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Editorial

Biotechnology for poultry health, food safety and sustainable production

S. M. Lutful Kabir*

Department of Microbiology and Hygiene, Faculty of Veterinary Science, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

*Corresponding author: S. M. Lutful Kabir, Department of Microbiology and Hygiene, Faculty of Veterinary Science, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh. E-mail: lkabir79@bau.edu.bd

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Poultry production is one of the fastest-growing components of the livestock sector and an important source of affordable animal protein, employment and rural livelihoods (Mottet and Tempio, 2017; Osei-Akoto *et al*., 2026). However, its expansion has been accompanied by infectious diseases, antimicrobial resistance, chemical residues, foodborne pathogens, environmental stress and climate-related risks (Sharma *et al*., 2025). These challenges are particularly relevant in developing poultry-producing countries such as Bangladesh, where intensive and small-scale production systems coexist with variable levels of biosecurity, veterinary services, processing infrastructure and food-safety enforcement (Hennessey *et al*., 2021). Improving productivity therefore requires simultaneous attention to poultry health, food safety, environmental sustainability and economic feasibility.

Biotechnology offers a growing range of tools to address these interconnected challenges. Its applications have expanded from poultry genetics, vaccines, diagnostics and feed technology to molecular diagnostics, genomics, microbiome manipulation, probiotics, bacteriophages, recombinant vaccines, phytobiotics, synbiotics and precision microbial interventions (Kabir and Islam, 2021; Abdelaziz *et al*., 2024). However, biotechnology should complement rather than replace good husbandry, biosecurity, veterinary services and food-safety governance within a One Health framework (Garcia *et al*., 2020). Poultry health is closely linked to the safety and quality of poultry products. Infectious diseases can reduce productivity, compromise welfare, increase antimicrobial use and facilitate contamination during slaughter and processing. Avian colibacillosis and salmonellosis are particularly important because of their economic and public-health implications (Kabir, 2010). Colibacillosis may also reduce egg production, linking disease control with productivity and food availability (Kabir *et al*., 2017). Studies in Bangladesh have documented poultry diseases in Gazipur (Hassan *et al*., 2016), *Salmonella* spp. in broiler farms (Mridha *et al*., 2020), and *Clostridium perfringens* in small-scale commercial broiler flocks in Mymensingh (Tresha *et al*., 2021).

Disease prevention must therefore begin at farm level. Codes of practice, vaccination, sanitation, appropriate stocking density, clean water, quality feed, pest control, all-in/all-out management and effective biosecurity remain fundamental (Akhter *et al*., 2018). Biotechnology should strengthen these measures rather than substitute for them. Antimicrobial resistance and chemical residues further demonstrate the need for biotechnology-based prevention. Multidrug-resistant *Campylobacter* spp. and residual antimicrobials have been reported at poultry farms and live bird markets in Bangladesh, while colistin residues have been detected in broilers at different growth stages (Bristy *et al*., 2019; Neogi *et al*., 2020). Heavy metals and antibiotic residues have also been reported in poultry feed and meat, and chromium exposure has raised additional risk-assessment concerns

(Islam *et al*., 2016; Alam *et al*., 2021). Molecular detection of resistance genes, genomic characterization of pathogens, improved vaccines and non-antibiotic interventions can support more responsible antimicrobial use (Ahmed *et al*., 2024).

Probiotics are among the most practically relevant biotechnology-based interventions. They can influence intestinal microbial balance, nutrient utilization, gut morphology, immunity and poultry performance. Their potential in poultry production has been extensively reviewed, including effects on broiler meat quality (Kabir, 2009a; Kabir, 2009b). Locally adapted strains are particularly important. *Lactobacillus* species isolated from poultry sources have been characterized for probiotic properties, while molecular identification of probiotic bacteria from broilers and associated environments has demonstrated the value of strain-level characterization (Kabir *et al*., 2016; Ferdous *et al*., 2020). *Bacillus*-based probiotics are especially promising because their spore-forming characteristics can improve stability during processing and storage. Beneficial effects on growth performance, gut morphology, intestinal microbiota and immune response have been reported in broilers maintained under low-biosecurity conditions (Arif *et al*., 2021). Beyond conventional probiotics, prebiotics can selectively stimulate beneficial microorganisms, while combinations of probiotics, prebiotics and plant-derived compounds are being explored for poultry productivity and meat quality (Ricke, 2018; Dong *et al*., 2024). Phytobiotics may also influence growth, gut microbiota, antioxidant activity and immunity (Urban *et al*., 2025).

Next-generation probiotics, including engineered microbial strains and synbiotic systems, represent a further development (Al-Surrayai *et al*., 2026). Integrating direct-fed microbials with poultry genomics could support more precise antibiotic-free production systems (Hassan *et al*., 2026). Nevertheless, engineered microorganisms require careful assessment of biosafety, genetic stability, ecological effects, regulatory compliance and consumer acceptance (Wei and Stewart, 2023). Bacteriophages provide another promising platform for controlling poultry pathogens. These bacterial viruses can selectively target susceptible bacteria and may reduce pathogens while causing less disruption to the broader microbiota. Applications against *Salmonella*, *Campylobacter* and pathogenic *E. coli* have received increasing attention (Abd-El Wahab *et al*., 2023). Group II *Campylobacter* phages, for example, may help reduce contamination across the poultry food chain (Rafiq *et al*., 2026). However, host specificity, phage resistance, environmental stability, delivery, regulation and variable efficacy remain challenges. Phage cocktails and combinations with probiotics or other biocontrol agents may improve effectiveness (Karamlou *et al*., 2025).

Vaccination remains central to disease prevention and antimicrobial reduction. Biotechnology has advanced vaccine development through recombinant antigens, reverse genetics, molecular pathogen characterization, novel adjuvants and improved delivery systems. Recent developments demonstrate opportunities to improve vaccine development, stability and delivery (Abdelaziz *et al*., 2024). Molecular surveillance can further support vaccine selection by identifying circulating strains and antigenic variation. In developing countries, stable formulations and practical delivery systems are particularly important where cold-chain infrastructure and technical capacity may be limited (Rukundo *et al*., 2026). Molecular biotechnology can also transform poultry disease surveillance. PCR, multiplex PCR, sequencing and related technologies can provide rapid and accurate pathogen detection and characterization. Molecular characterization has already demonstrated value for poultry-associated probiotic organisms (Kabir *et al*., 2016; Ferdous *et al*., 2020). Similar approaches can be applied to *Salmonella*, *Campylobacter*, pathogenic *E. coli* and other foodborne organisms to identify pathogens, virulence factors and antimicrobial-resistance characteristics (Batista *et al*., 2022). Future surveillance should connect samples from farms, feed, water, litter, slaughterhouses, processing facilities, markets and food products. Such integrated molecular epidemiology could identify points where pathogens enter, persist or amplify throughout the poultry food chain.

Food safety is fundamentally a farm-to-fork responsibility. Contamination can occur during production, transportation, slaughter, processing, storage, marketing and preparation. Meat and meat-product safety has previously been investigated in Bangladesh (Murshed *et al*., 2016), while contamination of ready-to-cook frozen chicken products in Mymensingh demonstrates the importance of surveillance beyond the farm (Arafat *et al*., 2025). Farm-level disease control therefore cannot alone guarantee food safety at consumption. Food handlers and poultry vendors are also important components of the food-safety system. Knowledge, attitudes and practices among poultry vendors in traditional markets can influence food safety (Islam *et al*., 2026). Biotechnology-based surveillance should consequently be supported by education, hygienic handling, cold-chain management and regulatory oversight. Egg safety requires similar attention. Egg quality and safety depend on shell integrity, microbial contamination, storage and processing. Advances in egg-white biotechnology and microbiology provide opportunities to better understand and improve egg quality and functionality (Mannott *et al*., 2026).

Feed is another critical pathway for food-safety hazards. Contaminated feed can expose poultry to microorganisms, mycotoxins, heavy metals and antimicrobial residues. Reports of heavy metals and antibiotic residues in poultry feed and meat in Bangladesh reinforce the importance of feed-quality surveillance (Alam *et al*., 2021), while chromium exposure has also been investigated in broiler production (Islam *et al*., 2016). Fermentation, enzyme supplementation, microbial detoxification and functional feed additives could improve feed safety and intestinal health. Economic feasibility remains essential for technology adoption. The production cost and marketing of probiotics strongly influence their accessibility to farmers (Kabir *et al*., 2023). Technologies that are scientifically effective but expensive, unstable or poorly adapted to local production systems are unlikely to achieve widespread impact. This consideration is particularly important in Bangladesh, where modern commercial farms coexist with numerous small-scale producers.

Climate change adds another dimension to poultry health and food safety through heat stress, changing pathogen ecology, water scarcity, feed-quality risks and agricultural supply-chain disruptions (Kabir, 2026). Climate-resilient poultry production will require improved disease surveillance, field-adapted vaccines, robust feed and water management, microbiome-based approaches and genetic strategies for resilience. These interconnected pressures reinforce the importance of developing poultry biotechnology within a One Health framework. The greatest future opportunity is therefore the integration of multiple technologies rather than dependence on any single intervention. A coordinated system could combine genomic surveillance, rapid molecular diagnostics, precision vaccination, next-generation probiotics, bacteriophages, phytobiotics, functional feed additives and digital traceability (Sahoo *et al*., 2022). Molecular surveillance could identify emerging pathogens or resistance patterns; genomic information could guide vaccine and phage selection; microbiome analysis could identify opportunities for probiotic intervention; and food-chain surveillance could assess whether interventions actually reduce contamination (Muteeb *et al*., 2025).

This integrated approach reflects the broader potential of biotechnology in poultry farming and the need for comprehensive strategies addressing poultry health, food safety and food security (Ricke, 2021; Kabir and Islam, 2021; Chowdhury *et al*., 2023). Nevertheless, biotechnology cannot independently resolve the sector's challenges. Regulation, farmer education, veterinary services, laboratory capacity and enforcement remain equally important. Veterinary professionals have a key role in connecting animal health with food safety and public health (Rahman and Kabir, 2013). Food-safety governance in Bangladesh has developed considerably, but continued strengthening of legislation, monitoring and enforcement is necessary (Rahman *et al*., 2014). Biotechnology should therefore be incorporated into national surveillance and food-safety strategies rather than developed only as commercial products. Research institutions, government agencies, industry and farmers should collaborate to establish validated diagnostics, monitor antimicrobial resistance and residues, and develop locally appropriate biological products. Such cooperation is consistent with the broader need for innovation and collaboration in biological and medical research (Kabir, 2024).

The poultry sector must increasingly balance productivity with disease prevention, food safety, antimicrobial stewardship, animal welfare and environmental resilience. Priorities include molecular surveillance, locally adapted probiotics and bacteriophages, improved vaccines, feed and residue monitoring, genomics–microbiome integration, and farm-to-retail food-safety surveillance. Biotechnology should complement, not replace, biosecurity and good farming practices; vaccination cannot compensate for poor biosecurity, probiotics cannot correct contaminated feed or water, and bacteriophages cannot replace hygiene. Rather, biotechnology should strengthen sound poultry management. An integrated approach combining healthy birds, safe feed, responsible antimicrobial use, biotechnology-based prevention, hygienic processing and effective food-safety governance can support more sustainable poultry production in Bangladesh and the wider Asian-Australasian region. The ultimate goal is healthier birds, safer food, lower antimicrobial dependence and greater resilience through evidence-based, economically feasible and locally appropriate biotechnology applications.

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