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Emerging Trends in Antimicrobial Resistance (AMR) and Innovative Non-Antibiotic Therapies in Veterinary Medicine

Arzoo Nisha*, Sundita Kumari, Sudhanshu Kumar, Bipin Kumar
Department of Veterinary Medicine, Bihar Veterinary College, Bihar Animal Sciences University, Patna-800014, Bihar, India
Corresponding author
Arzoo Nisha, PhD
Department of Veterinary Medicine, Bihar Veterinary College, Bihar Animal Sciences University, Patna-800014, Bihar, India
Phone number: 9918061807
Email address: arzoonisha117@gmail.com
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Abstract

Antimicrobial resistance (AMR) is one of the greatest threats to modern veterinary medicine, reducing the effectiveness of antibiotics and making bacterial infections harder to treat. The growing spread of multidrug-resistant bacteria demands smarter approaches to disease control. Recent advances in rapid diagnostics and non-antibiotic therapies- including bacteriophages, probiotics, antimicrobial peptides, phytocompounds, nanotechnology, CRISPR-based tools, vaccines, and immunomodulators- offer promising alternatives to reduce antibiotic dependence. Combined with antimicrobial stewardship and the One Health approach, these innovations can help protect animal health, improve food safety, and preserve the effectiveness of antibiotics for the future.

Keywords: Antimicrobial Resistance (AMR), One Health, Antimicrobial Stewardship, Non-antibiotic Therapies

1. Introduction

Antimicrobial resistance (AMR) has become one of the greatest threats to animal and public health worldwide. Defined by the World Organization for Animal Health (WOAH) as the ability of microorganisms to survive exposure to antimicrobial drugs, AMR is reducing the effectiveness of life-saving antibiotics. Although antibiotics have revolutionized veterinary medicine by improving animal health and productivity, their indiscriminate use in livestock and companion animals has accelerated the emergence of resistant bacteria. These pathogens can spread between animals, humans, food, and the environment, making AMR a

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major One Health challenge. Consequently, preserving antibiotic effectiveness through responsible use and innovative alternatives has become a global priority.

2. Current Scenario of Antimicrobial Use

Antibiotics remain indispensable for treating bacterial diseases in animals, but their use has increased dramatically over the past few decades. More than 100,000 tonnes of antibiotics are used annually in livestock production worldwide, and global consumption in food-producing animals is projected to rise from 131,109 tonnes in 2013 to 200,235 tonnes by 2030. Rising antibiotic use in both animals and humans has intensified the selection of resistant bacteria, accelerating the global spread of antimicrobial resistance. These trends highlight the urgent need for judicious antibiotic use, effective surveillance, and sustainable alternatives to preserve the efficacy of these life-saving drugs.

3. Major Drivers of Antimicrobial Resistance

Antimicrobial resistance (AMR) is mainly driven by the overuse and misuse of antibiotics, often without culture and susceptibility testing. Poor farmer awareness, easy access to antibiotics, and failure to follow proper doses or withdrawal periods further accelerate resistance.

Poor hygiene, overcrowding, and weak biosecurity increase disease outbreaks and antibiotic use, while antibiotic residues in the environment create reservoirs of resistant bacteria. Resistance also spreads rapidly through the exchange of resistance genes between bacteria. Weak surveillance and inadequate regulatory enforcement further hinder AMR control.

Combating AMR requires responsible antibiotic use, improved farm management, stronger surveillance, farmer education, and effective antimicrobial stewardship under the One Health approach.

4. Key Trends in Veterinary Antimicrobial Resistance

Antimicrobial resistance (AMR) is increasing worldwide, with rising numbers of ESBL-producing *Escherichia coli* and *Klebsiella* spp. and multidrug-resistant (MDR) bacteria in livestock and companion animals. Resistance to last-resort antibiotics such as carbapenems and colistin, driven by genes like blaNDM, blaOXA, and mcr-1, is also emerging.

Because resistant bacteria spread between animals, humans, and the environment, AMR is a major One Health challenge. Strengthening antimicrobial stewardship, surveillance, and alternative therapies is essential to slow its spread.

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5. Emerging Trends in Veterinary Antimicrobial Resistance

Antimicrobial resistance is advancing through the spread of genes such as mcr-1, blaNDM, and blaOXA, which move rapidly between bacteria. Modern tools like PCR and whole-genome sequencing (WGS) are improving the detection and tracking of resistant pathogens, strengthening One Health surveillance.

Global trade, animal movement, and non-antibiotic factors such as heavy metals and disinfectants also contribute to AMR spread. In addition, aquaculture and companion animals are emerging as important reservoirs of resistant bacteria. Advances in artificial intelligence and bioinformatics are further improving AMR prediction, surveillance, and antimicrobial stewardship.

6. Innovative Non-Antibiotic Therapies

As antibiotic resistance continues to rise, veterinary medicine is exploring safer alternatives that control infections while reducing antibiotic use. Among the most promising are bacteriophage therapy and probiotics, which help fight disease while preserving beneficial microbes.

6.1 Bacteriophage Therapy: Nature's Bacterial Predator

Bacteriophages (phages) are viruses that specifically infect and destroy bacteria without harming animal cells. Lytic phages, which kill bacteria directly, are preferred for treatment, whereas lysogenic phages are generally avoided because they may transfer resistance genes.

Phage therapy is highly specific, biodegradable, and effective against several antibiotic-resistant bacteria, including *Escherichia coli*, *Salmonella*, *Staphylococcus*, and *Klebsiella*. It has shown promising results in poultry, cattle, pigs, and companion animals. Although challenges such as limited host range and regulatory approval remain, phage therapy is emerging as a valuable tool for reducing antibiotic use under the One Health approach.

6.2 Probiotics: Boosting Natural Defenses

Probiotics are beneficial microorganisms that improve gut health and strengthen the immune system. They help prevent infections by competing with harmful bacteria, producing natural antimicrobial substances, and maintaining a healthy intestinal environment.

Common probiotics such as Lactobacillus, Bacillus, Enterococcus, and Saccharomyces are widely used in livestock and poultry to improve digestion, growth, and disease resistance while reducing diarrhea and antibiotic use. As interest in sustainable

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livestock production grows, probiotics are becoming an important part of disease prevention and reducing dependence on antibiotics.

6.3 Prebiotics: Feeding the Good Bacteria

Prebiotics are special food ingredients that nourish the beneficial bacteria already present in the gut. By supporting a healthy microbiome, they improve digestion, strengthen immunity, and reduce the growth of harmful bacteria.

Common prebiotics such as FOS, MOS, inulin, and β-glucans are widely added to livestock feed to improve gut health, enhance disease resistance, and reduce the need for antibiotics, making them an important part of sustainable animal production.

6.4 Antimicrobial Peptides: Nature's Built-in Antibiotics

Antimicrobial peptides (AMPs) are natural molecules that form part of the body's first line of defense against infections. They destroy bacteria by damaging their outer membrane, making them effective even against many antibiotic-resistant microbes.

Besides killing bacteria, AMPs help prevent biofilm formation, support the immune system, and promote tissue healing. They are being explored as promising alternatives to antibiotics for treating infections such as mastitis, wound infections, and respiratory and intestinal diseases.

As research advances, antimicrobial peptides are expected to become valuable tools for reducing antibiotic use and combating antimicrobial resistance in veterinary medicine.

6.5 Essential Oils and Phytocompounds: Nature's Answer to Resistant Bacteria

Plant-based compounds such as thymol, carvacrol, eugenol, and cinnamaldehyde are emerging as natural alternatives to antibiotics. They fight harmful bacteria by damaging their cell membranes, preventing biofilm formation, and reducing bacterial communication, making infections easier to control.

These natural compounds may also enhance the effectiveness of antibiotics, allowing lower doses to be used. Increasingly incorporated into livestock feed and disease-control programs, essential oils offer a promising, eco-friendly approach to improving animal health and reducing antibiotic dependence.

6.6 CRISPR-Cas Technology: Precision Gene Editing Against AMR

CRISPR-Cas is a revolutionary gene-editing technology that targets and removes antibiotic resistance genes from bacteria. Unlike antibiotics, which kill both harmful and beneficial bacteria, CRISPR acts with remarkable precision, reducing the spread of resistant microbes.

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The technology can eliminate resistance-carrying plasmids, restore bacterial sensitivity to antibiotics, and even disable genes that make bacteria harmful. Although still largely experimental, CRISPR-Cas has the potential to become a powerful tool for controlling antimicrobial resistance and supporting precision veterinary medicine in the future.

6.7 Nanotechnology: Smarter Drug Delivery

Nanotechnology is making veterinary treatments more effective by delivering medicines directly to the site of infection. Tiny carriers such as silver nanoparticles, liposomes, and polymeric nanoparticles improve drug delivery, help break down bacterial biofilms, and enhance antibiotic action.

By using lower doses, improving tissue penetration, and providing controlled drug release, nanotechnology can reduce side effects and support efforts to combat antimicrobial resistance. Although still developing, it shows great promise for treating infections such as mastitis, wound infections, and respiratory diseases.

6.8 Vaccines and Immunomodulators: Prevention is better than Cure

Preventing disease is one of the best ways to reduce antibiotic use. Vaccines protect animals by building immunity before infection occurs, while newer technologies such as recombinant and mRNA vaccines are making disease prevention faster and more effective.

Immunomodulators, including β-glucans, probiotics, and plant-based products, strengthen the animal's natural immune system and improve resistance to infection. Together, vaccines and immunomodulators reduce disease outbreaks, lower antibiotic use, improve animal health, and support sustainable livestock production.

7. Challenges and Future Perspectives

Although non-antibiotic therapies show great promise, their widespread use is still limited by high costs, regulatory hurdles, limited availability, and the need for large-scale field validation. Farmer awareness, standardized treatment protocols, and affordable production are also essential for successful adoption.

Future progress will depend on continued research, supportive policies, and the integration of these therapies with rapid diagnostics, antimicrobial stewardship, and the One Health approach to reduce antibiotic use and combat antimicrobial resistance.

8. Conclusion

Antimicrobial resistance is one of the biggest challenges facing veterinary medicine today. Combating it requires a combination of responsible antibiotic use, rapid diagnosis, vaccination, good biosecurity, and innovative non-antibiotic therapies.

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Emerging approaches such as bacteriophages, probiotics, antimicrobial peptides, CRISPR, phytocompounds, nanotechnology, and immunomodulators offer promising alternatives to reduce antibiotic dependence. With continued research, supportive policies, and global collaboration under the One Health approach, these innovations can help protect animal health, improve food safety, and ensure sustainable livestock production.

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