Review Article

Sustainable Poultry Production Systems: Integrating Innovation, Resilience, and Future Challenges

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Abstract | Poultry production plays a vital role in the global food system by contributing to food security, economic development, and sustainable nutrition. The increasing demand for poultry products has driven the adoption of advanced management practices encompassing nutrition, housing, health, welfare, and environmental sustainability. This review provides a comprehensive analysis of contemporary poultry production systems, highlighting recent scientific advancements and emerging challenges. Key areas discussed include precision nutrition, disease control strategies, housing innovations, environmental stress management, and the transition toward antibiotic-free production systems. Recent evidence underscores the growing importance of probiotics, precision feeding, and sustainable practices in improving productivity while minimizing environmental impact. Despite significant progress, challenges such as heat stress, antimicrobial resistance, and animal welfare concerns continue to constrain production efficiency. Therefore, integrating innovative technologies with sustainable management practices is essential to enhance resilience and ensure the long-term sustainability of the poultry industry.

Keywords | Poultry management, Nutrition, Poultry health, Probiotics, Sustainable farming, Heat stress

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INTRODUCTION

Poultry production is one of the fastest-growing sectors of global agriculture, playing a crucial role in ensuring food security and supplying high-quality animal protein at relatively low cost. Over the past several decades, the poultry industry has undergone substantial transformation due to advancements in genetics, nutrition, disease control, and management practices, resulting in significant improvements in productivity and efficiency (Korver, 2023; George and George, 2023). In this context, recent microbiological and physiological research has contributed markedly to enhancing poultry health and performance. For example, the identification of beneficial microbial communities, such as lactic acid bacteria isolated from the intestines of adult chickens, has highlighted their role in improving gut health and nutrient utilization (Al-Salhi *et al*., 2022). Furthermore, the application of formulated bacterial preparations has demonstrated improvements in hematological and biochemical parameters in laying hens, reflecting enhanced physiological performance and immune function (Al-Salhi and Al-Shatty, 2023; Al-Maamouri *et al*., 2026).

The global population is projected to exceed 9 billion by 2050, intensifying the demand for affordable and sustainable protein sources. Poultry meat and eggs have become essential in meeting this demand due to their short production cycles, efficient feed conversion ratios, and relatively lower environmental impact compared to other livestock species (Nadathur *et al*., 2017; Laca and Diaz, 2021). Consequently, poultry management has emerged as a multidisciplinary scientific field integrating nutrition, veterinary medicine, environmental science, and biotechnology. Modern poultry production systems encompass a wide range of practices aimed at optimizing bird performance, health, and welfare while minimizing production costs. These practices include feed formulation, housing design, environmental control, disease prevention, and waste management (Nassar and Abbas, 2025).

Despite significant advancements, the poultry industry continues to face several critical challenges. One of the most pressing issues is the widespread use of antibiotics as growth promoters and prophylactic agents, which has contributed to the emergence of antimicrobial resistance (AMR), posing serious risks to both animal and human health (Salam *et al*., 2023). Consequently, there has been a global shift toward antibiotic-free production systems, with increasing emphasis on alternative strategies such as probiotics, prebiotics, and phytogenic feed additives (Hussain *et al*., 2025).

Environmental challenges also represent a major constraint, particularly in regions characterized by high temperatures and humidity. Heat stress has been identified as a key factor negatively affecting feed intake, growth performance, immune function, and overall productivity in poultry (Fernandez-Novo *et al*., 2020). With the progression of climate change, these challenges are expected to intensify, necessitating the development of adaptive management strategies to enhance system resilience.

In addition, animal welfare has become a central concern in modern poultry production. Increasing consumer awareness and regulatory requirements have driven the adoption of higher welfare standards, including reduced stocking densities, improved housing conditions, and humane management practices. These factors not only address ethical considerations but also directly influence productivity and product quality (Ngongolo and Mrimi, 2024).

Technological innovation has further transformed poultry production through the introduction of precision livestock farming systems. These technologies utilize sensors, automation, and data analytics to monitor bird health, behavior, and environmental conditions in real time, enabling more efficient and informed decision-making (Bhavani and Gajendra, 2024).

Given the complexity of modern poultry production systems, there is a growing need for integrated management approaches that balance productivity, sustainability, and animal welfare. Therefore, this review aims to provide a comprehensive and up-to-date analysis of poultry management practices, with particular emphasis on recent scientific advancements, current challenges, and future prospects for sustainable poultry production.

Poultry production systems

The production systems of poultry are mostly categorized on the basis of production intensity, environmental factors and the management inputs. The systems are generally divided into intensive, semi-intensive, and extensive systems, all having variations in terms of productivity, animal welfare, and efficiency in the use of resources (Paskaš *et al*., 2026; Randa, 2025). The prevailing type of commercial poultry production in the world is the intensive systems because of their high efficiency and capability of producing meat and eggs in high volumes and short cycles of production. The systems are based on regulated environmental factors such as temperature, humidity, ventilation, and lighting with high stocking densities to achieve maximum output per unit area (Kasakuka, 2020). Nevertheless, in spite of their efficiency, intensive systems are commonly linked to higher risks of diseases spreading, metabolic problems, and the animal welfare issues because of the limited mobility and great production pressure (Maes *et al*., 2019). Semi-intensive systems are a hybrid system, which includes features of intensive and extensive systems. Birds are generally kept in the house, but with some exposure to the outdoors, where they can be permitted to develop their instinctive habits. This system is meant to strike a balance between productivity and better welfare results, though the level of performance is usually lower than in full intensive systems (Delsart *et al*., 2020). Large or free range systems allow birds to enjoy more freedom in movement and closer access to natural habitats. These systems are typified by low densities of stocking, minimized dependence on artificial inputs, and improved animal welfare. Nevertheless, productivity tends to be reduced because of environmental variability, ineffective biosecurity, and intermittent feed intake (Ibeagha-Awemu *et al*., 2025). Comprehensively, intensive systems are the most prevalent system in the world owing to their financial effectiveness, capacity to expand, and capacity to cater to the expanding need of poultry products (Kleyn and Ciacciariello, 2021).

Poultry nutrition management

Poultry nutrition constitutes a critical aspect of poultry management, which has a direct impact on growth performance, immune functionality, reproduction and productivity. Poultry diets are well-balanced to contain energy sources, protein sources, vitamins and minerals that satisfy physiological needs of birds at various growth stages. The major sources of energy are cereal grains (corn, wheat, barley) as they are highly digestible and rich in energy, and soybean meal is the main protein source, as it contains essential amino acids required to build up tissues (Selle *et al*., 2020). Moreover, vitamin and mineral supplementation plays a crucial role in ensuring metabolic balance, bone formation, and immune capability. Feed additives are important in improving the performance and gut health of poultry. Probiotics, prebiotics, enzymes, and organic acids are functional additives that are increasingly being used to enhance nutrient absorption and feed conversion efficiency (Krysiak et *et al*., 2021). The increasing interest in antimicrobial resistance has increased the trend towards antibiotic-free production systems, which has put the emphasis on natural growth promoters and microbiota-modulating feed additives (Iduu *et al*., 2025). Contemporary nutritional approaches are also more revolved around precision feeding whereby nutrient amounts are designed to meet the respective needs of birds at various physiological phases. This method minimizes feed waste, boosts the efficiency, and increases sustainability within the poultry production systems (Zhang *et al*., 2023). Moreover, other forms of protein food like insect meal, algae, and agro-industrial by-products are being considered as potential alternatives to conventional feeds to lessen reliance on traditional feeds (Pinotti *et al*., 2023). Even with these improvements, other issues like the unstable feed prices and the unstable supply chain in the world are also issues that are of great concern in poultry nutrition management (Abdel-Wareth and Ahmed, 2026).

Use of probiotics and alternatives to antibiotics

The extensive and uncontrolled administration of antibiotics in poultry rearing has been a major cause of antimicrobial resistance (AMR) which creates a severe disease risk to animals and humans (de Mesquita *et al*., 2022). There has been therefore an international movement towards alternative methods that are focused on sustaining productivity without over depending on antibiotics. The use of probiotics has become one of the most promising substitutes in contemporary poultry production. These positive microbes have the effect of enhancing the gut microbial balance, promoting intestinal integrity, and triggering immune responses. They consequently lead to better nutrient use, growth rate, and immunity to the pathogenic infections (Fathima *et al*., 2022). It has been proven through numerous studies that probiotic supplementation may be very helpful in improving growth performance, survival rates and disease resistance in both broiler and layer chickens (Jha *et al*., 2020). In addition to probiotics, other natural feed additives such as prebiotics and phytogenic compounds are increasingly being used. Prebiotics enhance the development of good gut bacteria, whereas phytogenic additives- based on plant extracts have antimicrobial, antioxidant, and growth-promoting effects. This is because the synergistic application of these alternatives is one of the strategies to shift towards the production systems of antibiotic-free poultry (Selaledi *et al*., 2020; Saeed and Liu, 2025). Recent advancements have also explored the utilization of sustainable and natural products in improving poultry farm hygiene and bird immunity. The development of multi-purpose natural disinfectants derived from restaurant waste has shown effective antimicrobial activity and potential application in farm sanitation practices (Naser *et al*., 2025). Furthermore, immunological enhancement strategies such as the supplementation of specific and non-specific IgY extracted from egg yolk have demonstrated a significant role in strengthening the immune response in broilers, offering a promising alternative to conventional disease control methods (Al-Salhi, 2026).

Poultry housing and environmental management

The housing systems are a major aspect of poultry management as it directly influences the welfare of the birds, the productivity, and the health condition. A well-designed housing will provide the best possible environmental conditions that will facilitate efficient growth and reduce losses due to stress (Oke *et al*., 2025). There are broad categories of poultry housing systems; deep litter, cage or aviary. Deep litter systems enable the birds to move freely on the bedding material giving them a more natural environment. Instead, cage systems are constructed to ensure that the available space is used to the fullest and management practices become easier, yet they are usually attacked due to their restrictive nature towards animal welfare. Aviary systems represent a more advanced approach, combining improved mobility with structured housing design to enhance both welfare and productivity (Nannoni *et al*., 2022). The temperature, humidity, ventilation and lighting are environmental factors that should be regulated to ensure the physiological conditions are in the best condition. The consequences of poor environmental management may include more stress, lowering feed intake, the weakening of the immune response, and lowered productivity (Endris and Feki, 2021).

Heat stress and climate challenges

Heat stress is a big problem for poultry farming, especially in places that are hot and humid. When birds get too hot, they can't cool down properly, which messes up their bodies and makes them not work as well. This happens when they can't cool off, and it causes a lot of problems. For instance, they might not grow as well because they eat less food, and they might not be able to turn their food into energy as well (Vandana *et al*., 2021). They may also lay fewer eggs. It can even kill the birds if the heat stress is really bad or lasts a long time. This can be very bad for farmers. Farmers are trying a few different things to fix this problem. One way to help the birds is to make the chicken coops' ventilation systems better so they can get more fresh air and cool down more easily. They're also thinking about how to make the coops so that the birds stay cooler. Another way to help them is to change how you feed them so that they get the nutrients they need even when they don't eat as much. Some farmers are even thinking about breeding birds that can handle heat better, which could be a long-term solution to the problem. This will help the birds stay healthy and productive even when it's hot outside (Thornton *et al*., 2022; Renaudeau *et al*., 2012).

Poultry health and disease control

Disease management is highly significant to the poultry farming since the infectious diseases are prone to spread very fast and are expensive to treat. Today, poultry farmers are focusing on disease prevention and not just treatment. Some of the most prevalent diseases that have the potential to damage the health and productivity of poultry are bird flu, Newcastle disease and coccidiosis (Grace *et al*., 2024). To prevent the spread of these diseases, farmers vaccinate their birds, apply stringent biosecurity measures, and routinely screen their birds. Recent studies have also emphasized the importance of methodological accuracy and innovative resource utilization in poultry research and management. Variations in blood sampling sites and repeated freezing cycles have been shown to significantly influence biochemical parameters in poultry serum, which may affect the reliability of diagnostic and research outcomes (Al-Salhi, 2025). In addition, sustainable approaches have been explored through the production of antibacterial compounds derived from poultry manure combined with plant materials such as Ziziphus spina-christi, demonstrating promising applications in waste valorization and disease control (Al-Salhi *et al*., 2025). Prevention of diseases is highly dependent on biosecurity. It involves ensuring the farm is clean, restricting access of people to the poultry spaces, and ensuring that there are good sanitation processes. Increasing numbers of farmers are adopting a combination of biosecurity strategies to reduce the chances of disease and do not need to use treatments so much. Such a technique allows the birds to remain healthy and reduces the use of antibiotics and other medication. Farmers can help keep their flocks healthy and stop the spread of diseases by doing these things. This is beneficial to the birds as well as the businesses of the farmers (Kolog, 2023).

Animal welfare in poultry production

The problem of animal welfare has grown to become a concern in modern poultry farming due to increased knowledge about it as well as regulations (Alonso *et al*., 2020). Both the morality and the manufacturability of things are directly connected with welfare problems. The right number of animals per square foot, access to clean water and a balanced diet, sufficient space to move around, and not stressful conditions are all important indicators of welfare. Increased stocking densities, especially, have been attributed to an increase in stress levels, a depressed immune system, and behavioral issues. Improvement of animal welfare not only meets the ethical requirements but also improves productivity, quality of products and economic gains and this makes it an intrinsic component of sustainable poultry production systems (Sardar *et al*., 2023).

Sustainable poultry farming

Sustainability has become a significant objective in the current poultry production due to the concerns regarding the environment, scarce resources, and an increase in the demand to have eco-friendly food systems (Rocchi *et al*., 2021). Sustainable poultry farming is aimed at maintaining high productivity with a minimum impact on the environment. The strategies that will focus on the efficient disposal of waste materials, alternative feed sources, and lowering greenhouse gasses produced during poultry production will be key strategies. The strategies will contribute to making the poultry industry more sustainable in the long-term perspective, through the use of more resources and less traditional inputs (Pal *et al*., 2024). Recent innovations in poultry production have also focused on integrating biotechnology with sustainable waste management practices. Additionally, the formulation of natural dietary supplements derived from quail eggs and plant materials such as arugula leaves has shown promising results in enhancing nutritional value and supporting overall poultry health and productivity (Al-Salhi, 2026). The development of bacterial starters combined with digital bio-fermenters has demonstrated the potential to convert poultry manure into valuable energy sources such as methane gas (CH_4), contributing to environmental sustainability and resource efficiency (Al-Salhi *et al*., 2026).

Technological advancements in poultry management

Within the recent years, new technologies transformed the manner in which poultry is handled in a transformative manner. Using AI, precision livestock farming, and automated feeding systems has made operations run more smoothly and made it easier to make decisions (Melak *et al*., 2024). With the help of these technologies, it is now possible to monitor the behavior of birds, their health and the surrounding environment in real time. This facilitates quick detection of problems and action. This results in increased productivity and reduced labor expenses and management errors.

Challenges in poultry management

Even with a lot of improvement, poultry production is still confronted with numerous challenges which affect productivity and sustainability. These are antimicrobial resistance, variable feed prices, environmental stressors and frequent disease outbreaks (Vidovic and Vidovic, 2020). Moreover, genetics of high-performing poultry breeds have driven the chickens near to their physiological boundaries, exposing them to increased vulnerabilities to metabolic disorders, stresses, and outbreaks. This makes the management practices more complex and requires more sophisticated and combined strategies (Tixier-Boichard, 2020).

CONCLUSION

Poultry management is an interdisciplinary and dynamic field that is significant in terms of food security and sustainability of agriculture around the globe. Increased efficiency in production has been achieved in the last several decades through nutrition and health management, housing systems, and technology. Nevertheless, significant challenges such as disease control, environmental stress, antimicrobial resistance, and sustainability still impact the industry. These challenges need a combination of scientific innovation, technological advancement, and sustainable practices to be addressed through integrated management strategies. The effective application of these long-term and proactive strategies will be the key to the long-term health and development of the poultry industry.

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NOVELTY STATEMENT

This review provides an updated and integrated perspective on sustainable poultry production by combining recent advances in precision nutrition, probiotic-based antibiotic alternatives, environmental management, animal welfare, disease control, and precision livestock technologies. It highlights current challenges and future directions, offering a comprehensive framework to support resilient and sustainable poultry production systems.

AUTHOR'S CONTRIBUTION

Teeb Adel AlMaamouri: Conceived and wrote the manuscript and handled the journal correspondence.
Karrar K. Abed Alameer, Zahraa R. Hamzah, and Eqbal Awadh Gatea:Collected and organized the scientific literature and previous studies.
Nasrallah Radhi Misjel: Translated and linguistically edited the manuscript. All authors reviewed and approved the final manuscript.

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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