	8.7	6.6–43.5
Medium education	6 (28.5)	10.1	12.4–52.9
Higher education	6 (28.5)	10.1	12.4–52.9
Destination of production			
Self-consumption	0 (0.0)	–	–
Local sale	1 (4.7)	4.7	0.5–30.8
National sale	20 (95.2)	4.7	69.1–99.4
Veterinary assistance			
Yes, always	21 (100.0)	0.0	–
Only when necessary	0 (0.0)	–	–
No	0 (0.0)	–	
Parasite control			
Yes	21 (100.0)	0.0	–
No	0 (0.0)	–	–
Disinfection of pens			
Yes	19 (90.4)	6.5	65.9–97.8
No	2 (9.5)	6.5	2.1–34.0
Participation in good farming practices programs			
Yes	2 (9.5)	6.5	2.1–34.0
No	17 (80.9)	8.7	56.4–93.3
Does not know	2 (9.5)	6.5	2.1–34.0
Participation in animal welfare programs			
Yes	2 (9.5)	6.5	2.1–34.0
No	17 (80.9)	8.7	56.4–93.3
Does not know	2 (9.5)	6.5	2.1–34.0

* Standard error of proportion.
** 95% confidence interval.

prevalent antibiotics were enrofloxacin (20.3%), penicillin (13.7%), florfenicol (11%), oxytetracycline (10.7%), tilmicosin (9.6%), tulathromycin (8.7%), and gentamicin (7.5%). The remains of the vials contained combinations of antibiotics. On average, producers had up to 16 antibiotics in stock. It should be noted that nine vials had expired, and the expiration date of another 26 could not be determined. According to the WHO's AWaRe surveillance tool, six of the 18 types of antibiotics used in the beef cattle production systems in feedlots were classified as ''Access'', two were classified as ''Watch'', and ten were not classified because they were not intended for human use. Conversely, based on the WOAH classification for antimicrobials of veterinary importance, all the antibiotics belonged to the Critically Important Antimicrobial Agents (VCIA) category (Fig. 2).

Discussion

This study examined patterns of antibiotic use, antibiotic administration practices, antibiotics used, and the most common diseases in feedlot beef cattle production systems within the municipality of Ezequiel Montes in the state of Querétaro, Mexico. Our research found that all the farmers were male, with a median age of 40 years, and had an above-basic educational level, as nearly 60% had an upper secondary or higher education. These results are comparable to those of a 2023 study conducted in Kenya[21], which reported that 77% of producers were male in semi-intensive production systems. In contrast, a study of small-scale cattle farmers in rural areas in Querétaro, Mexico, found a 92% male population with a median age of

Table 2 Statements addressing antibiotic use.

Statement	Beef cattle farmers n = 21 (%)	±SE*	95% CI**
Who decides to purchase antibiotics?			
Owner	2 (9.5)	6.5	2.1–34.0
Veterinarian	19 (90.4)	6.5	65.9–97.8
Characteristics that define the selection and purchase of antibiotics			
Active substance	0 (0.0)	–	6.6–43.5
Trade name	4 (19.0)	8.7	38.3–80.9
Broad-spectrum activity	13 (61.9)	10.8	2.1–34.0
Price	0 (0.0)	–	–
Administration route	2 (9.52)	6.5	2.1–34.0
Veterinary advice	2 (9.52)	6.5	2.1–34.0
Place of antibiotic purchase			
Livestock association	14 (66.6)	10.5	42.6–84.3
Veterinary pharmacy	6 (28.5)	10.1	12.4–52.9
From a veterinarian	1 (4.7)	4.7	0.5–30.8
What is the main route of antibiotic administration in animals?			
Intramuscular	21 (100.0)	0.0	–
Oral	0 (0.0)	–	–
Which of the following do you consider the most important reason for using antibiotics?			
It is impossible to produce animals without antibiotics	0 (0.0)	–	–
To save and prolong the lives of animals	18 (85.7)	7.8	61.2–95.7
Antibiotics help to improve production	3 (14.2)	7.8	4.2–38.7
They are not important; it is possible to raise animals without using them	0 (0.0)	–	–
Do you buy antibiotics with a prescription?			
Yes	0 (0.0)	–	–
No	21 (100.0)	0.0	–
If antibiotics were only available by prescription, could you buy them over the counter anywhere?			
Yes	6 (28.5)	10.1	12.4–52.9
No	15 (71.4)	10.1	47.0–87.5
Which of the following best describes who applied antibiotics to livestock?			
Applied by a veterinarian	9 (42.8)	11.0	22.6–65.8
Applied by any person according to veterinarian's instructions	12 (57.1)	11.0	34.1–77.3
Which of the following best describes the management of antibiotics during cattle feeding?			
It is not administered in the feed	15 (71.4)	10.1	47.0–87.5
It is administered in the feed to prevent disease (prophylaxis)	2 (9.5)	6.5	2.1–34.0
It is administered in the feed only when animals are sick	4 (19.0)	8.7	6.6–43.5
It is administered in the feed only as growth promoters	0 (0.0)	–	–
Which of the following best describes the management of antibiotics in drinking water?			
It is not administered in the water	6 (28.5)	10.1	12.4–52.9
It is administered in the water to prevent disease (prophylaxis)	7 (33.3)	10.5	15.6–57.3
It is administered in the water only when animals are sick	8 (38.1)	10.8	19.0–61.6
It is administered in the water only as growth promoters	0 (0.0)	–	–
What is the interval between the last administration of antibiotics to cattle and their sale?			
1–7 days	0 (0.0)	–	–
8–14 days	0 (0.0)	–	–
>14 days	21 (100.0)	0.0	–
Where do you dispose of used antibiotic vials?			
Trash	14 (66.6)	10.5	42.6–84.3
In a special container	4 (19.0)	8.7	6.6–43.5
Burn the vials	3 (14.2)	7.8	4.2–38.7
Protocols			
Yes	4 (19.0)	8.7	6.6–43.5
No	17 (80.9)	8.7	56.4–93.3

Table 2 (*Continued*)

Statement	Beef cattle farmers n = 21 (%)	±SE*	95% CI**
Inventories			
Yes	9 (42.8)	11.0	22.6–65.8
No	12 (57.1)	11.0	34.1–77.3
Records			
Yes	17 (80.9)	8.7	56.4–93.3
No	4 (19.0)	8.7	6.6–43.5
How do you estimate the body weight of the animal?			
Based on your own experience	21 (100.0)	0.0	–
Based on the veterinarian's experience	0 (0.0)	–	–
With a scale	0 (0.0)	–	–
How is the antibiotic dose calculated?			
Based on product label (ml/kg)	21 (100.0)	0.0	–
Based on active product (mg/kg)	0 (0.0)	–	–
Who decides the duration of the treatment?			
I decide the duration of treatment	2 (9.5)	6.5	2.1–34.0
Following veterinarian's instructions	18 (85.7)	7.8	61.2–95.7
Following label instructions	1 (4.7)	4.7	0.5 -30.8
Who decides if a second antibiotic is used?			
Veterinarian's indication	14 (66.6)	10.5	42.6–84.3
Based on previous results	7 (33.3)	10.5	15.6–57.3
Is a laboratory test carried out on sick animals?			
Yes	0 (0.0)	–	–
No	21 (100.0)	0.0	–
Have you requested necropsies of the dead animals?			
Yes	3 (14.2)	7.8	4.2–38.7
No	18 (85.7)	7.8	61.2–95.7
What would happen if you stopped using antibiotics?			
Nothing would happen	0 (0.0)	–	–
Diseases would increase	21 (100.0)	0.0	–
It would affect the quality of life of the animals	0 (0.0)	–	–
Decrease animal growth or production	0 (0.0)	–	–

* Standard error of proportion.
** 95% confidence interval.

58.5 years and an educational level close to basic education (74%)[16]. The higher educational level observed among farmers in intensive feedlot systems may have contributed to a better understanding of management practices and veterinary recommendations. However, without adequate technical training, this does not necessarily translate into the rational use of antibiotics. For example, in our study 90% of the farmers reported consulting a veterinarian before administering antibiotics; nevertheless, the recommendations were not based on microbiological testing. Conversely, livestock producers have been reported to seek veterinary advice at rates of 61.2% in Kenya[21], and 52.7% in Ethiopia[17]. Producers have even been known to use antibiotics they had in stock to treat sick animals before consulting a veterinarian. The lack of laboratory tests to guide treatment decisions fosters empirical antibiotic use and contributes to their misuse and overuse, further exacerbating the risk of AMR.

Our results showed that more than 90% of the meat produced from the animals raised by the surveyed farmers is destined to Mexico City for human consumption. This pattern aligns with Van Boeckel's (2015) projections, which suggest that the intensification and integration of supply chains toward large urban centers is common and will further drive antibiotic use to sustain productivity and mitigate losses in conditions of high animal density[35]. Given the magnitude of this market and its link to a major metropolitan population, ensuring the rational use of antibiotics in this livestock production system is critical to reduce the public health risk of AMR[22,32].

In terms of antibiotic use patterns, we found that the main sources of antibiotics in beef cattle production systems in Ezequiel Montes feedlots are the livestock association (>60%) and veterinary pharmacies (about 30%). The livestock association represents cattle farmers who sell medicines and other related supplies without examining the cattle.

Table 3 Main causes of morbidity and mortality in cattle and main antibiotics used for treating digestive and respiratory infection according to the cultural domains of beef cattle farmers.

Causes	Morbidity			Mortality		
	Frequency (%)	Average rank	Smith's index	Frequency (%)	Average rank	Smith's index
Pneumonia	100.0	1.0	0.9	95.2	1.0	0.9
Diarrhea	19.0	2.0	0.1	9.5	2.0	0.0
Piroplasmosis	14.3	1.6	0.1	–	–	–
Clostridium	9.5	3.0	0.0	–	–	–
Anaplasmosis	9.5	3.0	0.0	–	–	–
Tympanism	4.8	2.0	0.0	4.8	2.0	0.0
Trauma	4.8	2.0	0.0	9.5	1.0	0.0
Ruminal Acidosis	4.8	2.0	0.0	–	–	–
Ticks	4.8	2.0	0.0	–	–	–
Shipping fever	4.8	3.0	0.0	–	–	–

Antibiotics	Digestive infection			Respiratory infection		
	Frequency (%)	Average rank	Smith's index	Frequency (%)	Average rank	Smith's index
Penicillin	95.2	1.3	0.8	33.3	1.7	0.2
Gentamicin	23.8	1.8	0.8	–	–	-
Oxytetracycline	9.5	1.8	0.1	14.3	2.0	0.0
Enrofloxacin	9.5	1.5	0.0	85.7	1.7	0.6
Sulfonamides	4.8	1.0	0.0	–	–	-
Tilmicosin	4.8	2.0	0.0	28.6	2.1	0.1
Florfenicol	4.8	1.0	0.0	52.4	1.8	0.3
Tulathromycin	–	–	–	42.9	2.2	0.2
Marbofloxacin	–	–	–	4.8	2.0	0.0
Sulfamethoxazole/trimethoprim	4.8	1.0	0.0	–	–	-

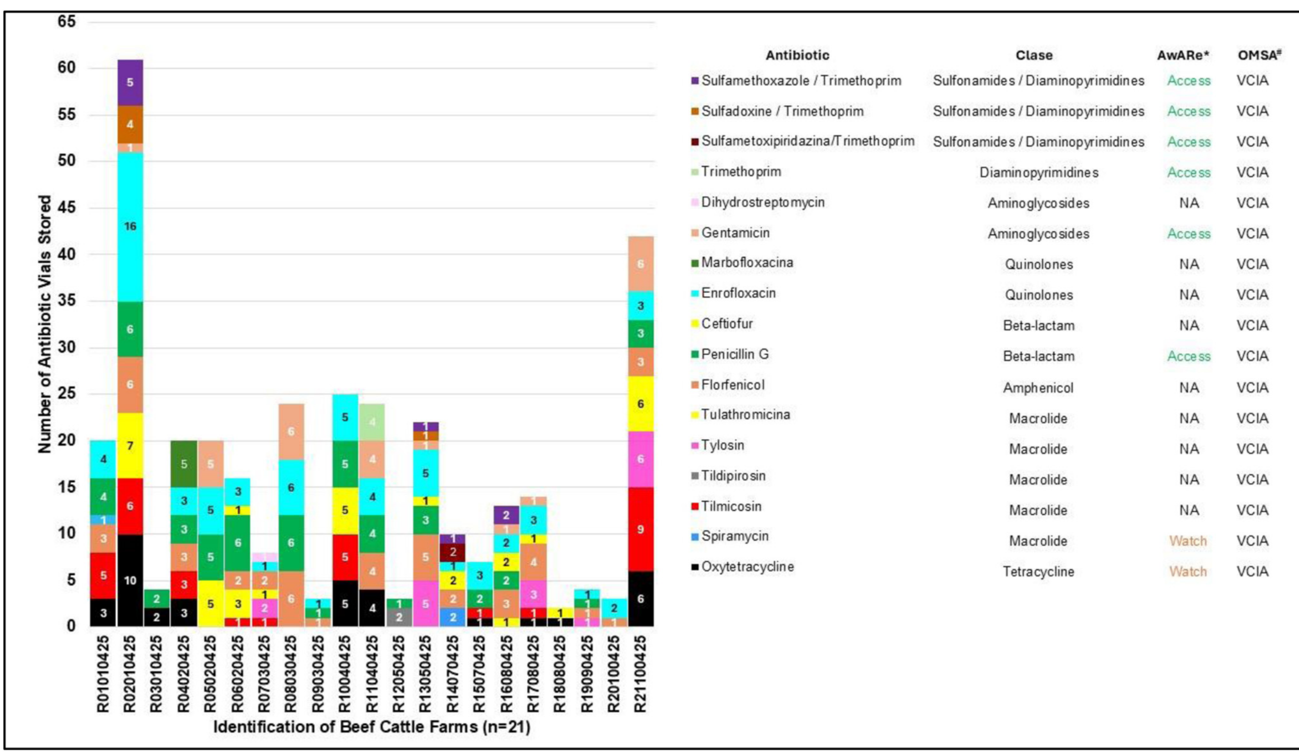

Figure 2 Antibiotic vials stored by beef cattle farmers for use in their animals. *AWaRe classification: acronym refers to the WHO's Access-Watch-Reserve classification. NA: classification not applicable[39]. ** WOAH classification: acronym refers to Critically Important Antimicrobial Agents (VCIA), Highly Important Antimicrobial Agents (VHIA) and Important Antimicrobial Agents (VIA)[42].

Table 4 Antibiotic prescription in clinical records.

Statement	Feed cattle farmers n = 20 (%)	±SE*	95% CI**
What is the main reason for the administration of antibiotics?			
Respiratory infection	18 (90.0)	6.8	64.4–97.8
Digestive infection	0 (0.0)	–	–
Injuries	2 (10.0)	6.8	2.1–35.5
Was a presumptive diagnosis of the disease made?			
Yes	5 (25.0)	9.9	9.9–50.2
No	15 (75.0)	9.9	49.7–90.1
Who prescribes the administered antibiotics?			
Veterinary	18 (90.0)	6.8	64.4–97.8
Other	2 (10.0)	6.8	2.1–35.5
Are the start and end dates of the antibiotic treatment described?			
Yes	20 (100.0)	0.0	–
No	0 (0.0)	–	–
Is the antibiotic described by its trade name or active substance?			
Trade name	0 (0.0)	–	–
Active substance	20 (100.0)	0.0	–
How is the antibiotic dose described?			
ml/kg	0 (0.0)	–	–
mg/kg	20 (100.0)	0.0	–
What route of administration is described?			
Oral	0 (0.0)	–	–
Intramuscular	20 (100.0)	0.0	–
Has an antibiogram test been performed?			
Yes	0 (0.0)	–	–
No	20 (100.0)	0.0	–

* Standard error of proportion.
** 95% confidence interval.

Additionally, the typical antibiotic usage pattern involved preventive measures, with over 30% of the farmers administering antibiotics in the water for prophylaxis, in addition to routine intramuscular injections for treatment or metaphylactic purposes. Our data differ from those of a 2023 study conducted in Kenya[21], in which 77% of the farmers purchased antibiotics from veterinary pharmacies, with 43.9% using them for prophylactic purposes. A study in Argentina found that antibiotic use for prophylaxis was higher than in our study (72.9%)[4]. The use of antibiotics in livestock water is primarily intended to treat, control, and prevent bacterial diseases, contributing to animal health and welfare, food safety, and the protection of livestock from disease outbreaks. However, their indiscriminate use poses serious risks, such as AMR, which hinders the treatment of infections in humans and animals, and causes environmental contamination, which affects public health and the environment[27].

In the present study, it was observed that beef cattle farmers in Ezequiel Montes utilized antibiotics to treat a wide range of diseases in accordance with veterinarians' recommendations, given the absence of confirmatory diagnostic tests, the perception of prevalent diseases (pneumonia), and the purchase of antibiotics without a prescription. This finding suggests a high proportion of empirical treatments. This use of antibiotics for infectious agents other than bacteria aligns with findings on antibiotic selection preferences among cattle farmers in northern Tanzania (2023)[24]. It was documented that farmers primarily purchased antibiotics from veterinary stores based on preference, independently of the type of disease.

Current Mexican legislation (NOM-064-Z00-2000) regarding the prescription and sale of antibiotics in the agricultural sector includes an agreement that establishes the classification and prescription of veterinary pharmaceutical products by a veterinarian[8,30]. However, supervision by health authorities is being adjusted and updated. Therefore, regulation of prescription antibiotics could reduce their indiscriminate use in this sector, which would significantly impact AMR. However, our results showed that antibiotics were being sold without a prescription. In Ezequiel Montes, all the surveyed farmers purchased antibiotics without a prescription, and nearly 30% admitted that they could obtain antibiotics without a prescription, even when a prescription was required. Additionally, only about 20% of the producers surveyed had formal protocols (documents containing guidelines and recommendations on when to use antibiotics, which antibiotic to use, for which diseases, the dosage, duration of treatment, and route of administration) for using antibiotics. Similarly, Nthambi et al.[24] mentioned in their study that, unlike developed countries, in low-and middle-income countries there are no strict regulations for the purchase of prescription antibiotics, as their study showed that producers preferred to buy antibiotics in agricultural stores because a prior medical consultation with a professional is not normally required, making these stores the main channels for the supply of antibiotics, selling them without prescriptions or instructions for use and facilitating administration without formal protocols. This same behavior of acquiring antibiotics by bypassing regulations occurs in the veterinary field in Mexico, as demonstrated by the results of our study, unlike the use of antibiotics, which is more strictly regulated in our country.

Beef cattle production systems in Ezequiel Montes feedlots showed high adherence to veterinary instructions regarding the duration of antibiotic treatment. More than 85% of the farmers followed the prescribed treatment length, whereas fewer than 10% determined the duration on their own, and about 5% stopped treatment once clinical improvement was observed. This level of compliance is consistent with a study conducted in Tequisquiapan, Querétaro, in which 86% of small-scale cattle farmers reported that they followed the recommended treatment duration guidelines, but only 76% respected the 15-day minimum period.[16] A study on cattle production systems in Ethiopia (2023)[17], found that when asked if they agreed that antibiotic withdrawal periods should be followed to avoid residues in meat or animal products, 56% of the farmers agreed. However, only 48.4% of farmers complied with these periods before sending animals to slaughter. Regarding antibiotic prescription duration, 50.5% of beef cattle farmers said they would suspend treatment if they observed improvement in the animals from the first day after treatment. Additionally, 46.2% stated that they would increase the dose and frequency of antibiotics if the animals showed no signs of recovery. These results suggest that, despite being aware of the withdrawal periods for medications, adherence to these practices is uncommon; some studies have shown that the main cause of antibiotic residues in food of animal origin is failure to comply with antibiotic withdrawal periods in different animal production systems[3,5].

With regard to the disposal of antibiotic vials, more than 60% of beef cattle production systems in Ezequiel Montes's feedlot discarded them in the trash, posing an environmental risk. A study conducted in southern Brazil reported that approximately 79.7% of farmers had not received information for the appropriate disposal of antibiotic containers, with most of them throwing glass and plastic vials into household trash (31–38%)[25]. The same study also found that 16.2% of farmers buried the glass bottles, and between 9.4% and 25.6% burned glass and plastic waste after finishing treatment. Van Boeckel (2015) highlights the global concern related to the mismanagement of antibiotic waste in animal production and the cycle of resistance that results from contaminating water bodies or soil[35]. When antibiotics reach the soil, they can contaminate water bodies and crops, which can cause bacteria present in these environments to become resistant to antibiotics, creating a serious public health problem. Antibiotic residues are chemically stable and are not eliminated in wastewater treatment processes, which can negatively affect human, animal, and environmental health[38].

In Mexico, expired antibiotics used in human medicine must be disposed of in special collection containers located in pharmacies or health centers. Once collected, the waste is destroyed using thermal processes in cement kilns. All these activities are carried out within the framework of a Management Plan registered with the Ministry of the Environment and Natural Resources (SEMARNAT). Ideally, these same systems for collecting waste antibiotics for human use could also be used to dispose of waste antibiotics generated in veterinary medicine, directing this effort towards better management in the veterinary field[8].

The inventory of antibiotic vials revealed a significant presence of broad-spectrum antibiotics that are crucial for veterinary medicine. Of the 335 vials identified, seven antibiotics were found to be the most common, including enrofloxacin, penicillin, oxytetracycline, and gentamicin. This pattern partially coincides with inventories from small-scale cattle farms in Tequisquiapan, where penicillin (34%), oxytetracycline (19%), gentamicin (13%), florfenicol (10%), and enrofloxacin (8%) were predominant[16]. Kisoo et al. (2023) reported that oxytetracycline was the most reported antibiotic in Kenyan production systems, followed by penicillin and streptomycin. Together, these three antibiotics accounted for 81% of all antibiotics reported[21]. In cattle production pens in Argentina, Bedford et al. (2024)[4], reported that macrolides were used most frequently (76.3%). The results of our study coincide with those reported in the latest WOAH report, which found that the most commonly used antibiotic classes in food-producing animals were tetracyclines (36.8%), beta-lactams (14.2%), and macrolides (11.1%)[28].

The antibiotics, such as enrofloxacin, florfenicol, tilmicosin, tulatromycin, marbofloxacin and tildipirosin, used in cattle production at the Ezequiel Montes feedlot are not classified in the WHO AWaRe tool because they are exclusively for human use[39]. These antibiotics are considered by the WOAH to be Veterinary Critically Important Antimicrobial Agents, and by the European Medicines Agency (EMA) to be in Category B (restrict) and Category C (caution)[6,11,42]. The EMA guidelines were developed due to the potential for cross-resistance between veterinary and human medicines. The guidelines define criteria and procedures for designating antibiotics (or groups of antibiotics) that should be reserved exclusively for treating certain human infections. They also offer recommendations and list of molecules, classes, and compounds, whose use in veterinary medicine should be restricted or prohibited to preserve their effectiveness in human medicine[10].

Enrofloxacin, a fluoroquinolone partially metabolized into ciprofloxacin (a first-line antibiotic in human medicine), is of particular concern. The intensive use of enrofloxacin in animal production systems has been linked to the selection of resistant strains of *Campylobacter* and other enterobacteria. This means that resistance could lead to infections that are difficult to treat in the human population. Resistance to fluoroquinolones can be encoded in plasmids, which can easily facilitate transfer to other bacterial species[19]. Similarly, broad-spectrum macrolides[15], particularly tilmicosin and tulathromycin, share the same class as erythromycin and azithromycin for human use, despite not being included in the AWaRe tool[39]. This structural similarity could lead to cross-resistance, resulting in the emergence of bacteria that cause human infections and are resistant to a broad group of antibiotics, posing a risk for AMR[15,19,31,36].

Our results showed that all 18 antibiotics used in the beef cattle production systems at the Ezequiel Montes feedlot are classified as ''Veterinary Critically Important Antimicrobials'' for veterinary medicine, posing several challenges. First, dependence on critically important antibiotics increases selective pressure on bacterial populations in intensive production systems, favoring the emergence and spread of multidrug-resistant strains. Second, since many of these antibiotics are closely related to those used in human medicine, there is a risk of transferring cross-resistance that could compromise public health treatments[18,42].

However, a specific agent, class, or subclass may be deemed essential for treating a particular disease in each species. As indicated in the comments in the WOAH list, there are few or no alternatives for treating specific diseases in the target species with certain antimicrobial agents. In this context, special attention should be given to the use of critically and highly important veterinary antimicrobial agents[42]. Research and communication about the rational use of antibiotics between human and veterinary medicine are essential to reducing antimicrobial resistance from a One Health perspective. To address these challenges, a strategy combining the standardization and registration of antibiotic treatment protocols, mandatory veterinary prescriptions for their purchase, planned rotation of antibiotic classes to reduce the risk of resistance, and implementation of integrated surveillance systems including lists of important antimicrobial agents for veterinary medicine and the AWaRe tool is essential[39]. The interconnectedness between humans, animals (whether linked to production chains, companion animals, or wildlife), and environmental health underscores the importance of addressing AMR from a One Health perspective[7,13]. Crucially, AMR does not spread only via foodborne pathways, it also moves through occupational and direct-contact exposures along production chains and through environmental routes such as manure management, wastewater, and contaminated soil and water. Therefore, to mitigate antimicrobial resistance, the ''One Health'' approach is vital[12,38].

The limitations of this study is the sample size (n = 21 farmers) and the sampling method, as the participants were not recruited through random selection. However, its relevance lies in the fact that this type of production system concentrates many animals in a small space. The 30 574 animals raised at these sites represent almost 35% of the municipal animal census and 15% of the animal census of the state of Querétaro. However, the results are not representative at the national level and cannot be extrapolated to other livestock production systems in Mexico, such as extensive or semi-intensive systems. The implementation of this tool in other regions could facilitate the identification of potential variations in antibiotic utilization across diverse production systems, including extensive, semi-intensive, dual-purpose, and intensive systems. This approach would offer a more comprehensive perspective on the association between antibiotic use and livestock practices in the context of beef production.

Conclusions

This study aims to strengthen knowledge and scientific understanding by conducting surveillance and research on the use and storage of antibiotics in intensive production systems. It also highlights the frequent acquisition of antibiotics without a veterinary prescription and the prevalence of agents classified as critically important by the WOAH, as set out in the Global Action Plan to combat antimicrobial resistance. This evidence can inform the design of recommendations and policies that promote a more responsible and rational use of antibiotics in beef production, while ensuring the continued availability of last-resort drugs for treating diseases. Additionally, it shows that veterinary technical support remains insufficient for beef cattle farmers to promote responsible antibiotic use practices based on accurate diagnoses. Therefore, it is essential to regulate the sale of antibiotics by requiring a veterinary prescription. Without effective enforcement of the regulatory framework, antibiotics are dispensed indiscriminately, undermining efforts to monitor and control their responsible use in animal production. These findings are important because they offer insight into the technical, regulatory, and cultural factors that influence antibiotic use in intensive livestock farming. Notwithstanding the absence of national representativeness, the study establishes a fundamental starting point for future comparative research in other regions of the country.

CRediT authorship contribution statement

All authors have read and approved the final version of the manuscript, and they all declared that they have no competing interests.

Ethical considerations

This study was approved by the Research Ethics Committee of the National Institute of Public Health as No. Cl 1863. In addition, a signed informed consent was obtained from the farmers, who approved their participation.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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