South African Journal of Animal Science 2023, 53 (No. 6)

Knowledge, attitudes, and practices of farmers on antibiotic use, resistance, and stewardship in food animal production systems in KwaZulu-Natal, South Africa

L.T. Mokhutsoane & S.Y. Essack

Antimicrobial Research Unit, College of Health Science, University of KwaZulu-Natal, Durban, South Africa

(Submitted 28 March 2023; Accepted 7 September 2023; Published 27 November 2023)

Abstract

Non-therapeutic use of antibiotics for metaphylaxis, prophylaxis, and growth promotion in food animal production systems contributes to the emergence and spread of antibiotic resistance. Antibiotic resistance can subsequently be transmitted within and between animals, humans, and the environment and consequently lead to treatment failure in humans and animals at a later stage. A questionnaire-based, cross-sectional, online survey was conducted to assess farmers' knowledge, attitudes, and practices (KAP) on antibiotic use, resistance, and stewardship in food animal production systems in KwaZulu-Natal. The questionnaire was divided into four sections and information on the socio-demographic features and employment experience, in addition to knowledge, attitudes, and practices were collected. Data was entered in Microsoft Excel and analysed using Statistical Package for the Social Science (SPSS) with average scores $\geq$ 50% considered adequate. In total, 82 respondents were received, of which 66 complete questionnaires constituted the final sample. Fifty-five percent (55%) and 50% of farmers stated that antibiotic(s) were different to anti-inflammatory and anti-pyretic medicines, respectively, while 42% considered them identical. Thirty-six percent of farmers agreed that the ban of antibiotic use as growth promoters in animals will have a negative effect on livestock production, and 45% agreed that it is difficult to produce high-quality livestock products without antibiotics. There are gaps in the overall knowledge, attitudes, and practices of farmers that should be improved through programs such as awareness campaigns and education and training on antibiotic use, resistance, and stewardship.

Keywords: antibiotic resistance, antibiotic stewardship, attitudes, knowledge, practices

Corresponding author: Email: lefamokhutsoane@gmail.com

Introduction

Non-therapeutic use of antibiotics in food animal production systems is among the factors that contribute to the emergence and spread of antibiotic resistance (ABR) globally (Chapot *et al.*, 2021). Prudent therapeutic use of antibiotics is essential for farmers to treat active infections in herds or flocks. However, the use of a sub-therapeutic doses of antibiotics for non-therapeutic purposes such as metaphylaxis to prevent the spread of active infection in the herd, prophylaxis to prevent the emergence and spread of suspected infection in the herd, and growth promotion to improve growth and production of food animals to maintain production and economic gain, are factors that contribute to the development and spread of ABR, which consequently leads to treatment failure at a later stage (Nkansa *et al.*, 2020). Antibiotics are extensively used in food animal production systems to improve health, welfare, and growth especially in cattle, pigs, and poultry, which are the top three sources of meat (Page

URL: http://www.sasas.co.za
ISSN 0375-1589 (print), ISSN 2221-4062 (online)
Publisher: South African Society for Animal Science
http://dx.doi.org/10.4314/sajas.v53i6.05

& Gautier, 2012) and sources of income in food animal production systems globally (Kimera *et al.*, 2020). As the demand for food animal products increases, antibiotics in food animal production are estimated to increase by 67% between 2010 and 2030 worldwide to sustain livestock production (van Boeckel *et al.*, 2015). The consequent increase in ABR can be transmitted within and between animals, humans, and the environment through various routes, including the consumption of foodborne pathogens in food animal products or the consumption of water or vegetables contaminated by animal manure used as fertilizer (Lambrecht *et al.*, 2021).

Various stakeholders have been collaborating to prevent the development and spread of ABR in food animals. The World Health Organization Advisory Group on the Integrated Surveillance of Antimicrobial Resistance (AGISAR) aims to promote prudent use of antibiotics in food animals and monitor the development of ABR (World Health Organization (WHO), 2017). The Food and Agriculture Organization (FAO) of the United Nations in collaboration with WHO published a guideline for strengthening national food control with five pillars, i.e., law and regulations, food control management, inspection services, food monitoring, and epidemiological data, and communication, information, education, and training to ensure food safety and quality (FAO & WHO, 2016). The tripartite alliance including FAO, WHO, and World Organization for Animal Health (WOAH) has endorsed the One Health approach as the health of animals, humans, and the environment are interconnected and affected by the excessive use of antibiotics in food animal production systems. The tripartite also asserts that ABR can be prevented by the reduction in antibiotic use in food animals through various strategies, including good animal husbandry, hygiene, and sanitation (WHO, 2021).

Various stakeholders have been working on improving farmers' knowledge, attitudes, and practices (KAP) on antibiotic use, resistance, and stewardship through different coordinated programs, including awareness campaigns, education and training, and research (Kalam *et al.*, 2021). Farmers are owners or caretakers of food animals and are responsible for the procurement, storage, and administration of antibiotics on their farms (Rayner *et al.*, 2019). This use is influenced by their KAP on antibiotic use, resistance, and stewardship (Dyar *et al.*, 2020). Understanding farmers' KAP on antibiotic use, resistance, and stewardship plays a significant role in planning strategies, restrictions, regulations, and policies promoting prudent use of antibiotics to prevent the emergence of ABR in food animal production systems (Farrell *et al.*, 2021). The current study assessed farmers' KAP on antibiotic use, resistance, and stewardship in food animal production systems in KwaZulu-Natal (KZN).

Materials and Methods

Ethical approval was obtained from the Humanities and Social Sciences Research Ethics Committee (HSSREC) of University of KwaZulu-Natal (UKZN) (HSSREC/00000998/2020) prior to conducting of the study. Informed consent was provided by all participants who volunteered to participate with explicit, voluntary, informed consent.

This was a descriptive, questionnaire-based, quantitative, cross-sectional study of farmers (owners and managers) of intensive, extensive, and small-scale food animal production systems, who are members of different agricultural organizations in KwaZulu-Natal (KZN), i.e., the Red Meat Producers' Organization (RPO), Veterinary House Hospital, National Chicks and Mountain Valley, KZN Agricultural Union (Kwanalu), Milk Producers Organization (MPO), the KZN branch of the South African Poultry Association (SAPA), and the South African Pork Producers Organization (SAPPO). The survey was conducted from mid-October 2020 to mid-March 2021, with periodic reminders to potential participants via their organizations.

The data was collected using an online, self-administered questionnaire on Survey Monkey using the membership database of the agricultural associations mentioned above. The questionnaire was adapted from different studies (Visschers *et al.*, 2015; Di Martino *et al.*, 2018; Sadiq *et al.*, 2018), prepared in English and translated into Afrikaans and IsiZulu. It was piloted amongst a state veterinarian and a veterinary academic. The questionnaire consisted of opened-ended questions, allowing participants to answer questions using their own knowledge or opinions and closed-ended questions, where participants chose from the options provided. The questionnaire was divided into four sections based on the specific objectives of the study and obtained data on (1) demographic characteristics and employment experience, (2) knowledge, (3) attitudes, and (4) practices of farmers related to antibiotic use, resistance, and stewardship.

The total score for each KAP component was calculated and then divided by the total number of questions to yield an average score. Farmers were considered to have adequate KAP if the average

score was >50%. This translated to a score of 3.5, 3, and 8 for the knowledge, attitudes, and practices categories, respectively.

Data were entered on a Microsoft Excel spreadsheet and analysed using the commercial Statistical Package for Social Sciences (SPSS), version 27. Descriptive and inferential statistics were calculated (including the percentage); the 95% confidence interval was determined for all positive responses to questions. The chi square test was used to test the association between categorical variables versus KAP scores. All the tests were two-tailed and the criterion for statistical significance were set at 5%.

Results

In total, 82 responses were received, of which 66 were fully completed and constituted the final sample. Thirty-six percent of the respondents were farm owners, 50% of farmers had working experience of less than 20 years, 18% from 0–10 years, and 32% from 11–20 years of working experience; 38% of farmers reared more than 100 animals. Thirty-three percent of farmers reared their animals in extensive farming systems, where food animals are kept outside or in a limited shelter, 27% reared their animals in intensive farming systems, where food animals are kept in a purpose-built house or shelter, and 5% indicated other systems, including small-scale, family farming systems where food animals are kept in a homebase land or in the yard (Table 1). Farmers reared various food animals with cattle farmers making up the majority (Figure 1). Farmers used antibiotics for metaphylaxis (36%), prophylaxis (6%), and growth promotion.

Table 1 Selected socio-demographic characteristics and employment experience of farmers (n = 66)

Variables		**N**	**%**
Responsibility or position on the farm	Owner	24	36%
	Manager	18	27%
	Other	2	3%
	Not indicated	22	33%
Years of work experience in your responsibility or position	0-10	12	18%
	11-20	21	32%
	21-30	11	17%
	Not indicated	22	33%
Size of the farm in terms of the number of birds or animals reared	<100	18	27%
	>100	25	38%
	Not indicated	23	35%
How are your animals reared?	Extensive system	22	33%
	Intensive system	18	27%
	Other	3	5%
	Not indicated	23	35%

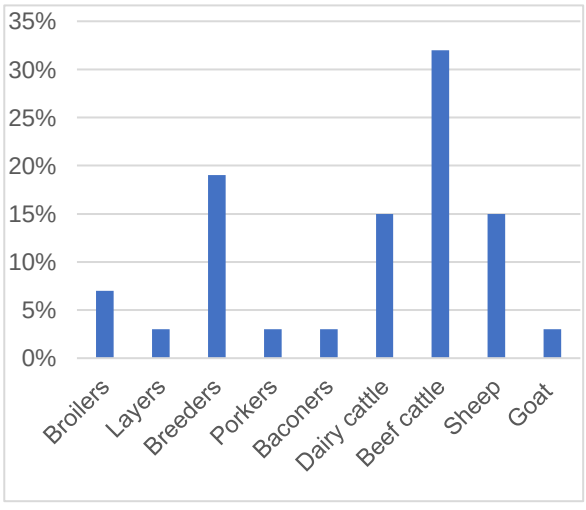

Figure 1: Food animals reared by farmers in KwaZulu-Natal

Knowledge

The majority of farmers had adequate knowledge on antibiotic use, resistance, and stewardship (Figure 2). Fifty-five percent and 50% stated that antibiotic(s) were different to anti-inflammatory and anti-pyretic medicines, respectively, while 3% considered them identical. Fifty-two percent of farmers stated that antibiotics should only be administered to sick animals, 3% stated that it was acceptable to use a lower or lesser dose of antibiotic than that prescribed by a veterinarian, 58% were aware of the correct dosage of antibiotics to be administered, whereas 50% were aware that antibiotics could have harmful effects on animals. Equal numbers of farmers (29% agreed and disagreed that antibiotics should be stopped as soon as the animals' condition improved, while 42% did not answer the question).

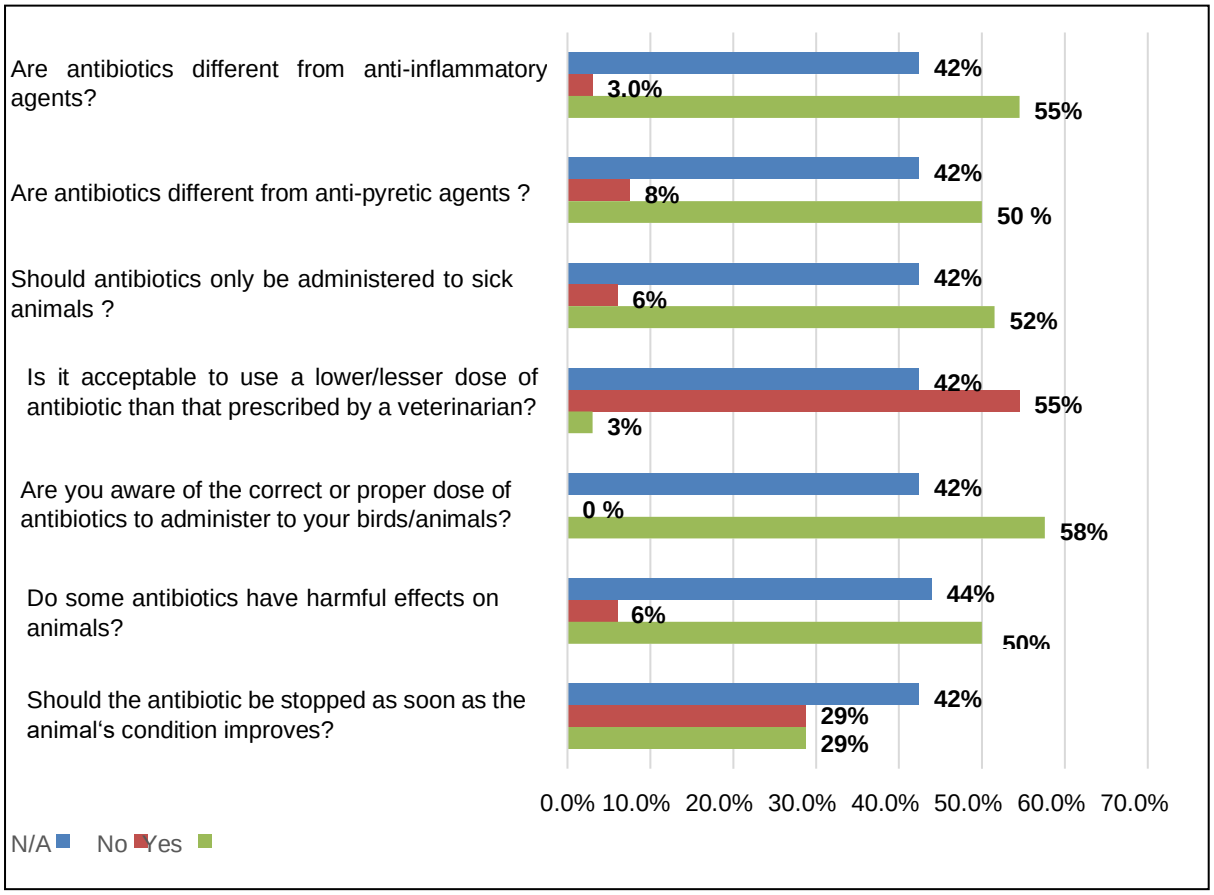

Figure 2: Farmers knowledge on antibiotic use

Farmers had different levels of knowledge on antibiotic use, resistance, and stewardship. Sixty-seven percent of farmers agreed that antibiotic resistance is one of the most challenging problems in livestock production, 81% agreed that antibiotics are not effective in humans because of their misuse and overuse in humans, 44% agreed that antibiotics are not effective in humans because of their misuse and overuse in animals, and 72% agreed that many common infectious diseases in human and animals will be incurable in the future because of antibiotic resistance.

Farmers used various antibiotics to treat possible infections based on their knowledge. For example, 8% used sulphamethazine to treat diarrhoea, tetracycline to treat fever, penicillin (Duplocillin) to treat urinary tract infection (UTI), and a fluoroquinolone (Entrovert) to treat respiratory tract infection; 3% used penicillin (Duplocillin) to treat skin infection and ecto-parasitic infections, and 3% used penicillin to treat parasitic gastroenteritis. Some farmers used antibiotic alternatives, such as antiprotozoal halofuginone, vitamins, and broccoli for diarrhoea; non-steroidal anti-inflammatory drugs (NSAID’s) and paracetamol for fever; Poulvac *E. coli* vaccine for UTI; NSAIDs for respiratory tract infections; antiseptics for skin conditions; anti-parasitics, such as ivermectin, for ecto-parasitic infections; and anti-parasitics in combination with antispasmodics for parasitic gastro-enteritis. Most farmers called on veterinarians to advise on treatment.

Attitudes

With respect to attitudes on antibiotic use, resistance, and stewardship (Table 2), 32% of farmers indicated that they kept antibiotics on their farms for various reasons, including for emergency or later use and to avoid travelling to veterinarians, 24% indicated that they last used antibiotics in the previous month, 36% mentioned that the last antibiotic they used was prescribed by a veterinarian, 24% indicated that they obtained the antibiotic that they last used from a veterinarian, 47% indicated that they observed the specified withdrawal period for each antibiotic used, and 44% indicated that they sought guidance from a veterinarian before they used the product.

Table 2 Farmer's attitudes on antibiotic use in KwaZulu-Natal

Variables		**N**	**Percent**
Do you store or keep antibiotics on your farm?	No	10	15 %
	Yes	21	32%
	N/A	35	53%
When was the last time you used antibiotics on your animals?	In the last 6 months	8	12%
	In the last month	16	24%
	Last year	3	5%
	Other	4	6%
	Not indicated	35	53%
Was the last antibiotic you used prescribed by a veterinarian?	No	7	11%
	Yes	24	36%
	N/A	35	53%
Where did you buy the last antibiotic(s) you used?	Co-operative	6	9%
	Drug company	3	5%
	Drug company (via representative)	2	3%
	Veterinarian	16	24%
	Other	4	6%
	N/A	35	53%
Do you observe the specified withdrawal period for each antibiotic you use to treat animals/birds?	Yes	31	47%
	Not indicated	35	53%
Do you seek guidance from a veterinarian before using antibiotic (s) on your farm?	No	2	3%
	Yes	29	44%
	N/A	35	53%

Additionally, 94% of farmers believed that antibiotic use was associated with the risk of antibiotic resistance emerging in animals, 84% believed that antibiotics can be easily and quickly given to animals, 97% believed that antibiotics work effectively and quickly on sick animals, and 94% agreed that antibiotics greatly reduce the rate of morbidity and mortality in animals. All participants (100%) agreed that antibiotics should only be administered to animals after consulting veterinarians (Figure 3).

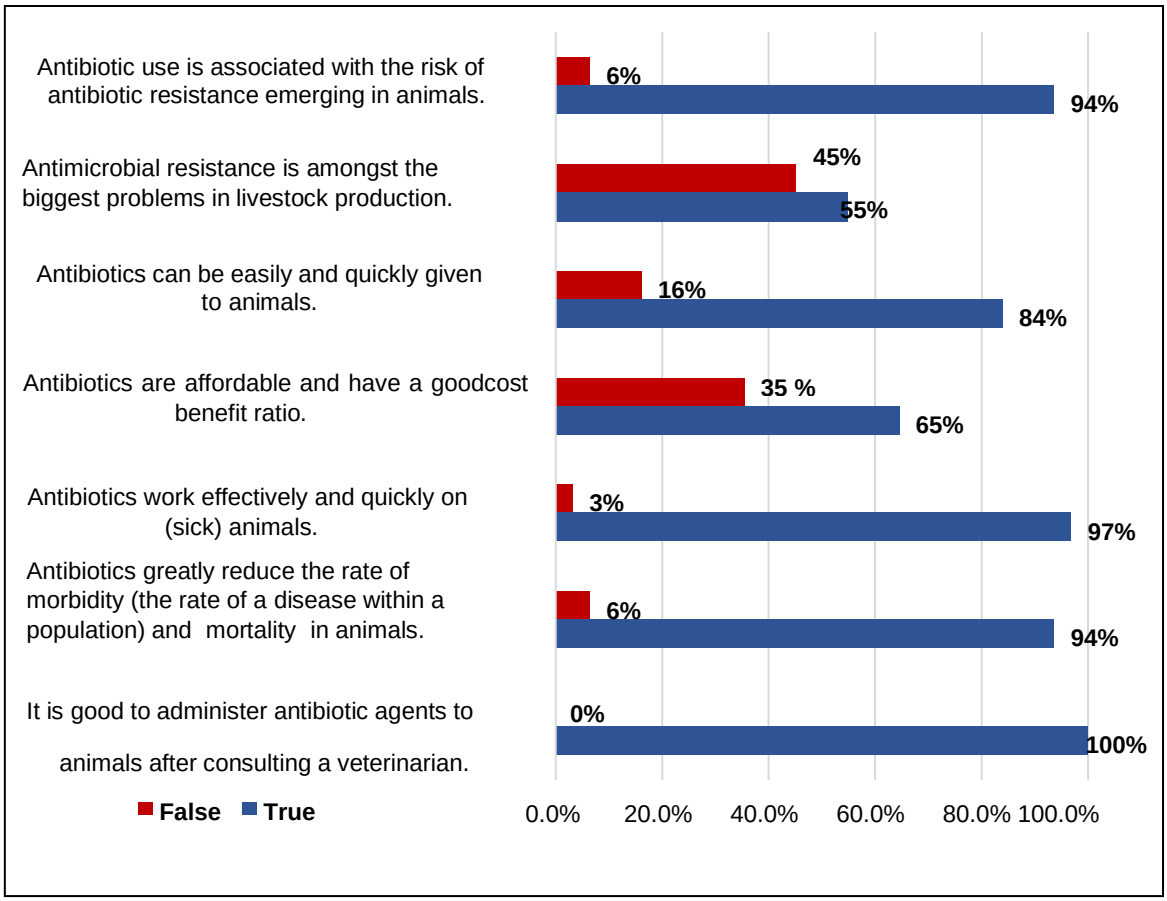

Figure 3 Farmers' attitudes on antibiotic resistance and stewardship

Eighty four percent (84%) of farmers agreed that technical progress in animal husbandry, such as animal welfare, biosecurity, and hygiene decreases the need for and use of antibiotics and 48% agreed that if consumers become aware of the current level of antibiotic use in food animal production, they would buy less livestock; 36% agreed that the ban of antibiotic use as growth promoters in animals will have a negative effect on livestock production; and 45% agreed that it was difficult to produce high-quality livestock products at a reasonable price without antibiotics. Additionally, 13% of farmers agreed that people working in food animal production systems were at high risk of carrying antibiotic resistance, 52% agreed that antibiotics reduced the risk of spreading infections from animals to humans and vice versa, 45% agreed that antibiotic use in food animal production systems reduced the effectiveness of the antibiotic in human medicine, 55% agreed that antibiotics were overused in food animal production systems, 58% disagreed that disease in food animal production could be treated without antibiotics, 68 % disagreed that it was less expensive to keep animals healthy using antibiotics than improving flock or herd management, 45% disagreed that rearing a large number of animals was only possible with the use of antibiotics, 58% disagreed that disease caused by the conditions of intensive food animal production could only be cured by antibiotics, 68% agreed that the quantity of antibiotics used on a farm was a good indicator of the husbandry conditions; and 88% agreed that farmers can help to reduce or stop the wide spread of antibiotic resistance (Figure 4).

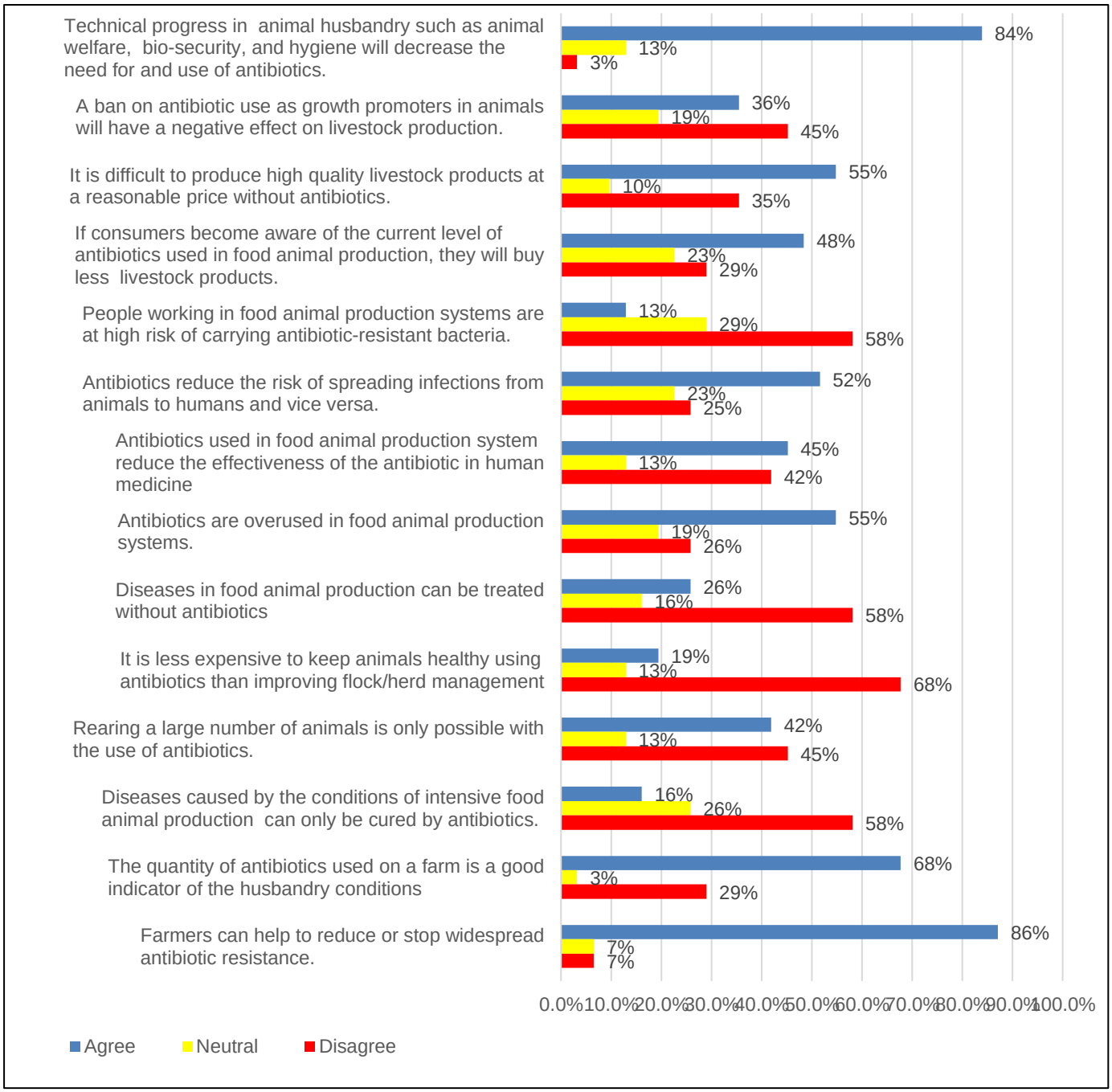

Figure 4: Farmers' attitudes on antibiotic use, stewardship, and antibiotic alternatives in food animal production systems

Practices

In terms of practices on antibiotic use and stewardship, 42% of farmers consulted a veterinarian before they used antibiotics on their animals, 46% administered antibiotics following the instructions of the veterinarians, 27% administered antibiotics following the instructions on package inserts/leaflets, 84% mentioned that their veterinarians informed them about the risk of antibiotic use in their animals, 97% mentioned that their veterinarians guided them on how to use antibiotics, 84% mentioned that their veterinarians informed them about alternatives to antibiotics and how to use them, and 75% mentioned that they consulted their veterinarians primarily for prescribing the drug they need. All farmers (100%) mentioned that their veterinarians were the first point of contact for questions about diseases in their animals. Additionally, 61% of farmers mentioned that their veterinarians prescribed antibiotics after examination of animals, 94% disagreed that feed experts provide better advice on antibiotics than

veterinarians, 68% kept records of all drugs used on their farm, 68% stated that they were not guided by feed experts on the use of antibiotics and how they work, 57% mentioned that their feed expert did not warn them about the risk of antibiotic use, 68% stated that their feed expert did not inform them about alternatives to antibiotics and how to use them, and 81% mentioned that their feed expert was not the first point of contact for questions about diseases in their animals (Figure 5).

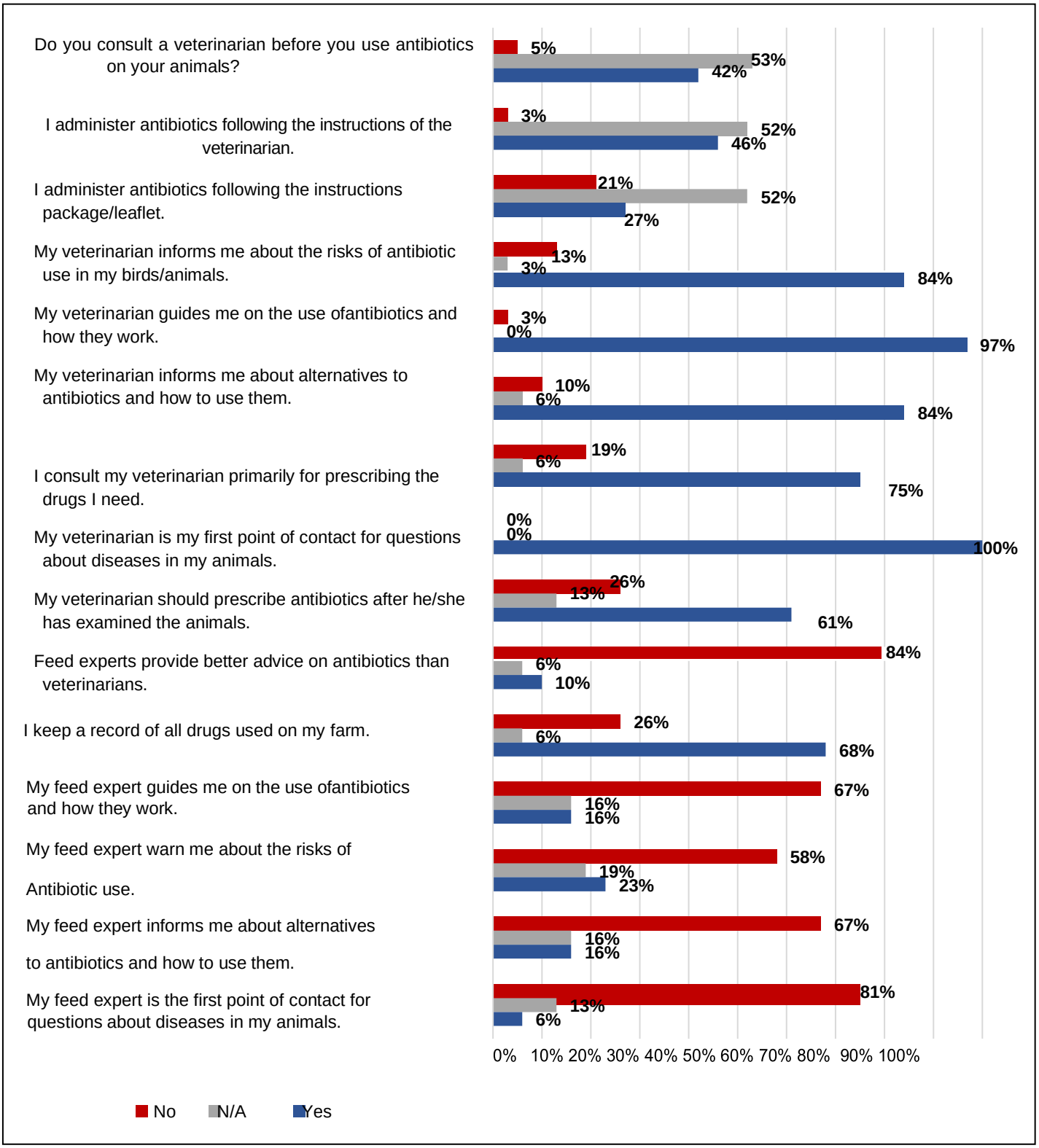

Figure 5: Farmers' practices on antibiotic use and stewardship

Farmers had different opinions on the strategies that could be used to keep animals healthy other than antibiotic(s): 77% of farmers believed that feed quality and food that was adapted to the animal's age was very effective, 90% of farmers believed that fresh and clean drinking water was important, 22% believed that an organic acid in the feed or water was effective, 71% believed that rearing fewer animals in a larger space (stocking density) was effective, 90% believed that a stable climate or animal environment (optimal air humidity, optimal ventilation, optimal temperature, and light) was effective, 16% believed that the use of medicinal plant extracts (e.g., eucalyptus or sage) to improve animals health (phytotherapy) was effective, 45% believed that the use of anti-inflammatory agents or painkillers was effective, 97% believed that systematic cleaning and disinfection of the animal production system (hygiene program) was effective, and 97% of farmers believed that animal stress reduction (improved transfer management and keeping age groups together) was effective.

Discussion

It is important to understand the KAP of non-veterinary personnel, such as farmers, on antibiotic use, resistance, and stewardship to consider society's approach to containing ABR. Farmers are personally responsible for the administration of antibiotics in their food animal production systems and are driven or guided by their KAP (Chambers *et al.*, 2020). Understanding these factors will contribute to the development of strategies that must be implemented to improve the prudent use of antibiotics and minimize the health hazards of ABR in food animal production systems (Gemeda *et al.*, 2020). A descriptive, quantitative, questionnaire-based, online survey was conducted to assess farmers' knowledge, attitudes, and practices to antibiotic use, resistance, and stewardship in food animal production systems in KZN.

The majority of farmers were able to differentiate antibiotics from anti-inflammatory and anti-pyrectics, while a minority considered them identical. Farmers who do not understand the mechanisms of action of antibiotics as distinct from anti-inflammatories, analgesics, and antipyretics are more likely to use them inappropriately (Ozturk *et al.*, 2019). The majority of farmers agreed that antibiotics should only be administered to sick animals while disagreeing with the administration of the lower or lesser dose of antibiotic than that prescribed by a veterinarian, because of the consequences of such inappropriate practice on ABR. The majority of farmers agreed that antibiotic resistance was one of the most challenging problems in livestock production, and antibiotics were not effective in humans because of their misuse and overuse in humans and animals. They also agreed that many common infectious diseases in humans and animals would become incurable in the future because of antibiotic resistance. Although they are concerned about ABR, some studies have demonstrated that farmers see the use of antibiotics in food animal production systems as a tool to maintain and improve their production, income, and profits, disregarding the evidence that inappropriate use of antibiotics in animals will contribute to the development and spread of ABR, affecting both animal and human health (Reyher *et al*., 2017).

Farmers used various antibiotics i.e. penicillin (Duplocillin), a fluoroquinolone (Entrovert), tetracycline, and sulphamethazine to treat illnesses such as diarrhoea, fever, urinary, and respiratory tract infections, skin infections, ectoparasitic infections, and parasitic gastro-enteritis in their food animals. Some of these antibiotics, such as penicillins, sulphamethazine, fluoroquinolones, and tetracyclines are also used in humans. The use of the same classes of antibiotics in both humans and animals is among the factors that contribute to the development and spread of ABR globally (Carrique-Mas *et al.*, 2015) especially where the antibiotic is considered critically important for human health (Abdalla *et al.*, 2021). Once bacteria develop resistance towards one specific antibiotic in a certain class whether in humans or animals, they may easily become resistant to the rest of the antibiotic class or even unrelated antibiotic classes (WHO, 2015).

Farmers indicated that they kept antibiotics on their farms for various reasons, including for emergency or later use and to avoid long travelling distances to veterinarians, as some live in rural areas and taking a large number of animals to the veterinarian is expensive. Some farmers stated that they keep antibiotics and use them when they are sure of the disease or after calling the veterinarian for the confirmation of the correct use and dose. According to one study that was conducted in Guatamala, farmers stored and kept antibiotics on their farms due to difficulty in accessing antibiotics and veterinarians, especially in rural areas. This led to inappropriate practices on antibiotic use and subsequent ABR, due to lack of support and supervision from veterinarians (Snively-Martinez, 2019). Farmers mentioned that the last antibiotic they used was prescribed by a veterinarian, and they also obtained the antibiotic that they last used from a veterinarian. Farmers mentioned that they seek guidance from a veterinarian before they use antibiotics, and they observed the specified withdrawal

period for each antibiotic they used to treat their food animals. This demonstrated positive attitudes of farmers. Previous studies mentioned that obtaining and using antibiotics without prescription and lack of supervision by an authorized veterinarian is among the factors that contribute to inappropriate use of antibiotics, including administration of the wrong antibiotic and wrong dosage for specific infections or purposes, all of which contribute to the emergence/escalation of ABR (Phares *et al.*, 2020).

All participants agreed that antibiotics should only be administered to animals after consulting veterinarians, as a previous study stated that easy accessibility to antibiotics by over-the-counter purchase by farmers also contributes to inappropriate use of antibiotics (Moudgil *et al.*, 2018). Farmers using antibiotics without the supervision of veterinarians may fail to comply with withdrawal periods, defined as “the minimum time that must pass after the last administration of antibiotics to food animals before entering the food supply chain”, to ensure that no antibiotic residues remain in the animal-derived products and this may spread ABR through consumption of animal-derived products contaminated with antibiotic residues (Xu *et al.*, 2020). The majority of farmers said it is less expensive to keep food animals healthy using antibiotics than improving flock or herd management, and that it was difficult to produce high-quality livestock products at a reasonable price without antibiotics; they agreed that technical progress in animal welfare such as animal husbandry, biosecurity and hygiene will decrease the need for and use of antibiotics. Management and animal husbandry are among the strategies that can be used to minimize the use of antibiotic(s) and the development of ABR in food animal production systems through maintenance of herd hygiene, cleanliness, and sanitation (Katsnelson, 2020). The majority of farmers agreed that people working in food animal production systems were at high risk of carrying antibiotic resistance during food production practices such as slaughtering, packaging, and transportation (Van den Honert *et al.*, 2018).

Farmers consulted a veterinarian before they use antibiotics on their animals, and administered antibiotics following the instructions of the veterinarians and/or insert package or leaflet. All farmers mentioned that their veterinarians were the first point of contact for questions about diseases in their animals. Farmers who consult veterinarians generally display better practices on antibiotic use, resistance, and stewardship as they learn from their veterinarians (Schneider *et al.*, 2018). Farmers believed that feed quality and food that is adapted to the animal’s age, fresh and clean drinking water, rearing fewer animals in a larger space (stocking density), and systematic cleaning and disinfection of the food animal production system are effective non-antibiotic strategies. Various non-antibiotic strategies including, but not limited to, infection control, biosecurity, vaccination, nutrition, hygiene, herd health programmes, diagnostics, optimal housing, and transport management must be prioritized to minimize the use of antibiotics in food animal systems (McCall, 2021). Farmers and other stakeholders, including veterinarians, should lead the implementation of these strategies to reduce the use of antibiotics in food animal production systems while maintaining food animal health, welfare, and productivity (Kahn *et al.*, 2019).

Conclusion

The majority of farmers (60%) who participated in the study, were from extensive (33%) and intensive (27%) farming systems and showed an overall adequate level of knowledge, attitude, and practice. They appeared to have better access to veterinarians and most received adequate education and training on antibiotic use, resistance, and stewardship. However, there were gaps in the overall KAP of farmers that can be improved through programs such as awareness campaigns, and education and training on antibiotic use, resistance, and stewardship, including but not limited to, the non-antibiotic strategies mentioned above. The implementation of antibiotic stewardship must be intensified to prevent the use of “critically-important antibiotics” for human use in food animal production for therapeutic and non-therapeutic purposes.

Acknowledgements

We thank all the farmers who participated in the study and the farmer organizations that facilitated the distribution and completion of the questionnaire. K. Ngwenya is thanked for assisting with the online survey questionnaire and support during data collection. Z.G. Dessie is thanked for assisting and facilitating the data analysis.

Competing interests

Professor Essack is the chairperson of the Global Respiratory Infection Partnership and member of the Global Hygiene Council, both sponsored by unrestricted educational grants from Reckitt UK. Other authors do not have any conflict of interest.

Author contributions

S.Y.E., M.N. & L.T.M. co-conceptualized the project. L.T.M. did the fieldwork and wrote the draft manuscript, and S.Y.E. undertook critical revision of the manuscript

Data availability statement

Data are available as supplementary material.

Disclaimer

Views and opinions presented in this article are those of the authors. They do not reflect the official policy or position of any of the author-affiliated agencies

References

Abdalla, S.E., Akebe L.K.A., Amoako, D.G., Perrett, K., Bester, L.A., Essack, S.Y., 2021. From farm-to-fork: *E. coli* from an intensive pig production system in South Africa shows high resistance to critically important antibiotics for human and animal use. J. Antibiot. 10 (2), 178. https://doi.org/10.3390/antibiotics10020178

Carrique-Mas, J., Nguyen, J., Trung, V., Hoa, N.T., Mai, H.H., Tuyen, H., James, T., Campbell, I., Wagenaar, J.A., Hardon, A., Hieu, T.Q., Schultsz, C., 2015. Antimicrobial usage in chicken production in the Mekong Delta of Vietnam. *Zoonoses Public Health* 62, 70–78. https://doi.org/10.1111/zph.12165

Chambers, J.A., Crumlish, M., Comerford, D.A., O'Carroll, R.E., 2020. Antimicrobial resistance in humans and animals: Rapid review of psychological and behavioral determinants. J. Antibiot. 9(6), 285. https://doi.org/10.3390/antibiotics9060285

Chapot, L., Sarker, M.S., Begum, R., Hossain, D., Akter, R., Hasan, M.M., Bupasha, Z.B., Bayzid, M., Salauddin, M., Parvej, M.S., Uddin, A.M., Hoque, F., Chowdhury, J., Ullah, M.N., Rahman, M.K., Siddiky, N.A., Fournié, G., Samad, M.A., 2021. Knowledge, attitudes, and practices regarding antibiotic use and resistance among veterinary students in Bangladesh. J. Antibiot. 10(3), 1–16. https://doi.org/10.3390/antibiotics10030332

Di Martino, G., Crovato, S., Pinto, A., Dorotea, T., Mascarello, G., Brunetta, R., Agnoletti, F., Bonfanti, L., 2018. Farmers' attitudes towards antimicrobial use and awareness of antimicrobial resistance: A comparative study among Turkey and rabbit farmers. Ital. J. Anim. Sci. 18(1), 194–201. https://doi.org/10.1080/1828051X.2018.1504236

Dyar, O.J., Zhang, T., Peng, Y., Sun, M., Sun, C., Yin, J., Ding, L., Sun, C., Wang, Y., Sun, Q., Greko, C., Stålsby, L.C., 2020. Knowledge, attitudes, and practices relating to antibiotic use and antibiotic resistance among backyard pig farmers in rural Shandong province, China. Prev. Vet. Med., 175 104858. https://doi.org/10.1016/j.prevetmed.2019.104858

Food and Agriculture Organization and World Health Organization. *Risk communication applied to food safety: Handbook*. Rome: Food and Agriculture Organization., 2018. [Online] Available from: http://www.fao.org/3/i5863e/i5863e.pdf

Farrell, S., McKernan, C., Benson, T., Elliott, C., Dean, M., 2021. Understanding farmers' and veterinarians' behavior in relation to antimicrobial use and resistance in dairy cattle: A systematic review. J. Dairy Sci. 104(4), 4584–4603. https://doi.org/10.3168/jds.2020-19614

Gemeda, B.A., Amenu, K., Magnusson, U., Dohoo, I., Ström Hallenberg, G., Alemayehu, G., Desta, H., Wieland, B., 2022. Antimicrobial use in extensive smallholder livestock farming systems in Ethiopia: Knowledge, attitudes, and practices of livestock keepers. Front. Vet. Sci. 7, 55. https://doi.org/10.3389/fvets.2020.00055

Kahn, L.H., Bergeron, G., Bourassa, M.W., De Vegt, B., Gill, J., Gomes, F., Malouin, F., Opengart, K., Ritter, G.D., Singer, R.S. and Storrs, C., 2019. From farm management to bacteriophage therapy: Strategies to reduce antibiotic use in animal agriculture. Ann. N.Y. Acad. Sci, 1441(1), 31–39. https://doi.org/10.1111/nyas.14034

Kalam, M. A., Alim, M. A., Shano, S., Nayem, M. R. K., Badsha, M. R., Mamun, M. A. Al, Hoque, A., Tanzin, A. Z., Khan, S. A., Islam, A., Islam, M. M., and Hassan, M. M. 2021. Knowledge, attitude, and practices on antimicrobial use and antimicrobial resistance among poultry drug and feed sellers in Bangladesh. J. Vet. Sci. 8(6), 111. https://doi.org/10.3390/vetsci8060111

Katsnelson, A., 2020. Building a healthy herd without antibiotics. ACS Cent. Sci. 6(1), 8–10. https://doi.org/10.1021/acscentsci.0c00009

Kimera, Z.I., Mshana, S.E., Rweyemamu, M.M., Mboera, L.E.G., Matee, M.I.N., 2020. Antimicrobial use and resistance in food-producing animals and the environment: an African perspective. Antimicrob Resist Infect Control 9, 1–12. https://doi.org/10.1186/s13756-020-0697-x

Lambrecht, E., Van Coillie, E., Boon, N., Heyndrick, M., Van de Wiele, T., 2021. Transfer of antibiotic resistance plasmid from commensal *E. coli* towards human intestinal microbiota in the M-SHIME: effect of *E. coli* dosE, human individual, and antibiotic use. Life 11(3), 192. https://doi.org/10.3390/life11030192

McCall, B., 2021. *Using behavioural science to help farmers change the way they manage their animals' health*. [Online] Available from: https://www.irishtimes.com/sponsored/innovation-partner-profiles/teagasc-project-aims-to-reduce- antibiotic-use-in-agriculture-1.4612450

Moudgil, P., Bedi, J.S., Moudgil, A.D., Gill, J.P.S., Aulakh, R.S., 2018. Emerging issue of antibiotic resistance from food producing animals in India: Perspective and legal framework. *Food Rev. Int.* 34(5), 447–462. https://doi.org/10.1080/87559129.2017.1326934

Nkansa, M., Agbekpornu, H., Kikimoto, B.B., Chandler, C.I.R., 2020. Antibiotic use among poultry farmers in the Dormaa municipality, Ghana. Report for Fleming Fund Fellowship Programme. [Online] Available from: https://doi.org/10.17037/PUBS.04658868

Ozturk, Y., Celik, S., Sahin, E., Acik, M.N., Cetinkaya, B., 2019. Assessment of farmers' knowledge, attitudes, and practices on antibiotics and antimicrobial resistance. J. Anim. 9(9), 653. https://doi.org/10.3390/ani9090653

Page, S.W., Gautier, P., 2019. Use of antimicrobial agents in livestock. Revue Scientifique et Technique-OIE 31 (1), 145. https://doi.org/10.20506/rst.31.1.2106

Phares, C.., Danquah, A., Atiah, K., Agyei, F.K. Michael, O.T., 2020. Antibiotics utilization and farmers' knowledge of its effects on soil ecosystem in the coastal drylands of Ghana. PloS One 15 (2), e0228777. https://doi.org/10.1371/journal.pone.0228777

Rayner, A.C., Higham, L.E., Gill,R., Michalski, J.P., Deakin, A., 2019., A survey of free-range egg farmers in the United Kingdom: knowledge, attitudes, and practices surrounding antimicrobial use and resistance. Vet. Animal. Sci. 8, 100072. https://doi.org/10.1016/j.vas.2019.100072

Reyher, K., David C., Tisdall, D.A., 2017. Achieving responsible antimicrobial use: Communicating with farmers. In Pract. 39(2), 63–71. https://doi.org/10.1136/inp.j341

Sadiq, M.B., Syed-Hussain, S.S., Ramanoon, S.Z., Saharee, A.A., Ahmad, N.I., Mohd Zin, N., Khalid, S.F., Naseeha, D.S., Syahirah, A.A., Mansor, R., 2018. Knowledge, attitudeS, and perception regarding antimicrobial resistance and usage among ruminant farmers in Selangor, Malaysia. Prev. Vet. Med. 156, 76–83. https://doi.org/10.1016/j.prevetmed.2018.04.013

Schneider, S., Salm, F., Vincze, S., Moeser, A., Petruschke, I., Schmücker, K., Ludwig, N., Hanke, R., Schröder, C., Gropmann, A., Behnke, M., 2018. Perceptions and attitudes regarding antibiotic resistance in Germany: A cross-sectoral survey amongst physicians, veterinarians, farmers, and the general public. J. Antimicrob. Chemother. 73(7), 1984–1988. https://doi.org/10.1093/jac/dky100

Van Boeckel, T.P., Brower, C., Gilbert, M., Grenfell, B.T., Levin, S.A., Robinson, T.P., Teillant, A., Laxminarayan, R., 2015. Global trends in antimicrobial use in food animals. PNAS. 112(18), 5649–5654. https://doi.org/10.1073/pnas.1503141112

Van den Honert, M.S., Gouws, P.A., Hoffman, L.C., 2018. Importance and implications of antibiotic resistance development in livestock and wildlife farming in South Africa: A Review. S. Afr. J. Anim. Sci. 48 (3), 401–412. https://doi.org/10.4314/sajas.v48i3.1

Visschers, V.H.M., Backhans, A., Collineau, L., Iten, D., Loesken, S., Postma, M., Belloc, C., Dewulf, J., Emanuelson, U., Beilage, E., Siegrist, M., Sjoilound, M., Stärk, K., 2015. Perceptions of antimicrobial usage, antimicrobial resistance, and policy measures to reduce antimicrobial usage in sample of Belgian, French, German, Swedish, and Swiss pig farmers. Prev. Vet. Med. 119(1–2), 10–20. https://doi.org/10.1016/j.prevetmed.2015.01.018

World Health Organization, 2017. Integrated surveillance of antimicrobial resistance in foodborne bacteria: Application of a One Health approach: Guidance from the WHO Advisory Group on Integrated Surveillance of Antimicrobial Resistance (AGISAR). [Online] Available from: https://apps.who.int/iris/handle/10665/255747

World Health Organization, 2015. Global action plan on antimicrobial resistance. World Health Organization. [Online] Available from: https://apps.who.int/iris/handle/10665/193736

World Health Organization, 2021. WHO integrated global surveillance on ESBL-producing *E. coli* using a "One Health" approach: Implementation and opportunities. [Online] Available from: https://apps.who.int/iris/bitstream/handle/10665/340079/9789240021402-eng.pdf?sequence=1.

Xu, J., Sangthong, R., McNeil, E., Tang, R., Chongsuvivatwong, V., 2020. Antibiotic use in chicken farms in northwestern China. Antimicrob. Resist. Infect. Control. 9(1), 1–9. https://doi.org/10.1186/s13756-019-0672-6.