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Redefining Herd Health: No-Antibiotic Strategies for Revolutionizing Sustainable Dairy Development

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Abstract

This study investigates the potential of no-antibiotic strategies to transform herd health management and promote sustainable dairy development. Rising concerns over antimicrobial resistance (AMR) and the environmental consequences of antibiotic use have intensified the demand for alternative, sustainable disease management approaches. No-antibiotic strategies emphasize preventive health measures, biosecurity, and holistic practices, including optimized nutrition, vaccination, and natural antimicrobial alternatives. The study evaluates diverse management interventions, such as precision livestock farming, genetic selection for disease resistance, and the use of probiotics, prebiotics, and essential oils, to strengthen herd immunity and reduce disease incidence. It also highlights the importance of improved housing systems, stress management, and pasture-based practices in maintaining animal health without antibiotics. Integrating these strategies provides dual benefits, enhancing animal welfare while supporting the long-term sustainability of dairy operations. By shifting from reactive to preventive health measures, no-antibiotic approaches not only improve productivity but also mitigate public health risks associated with AMR. This study offers a comprehensive review of current no-antibiotic strategies and presents practical recommendations for their implementation globally, aiming to establish dairy systems that are both economically viable and environmentally responsible.

Keywords: Antimicrobial resistance, biosecurity, herd health, natural antimicrobials, preventive management, sustainable dairy, vaccination strategies

INTRODUCTION

Antibiotic use in dairy farming has long been an essential tool for managing diseases, promoting growth, and ensuring high productivity [1–3]. However, the growing concerns regarding antimicrobial resistance (AMR) have highlighted the risks associated with excessive antibiotic use in animal husbandry [4–6]. AMR poses a significant threat to public health, as resistant pathogens can be transferred from animals to humans through the food chain. Consequently, there is increasing pressure on dairy farms to adopt alternative, more sustainable disease management practices that reduce or eliminate reliance on antibiotics [7–9]. No-antibiotic strategies focus on preventive health measures that promote the overall well-being of dairy cattle while minimizing the risks associated with drug resistance [10, 11].

The implementation of no-antibiotic strategies involves various innovative practices aimed at improving animal health and disease management without the use of traditional antibiotics [4, 12]. These strategies emphasize biosecurity, disease prevention, and the use of natural alternatives, such as probiotics, prebiotics, and herbal remedies, to enhance herd immunity and prevent infections [4,

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12, 13]. In addition, managing animal stress through improved housing, proper nutrition, and environmental enrichment is crucial for minimizing the occurrence of disease [11, 14]. Precision livestock farming techniques, including the use of advanced diagnostics and monitoring tools, also play a vital role in detecting early signs of health issues, enabling timely interventions without the need for antibiotics [7, 15].

This study is novel in its comprehensive approach to understanding and promoting no-antibiotic strategies in dairy farming. While previous research has explored individual aspects of alternative disease management, this work consolidates the full spectrum of no-antibiotic practices into a unified framework. It offers new insights into the integration of natural antimicrobials, precision management, and animal welfare practices, demonstrating how these methods can collectively support sustainable dairy farming. By focusing on preventive health and disease resilience, the study provides valuable recommendations for transitioning to antibiotic-free dairy systems that align with global health and environmental goals.

SIGNIFICANCE OF THE STUDY

The study comprehensively reviews preventive herd health strategies that eliminate antibiotic reliance in dairy farming. It consolidates evidence-based practices across biosecurity, nutrition (e.g., probiotics, prebiotics, phytogenics), natural antimicrobials (e.g., essential oils, herbal remedies), vaccination, precision livestock farming, and welfare improvements like stress reduction and housing, demonstrating their potential to enhance animal immunity, productivity, and milk quality while minimizing disease incidence. This framework not only promotes economic viability and environmental stewardship but also aligns with One Health goals, offering actionable recommendations for transitioning dairy operations worldwide toward sustainability, particularly relevant for regions like Bangladesh facing AMR pressures in livestock production (Figure 1).

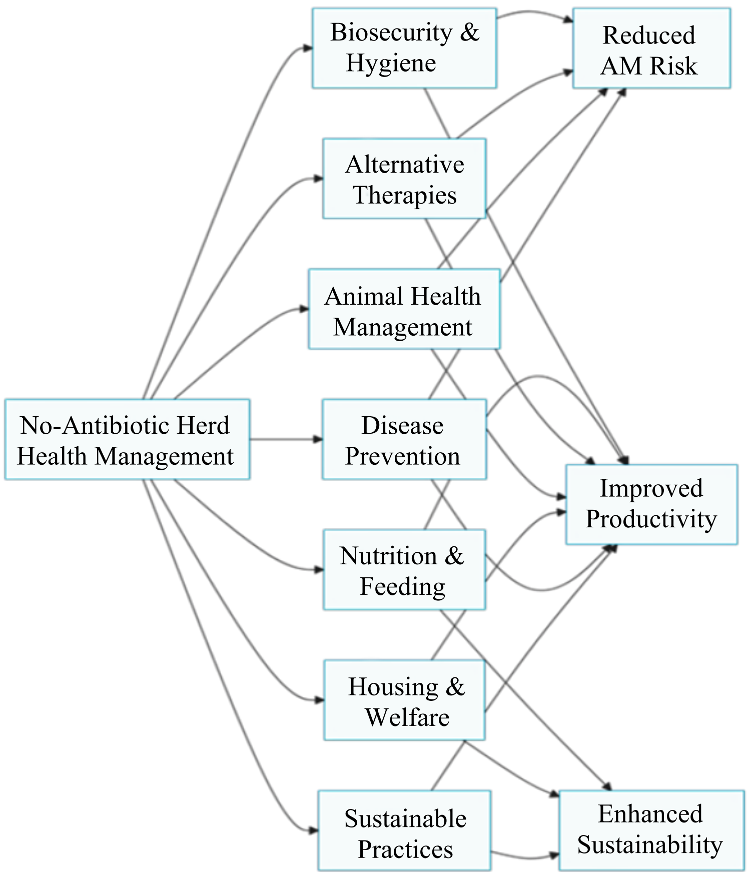

Figure 1. A simple conceptual framework illustrating no-antibiotic herd health for sustainable dairy farming.

Industry Benefits

Dairy producers gain from enhanced herd immunity via biosecurity, nutrition, and natural alternatives, leading to higher productivity, better milk quality, and reduced treatment costs without antibiotics. These approaches improve animal welfare and farm resilience, supporting economic viability in regions like Bangladesh amid rising AMR pressures.

Policy Implications

Policymakers can leverage the framework to craft regulations favoring preventive herd management, aligning with global One Health initiatives to mitigate AMR transmission from farms to humans via the food chain. It provides evidence for incentives on vaccination, precision farming, and sustainable waste practices, fostering environmental stewardship in livestock sectors.

Theoretical Contributions

The paper integrates diverse literature into a novel systems-level framework, highlighting synergies (e.g., nutrition enhancing vaccination efficacy while improving welfare). This approach advances One Health theory by connecting farm-level interventions to public health and environmental outcomes, addressing the lack of prior comprehensive models.

Practical Contributions

The study provides actionable recommendations for farmers in resource-limited settings, such as Bangladesh, including neem-based pest control and rotational grazing. These strategies support economic sustainability by reducing treatment costs and maintaining consistent milk production.

Novelty and Relevance

The paper's comprehensive synthesis of natural antimicrobials, precision tools, and welfare innovations distinguishes it from siloed prior work, offering real-world applicability for transitioning antibiotic-reliant farms to resilient systems amid 2026 AMR crises.

Research Gap

The study identifies a key research gap in the lack of empirical field trials validating the integrated framework's long-term efficacy across diverse agro-climatic zones. While it consolidates preventive practices like biosecurity, phytogenics, and precision farming, no quantitative data exists on disease incidence reductions, economic returns, or AMR mitigation from holistic implementation, unlike siloed studies on individual interventions. Future research should prioritize randomized controlled trials in smallholder systems (e.g., Bangladesh) measuring outcomes via LCA metrics and genomic resistance tracking. This addresses the novelty gap, as recent initiatives like Dairy HERD highlight needs for data linking health management to environmental/economic impacts.

METHODOLOGY

Study Design

It adopts a comprehensive qualitative review framework, organizing preventive practices thematically into sections like biosecurity, nutrition, alternative therapies, health management, housing, disease prevention, and sustainable practices, without primary data collection or controlled trials. This consolidated model emphasizes holistic integration over isolated tactics, drawing from global dairy contexts to propose a unified pathway from reactive antibiotic use to proactive management.

Data Sources

Content relies on 114 cited references (numbered 1–114), spanning peer-reviewed articles, reports, and guidelines on topics, such as AMR epidemiology, phytogenic efficacy, vaccination protocols, and precision farming tools, primarily from veterinary, nutritional, and agricultural journals. Sources include studies on probiotics (e.g., Refs. 31–32), essential oils (33–34), and biosecurity (16–17), reflecting evidence up to the publication date without meta-analytic pooling.

Analysis Methods

No quantitative statistical analyses, meta-analyses, or modeling were conducted; instead, the author used descriptive synthesis, highlighting synergies among strategies through expert interpretation and practical recommendations. This approach identified implementation barriers and benefits qualitatively, filling a gap in unified frameworks despite the absence of original data validation.

Limitations

Lack of standardized protocols prevents replicability, as readers cannot verify search comprehensiveness or inclusion rationale from the 114 cited references. Absence of quantitative synthesis (e.g., no meta-analysis) limits assessment of evidence strength, relying instead on qualitative interpretation prone to author subjectivity. This approach risks incomplete coverage of contradictory findings and offers lower methodological rigor compared with systematic reviews, reducing confidence in holistic framework recommendations for no-antibiotic strategies. Empirical validation through primary trials remains necessary.

BIOSECURITY AND HYGIENE

Biosecurity Measures

Strict biosecurity measures are fundamental to preventing the entry and spread of pathogens in dairy farms. Preventing external infections through proper animal quarantine, controlling farm visitors, and regulating the movement of livestock can significantly reduce disease risks [16, 17]. By minimizing contact with infected animals or contaminated materials, non-antibiotic strategies help maintain herd health without relying on antibiotics for disease control.

Farm Sanitation Practices

Improved sanitation practices are essential in maintaining a disease-free environment. Regular cleaning of barns, feeding equipment, and milking systems reduces pathogen load and minimizes infection risks [16, 17]. Ensuring that all surfaces are disinfected properly and removing manure promptly prevents bacterial buildup. These sanitation measures support an antibiotic-free approach by reducing the need for pharmaceutical treatments and promoting natural disease resistance.

Hygienic Milking Practices

Promoting hygienic milking practices is crucial for preventing mastitis and other udder infections. This includes regular washing and sanitizing of teats, using clean cloths, and ensuring milking machines are disinfected [18–20]. By reducing the risk of infections through these practices, dairy farmers can prevent the need for antibiotics, leading to healthier cows and higher-quality milk without compromising animal welfare.

Rodent Control

Effective rodent control is vital for preventing disease transmission from pests to livestock. Rodents can carry diseases, such as leptospirosis and salmonella, which can lead to outbreaks in dairy herds [21–25]. Implementing rodent control measures, such as sealing entry points, using traps, and maintaining cleanliness around the farm, reduces the need for antibiotics by minimizing pathogen exposure and supporting overall herd health.

Prevent Wild Animal Exposure

Exposure to wild animals and birds can introduce harmful pathogens to the farm, leading to infections and disease outbreaks. Preventing wildlife from accessing barns or feed storage areas is a critical aspect of disease prevention [21–23]. Netting, proper fencing, and securing feed supplies reduce the risk of zoonotic diseases, promoting herd health and eliminating the need for antibiotic interventions in the process.

Prevent Water Stagnation

Water stagnation around the farm provides breeding grounds for pathogens and disease vectors such as mosquitoes. Ensuring proper drainage and preventing water accumulation reduces the chances of infection spread [19, 26, 27]. Clean, flowing water sources are essential for maintaining herd health. By managing water effectively, dairy farms can avoid waterborne diseases and reduce reliance on antibiotics for disease control and prevention.

Feeding Equipment Cleanliness

Regular cleaning of feeding equipment is essential to ensure that food remains uncontaminated and free of pathogens. Improperly cleaned troughs and feeders can harbor bacteria and parasites, leading to digestive issues and infections [28–30]. Ensuring cleanliness through regular disinfecting procedures helps prevent diseases, reducing the need for antibiotic treatments and promoting overall animal health without compromising milk production.

Clean Bedding for Mastitis

Clean bedding is crucial in preventing mastitis, a common infection that requires antibiotic treatment. Dirty or damp bedding increases the risk of bacterial infection, leading to udder inflammation [18–20]. By providing clean, dry, and well-maintained bedding, dairy farmers can reduce the likelihood of mastitis and other infections, fostering a healthier, antibiotic-free herd that naturally resists diseases.

Calving Pen Cleanliness

Maintaining clean and dry calving pens is essential for preventing infections in newborn calves. A hygienic environment reduces the risk of neonatal diseases such as diarrhea and respiratory infections [18–20]. By ensuring that calving pens are regularly cleaned and disinfected, dairy farmers can promote calf health and minimize the need for antibiotics, supporting sustainable practices and fostering a resilient dairy herd.

Iodine Disinfectant Use

Applying iodine-based disinfectants to teats before and after milking is an effective way to prevent mastitis and other udder infections [26]. Iodine acts as a powerful antiseptic that reduces bacterial load, thus minimizing the need for antibiotics. By integrating iodine disinfectants into routine milking procedures, dairy farmers can maintain udder health and ensure high-quality milk production without resorting to antibiotic treatments.

NUTRITION AND FEEDING

Probiotics for Gut Health

Enhancing animal nutrition with probiotics supports healthy gut microbiota, which is crucial for digestion and immune function. Probiotics help balance beneficial bacteria, improving nutrient absorption and reducing the risk of gut infections [31, 32]. By promoting natural disease resistance and improving overall health, probiotics reduce the need for antibiotics and contribute to sustainable dairy farming practices that prioritize animal wellness.

Prebiotics for Gut Health

Prebiotics play an essential role in enhancing gut health by promoting the growth of beneficial bacteria. Including prebiotics in the diet strengthens the digestive system, improving nutrient absorption and immune responses [31, 32]. By supporting the natural defense mechanisms of dairy cattle, prebiotics reduce susceptibility to infections, minimizing the reliance on antibiotics and fostering long-term sustainability in dairy farming practices.

Organic Acids in Feed

Incorporating organic acids into animal feed helps regulate the digestive system by lowering pH levels in the stomach and inhibiting the growth of harmful pathogens [33, 34]. Organic acids, such as formic acid, also improve the absorption of essential minerals and nutrients. These feed additives promote gut health and support disease prevention, enabling dairy farmers to maintain herd health without the use of antibiotics.

Phytogenics as Growth Promoters

Phytogenics, including essential oils, plant extracts, and herbs, are natural growth promoters that improve feed efficiency and overall animal health. These plant-based additives support digestion, reduce inflammation, and enhance immunity [16, 35, 36]. By using phytogenics as natural alternatives to synthetic growth promoters, dairy farmers can reduce antibiotic use while improving animal performance and ensuring a more sustainable and eco-friendly dairy operation.

Moldy or Contaminated Feed

Feeding moldy or contaminated feed poses significant health risks to dairy cattle, including gastrointestinal infections and mycotoxicosis [33, 34]. These conditions often require antibiotic treatments, which can contribute to antibiotic resistance. Ensuring that feed is stored properly and regularly inspected for mold and contaminants reduces the risk of disease outbreaks, promoting a healthier herd and eliminating the need for antibiotics in disease management.

Feed Toxin Testing

Regularly testing feed for toxins is essential in preventing the adverse effects of contaminated feed on animal health. Feedborne toxins, such as aflatoxins, can cause various health issues and increase the likelihood of infections, leading to antibiotic use [16, 35, 36]. Routine testing helps detect potential contaminants early, allowing for the removal of toxic feed and minimizing the risk of disease, thus supporting a non-antibiotic approach in dairy farming.

Forage-Based Diets

Promoting forage-based diets helps reduce the risk of acidosis and other digestive disorders in dairy cattle. Forages, such as grass and hay, provide the necessary fiber to maintain healthy rumen function and pH balance [16, 35, 36]. By prioritizing forage in the diet, dairy farmers can reduce the need for antibiotics to manage digestive health, promoting a more natural and sustainable approach to cattle nutrition and health.

Balanced Calcium and Phosphorus

Ensuring a balanced supply of calcium and phosphorus in feed is essential for optimal growth, reproduction, and bone health in dairy cattle [16, 35, 36]. Deficiencies or imbalances in these minerals can lead to metabolic disorders, such as milk fever, which often requires antibiotic intervention. By maintaining proper calcium and phosphorus levels, dairy farmers can prevent these conditions, supporting a healthier herd and reducing the reliance on antibiotics for treatment.

Salt Licks for Mineral Balance

Providing free access to salt licks is crucial for maintaining mineral balance and supporting overall animal health. Salt licks help regulate electrolyte levels, which are vital for hydration, digestion, and immune function [32, 36–39]. By ensuring that dairy cattle have access to sufficient salt and minerals, farmers can improve herd health and prevent deficiencies that may otherwise lead to disease, reducing the need for antibiotics.

Minimize Feed Wastage

Minimizing feed wastage is important for preventing contamination and maintaining a clean feeding environment. Spoiled or uneaten feed can become a breeding ground for harmful bacteria and pathogens, increasing the risk of infections [32, 36–39]. By managing feed efficiently, ensuring proper storage, and reducing waste, dairy farmers can improve herd health and minimize the need for antibiotics, contributing to sustainable and effective disease management.

ALTERNATIVE THERAPIES AND NATURAL ANTIMICROBIALS

Essential Oils as Antimicrobials

Essential oils, such as thyme, oregano, and eucalyptus, possess antimicrobial properties that help control pathogens in dairy cattle without the need for antibiotics. These oils can be incorporated into feed or applied topically to reduce infection risks [33, 34]. By replacing conventional antibiotics with essential oils, dairy farmers can promote natural disease resistance and support herd health, fostering a more sustainable farming system.

Herbal Remedies for Disease Prevention

Herbal remedies, such as garlic, turmeric, and ginger, offer natural disease prevention by boosting immunity and possessing antimicrobial properties [40–42]. These herbs can be included in the diet or applied as topical treatments to enhance cattle health. By reducing the need for antibiotics, herbal remedies contribute to more sustainable and environmentally friendly disease management strategies, benefiting both animal welfare and farm profitability.

Neem-Based Sprays for Pest Control

Neem-based sprays serve as effective natural pesticides, repelling harmful insects and parasites without harming livestock or the environment. Neem's natural compounds, including azadirachtin, disrupt the life cycles of pests and prevent infestations [40–42]. By utilizing neem-based sprays, dairy farmers can reduce the use of chemical pesticides and antibiotics, ensuring healthier cattle and promoting sustainable farming practices.

Herbal Dewormers for Parasite Control

Herbal dewormers, including garlic, pumpkin seeds, and wormwood, are natural alternatives to chemical anthelmintics for controlling internal parasites in dairy cattle [43–47]. These herbs possess natural antiparasitic properties that support digestive health and reduce the reliance on synthetic medications [43–47]. By integrating herbal dewormers into routine parasite management, farmers can maintain herd health and minimize antibiotic use, promoting a more holistic approach to disease prevention.

Fermented Plant Extracts for Health

Incorporating fermented plant extracts into animal diets enhances gut health and promotes overall wellness. These extracts contain beneficial microorganisms that improve digestion and boost the immune system [40–42]. Fermentation also increases the bioavailability of nutrients, ensuring optimal absorption. By using fermented plant extracts, dairy farmers can promote sustainable health management, reducing the need for antibiotics while fostering a resilient and healthy herd.

Natural Saponins for Gut Health

Natural saponins, found in plants like yucca and quinoa, help improve gut health by enhancing nutrient absorption and promoting beneficial gut bacteria. Saponins also have antimicrobial effects that reduce harmful pathogens in the digestive tract [40–42]. By incorporating saponins into the diet, dairy farmers can reduce the need for antibiotics, promote natural disease resistance, and improve overall herd health and productivity.

Tannins as Antimicrobials

Tannins, naturally occurring compounds in plants, such as oak and chestnut, exhibit strong antimicrobial and anti-inflammatory properties [43–47]. They can help control pathogens and improve gut health by reducing harmful bacteria and supporting beneficial microbes [40–42]. By using tannins as natural antimicrobials, dairy farmers can reduce antibiotic use and manage diseases more sustainably, contributing to healthier animals and promoting sustainable farming practices.

Live Yeast in Feed

Adding live yeast to feed enhances gut health by promoting beneficial microbial growth in the rumen [43–47]. Yeast helps break down complex feed components, improving digestion and nutrient absorption while reducing the risk of pathogenic bacterial overgrowth [40–42]. By incorporating live yeast, dairy farmers can improve herd health and reduce the need for antibiotics, fostering a more sustainable and efficient dairy production system.

Immune-Boosting Feed Additives

Immune-boosting feed additives, such as vitamins, minerals, and probiotics, support the cattle's immune system, making them more resilient to infections [40–42]. These additives help strengthen natural defenses and improve overall health, reducing the need for antibiotics. By incorporating immune-boosting additives into daily feed regimens, dairy farmers can enhance animal well-being and promote a no-antibiotic approach to disease prevention and management.

Homeopathy as Alternative Therapy

Homeopathy offers a holistic approach to treating diseases in dairy cattle, utilizing highly diluted natural substances to stimulate the body's healing processes. By targeting the underlying causes of illness rather than just the symptoms, homeopathy provides a safe, non-invasive alternative to antibiotics [43–47]. This therapy can complement other non-antibiotic strategies, promotes long-term health and wellness while reducing reliance on pharmaceutical treatments.

ANIMAL HEALTH MANAGEMENT

Robust Vaccination Programs

Implementing comprehensive vaccination programs is key to preventing disease outbreaks in dairy herds [48–51]. Regular vaccinations help protect cattle from a range of infectious diseases, reducing the need for antibiotics. By focusing on proactive prevention rather than reactive treatment, vaccination programs support herd health, minimize disease transmission, and foster long-term sustainability in dairy farming practices, contributing to non-antibiotic strategies.

Regular Health Screenings

Conducting routine health screenings allows for the early detection of diseases, improving the chances of effective intervention before infections spread [48–51]. Advanced diagnostic tools, such as blood tests and imaging, help identify issues that may not be visible. Early detection minimizes the need for antibiotics, supporting sustainable management practices and reducing the impact of disease on animal welfare and farm productivity.

Advanced Diagnostics for Health Monitoring

Utilizing advanced diagnostics, such as PCR testing and microbiological cultures, enhances the ability to monitor animal health accurately [48–51]. These diagnostic tools provide detailed information on infections, pathogens, and disease prevalence, enabling timely interventions. By preventing the escalation of diseases, advanced diagnostics reduce antibiotic use, promote early treatment, and ensure more sustainable health management in dairy farming systems.

Colostrum Management in Calves

Proper colostrum management ensures that newborn calves receive sufficient antibodies, which protect them against diseases in the early stages of life [52–58]. Ensuring high-quality colostrum feeding reduces the risk of infections and the need for antibiotics. By prioritizing colostrum management, dairy farmers can strengthen calf immunity, promote healthy growth, and minimize the need for antibiotic interventions in the early life stages.

Routine Deworming Programs

Routine deworming is essential for maintaining healthy digestive systems in dairy cattle. By periodically removing internal parasites, such as worms, farmers can reduce the risk of gastrointestinal infections, which often require antibiotic treatments [56–58]. With effective parasite control, farmers can maintain herd health, prevent disease spread, and reduce the need for antibiotics, contributing to more sustainable livestock management practices.

Reducing Overcrowding

Overcrowding in dairy sheds increases the risk of disease transmission, stress, and injury among cattle [39, 41, 42, 59–62]. Ensuring that animals have adequate space reduces the spread of infections and promotes overall well-being. By maintaining proper stocking densities, dairy farmers can enhance animal comfort and reduce the likelihood of diseases that would require antibiotic treatment, supporting a more sustainable and humane farming environment.

Strategic Silage and Hay Use

Strategic use of silage and hay ensures that dairy cattle receive optimal nutrition while minimizing the risk of digestive disorders. Forage-based diets, such as high-quality silage, help maintain rumen health and reduce incidences of acidosis [39, 41, 42, 61, 62]. By carefully managing feed quality, dairy farmers can improve cattle health, enhance productivity, and reduce reliance on antibiotics to manage digestive or metabolic issues.

Monitoring Body Condition Scores

Regular monitoring of body condition scores (BCS) helps ensure that dairy cattle are in optimal health [39, 41, 42, 61, 62]. A healthy BCS indicates that animals are well-nourished and are less likely to suffer from metabolic disorders, reducing the need for antibiotic treatments. By tracking BCS and adjusting feeding regimens as necessary, dairy farmers can prevent health problems and contribute to a sustainable, no-antibiotic approach to animal management.

Maintaining Hoof Health

Maintaining hoof health is crucial for preventing lameness, which can lead to infections and the need for antibiotic treatment. Regular hoof trimming, inspection, and proper bedding management help keep hooves in good condition [39, 41, 42, 61, 62]. By proactively addressing hoof health, dairy farmers can reduce the incidence of lameness, improving animal welfare and reducing the reliance on antibiotics for treatment.

Dry Period Management

Proper dry period management is essential for ensuring the health and productivity of dairy cows. During the dry period, cows should be given adequate rest and nutrition to prepare for the next lactation [39, 41, 42, 61, 62]. By carefully managing this phase, farmers can reduce the risk of mastitis and other infections that may require antibiotics, promoting a healthier and more sustainable dairy operation.

HOUSING AND WELFARE

Better Housing to Reduce Stress

Providing better housing conditions is essential for reducing stress in dairy cattle. Comfortable, spacious barns with sufficient bedding and space allow animals to move freely and rest, which enhances overall well-being [8, 28, 63–65]. By reducing stress, farmers can promote healthy growth, improve milk production, and minimize disease susceptibility, leading to less reliance on antibiotics and fostering more sustainable farming practices.

Proper Ventilation in Barns

Ample ventilation in barns ensures a constant supply of fresh air, reducing the risk of respiratory diseases and enhancing animal comfort [39, 41, 42, 61, 62]. Proper airflow helps maintain a consistent temperature and humidity level, preventing heat stress and promoting healthy breathing conditions. By addressing ventilation issues, dairy farmers can reduce the occurrence of respiratory infections, reducing the need for antibiotic treatment.

Managing Heat Stress

Effective heat stress management is crucial for maintaining animal health during hot weather conditions. Providing access to cool, shaded areas, and installing cooling systems, such as fans or misting systems, helps cows maintain a comfortable body temperature [8, 28, 63–65]. Managing heat stress reduces the risk of metabolic disorders and infections, ensuring healthier cows and reducing the need for antibiotics during heat-related stress periods.

Shade and Cooling Systems

During summer months, providing shade and cooling systems is essential for reducing heat stress in dairy cattle. Shade can be provided through trees, shade netting, or specially designed barn roofs, while cooling systems, such as fans or misting, reduce the ambient temperature around the animals [8, 28, 63–65]. By minimizing heat stress, farmers can prevent heat-induced illnesses and infections that may otherwise require antibiotics.

Shade Netting for Barns

Shade netting is a simple yet effective solution for providing shade in dairy barns during hot weather. This technique helps reduce temperature fluctuations, creating a cooler environment for cows [8, 28, 63–65]. By incorporating shade netting into barn design, farmers can minimize heat stress, improve animal comfort, and reduce the likelihood of heat-related health issues, decreasing the need for antibiotics.

Avoid Overcrowding in Calving Areas

Overcrowding in calving areas can lead to stress, injury, and the spread of diseases. Ensuring that calving areas are spacious and provide sufficient privacy for each cow allows for a smoother, less stressful calving process [8, 63–65]. By reducing overcrowding, dairy farmers can minimize the risk of infections and complications, ultimately reducing the need for antibiotic treatments and fostering a healthier, more sustainable operation.

Individual Housing for Young Calves

Providing individual housing for young calves ensures they have sufficient space to rest, feed, and develop without competition or stress. Proper housing minimizes the risk of disease transmission and allows for easier management of health and nutrition [8, 63, 64]. By promoting the well-being of young calves through individualized housing, dairy farmers can reduce the need for antibiotics and promote healthier, more robust animals.

Rotational Grazing for Pathogen Control

Rotational grazing helps prevent the buildup of pathogens in pastures by allowing grasses to recover between grazing periods [8, 63, 64]. This practice promotes healthier pastures and reduces the risk of parasites and infections among cattle. By implementing rotational grazing systems, dairy farmers can minimize disease transmission and reduce the need for antibiotics, supporting sustainable and eco-friendly farming practices.

Reducing Transport Stress

Minimizing long-distance transport stress is essential for animal welfare. Long journeys can cause dehydration, exhaustion, and exposure to infection, all of which increase the likelihood of requiring antibiotics [8, 63, 64]. By limiting travel times and providing adequate rest stops and hydration, dairy farmers can reduce stress-related health issues, ensuring better overall health and reducing reliance on antibiotics for managing transport-related illnesses.

Low-Stress Weaning Techniques

Promoting low-stress weaning techniques is key to minimizing the negative impacts of weaning on both the calf and the cow. Gradual weaning, using methods, such as fence-line contact and introducing solid foods before full separation, reduces stress and promotes better health outcomes [8, 63, 64]. By reducing stress during weaning, dairy farmers can prevent health issues and minimize the need for antibiotics, supporting a more humane and sustainable dairy system.

DISEASE PREVENTION STRATEGIES

Genetic selection for disease resistance

Genetic selection for disease resistance involves breeding dairy cattle with traits that enhance their natural immunity. By prioritizing disease-resistant traits, farmers can reduce the susceptibility of cattle to infections, thus minimizing the need for antibiotics [66, 67]. This strategy supports long-term herd health, enhances farm sustainability, and decreases reliance on pharmaceutical interventions, promoting a more resilient dairy system.

Immune Modulators for Resistance

Using immune modulators in cattle feed can help enhance the animal's natural defense mechanisms. These additives improve immune function, enabling cattle to better fight off infections [2, 68]. By boosting disease resistance through immune modulation, farmers can reduce the frequency and severity of illnesses, leading to fewer antibiotic treatments and fostering a more sustainable, non-antibiotic approach to dairy farming.

Training Farm Staff

Training farm staff in disease management practices is crucial for ensuring that all personnel are equipped with the knowledge and skills necessary to identify and manage diseases promptly [10, 40]. Well-trained staff can recognize early signs of illness and implement preventative measures, reducing the need for antibiotics. By focusing on education, farms can achieve better herd health and more sustainable farming practices.

Early Disease Reporting

Encouraging farm workers to report early signs of disease ensures prompt intervention before infections spread. Early disease detection and swift action reduce the risk of outbreaks and the subsequent need for antibiotic treatments [69, 70]. By fostering a culture of proactive health management and early reporting, dairy farms can prevent costly infections and support the transition to non-antibiotic strategies.

Quarantine Protocols

Implementing effective quarantine protocols for new animals prevents the introduction of diseases into the herd. Isolating incoming animals for a specified period allows for the observation and testing of potential diseases before integration [69, 70]. By preventing disease outbreaks, quarantine protocols reduce the need for antibiotics and ensure the continued health of the existing herd, promoting a more sustainable dairy system.

Biocontrol Agents for Pest Management

Using biocontrol agents to manage pests, such as flies and rodents, reduces the reliance on chemical pesticides and antibiotics. These natural agents help control pests without harming the environment or animal health [13, 71, 72]. By minimizing pest-related stress and diseases, biocontrol agents contribute to overall herd health, reducing the need for antibiotic treatments and supporting a sustainable, eco-friendly dairy farm operation.

Breed-Specific Disease Management

Promoting breed-specific disease management strategies involves tailoring health protocols to the unique genetic and environmental characteristics of different breeds. By focusing on breed-specific needs, farmers can improve disease resistance, minimize the risk of infections, and reduce antibiotic use [13, 71, 72]. This approach leads to healthier herds and more efficient, sustainable dairy farming practices, aligning with the goals of non-antibiotic strategies.

Biological Pest Control

Biological pest control methods, such as introducing natural predators or using beneficial microorganisms, help manage pests and reduce the need for chemical interventions. By using these biological alternatives, dairy farmers can minimize pest-related diseases that may require antibiotics [57, 73, 74]. This approach supports a healthier, more sustainable farming environment, reducing both environmental impact and reliance on antibiotics.

Natural Gut Microbiota Stability

Encouraging natural gut microbiota stability through probiotic supplements or foraging practices promotes digestive health in dairy cattle [75–77]. A balanced gut microbiota enhances nutrient absorption and strengthens the immune system, reducing the likelihood of infections. By fostering natural gut health, dairy farmers can minimize the need for antibiotics and improve overall herd health, contributing to more sustainable farming practices.

Testing Milk Quality for Mastitis

Regular testing of milk quality helps detect mastitis early, allowing for timely interventions before the condition worsens. By identifying mastitis early, farmers can reduce the spread of infection and avoid the use of antibiotics [78, 79]. Monitoring milk quality not only ensures animal welfare but also improves the overall sustainability of the farm by minimizing antibiotic usage and enhancing milk production efficiency.

SUSTAINABLE FARM PRACTICES

Precision Livestock Farming Tools

Introducing precision livestock farming tools allows farmers to monitor animal health and performance with high accuracy. Technologies, such as sensors and automated systems, provide real-time data on animal behavior, feeding, and health [80, 81]. By leveraging these tools, farmers can make data-driven decisions, optimizing herd management, reducing antibiotic use, and promoting sustainable dairy farming practices through targeted interventions.

Composting for Manure Management

Composting is an effective method for managing manure and reducing its environmental impact. By applying composting techniques, farmers can turn animal waste into valuable organic fertilizer, reducing the spread of diseases and minimizing water contamination [71]. This practice reduces reliance on synthetic fertilizers and supports sustainable farming by improving soil health and promoting nutrient cycling within the farm ecosystem.

Managing Animal Waste

Proper management of animal waste is crucial for reducing disease transmission and maintaining a clean environment [29, 71, 82]. Implementing waste management systems that minimize the spread of pathogens helps prevent infections that might otherwise require antibiotic treatments. By managing waste responsibly, farmers can support herd health, improve environmental sustainability, and reduce the need for antibiotics in disease prevention.

Farm-Level Composting for Organic Waste

Farm-level composting of organic waste, including crop residues and manure, reduces waste disposal costs while enhancing soil fertility. This practice minimizes the environmental footprint of dairy operations and prevents the spread of pathogens that could infect livestock [72, 83]. By using organic composting methods, farmers can support sustainable agriculture and reduce the reliance on antibiotics for disease control.

Solar Disinfection for Water

Applying solar disinfection (SODIS) techniques to water sources provides an affordable, eco-friendly way to ensure clean water for livestock [29, 71, 82]. By exposing water to solar radiation, harmful pathogens are killed, reducing the risk of waterborne diseases. This method promotes the health of dairy cattle, decreases the need for antibiotics, and supports sustainable water management practices on the farm.

Biosecure Feed Storage Systems

Biosecure feed storage systems ensure that feed is kept free from contamination by pests, mold, or pathogens. These systems protect the nutritional quality of feed while minimizing the risk of infections that could necessitate antibiotic use [72, 83]. By maintaining high standards in feed storage, farmers can promote animal health and enhance the sustainability of their farming operations.

Pasture Management Techniques

Pasture management techniques, such as rotational grazing, reduce pathogen exposure by allowing pastures to recover between grazing periods [11, 81, 84]. These techniques prevent the overgrazing of land, promote healthy grass growth, and minimize the buildup of pathogens that could infect livestock. By managing pastures effectively, farmers can reduce antibiotic use and promote more sustainable, natural farming practices.

Thermal Regulation Strategies

Thermal regulation strategies are essential for managing temperature extremes and ensuring animal comfort. Providing shade, cooling systems, or heating systems helps maintain an optimal environment for dairy cattle [11, 81, 85]. By preventing heat stress or cold-related illnesses, farmers can reduce the need for antibiotics and improve overall herd health, supporting the transition to more sustainable farming practices.

Hygienic Practices During Artificial Insemination

Maintaining hygienic practices during artificial insemination is critical for preventing infections and ensuring successful conception [86–88]. Using sterile equipment, clean facilities, and proper technique reduces the risk of introducing pathogens that may require antibiotic treatment. By promoting hygiene during insemination, farmers can improve fertility rates, animal health, and reduce antibiotic usage in their dairy operations.

Rotational Feeding Practices

Rotational feeding practices help ensure that cattle receive a balanced and varied diet while minimizing the risk of nutrient deficiencies and digestive issues. By rotating pastures or feed sources, farmers can reduce the buildup of pathogens and parasites, leading to healthier animals and less reliance on antibiotics [11, 81, 85]. This practice supports sustainability by improving feed utilization and promoting more natural grazing behavior.

ADVANCED TECHNOLOGY INTEGRATION

Somatic Cell Count Monitoring

Monitoring somatic cell counts in milk is a vital tool for early detection of mastitis and other milk-related diseases [70, 89]. By regularly assessing somatic cell levels, farmers can identify infections before they escalate, reducing the need for antibiotics. This practice not only ensures milk quality but also promotes herd health, supporting sustainable farming practices through effective disease management.

Advanced Diagnostic Tools

Advanced diagnostic tools enable quick and accurate detection of diseases in dairy cattle. These tools, including blood tests, PCR assays, and rapid diagnostic devices, allow for early identification of infections [90–92]. By detecting diseases at an early stage, farmers can implement targeted treatments and reduce the reliance on antibiotics, enhancing farm sustainability and animal welfare.

Multi-Enzyme Feed Supplements

Using multi-enzyme feed supplements improves nutrient digestion in dairy cattle by breaking down complex feed components. This enhances nutrient absorption and reduces digestive disorders, improving overall health [70, 89]. With better digestion, the incidence of diseases related to poor feed utilization decreases, minimizing the need for antibiotics and promoting sustainable feeding practices for optimal livestock health.

Functional Feed Additives

Incorporating functional feed additives into cattle diets supports overall health by improving immune function, digestive efficiency, and disease resistance [90–92]. These additives, such as prebiotics, probiotics, and antioxidants, enhance cattle well-being without relying on antibiotics. By boosting animal health through nutrition, farmers can reduce antibiotic usage and promote a sustainable, natural approach to disease management.

Fermented Feeds for Gut Health

Fermented feeds, such as silage, provide beneficial probiotics and enzymes that improve gut health in dairy cattle. By incorporating these feeds into the diet, farmers can promote the growth of beneficial gut microbiota, improving digestion and immune function [70, 89]. This reduces the risk of infections, minimizes the need for antibiotics, and supports overall herd health in a sustainable farming environment.

Fly Control with Manual Traps

Providing manual fly traps for vector control helps reduce the prevalence of fly-borne diseases, such as mastitis, in dairy herds [60, 93]. These traps reduce the need for chemical pest control, offering an eco-friendly alternative that minimizes the risk of pathogen transmission. By controlling fly populations, farmers can improve herd health and reduce the need for antibiotic interventions in disease prevention.

Copper Sulfate Foot Baths

Using copper sulfate foot baths promotes hoof health by preventing lameness and infections caused by pathogens in the environment. Regular foot baths can significantly reduce the need for antibiotics used in hoof care and infection management [70, 89]. By maintaining good hoof hygiene, farmers ensure that their dairy cattle remain healthy, improving production efficiency and sustainability without relying on antibiotics.

Precision Health Monitoring Systems

Implementing precision health monitoring systems allows for real-time tracking of cattle health metrics such as temperature, activity, and feed intake. These systems provide valuable insights that enable early disease detection and prompt intervention [62, 65]. By identifying potential health issues before they escalate, farmers can reduce antibiotic use and improve overall herd health through targeted, data-driven management practices.

Trace Mineral Supplementation

Providing trace mineral supplementation ensures that dairy cattle receive essential micronutrients, which support immune function, growth, and disease resistance. These minerals, such as zinc, copper, and selenium, play a key role in maintaining health and preventing infections [70, 89]. By optimizing mineral nutrition, farmers can reduce the incidence of diseases that require antibiotics, promoting sustainable herd health and overall productivity.

Thermal Imaging for Heat Stress

Regularly conducting thermal imaging allows farmers to monitor cattle for heat stress, which can affect production and overall well-being [62, 65]. By detecting early signs of heat stress, farmers can implement cooling strategies, such as shade or ventilation, preventing heat-related illnesses. This reduces the need for antibiotics and enhances animal welfare, supporting sustainable dairy farming practices.

ENVIRONMENT AND GRAZING

Rotational Grazing for Pasture Recovery

Promoting rotational grazing allows pastures to rest and regenerate between grazing periods, improving soil fertility and reducing overgrazing. This practice enhances plant health, reducing the likelihood of pathogen buildup [26, 39]. By giving the land time to recover, farmers can improve pasture productivity and reduce the need for antibiotics, fostering a more sustainable and environmentally friendly grazing system.

Vector Population Control

Effectively controlling vector populations, such as flies and ticks, reduces the transmission of vector-borne diseases in dairy cattle [63, 94]. Using integrated pest management (IPM) techniques, such as biological control and strategic chemical use, minimizes reliance on pesticides and antibiotics. By managing these pests, farmers can reduce health risks for cattle and promote sustainable farming practices that support herd health.

Clean and Shaded Grazing Areas

Maintaining clean and shaded grazing areas is crucial for protecting cattle from heat stress, injuries, and exposure to harmful pathogens [26, 39]. Shaded areas help cattle maintain a comfortable body temperature, while clean conditions reduce the risk of disease transmission. By promoting these practices, farmers can improve animal welfare, reduce antibiotic use, and contribute to sustainable land management.

Toxic Plant Control

Minimizing exposure to toxic plants in grazing areas is vital for preventing poisoning and related health issues in dairy cattle. Regularly inspecting pastures and removing harmful plants reduces the risk of cattle ingesting toxic substances [84, 95]. By managing grazing areas properly, farmers can prevent illness that may otherwise require antibiotic treatment, supporting both animal health and sustainable farming practices.

Pasture-Based Parasite Management

Introducing pasture-based parasite management, such as rotational grazing and the use of natural dewormers, reduces the reliance on chemical treatments for parasite control. These methods help manage parasite load in a sustainable way, promoting healthier cattle and preventing the development of antibiotic-resistant parasites [96, 97]. By maintaining healthy pastures and livestock, farmers can reduce antibiotic use and improve the sustainability of their operations.

Reducing Pathogen Buildup

Reducing pathogen buildup in grazing lands through practices, such as rotating grazing areas and controlling manure accumulation helps maintain a healthy environment for dairy cattle. By preventing pathogens from proliferating, farmers reduce the risk of disease transmission, minimizing the need for antibiotics [84, 95]. This approach fosters both herd health and environmental sustainability, contributing to long-term farming viability.

Ecological Balance and Pesticide Reduction

Maintaining ecological balance by reducing pesticide use promotes biodiversity and reduces the risk of harmful chemical buildup in the environment [98, 99]. By relying on natural pest control methods and reducing pesticide dependence, farmers can protect beneficial species and minimize environmental damage. This approach enhances sustainability by reducing the need for antibiotics, promoting healthier ecosystems and more resilient farming systems.

Integrated Pest Management (IPM)

Promoting integrated pest management strategies combines biological, cultural, and chemical methods to control pests in a sustainable and eco-friendly way [8, 65, 85, 100]. IPM minimizes the use of antibiotics by preventing pest-related diseases and reducing the need for chemical treatments. By implementing IPM, farmers can manage pest populations while supporting animal health and contributing to more sustainable farming practices.

Natural Predator Control

Using natural predators to control pests in grazing areas is an environmentally sustainable strategy that reduces the need for chemical pest control. By encouraging the presence of beneficial predators, such as birds, bats, or predatory insects, farmers can naturally regulate pest populations [101–104]. This reduces the need for pesticides and antibiotics, enhancing the ecological balance and promoting long-term farm sustainability.

Soil Erosion Prevention

Minimizing soil erosion through controlled grazing systems ensures the long-term health of grazing lands and improves soil fertility [105–107]. By preventing overgrazing and encouraging pasture recovery, farmers can maintain soil structure, reduce erosion, and enhance nutrient cycling. These practices help sustain healthy ecosystems, minimize the need for antibiotics, and ensure the resilience of farming systems in the face of environmental challenges.

HEALTH RECORD MANAGEMENT AND TRAINING

Detailed Health Records

Maintaining detailed health records for all animals ensures that farmers have comprehensive data on individual animal health, treatment history, and disease patterns. This enables better decision-making and early intervention when health issues arise [10, 40]. By tracking health trends, farmers can minimize the need for antibiotics, enhance disease prevention, and contribute to the overall sustainability of dairy farming practices.

Herd Health Planning

Conducting herd health planning in collaboration with veterinarians allows for the development of tailored health strategies based on individual farm needs. These plans help in managing disease outbreaks, improving animal welfare, and minimizing antibiotic use [39, 69, 90]. A proactive health management approach, based on veterinary guidance, ensures sustainable dairy operations while prioritizing herd health and reducing environmental impact.

Sustainable Farm Worker Training

Training farm workers in sustainable practices ensures that all staff are knowledgeable about biosecurity, disease prevention, and ethical farming methods. Educated workers are better equipped to implement non-antibiotic strategies, such as hygiene management and proper feeding techniques [10, 40]. This training helps reduce the dependency on antibiotics while improving farm efficiency, promoting long-term sustainability in dairy farming operations.

Biosecurity Protocol Updates

Regularly updating staff on biosecurity protocols is essential for maintaining a disease-free environment on the farm. Keeping the workforce informed about best practices, including preventing disease transmission and identifying early signs of illness, ensures better disease control [80, 108, 109]. By adhering to updated protocols, farms can significantly reduce antibiotic usage and mitigate the risk of infections, promoting sustainable farming practices.

Awareness of Antimicrobial Resistance

Promoting awareness of antimicrobial resistance (AMR) among farm staff is crucial in combating the overuse of antibiotics. Educating workers on the risks associated with AMR fosters responsible antibiotic use and encourages alternative disease management strategies [10, 40]. By addressing AMR, farms can reduce the reliance on antibiotics, contributing to better herd health and long-term sustainability in dairy production.

Immediate Health Issue Reporting

Encouraging farm workers to report health issues immediately helps in early detection and intervention. Early disease identification allows for more effective non-antibiotic treatments and management strategies [13, 110, 111]. Timely reporting reduces the spread of infections, minimizes the need for antibiotics, and ensures that animals receive proper care, supporting sustainable farming practices and improving overall herd welfare.

Regular Disease Management Workshops

Conducting regular workshops on disease management enhances farm workers' understanding of disease prevention, early diagnosis, and non-antibiotic treatment methods. These workshops provide valuable knowledge on how to reduce antibiotic use and implement best practices for herd health [10, 40]. Well-trained staff can more effectively manage health challenges, reducing the reliance on antibiotics and promoting sustainable farming practices.

Community-Level Disease Surveillance

Promoting community-level disease surveillance helps in early identification of diseases that could affect local dairy herds. By collaborating with neighboring farms, farmers can share information, monitor trends, and implement preventive measures [11, 24, 112]. This collaborative approach minimizes disease spread and the need for antibiotics, fostering a collective effort towards sustainable farming practices and improving regional herd health.

Expert Collaboration for Training

Collaborating with experts for advanced training provides farm workers with up-to-date knowledge on the latest disease management practices and sustainable farming techniques. Expert-led training programs enhance the farm's ability to implement non-antibiotic strategies effectively, improving animal health and reducing antibiotic usage [10, 40]. This collaboration supports the continuous development of best practices for sustainable dairy farming.

Centralized Health Record Management

Using technology for centralized health record management streamlines data collection, storage, and analysis, ensuring that health information is easily accessible and up-to-date. Centralized systems allow for better tracking of animal health, disease trends, and treatment history [72, 83, 113, 114]. This technological approach improves farm management, reduces antibiotic use, and contributes to more sustainable practices by enabling quick identification of health issues and effective decision-making.

CONCLUSION

Adopting non-antibiotic strategies in dairy farming provides a sustainable approach to enhancing herd health while reducing the risk of antimicrobial resistance. By emphasizing preventive measures, such as biosecurity, optimal nutrition, and the use of natural alternatives, dairy farmers maintain healthy herds without dependence on antibiotics. This study underscores the value of integrating advanced technologies, improved housing practices, and effective stress management to strengthen disease prevention. The proposed framework delivers a comprehensive strategy that aligns animal welfare, productivity, and environmental stewardship. Going forward, these measures can play a pivotal role in transforming dairy systems worldwide, supporting the long-term sustainability of the industry while protecting public health.

FUTURE DIRECTIONS

Future directions for antibiotic-free disease management in dairy farming should prioritize research on the efficacy and long-term benefits of natural alternatives, including probiotics, prebiotics, and phytochemicals. The advancement of precision livestock farming technologies will be crucial for early disease detection, enabling targeted interventions without antibiotics. The continued exploration of genetic selection for disease-resistant breeds could further reduce reliance on pharmaceutical treatments. Expanding understanding of gut microbiota and its role in disease prevention will also be vital for enhancing overall animal health. Moreover, evaluating the economic impact of transitioning to non-antibiotic systems is essential for wider adoption, particularly regarding cost-effectiveness and profitability. Collaborative efforts among researchers, farmers, and policymakers are necessary to establish supportive frameworks that encourage antibiotic-free practices. Ultimately, integrating these strategies globally will foster a more sustainable and resilient dairy industry while improving general public health outcomes.

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