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REVIEWS

Antibiotic usage and resistance in animal production in Vietnam: a review of existing literature

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Abstract

Inappropriate use of antibiotics in animal production system is one of the major factors leading to the antibiotic resistance (ABR) development. In Vietnam, the ABR situation is crucial as antibiotics have been used indiscriminately for disease prevention and as growth promoters in animals. Thus, a thorough understanding on the ABR in veterinary settings would be beneficial to the Vietnam public health authority in formulating timely interventions. This review aimed to provide information on the current status of antibiotic usage in animal husbandry in Vietnam, identified gaps in research, and suggested possible solutions to tackle ABR. To this end, data on ABR in animals were extracted from 3 major electronic databases (PubMed, Web of Science, and ScienceDirect) in the period of January 2013–December 2020. The review findings were reported according to PRISMA, which highlighted the emergence and persistence of ABR in bacterial isolates, including *Escherichia coli*, *Enterococcus* spp., and *Salmonella* species, obtained from pigs and poultry. The lack of awareness of Vietnamese farmers on the antibiotic utilization guidelines was one of the main causes driving the animal ABR. Hence, this paper calls for interventions to restrict antibiotics use in food-producing animals by national action plan and antibiotics control programs. Additionally, studies to evaluate knowledge, attitude, and practice (KAP) of the community are required to promote rational use of antibiotics in all sectors.

Keywords Antibiotic use · Antibiotic resistance · Veterinary · Animal husbandry · Chicken farm · Pig farm · Vietnam

Highlights

- Inappropriate use of antibiotics in animal production is one of the major factors leading to the development of antibiotic resistance globally, especially in Vietnam.
- Crucial emergence and persistence of antibiotic resistance in bacterial isolates (*Escherichia coli, Enterococcus* spp., and *Salmonella* spp.) obtained from pigs and poultry in Vietnamese farms.
- This review provides information on the current status of antibiotic usage in animal husbandry in Vietnam, identify gaps in research, and suggest interventions to tackle antibiotic resistance.

Introduction

Antibiotics play a crucial role in the infectious disease treatments in both human and animals. Since the first introduction of penicillin in the 1940s, a wide variety of antibiotics have been produced in large scale to fight against bacterial infections. Without antibiotics, various achievements in human medicine, including cancer chemotherapy, preterm-baby cares, organ transplantation, and major surgery, are unlikely to be obtained (Laxminarayan et al.

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2013). Nevertheless, antibiotics efficacy has been declining in recent years due to the emergence of antibiotic-resistant bacteria (Jacob et al. 2013). The overuse and misuse of antibiotics has led to a high selection pressure for resistant strains, forcing clinicians to switch to more highly priced and broader spectrum antibiotics for patient treatments and managements. In the veterinary medicine, besides disease treatment purposes, antibiotics are also used to improve feed efficiency and increase productivity (Binh et al. 2018; Tuat et al. 2017). Therefore, the antibiotics utilization in food-producing animals has been escalating, thus putting heavy antimicrobial drug-selective pressure to bacterial populations, leading to the emergence and spread of antibiotic-resistant organisms to the community (Goutard et al. 2017; Nhung et al. 2016). To solve this issue on antibiotic resistance (ABR), in 2017, the World Health Organization (WHO) has launched guidelines on the use of antimicrobials in food-producing animals, recommending the stop of antibiotics abuse for growth promotion and disease prevention in healthy animals (WHO 2017). Nevertheless, the guidelines adherence was limited since numerous antimicrobial-resistant bacteria found in animals have been increasingly reported, including *Acinetobacter* spp., *Pseudomonas* spp., *Klebsiella* spp., *Escherichia coli* (*E. coli*), *Streptococcus suis* (*S. suis*), and *Staphylococcus aureus* (*S. aureus*) (Thuy et al. 2018; Nhung et al. 2020). Therefore, it is crucial to tackle the ABR in veterinary settings systematically, especially in the developing countries with loose regulation on antibiotics usage such as Vietnam.

Vietnam, the easternmost country on the Indochina Peninsula with a population of approximately 98 million (as of March 13, 2021), is one of the leading Southeast Asian countries in meat and animal product manufacturing. In the veterinary sector, Vietnam has experienced high incidences of disease outbreaks, including bacterial infections, in livestock production. To avoid economic loss, farmers have opted to use antibiotics for disease prevention, as well as growth promotion, in healthy animals (Laxminarayan and Heymann 2012; Carrique-Mas et al. 2014; Pham Kim et al. 2013; Nhung et al. 2015; Laxminarayan et al. 2013). Several studies in Vietnam have reported the indiscriminate use of antibiotics, including quinolones, macrolides, aminoglycosides, and beta-lactams, in animal production (Nhung et al. 2016; Van Cuong et al. 2016; MARD 2017; Pham Kim et al. 2013; Vounba et al. 2019). Consequently, Vietnam is one of the top countries with high levels of ABR (Tornimbene et al. 2018; WHO 2014). However, to the best of our knowledge, no systematic review has been conducted addressing this urgent issue in Vietnam.

This study aimed to review the antibiotic usage and resistance in animal production in Vietnam based on the published reports in the period of January 2013–December 2020 using a systematic approach on three major databases (PubMed, Web of Science, and ScienceDirect). Findings in appropriate reports were summarized individually. Critical discussions and suggestions on interventions to tackle ABR, especially in the field of animal production, were proposed based on the obtained information.

Methodology

To summarize the current evidences related to this topic, a systematic review according to the Preferred Reporting Items for Systematic Reviews (PRISMA) was performed (Shamseer et al. 2015).

Search strategy

PubMed (https://pubmed.ncbi.nlm.nih.gov/), Web of Science (https://apps.webofknowledge.com/), and ScienceDirect (https://sciencedirect.com/) electronic databases were used to search for articles published in English from January 2013 to December 2020. A research string with key words "[antibiotic*] AND [antibiotic resistance] AND [veterinary] OR [animal husbandry] OR [chicken farm] OR [pig farm] AND [in Vietnam]" was strictly used to obtain relevant articles. Searches were supported by hand searching and retrieval of additional articles satisfying eligibility criteria that were cited in reference lists.

Eligibility criteria

The inclusion criteria were studies (i) published in peer-review journals with English language, (ii) reported antibiotic usage and ABR in animal production in Vietnam from January 2013 to December 2020, (iii) focused on veterinary or animal husbandry, including pig, chicken, and duck; and (iv) conducted with standardized experiments and sufficient replications.

The exclusion criteria included (i) articles reporting antibiotic usage and ABR before January 2013 and after December 2020; (ii) articles focused on laboratory tests of consumed animal meat production; (iii) manual or experimental guidelines, systematic and/or literature review papers, (meta)-analysis, content volume, author index, books, book chapters, and paper alert; (iv) unpublished studies and non-peer-reviewed articles; and (v) papers in which full text was not available in English.

Data collection and extraction process

The titles and abstracts of the obtained articles were firstly scanned by two independent authors. Papers fulfilling the inclusion criteria were selected for further screening and full-text review. Agreement on paper inclusion and exclusion

must be consistent between two raters. Then, original articles reporting ABR in veterinary, animal husbandry, chicken farm, and pig farm were chosen. Mendeley program was used to select and remove duplicates. Extracted data were authors, published year, study species, sample source, bacterial strains, research focus, and principle findings. All necessary data for the review were published within the papers, so no contact with authors was required. Figure 1 describes the article screening and selecting process.

Results and discussions

Out of a total of 951 articles (273 in PubMed, 563 in Web of Science, and 115 in ScienceDirect database), 562 were selected after duplication removal, in which 62 were appropriate for full-text review. Among them, 15 satisfied studies have been included in this review, followed by critically summarized and discussed in the issue of animal antibiotic usage and resistance. For ease of understanding, we first discussed the overview of antibiotic usage in animal production in Vietnam, focused on poultry and pigs. Then, we shifted our concern into the ABR issue of these respective animals. Finally, critical suggestions to improve the situation were proposed.

Overview of antibiotic usage for animal husbandry in Vietnam

Antibiotic usage for animal husbandry in Vietnam is regulated by the Ministry of Agriculture & Rural Development (MARD). Nevertheless, antibiotics have been used indiscriminately for disease prevention and treatment by veterinarians and farmers in Vietnam for a long time (Pham Kim et al. 2013). In chickens and pigs, most antibiotics were administered for disease prevention without specific diagnosis (73.3% and 66.7%, respectively, of the total antibiotics used) (Nguyen et al. 2016). Seriously, approximately 43.7% of the commercial animal feed available in Vietnam had at least one antibiotic, and 21.5% and 5.4% of pig and chicken feed formulation, respectively, had at least 2 antibiotics (Cuong et al. 2016). It is estimated that 77.4 and 286.6 mg of in-feed antibiotics are currently used to raise 1 kg of chicken and pig, respectively (Cuong et al. 2016). To this

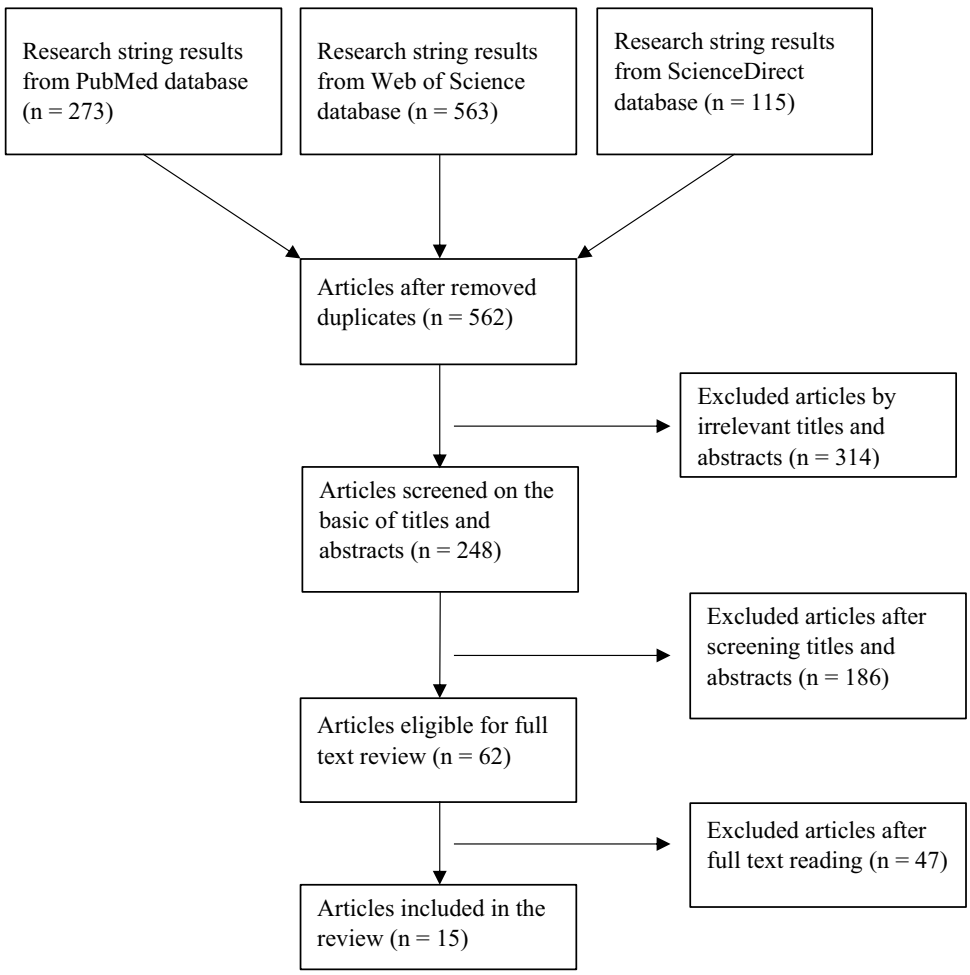

Fig. 1 PRISMA diagram of the article selection procedure for published articles from January 2013 to December 2020

end, bacitracin, chlortetracycline, colistin, and enramycin were mostly used in chicken (30.8, 26.0, 14.8, and 3.9 mg, respectively, to raise 1 kg), and florfenicol, chlortetracycline, colistin, and bacitracin were popularly given to pigs (66.9, 59.7, 57.5, and 41.2 mg, respectively, to raise 1 kg) (Cuong et al. 2016). In comparison, intestinal microorganisms of chickens in Vietnam carried a higher level of ABR than pigs (Nguyen et al. 2016). In terms of sectors, antibiotics were used in a smaller scale in household feed (up to 20%), compared to semi-industrial farms (about 43.3%) and industrial feeding systems (approximately 66.7%) (Pham Kim et al. 2013). Generally, farms utilized 3 to more than 6 antibiotics in chicken and pig feeds, representing 16.7% and 26.7% of the farms total feeds, respectively. Moreover, 50% of the pork and/or poultry products available in the market contained at least two or more antibiotics residues (Nguyen et al. 2016).

In terms of antibiotics types, in 2016, the MARD issued a list of antibiotics that could/could not be used in animal feeds in Vietnam (Table 1, MARD 2016). Accordingly, 19 antibiotics were banned, while 16 compounds were allowed with limited use as growth promoters and 11 were for general use (MARD 2016) (Table 1). Noticeably, some compounds were allowed for both general use (e.g., bacterial/parasitic infection treatments) and animal growth, including bambermycin, monensin, salinomycin, tylosin phosphate, and virginiamycin. Practically, a total of 45 different antibiotics have been reported for use in animal husbandry, which belonged to 10 antibiotic classes in the Northern (Pham Kim et al. 2013) and 8 classes in the Southern region of Vietnam (Cuong et al. 2016). The most commonly used antibiotics for animal production included chlortetracycline, oxytetracycline, salinomycin, ampicillin, enramycin, colistin, gentamicin, and tylosin (Pham Kim et al. 2013; Nguyen et al. 2016). Among them, oxytetracycline, colistin, and chlortetracycline were on top of the list. A recent study also showed the use of colistin, an important medicine for human, for food-producing animals (Nguyen et al. 2016).

Antibiotic use in poultry feeding

In Vietnam, smallholder farmers raise poultry (mainly chicken and duck) not only for self-supply of cheap animal protein, but also to earn their livings from trading live birds, meats, and eggs (Tuat et al. 2017; Phu et al. 2019; Yen et al. 2020). This is the most common production system in this country (< 50 chickens and/or ducks per holder) as compared to semi-intensive medium scale (51 to 2000 birds flock size), and intensive industrial scale (2000 to 100,000 birds) (Burgos et al. 2007).

Antibiotics have been used extensively in chicken production in Vietnam (Carrique-Mas et al. 2015, 2019; Choisy et al. 2019; Cuong et al. 2019) with the amounts of six times greater than that of the UK (Henry et al. 2017; Hughes et al. 2008). Approximately 84% of antibiotic usage in poultry farms was for prevention of bacterial infection rather than for treatment purposes (Carrique-Mas et al. 2015). The antibiotics used in most chicken farms were aminoglycoside, penicillin, tetracycline, and colistin, with the percentages of usage ranged from 10.1 to 18.6% (Trung et al. 2017a). Other less frequently used antibiotics, including sulfonamides/trimethoprim, fluoroquinolones, and lincosamides, possessed a common dose of 2.78, 3.16, 5.2, and 8.27 mg/week/chicken, respectively (Carrique-Mas et al. 2015). In terms of administrative route, antibiotics were mostly delivered through water (81.5%), followed by feed and water (9.5%), feed only (4.2%), and injection (4.2%) (Carrique-Mas et al. 2015). Interestingly, to produce 1 kg of chicken, a total of 46.1 to 77.4 mg antibiotics (comparable quantity) was presently utilized (Nguyen et al. 2016; Cuong et al. 2016); this number was significantly increased to 470.4 mg in the production of one "meat" chicken (Carrique-Mas et al. 2015). The reason for these differences might come from the management practice in relation with intensification of poultry farming system in Vietnam.

Table 1 Antibiotics that are allowed with limited use and banned in animal feeds in Vietnam (MARD 2016). General use includes, but not limited to, bacterial and parasitic infection treatments

Antibiotics that are allowed with limited use			Banned antibiotics	
General use	Growth promoters			
Ampicillin	Bacitracin methylene disalicylate	Monensin	Bacitracin Zn	Furazolidone
Avilamycin	Bambermycin	Narasin	Carbadox	Green malachite
Avoparcin	Chlortetracycline	Neomycin sulfate	Chloramphenicol	Gentian violet
Bambermycin	Colistin sulfate	Nosiheptide	Ciprofloxacin	Metronidazole
Gentamicin	Enramycin	Oxytetracycline	Clenbuterol	Nitrofuran derivatives
Meticlorpidol	Kitasamycin	Salinomycin	Dichlorvos	Ofloxacin
Monensin	Lasalocid sodium	Tylosin phosphate	Diethylstilbestrol	Olaquindox
Salinomycin	Lincomycin	Virginiamycin	Dimetridazole	Ractopamine
Spiramycin			Dipterex	Salbutamol
Tylosin phosphate			Eprofloxacin	
Virginiamycin				

Antibiotic use in pig feeding

Pig production, the essential source of Vietnamese economy, has become a matter of concern in terms of antibiotic overuse (Lemke 2008). Similar to the poultry section, small-scale pig farming system accounted for 80% of pig production in Vietnam (Lapar et al. 2003). The indiscriminate use of antibiotics occurred through the addition of antibiotics to the feed for growth promotion and disease prevention purposes (Page and Gautier 2012). The most commonly used antibiotics in pigs were fluoroquinolones, beta-lactams, fenicols, tetracyclines, and aminoglycosides (Pham Kim et al. 2013). Severely, lincomycin, tetracyclines, colistin, and amoxicillin are crucial for human medicine, but accounted for 57% of the total antibiotic use in pig production in Vietnam (Cuong et al. 2016). Furthermore, virginiamycin, vancomycin, erythromycin, and avilamycin have been banned as animal growth promoters in the European Union. Nevertheless, these drugs are still in use for pig production in India and other developing countries, including Vietnam (Center for Disease Dynamics Economics & Policy 2016). To produce 1 kg of pig, 52.0 to 286.6 mg antibiotics (comparable quantity) was presently utilized (Nguyen et al. 2016; Cuong et al. 2016). In terms of antibiotics choice, combinations of two antibiotics, such as sulfonamide and trimethoprim, provided synergistic effects for the bacterial infection treatment (Tinh et al. 2006). Colistin was the most common compound used to prevent and treat gastrointestinal disorders in piglets caused by Gram-negative bacteria (e.g., *Salmonella* spp. and *E. coli*) (Pham Kim et al. 2013).

Antibiotic resistance in animal husbandry in Vietnam

Due to the high rate of disease incidences in animals, livestock production annually in 2050 was estimated to be reduced 3–8%, thus expected to affect 6.2–18.7 million people from under-resourced countries (Adeyi et al. 2017). To this end, the Asia used the largest amount of antimicrobials in 2017 (57,167 tonnes) for animal feed. This figure was estimated to increase 10.3% to 63,062 tonnes in 2030, representing 68% of the total antimicrobials use worldwide in 2017 (Van Boeckel et al. 2015; Tiseo et al. 2020). Moreover, despite the warnings from international health authorities on the misuse and overuse of antibiotics in humans and animals, statistics showed that 110 over 130 WHO member countries have not yet issued and adhered to legislation and/or regulation regarding import, manufacturing, distribution, dissemination, and usage of antibiotics (Goutard et al. 2017; Adeyi et al. 2017).

Table 2 demonstrates the findings obtained from 15 recent studies (January 2013–December 2020) carried out in Vietnam on the antibiotic susceptibility profiling of bacteria isolated mainly from fecal materials of poultry and pigs. These studies highlighted the emergence and persistence of *E. coli*, *Salmonella* spp., and *Enterococcus* spp. with high levels of resistance against antibiotics. These included ampicillin, tetracycline, oxytetracycline, gentamicin, ciprofloxacin, and third-generation cephalosporins for *E. coli* (Nhung et al. 2015; Nguyen et al. 2015); penicillins and fluoroquinolones for *Salmonella* spp. (Nhung et al. 2018); oxytetracycline and fluoroquinolones for *Enterococcus* spp. (Usui et al. 2014). Seriously, resistance to the abovementioned antibiotics has also been reported in clinical settings in Vietnam (Thuy et al. 2018).

Compared to the wildlife strains, bacteria isolated from farmed animals at Mekong Delta in Vietnam had higher rates of ABR (Nguyen T Nhung et al. 2016). A high prevalence of multidrug-resistant bacteria (resistant to more than 3 antibiotic types), such as non-typhoidal *Salmonella*, was observed among pig (86.7%) and poultry isolates (66.9–72.7%) (Nhung et al. 2015; Trung et al. 2017a). More importantly, clear evidence has been reported on the association of ABR in the farm isolates with the environmental isolates in the Mekong Delta in Vietnam (Nhung et al. 2016). Therefore, intensive research on the transmission dynamics of *Salmonella* from animals to human is required to prevent human infection. In terms of antibiotic types, Nhung et al. (2018) showed the presence of macrolides, tetracyclines, and sulfonamides in poultry and pig samples. In view of the development of ABR, it is crucial to step up measures to encourage more responsible use of antibiotics in animal production. The inadequate knowledge and awareness of policies and regulations regarding antibiotic usage among animal farmers hinders the prevention and spread of ABR in the animal production system in Vietnam (Hoelzer et al. 2017).

Suggestions to improve the current situation

Arguably, the inappropriate sale and wide use of non-prescription antibiotics for livestock in Vietnam have intensified the emergence and spread of resistant bacterial strains in both humans and animals. For this reason, the government of Vietnam has conducted various legislation documents and programs. For instance, the Vietnam Ministry of Health (MOH) has established a National Steering Committee for Anti-Drug Resistance in 2016–2020 (decision No. 5888/QD-BYT, issued in Oct 2016) to strengthen and support a multidisciplinary approach to control ABR in animal husbandry in Vietnam (MARD 2017). Also in 2017, a surveillance system has been initiated by the Department of Animal Health of Vietnam (DAH), FAO of the United Nations, and Oxford University Clinical Research Unit (OUCRU) to assess ABR rate in chicken and pig production in this country (Tuat et al. 2017). To this end, pig and chicken samples were collected

Table 2 A review of recent studies (January 2013–December 2020) on ABR investigations in Vietnam. *NA* not available

	Author/published year	Sample source(s)	Bacterial strain(s)	Research focus	Principle findings
1	Pham Kim et al. (2013)	Chicken Pig	NA	Antibiotics use in chicken and pig farms	- 15 out of 45 antibiotics surveyed were used inappropriately for disease treatment, prevention, and growth promotion of chicken and pigs - Oxytetracycline, chlortetracycline, and colistin are the most common used antibiotics in the farms
2	Usui et al. (2014)	Chicken feces	*E. faecium*, *E. faecalis*, *E. coli*	The susceptibility of antimicrobials in chicken isolates	- High resistance of chicken isolates to the following antibiotics was reported: oxytetracycline: 92.2% (*E. faecium*), 69.2% (*E. faecalis*), 73.6% (*E. coli*); fluoroquinolones: 82.8% (*E. faecium*), 17.9% (*E. faecalis*), 48.8% (*E. coli*)
3	Nhung et al. (2015)	Chicken Pig Duck	*E. coli*	Antimicrobial resistance of *E. coli* in livestock	- Compared to wildlife species, *E. coli* isolated from farm animals had higher rates of resistance: ciprofloxacin (24.9% vs. 7.3%), amoxicillin/clavulanic acid (36.6% vs. 34.5%), chloramphenicol (39.9% vs. 22.5%), trimethoprim/sulfamethoxazole (52.1% vs. 18.8%), ampicillin (78.9% vs. 85.9%), and tetracycline (84.7% vs. 25.6%) - The prevalence of multidrug-resistant bacteria (resistant to more than 3 antibiotic types) were 66.9–72.7% and 86.7% in poultry and pigs, respectively
4	Nguyen et al. (2015)	Chicken	*E. coli*	Prevalence of antimicrobial resistance among commensal *E. coli* isolates on household and small-scale chicken farms	- *E. coli* resisted to gentamicin, ciprofloxacin, and third-generation cephalosporins was detected on 201 (96.6%), 191 (91.8%), and 77 (37.0%) of the farms, respectively - Of the 895 *E. coli* isolates, resistance to gentamicin, ciprofloxacin, and third-generation cephalosporins was detected in 178 (19.9%), 291 (32.5%), and 29 (3.2%) of the isolates, respectively - Ciprofloxacin resistance was significantly associated with quinolone and tetracycline usage
5	Cuong et al. (2016)	Chicken Pig	NA	The use of antimicrobials in medicated feeds in pigs and chickens	- The estimated quantities of antimicrobial use in pig and chicken feeds were 62.3 and 25.7 mg/kg, respectively - 286.6 and 77.4 mg of in-feed antibiotics were needed to raise 1 kg of live pig and chicken, respectively - Bacitracin, lincomycin, neomycin, tetracycline, colistin, and amoxicillin accounted for 57% of the total antibiotic use in pig production
6	Trung et al. (2017a)	Chicken Human	Non-typhoidal *Salmonella*	The colonization of non-typhoidal *Salmonella* in humans and chickens	- Non-typhoidal *Salmonella* colonized 2.6% unexposed individuals, 4.4% farmers, and 45.6% chicken farms - 20 to 40% of bacterial isolated from chicken farms were resistant to ampicillin, sulfamethoxazole-trimethoprim, chloramphenicol, and tetracycline

Table 2 (continued)

	Author/published year	Sample source(s)	Bacterial strain(s)	Research focus	Principle findings
7	Trung et al. (2017b)	Chicken Human	NA	Colistin use and resistance in chicken farms	- The use of colistin contributes to the high prevalence (59.4%) of mcr-1 gene in fecal samples from chickens - The study discussed the consequences of the zoonotic transmission of the bacterial mcr-1 gene
8	Nhung et al. (2018)	Chicken Pig Cow	Non-typhoidal *Salmonella*	The resistance and residues of antimicrobials against non-typhoidal Salmonella in poultry production	- High level of antibiotic residue contamination was found in meat products - Antimicrobial residues such as macrolides, tetracycline, and sulfonamides were found in poultry - High levels of resistance among non-typhoidal *Salmonella* isolates against penicillins and quinolones were reported
9	Vounba et al. (2019)	Chicken	*E. coli*	Prevalence of colistin resistance and mcr-1/mcr-2 genes in extended-spectrum β-lactamase/AmpC-producing *E. coli* isolated from chickens	- In Vietnam, most chicken farms were found with co-existence of the ESBL/AmpC and mcr-1 gene, and the high level of multidrug resistance in all colistin-resistant *E. coli* isolates
10	Carrique-Mas et al. (2019)	Chicken	*Streptococcus suis*	The association between antibiotic use and mortality in small-scale chicken flock	- An exceptionally high mortality in chicken flock in the Mekong Delta of Vietnam was confirmed - Nearby access activity to antimicrobials was associated with antimicrobial usage, which highly correlated with consecutive cycles of meat chicken flocks
11	Choisy et al. (2019)	Chicken	NA	Clinical signs and antimicrobial misuse in chicken farms	- A vast majority of disease episodes were not treated effectively, representing an important loss for the farmers - The naïve Bayes framework can be applied to any setup, including human infections and can also be used to improve the current animal treatments
12	Phu et al. (2019)	Chicken	NA	Role of veterinary drug shops in supplying antimicrobials and advising antimicrobial use to small-scale poultry farmers	- Antimicrobials represented 15.0% of the shops' income - Fifty-seven percent shop owners were linked with the veterinary authority, and 57% provided diagnostic services - The median number of drug shops supplying antimicrobials to each farm during one production cycle was 2
13	Cuong et al. (2019)	Chicken	NA	Antimicrobial consumption in small-scale chicken farms	- A total of 236 commercial animal feeds were identified, containing 42 different antimicrobial active ingredients - 76.2% products contained antimicrobials of "critical importance." - Antimicrobial use was more common early in the production cycle and was highly skewed, with the upper 25% quartile of flocks accounting for 60.7% of the total antimicrobial use

Table 2 (continued)

	Author/published year	Sample source(s)	Bacterial strain(s)	Research focus	Principle findings
14	Nhung et al. (2020)	Chicken	*Streptococcus suis*	The colonization of *S. suis* in chicken with high level of antibiotic resistance	- Chicken is a potential infection source of *S. suis* to in-contact pig and human - Isolated samples from chicken were found with very high levels of resistance against ceftriaxone (15%), and intermediate resistances against penicillin (35%), erythromycin (95%), clindamycin (100%), and tetracycline (100%)
15	Yen et al. (2020)	Chicken	*A. endocarditidis* *G. anatis* *O. rhinotracheale*	Non-critically important antimicrobials against chicken pathogens	- Doxycycline would be the drug of choice for *A. endocarditidis* (11.8% presumptive non-wild type) and *G. anatis* infections (5.3% presumptive non-wild type) - A total of 13.6% *O. rhinotracheale* isolates were non-wild type with regard to oxytetracycline, making it the drug of choice against this pathogen

from abattoirs or slaughterpoints using standard operating procedure, followed by the isolation, identification, and susceptibility testing of *E. coli* and non-typhoidal *Salmonella*. On the other hand, numerous meetings and workshops have also been organized by the government and international agencies to overcome barriers and to identify knowledge gaps to fight against ABR. Additionally, national action plan (NAP) covering stewardships and surveillances for antibiotic use and resistance has been introduced in Vietnam, as well as other under-resourced countries in the Southeast Asia (i.e., Philippines, Mongolia, Cambodia, and Brunei) (Long 2017).

However, these actions were inadequate as the ABR in animal husbandry has increased significantly, previously discussed in the present study. Thus, to further improve the current situation, implementation of good farming practice should be prioritized. It is crucial to educate and train farmers and veterinarians on the proper use of antibiotics as well as to disseminate information on the detrimental consequences due to antibiotics inappropriate uses. The government might need to review animal husbandry legislation and make necessary adjustments based on the definitions and guidelines of international organizations, i.e., FAO, World Organization for Animal Health (OIE), and WHO. The establishment of a hotline would be useful to advise farmers on antibiotic use. Moreover, policy makers should commit, with civil society engagement and accountability, a financed-supported and comprehensive NAP to intensify laboratory and surveillance capacity; assure fully accessed and high-quality sources of important medicines; promote and control prudential use of antibiotics in all sectors of human, agriculture, and animal husbandry; strengthen the prevention strategies for infections; and substitute research and development or innovations with novel tools (Tornimbene et al. 2018). In addition, mass media program and training courses on antibiotic usage guideline and policy updates are required to improve the awareness of Vietnamese farmers on the use of antibiotics and ABR.

Lastly, publications providing up-to-date, relevant, and reliable information, are necessary for the public health authority to respond to the undesirable consequences of ABR. All professionals, academia, policy makers, and farmers in national and global perspectives should work together with multifaceted actions to develop and improve the current animal production systems. Numerous low- and middle-income countries have already set off endeavors to control ABR, focusing its impact on human health (Founou et al. 2016). Nevertheless, quantitative study concerning antibiotics use for prophylactic and therapeutic purposes in animal feeding production are still lacking in Vietnam (Nguyen et al. 2016). Hence, further research on animal husbandry and production are necessary to fulfil this critical knowledge gap.

Conclusions

This systematic review summarized the antibiotic usage and resistance in animal production in Vietnam from January 2013 to December 2020. Expectedly, the findings showed that these issues have become significant in recent years. As antibiotic resistance presents a serious health issue in both human and veterinary medicine, Vietnam should possess a tighter control on the use of antibiotics in livestock, especially poultry and pig productions. Apart from government agencies' effort, the cooperation of farmers and the animal production community is necessary. Hence, understanding the levels of knowledge, attitude, and behaviors of personnel directly involved in the animal husbandry system in Vietnam would be paramount for implementation of effective control strategies against antibiotic resistance.

Abbreviations ABR: Antibiotic resistance; KAP: Knowledge, attitude, and practice; WHO: World Health Organization; MARD: Ministry of Agriculture & Rural Development; FAO: Food and Agriculture Organization; OIE: World Organization for Animal Health; MOH: Ministry of Health; DAH: Department of Animal Health of Vietnam; PRRS: Porcine reproductive and respiratory syndrome; OUCRU: The United Nations and Oxford University Clinical Research Unit; PRISMA: Preferred Reporting Items for Systematic Reviews; NAP: National action plan

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Declarations

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