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Use of Antibiotic Alternatives in Nepal: A Strategy for Sustainable Animal Nutrition

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ABSTRACT

The routine use of antibiotics in animal nutrition has historically improved growth and productivity. However, the continued and often indiscriminate use of these compounds has accelerated the emergence of antimicrobial resistance (AMR), posing serious risks to animal health, food safety, and public health. Nearly three-quarters of antimicrobials are consumed by livestock, allowing resistant pathogens to cross animal, human, and environmental boundaries and undermining the concept of One Health. The present study aimed to assess sustainable feed-based alternatives to antibiotics and their effectiveness in enhancing animal health in the Nepalese context. Based on global evidence and national experiences, the review synthesizes the roles of probiotics, prebiotics, phytobiotics, organic acids, enzymes, precision feeding, and complementary management practices in maintaining animal performance while reducing reliance on antibiotics. Nepal presents both urgency and opportunity for this transition, as livestock production remains largely smallholder-based, regulatory enforcement is uneven, and antimicrobial residues continue to be detected in animal-derived foods. At the same time, increasing awareness, ethno-veterinary knowledge, emerging feed innovations, and recent policy commitments under the national AMR action framework signal positive momentum. The review suggests that replacing antibiotics with alternatives should not be viewed as a simple substitution but rather as a system-level transformation integrating nutrition, biosecurity, vaccination, farmer capacity building, and governance within a One Health framework. Strengthening locally adaptable, cost-effective solutions through field-based research and extension will be critical for sustaining productivity while contributing to national and global efforts to mitigate AMR.

Keywords: Antimicrobial resistance, Feed additive, Sustainable livestock production, One Health

INTRODUCTION

The use of antibiotics in animal agriculture, particularly as growth promoters, has played a central role in enhancing livestock health and productivity. Antibiotic growth promoters enhance feed efficiency and weight gain by inhibiting pathogenic bacteria and promoting intestinal health (Dibner and Richards, 2005; Adegbeye et al., 2020). Globally, almost three-quarters of antimicrobials are used in farm animals, often in non-therapeutic contexts such as prophylaxis and growth promotion (Mulchandani et al., 2023). While these practices transformed modern production systems, they have also accelerated the development of antimicrobial resistance (AMR; Enshaie et al., 2025). Excessive and inappropriate antimicrobial use in animal production systems has accelerated the emergence of antimicrobial-resistant bacteria, increasing the risk of transmission of resistant pathogens and resistance genes across animal, human, and environmental interfaces (Zhang et al., 2024). Projections indicate that, without effective intervention, the annual mortality could rise to nearly 10 million by 2050 (WHO, 2021). Resistance to One Health is further threatened by the spread of pathogens from animals to humans through food, direct contact, and environmental contamination, as exemplified by plasmid-mediated colistin resistance. The *mobilized colistin resistance* gene (*MCR-1*) was first detected in livestock and subsequently reported in humans (Liu et al., 2016). In response to the growing risks of antimicrobial resistance, the European Union implemented a major policy reform in 2006 that prohibited the use of antibiotics as growth promoters in animal production, which marked a significant transition in modern livestock management practices (Attia et al., 2015). Sweden's antibiotic-free system, established after 1985, demonstrated that high productivity can be achieved without routine antibiotic use (Grundin et al., 2020).

Globally, consumer demand for antibiotic-free products, including meat, milk, and eggs, has been increasing rapidly, prompting producers to adopt safer production systems (Hussain et al., 2025). Similarly, in Nepal, increasing concerns regarding antimicrobial resistance, rising consumer awareness about food safety, and the growing emphasis on

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sustainable livestock production have intensified the need for strategies that reduce antimicrobial dependence in animal production. Recent reports indicate a gradual decline in antimicrobial use in food-producing animals, reflecting increasing awareness and stewardship efforts toward prudent antimicrobial use and sustainable livestock management (Upadhyaya et al., 2023). Agriculture contributes approximately 25% to Nepal's national Gross Domestic Product (GDP) and remains a major source of employment and livelihood. Within the agricultural sector, livestock contributes about 25% to the Agricultural GDP (AGDP) and nearly 6% to the national GDP, while the poultry sector alone contributes around 4% to the national GDP and approximately 8% to the AGDP, highlighting its growing economic importance in Nepal (MOF, 2023; MOALD, 2024). The livestock sector contributes significantly to household income, food security, and rural livelihoods, with dairy production, largely dominated by cattle and buffalo, playing a major role in the subsector (FAO, 2023a; MOALD, 2024). Ensuring sustainable and antibiotic-free livestock production systems is not only a public health necessity but also an important economic priority for Nepal (Upadhyaya et al., 2023; WOAH, 2023).

Several studies have reported that probiotics, phytogenic feed additives, organic acids, emulsifiers, neutral feed additives, and exogenous enzymes are promising alternatives to antibiotic growth promoters for improving gut health and production performance in poultry (Vahdatpour and Babazadeh, 2016; Siyal et al., 2017). Such alternatives support gut health, immunity, and performance without contributing to AMR (Attia, 2018; Adegbeye et al., 2020; Zhu et al., 2022). Improvements in intestinal morphology and growth have been well documented in piglets supplemented with *Lactobacillus* spp., highlighting their potential in the antibiotic-free era (Yi et al., 2018; Wang et al., 2019). Alternative nutritional and management strategies should be viewed as part of a broader approach to sustainable and resilient livestock production rather than simply as replacements for antibiotics. Combined with improved biosecurity, vaccination, and precision nutrition, these approaches can help protect animal health, ensure food safety, and reduce antimicrobial resistance (Van Boeckel et al., 2019). For Nepal, adopting these strategies offers a unique opportunity to align livestock development with One Health principles while meeting domestic food security needs and international standards for safe animal products. Therefore, the current review aimed to synthesize current knowledge on antibiotic alternatives in livestock production, with emphasis on their mechanisms, efficacy, and practical applicability within Nepal as a low- and middle-income context.

METHODOLOGY

A narrative synthesis approach was employed to collate and critically interpret published evidence on antibiotic alternatives in livestock production. Relevant literature was retrieved through systematic searches of Scopus, Web of Science, PubMed, ScienceDirect and Google Scholar, including peer-reviewed research articles, review papers, meta-analyses and policy documents published primarily between 2005 and 2025. Search strategies combined terms related to antibiotic alternatives, antimicrobial resistance, livestock nutrition, probiotics, phytogenic, precision nutrition, biosecurity, and One Health, alongside Nepal-focused keywords. Studies were included if non-antibiotic interventions in food-producing animals and reported outcomes are associated with animal health, growth performance, immune function, or reductions in antimicrobial usage. In addition, policy and surveillance documents from WHO, FAO, WOAH, Codex Alimentarius, and relevant national authorities were consulted to provide regulatory and contextual perspectives. The selected literature was examined critically and synthesized thematically, with emphasis on biological plausibility, field-level feasibility, and consistency with One Health principles.

Alternatives to antibiotics

Farmers are now shifting from irrational antibiotic use to safer alternatives in livestock and poultry production due to rising concerns about AMR, regulatory restrictions, and consumer demand for safe products (Tang et al., 2017; Lambo et al., 2021; Leistikow et al., 2022; Hussain et al., 2025). At the same time, increasing consumer preference for antibiotic-free animal products has created market incentives and premium value for safer production systems (Hussain et al., 2025). Antibiotic alternatives have shown potential to improve growth, health, and productivity, as well as reduce AMR risks (Wang et al., 2024). Natural feed additives, such as phytobiotics, essential oils, and medicinal plants, are widely recognized for their antimicrobial, antioxidant, and digestive benefits (Lillehoj et al., 2018). Compounds such as eucalyptol and eugenol (Brenes and Roura, 2010), ginger extracts, tannins, and turmeric (Abd El-Hack et al., 2022), and moringa-derived bioactive compounds, including moringin (Khan et al., 2021), have demonstrated efficacy in enhancing gut health, nutrient absorption, immunity, and resilience, particularly in antibiotic-free production systems. Probiotics and prebiotics represent another robust category; probiotics improve intestinal morphology and secrete antimicrobial metabolites, such as bacteriocins, while prebiotics selectively stimulate beneficial microbes and enhance nutrient utilization (Pourabedin and Zhao, 2015; Solís-Cruz et al., 2020). Spore-forming probiotics, including specific *Bacillus* strains, are remarkably resilient, helping to stabilize the gut microbiota and improve performance (Grant et al., 2018).

In addition to botanical and microbial alternatives, short- and medium-chain fatty acids are known to suppress harmful bacteria, such as *Escherichia coli* and Salmonella (Van Immerseel et al., 2006). Organic acids also improve carcass characteristics and overall meat quality, making them valuable components of antibiotic-free feeding strategies (Szabó et al., 2023). Insect meal has emerged as an innovative protein source with immunostimulatory benefits, reducing dependency on antibiotics. Similarly, bacteriophages that selectively target bacteria offer precise control of infections without disrupting beneficial microbiota, while antimicrobial peptides (AMPs), as components of innate immunity, provide broad-spectrum bactericidal activity with a low risk of resistance development (Kumar et al., 2020; Łusiak-Szelachowska et al., 2022). Emerging technologies, including nanotechnology and immunomodulators, further expand the toolbox of sustainable alternatives by enhancing nutrient delivery and strengthening host defenses (Adegbeye et al., 2020). In addition, natural plant-derived phytogenic feed additives have been extensively investigated and shown to support health, performance, and immunity while reducing antibiotic dependence in livestock production (Wang et al., 2024).

Table 1. Commonly used alternatives to antibiotics in livestock and poultry production systems in Nepal

Alternatives to antibiotics	Examples	References
Ethnoveterinary remedies (traditional plant-based)	Turmeric (*Curcuma longa*), garlic (*Allium sativum*), ginger (*Zingiber officinale*), neem (*Azadirachta indica*), tulsi (*Ocimum* spp.)	Uprety et al. (2022)
Herbal growth promoters / phytogenic herbs (on-farm and premixes)	Tulsi, amla (*Phyllanthus emblica*), ashwagandha (*Withania somnifera*)	Sanjyal and Sapkota (2011)
Probiotics (bacterial/yeast preparations)	*Lactobacillus* spp., *Bacillus* spp., yeast products (commercial probiotic premixes/water supplements)	Gupta et al. (2023)
Synbiotics (probiotic plus prebiotic blends)	Synbiotic premixes in feed/water (routine or targeted phases)	Acharya et al. (2024)
Organic acids/acidifiers	Citric acid, sorbic acid, formic/propionic blends; feed/water acidifiers (commercial)	Jha (2019)
Biosecurity plus hygiene (management alternative replacing “routine prophylaxis”)	Footbaths, controlled entry, litter management, water sanitation, rodent control, downtime/all-in-all-out (where feasible)	Poudel et al. (2024)
Vaccination as an AMU-reduction strategy (prevention-first)	ND vaccination (poultry); routine livestock vaccines (FMD/PPR programs in ruminants)	Shahi et al. (2023)
Training/stewardship interventions (behavioral alternative)	Farmer awareness, prudent-use guidance, and reduced preventive antibiotic use	Shahi et al. (2023)

AMU: Antimicrobial use, ND: Newcastle disease, FMD: Foot and mouth disease, PPR: Peste des petits ruminants.

Alternatives to antibiotics in Nepal’s livestock farming

Livestock and poultry are central to Nepal’s agriculture, engaging nearly two-thirds of the population and ensuring food security (Bagale et al., 2022; Upadhyaya et al., 2023). However, antibiotic use is widespread and poorly regulated, with about 90% of poultry farms in the Kathmandu Valley administering critically important drugs, often without veterinary oversight (Koirala et al., 2021; Subedi et al., 2023). Awareness of antibiotic resistance is limited, as only one-third of farmers report understanding AMR (Lambrou et al., 2021). Notably, national antimicrobial consumption decreased from 91,088 kg in 2018 to 45,671 kg in 2020, accompanied by a decline in the use of WHO Class I drugs (Upadhyaya et al., 2023). A range of antibiotic alternatives is already in use in Nepal’s livestock sector, particularly in poultry and smallholder dairy systems (Upadhyaya et al., 2023). Ethnoveterinary remedies such as turmeric (*Curcuma longa*), ginger, and garlic are commonly used in backyard production for infection control and immune support (Uprety et al., 2022), while herbal feed additives, including tulsi (*Ocimum sanctum*), moringa, and neem, are increasingly adopted to improve gut health, growth performance, and disease resistance (Sanjyal and Sapkota, 2012; Yadav et al., 2022). Probiotics and yeast-based supplements are used across poultry and dairy systems to stabilize the gut microbiota and reduce reliance on antibiotics (Gupta et al., 2023). Preventive vaccination against major diseases and the use of phytogenic compounds from essential oils further limit the need for therapeutic antibiotics (Acharya and Wilson, 2019; Koirala et al., 2021; Poudel and Bhatt, 2024). Complementary biosecurity measures, including footbaths, litter management, and controlled farm entry, also play a key role in lowering infection pressure and antimicrobial use (Dhakal and Gompo, 2022; Dhakal et al., 2025). Despite progress in antimicrobial resistance awareness, antibiotic use regulations, and national policy development, challenges persist in residue monitoring, farmer education, and policy enforcement. Although Nepal has endorsed a One Health approach, implementation at the grassroots level remains weak, necessitating stronger awareness programs, effective regulatory mechanisms, and greater investment in sustainable alternatives (Acharya et al., 2019; Bagale et al., 2023). Common alternatives to antibiotics used in Nepal are shown in Table 1.

Biosecurity, hygiene, and antibiotic alternatives

Reducing infection pressure through strict biosecurity, as well as water, sanitation, and hygiene, remains the foundation of antimicrobial stewardship (FAO, 2021). Strict biosecurity protocols, including controlled farm entry, flock/herd compartmentalization, and pathogen exclusion at housing and equipment levels, significantly reduce pathogen pressure and unnecessary antimicrobial exposure (Postma et al., 2017). Environmental regulations play a significant role in minimizing AMR risks (UNEP, 2023). Likewise, hygiene, clean water systems, litter quality control, and routine sanitation lower the environmental pathogen load, thereby enhancing the baseline performance of alternative strategies such as probiotics or phytobiotics (Lambrou et al., 2021). Vaccination programs further reinforce the framework by establishing herd immunity against high-impact diseases (Newcastle disease virus [NDV], foot-and-mouth disease [FMD], and peste des petits ruminants [PPR]), reducing the frequency and severity of clinical outbreaks, and lowering reliance on therapeutic antibiotics (OIE, 2021). Equally important is manure and waste management, where regulated composting and controlled disposal interrupt the environmental spread of antibiotic residues, resistant bacteria, and resistance genes (He et al., 2020). Aerobic composting has been shown to reduce antibiotic resistance genes (ARGs) and mobile genetic elements by 70-90%, preventing their dissemination into soil–water ecosystems (Keenum et al., 2021; Wang et al., 2024). Once the preventive foundation is established, nutrition-based alternatives such as probiotics, phytobiotics, organic acids, yeast derivatives, and competitive exclusion cultures become more effective in supporting gut health, immunity, and production performance (Gadde et al., 2017; Diaz Carrasco et al., 2019). Probiotics, phytogenic compounds, organic acids, enzymes, and related feed additives should not be considered replacements for effective management practices; rather, such interventions function as complementary strategies integrated with strong production system controls to improve gut health, immunity, and animal resilience while reducing reliance on antimicrobial agents (Gadde et al., 2017; Yaqoob et al., 2022). The One Health approach integrates farm-level biosecurity, environmental hygiene, public health protection, and antimicrobial resistance (FAO, UNEP, WHO, WOAH, 2022).

Precision nutrition and smart farming

Precision nutrition aims to optimize nutrient supplementation based on the specific requirements of individual animals (González et al., 2018). The optimization is made possible by data-based rationing and feed supplementation, which are implemented only after assessing feed quality and reducing excretion (Zuidhof, 2020). In the case of poultry, the integration of metabolites into precision feeding has shown better performance effects, and sustainability is promising (Abd El-Hack et al., 2025). The integration of precision livestock farming technologies, sensors, analytics, and decision dashboards can detect deviations in animal health status through behavioral, acoustic, and thermal cues, thereby enabling timely interventions and reducing the need for antibiotics (Rowe et al., 2019; Schillings et al., 2021). Furthermore, advancements in biosensors have enabled the rapid detection of pathogens and increased the effectiveness of preventive systems over curative ones (Boodhoo et al., 2024).

Policies, awareness, and capacity building

A coordinated global effort to improve antimicrobial stewardship is advancing through joint leadership from the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO), the World Organization for Animal Health (WOAH, formerly OIE), and the United Nations Environment Program (FAO, UNEP, WHO, WOAH, 2022). The organizations are aligning strategies to reinforce veterinary governance, laboratory systems, and AMR monitoring. Key instruments supporting this agenda include the FAO Action Plan on AMR (2021-2025), the Progressive Management Pathway for AMR (PMP-AMR), and WOAH's Performance of Veterinary Services (PVS) framework, all of which are designed to strengthen national capacities and coordinated surveillance within animal health systems (FAO, UNEP, WHO, WOAH, 2022). At the same time, the Codex Alimentarius has raised concern regarding guidelines for monitoring and managing food-borne antimicrobials, providing a global benchmark for countries to integrate responsible antibiotic use into their food safety systems (Codex Alimentarius, 2021; FAO, 2022; WHO, 2024). Nepal has taken steps to align with these global directives. The National Action Plan on AMR (2024–2028), which adopts a One Health approach, is currently being implemented by the Ministry of Health and Population (MoHP; National Action Plan on Antimicrobial Resistance 2024-2028 endorsed by WHO and led by the MoHP), supported through a One Health approach. Similarly, a national AMR steering committee and technical working groups function as governing bodies at the national level. The regulation of veterinary antimicrobial use in Nepal is primarily governed by the Drugs Act of 1978, which provides the legal framework for the registration, production, importation, distribution, inspection, and quality control of veterinary medicines (Government of Nepal, 1978). Under this framework, relevant government agencies oversee the authorization, monitoring, and regulation of veterinary drugs in the country. Furthermore, the FAO and Codex have begun integrating AMR surveillance into the poultry value chain, thereby helping to ensure both animal and food safety (FAO, 2023b). Despite these advancements, gaps remain in residue monitoring, farmer awareness, and community-level enforcement. To achieve meaningful outcomes, provincial action plans must be strengthened, awareness campaigns expanded, and reliable alternatives promoted.

National antimicrobial resistance response and ongoing interventions

Nepal has undertaken a range of coordinated actions to address AMR through policy development, surveillance, education, and stewardship within a One Health framework. The national action plan on AMR provides the central policy platform for integrating human and animal health interventions and aligning national efforts with global AMR priorities (Khanal et al., 2023; Yadav et al., 2023). Antimicrobial resistance surveillance, initiated in 1999, focuses on priority pathogens but remains constrained by limited laboratory capacity and insufficient sentinel sites, underscoring the need for system expansion and strengthening (Frumence et al., 2021; Maharjan et al., 2023). Complementary initiatives include awareness and training programs targeting healthcare providers, veterinarians, and the public to promote rational antimicrobial use (Ayukekbong et al., 2017; Acharya and Wilson, 2019; Gahimbare et al., 2023), alongside the gradual implementation of antimicrobial stewardship programs in human and veterinary sectors to curb inappropriate prescribing and non-therapeutic antibiotic use (Saha et al., 2019; Mutua et al., 2020; Leung et al., 2024). Sustained investment, regulatory enforcement, and multisectoral collaboration supported by international frameworks and partners remain essential for effective AMR mitigation in Nepal.

Challenges and prospects

Despite growing evidence supporting antibiotic alternatives, their adoption in Nepal remains limited due to economic constraints, weak extension systems, and insufficient field-based evidence. Smallholder-dominated production systems rely heavily on low-cost antibiotics for growth promotion and disease prevention, as many alternatives, such as probiotics, phytobiotics, essential oils, and precision feeding tools, remain financially inaccessible and largely imported, limiting farmer uptake (Acharya and Wilson, 2019; Lambrou et al., 2021). Cost constraints are further exacerbated by weak rural infrastructure, fragmented supply chains, and limited local production of feed additives, collectively hindering reliable access to alternatives and reinforcing dependence on conventional antimicrobials (Saud et al., 2019; Sharma et al., 2025). In addition, gaps in farmer knowledge and technical capacity reduce confidence in non-antibiotic interventions, as limited extension services and training opportunities restrict understanding of appropriate application, expected outcomes, and long-term benefits (Subedi et al., 2023). Addressing the challenges requires specific, integrated strategies, including targeted financial incentives for antibiotic-free inputs, promotion of local production and entrepreneurship, strengthened extension and capacity-building programs of para-veterinary professionals, and further study in multi-season, on-farm field trials that evaluate the productivity and economic viability of alternative approaches under local conditions (Charoenratana and Kharel, 2024). Such measures are essential to shift antibiotic alternatives from experimental options to scalable, mainstream components of Nepal's antimicrobial stewardship and sustainable livestock development pathways.

Global collaboration for safer animal products

The transition to safer animal production systems and the effective containment of AMR critically depend on strong global collaboration, particularly to bridge implementation gaps observed across countries such as Nepal. Although many countries have developed national AMR action plans, uneven enforcement, weak surveillance, and limited institutional capacity continue to undermine their effectiveness, underscoring the need for harmonized standards, interoperable monitoring systems, and coordinated cross-border actions (Woolhouse et al., 2015; Boeckel et al., 2019). International frameworks such as the Codex Alimentarius, the FAO Progressive Management Pathway for AMR, and the WOAH Performance of Veterinary Services Pathway provide guidance for aligning national policies with global antimicrobial resistance mitigation efforts (WOAH, 2019; FAO, 2022). In Nepal, irrational and routine antibiotic use in animal husbandry, driven by limited regulatory enforcement, inadequate laboratory infrastructure, and poor surveillance, has been identified as a major contributor to AMR, including the emergence of multidrug-resistant pathogens in animal-derived foods with direct public health implications (Acharya and Wilson, 2019; Subedi et al., 2023; Mim et al., 2024). Strengthening laboratory networks, workforce development, and traceability systems through targeted international support is therefore essential to translate farm-level interventions into population-wide reductions in AMR risk (Al Bakri et al., 2025). Moreover, facilitating international trade in animal products produced under responsible antibiotic-use standards can provide economic incentives for producers to adopt safer practices, aligning market access with global food safety expectations (Maffioli et al., 2025). The effective global collaboration against AMR must combine adherence to international frameworks with sustained investments in local capacity, stakeholder engagement, and innovation, thereby safeguarding public health while promoting resilient and sustainable animal production systems (Elbehiry et al., 2025; Obolensky et al., 2025).

CONCLUSION

Nutrition-based alternatives, including probiotics, phytobiotics, organic acids, enzymes, and precision feeding approaches, offer practical, evidence-based ways to sustain animal health and productivity while progressively reducing reliance on antibiotics. A coordinated, system-level strategy that integrates nutritional innovations with strengthened biosecurity, preventive vaccination, farmer-oriented training, and effective policy enforcement will achieve better results in AMR. Further studies on cost-effective, locally adaptable alternatives are needed to support broader adoption and achieve long-term reductions in antimicrobial resistance in Nepal.

DECLARATIONS

Authors' contributions

Arjun Acharya and Utshav Pandey wrote the article. Arjun Acharya collected the information and prepared the original manuscript draft. Both authors contributed to the review and editing of the manuscript. Both authors read and approved the final version of the manuscript before publication in the present journal.

Availability of data and materials

All information used in the current study was derived from publicly available articles, which have been appropriately cited in the manuscript.

Competing interests

The authors declare no competing interests.

Ethical considerations

Ethical issues, including plagiarism, consent to publish, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been carefully checked and confirmed by the authors. The authors confirmed that no AI website or software programs were used to prepare, write, or revise this article.

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