Berkala **PENELITIAN HAYATI**

ISSN: 08526834 | E-ISSN:2337-389X

Volume 30 | No. 3 | **December** | 2024

Original Article

Climate change and poultry production: Enhancing resilience and sustainability through climate-smart practices, a review

Kelvin Ngongolo* and Doreen Mrimi

Department of Biology, University of Dodoma, Benjamin Mkapa Road, 41218 Iyumbu, Dodoma

Abstract

Chicken production plays a crucial role in global food security by providing essential protein to billions, especially in developing countries. However, climate change introduces significant challenges such as temperature stress, water scarcity, feed disruptions, disease prevalence, and economic impacts. This review explores these effects on poultry production, highlighting key challenges and potential solutions. Poultry production systems differ in their vulnerability and adaptability to climate change. Backyard systems, though highly vulnerable, demonstrate resilience through native breeds. Semi-intensive systems face resource-related challenges but show some adaptability. Intensive systems, despite advanced technologies, struggle with heat and energy issues. Free-range systems offer natural adaptability but are exposed to outdoor risks. Organic systems prioritize sustainability but encounter difficulties with feed management and disease control. Integrated systems foster both sustainability and resilience but also face their own set of risks. To enhance resilience, essential strategies include improving housing, water management, feed efficiency, disease control, and genetic selection. Effective implementation of these strategies requires collaboration among industry stakeholders, researchers, and policymakers to ensure food security, economic stability, and environmental sustainability. This review also emphasizes climate-smart techniques, such as integrating renewable energy and optimizing waste management, to bridge knowledge gaps and promote effective practices across various poultry production systems.

Keywords: Climate change, Poultry industry, Adaptation strategies, Temperature stress, Food security

Received: July 26, 2024 Revised: October 10, 2024 Accepted: November 22, 2024

Introduction

Production of chicken is essential to the world's food systems since it provides billions of people with their main source of protein (Demissu et al., 2018; Ngongolo et al., 2021). In developing nations, where it plays a major role in rural economies and livelihoods, the chicken business is especially important for both economic stability and food security. A previous study in Tanzania showed that chickens provide benefits to local communities, such as employment, meat, manure, and authentic value, regardless of challenges like diseases, low productivity, and predation (Chota et al., 2021; Mramba, 2023; Ngongolo et al., 2021; Ngongolo, Omary, et al., 2020; Ngongolo & Chota, 2021, 2022). Because they effectively turn feed into meat and eggs, chickens are a favored livestock option for farmers trying to fulfill the increasing demand for animal protein (Escobedo del Bosque et al., 2021; Mujyambere et al., 2022; Passarelli et al., 2022). A study in Ethiopia highlighted the economic and nutritional benefits of chickens. The nutrition-sensitive behavior modification emphasized children's health and feeding advantages, while the group without these interventions focused on economic gains. Major challenges included chicken illnesses, disease outbreaks, and implementation issues at both project and household levels(Passarelli et al., 2022). The industry's potential to expand quickly and scale up again emphasizes how crucial it is to meeting dietary needs and promoting economic growth.

Significant changes in worldwide weather patterns are being brought about by climate change, which is being caused by rising greenhouse gas concentrations (Kondratyev & Varotsos, 1995; Kumar, 2018; Ramanathan & Feng, 2009). A paper presented by (Kumar, 2018) has revealed that, Global warming is the result of anthropogenic actions that have greatly expanded the usage of fossil fuels, smog, and greenhouse gases. Increased emissions and energy consumption are associated with urbanization. The objective of the Paris Climate Conference (COP21) was to limit global warming to less than 2°C (Kumar, 2018). Among the notable effect of climate change includes; Climate change leads to rising temperatures, melting ice caps, and sea level rise, exacerbating extreme weather events like hurricanes and droughts. It disrupts ecosystems, affects agriculture and water resources, and poses health risks. Economic impacts include damage to infrastructure and increased costs. Climate refugees emerge due to social displacement, necessitating urgent global action(Classen et al., 2015; Kahn et al., 2021; Loo et al., 2015; Raupach et al., 2021). These modifications show up as increased frequency and intensity of extreme weather events, temperature increases, changed precipitation patterns, and a rise in the frequency of floods and droughts. Due to its heavy reliance on the climate, agriculture such as chicken production is especially susceptible to environmental shifts (Malhi et al., 2021). Reduced agricultural yields, changed dynamics of pests and diseases, and degraded water quality and availability are some of the effects of climate change on agriculture. Livestock such as chicken production are also at risk of being affected by climate change (Thornton et al., 2009). The sustainability of agricultural systems particularly livestock keeping and food security are both threatened by these variables taken together.

*Corresponding Author:
Kelvin Ngongolo
Department of Biology, University of Dodoma, Benjamin Mkapa Road, 41218 Iyumbu, Dodoma
E-mail: kelvinkngongolo@yahoo.com or kelvin.ngongolo@udom.ac.tz

http://dx.doi.org/10.23869/bphjbr.30.3.20243
Published by © PBI East Java. Open Access www.berkalahayati.org

Purpose and scope of the review

This review study aims to examine the intricate effects of climate change on chicken production, emphasizing the primary challenges and exploring potential solutions. By merging recent research and case studies, the study seeks to provide a comprehensive picture of how climate change is influencing chicken productivity, health, and the general profitability of the poultry business. The review will address specific implications like as water scarcity, temperature stress, feed supply fluctuations, and disease prevalence. Additionally, it will highlight innovative methods for adaptation and mitigation that might strengthen the resilience of the systems utilized to produce hens. The ultimate objective is to educate researchers, policymakers, and industry stakeholders about the actions required to maintain and enhance chicken production in the face of continuous climate change.

Impact of climate change on chicken

Temperature stress

Temperature stress significantly affects chicken production, posing challenges to both health and productivity. Heat stress induces physiological strain, leading to reduced feed intake, impaired growth rates, and decreased egg production(Kpomasse et al., 2021). Findings in low-income countries have revealed that, Climate change exacerbates heat stress in hens, which stunts growth, decreases feed intake, diminishes egg production, and raises death rates. Heat stress poses serious issues for rural poultry, which is essential for providing additional nutrition and income in developing nations(Nyoni et al., 2019; Thornton et al., 2009). Therefore, research into effective management strategies and sustainable production practices is urgently needed.

Extended exposure to high temperatures has the potential to increase hen mortality rates. On the other hand, cold stress can impair development and reproductive function in several areas by interfering with metabolic processes(Vieira et al., 2019). Low temperatures can make it necessary to use more energy to produce heat, which would take resources away from development and egg production. Cold stress also makes birds more vulnerable to respiratory illnesses and frostbite, which further jeopardizes their health and welfare(Rosinger, 2023). Comprehending the consequences of temperature stress on hens is essential for putting into practice efficient management techniques to lessen its influence. This entails putting in place appropriate heating and cooling systems and ventilation during heat waves, as well as insulation and heating measures in colder regions (Kpomasse et al., 2021; Nyoni et al., 2019; Rosinger, 2023; Vieira et al., 2019). Under changing weather conditions, proactive steps can reduce temperature stress and maximize chicken output.

Water availability and quality

Water availability and quality are pivotal factors affecting chicken production, particularly under the influence of climate change. Droughts and water scarcity exert significant pressure on poultry operations, limiting access to sufficient water for drinking, cooling, and sanitation(Rabie, 2020). Reduced water availability can compromise bird health and welfare, leading to dehydration, heat stress, and decreased productivity (Gonzalez-Rivas et al., 2020). Moreover, changes in water quality due to climate-induced factors such as increased temperatures and altered precipitation patterns can negatively impact poultry health (Gonzalez-Rivas et al., 2020; Rabie, 2020). Contaminants, pathogens, and high mineral concentrations in water sources can contribute to digestive disorders, impaired immune function, and reduced egg quality(Soliman & Safwat, 2020). Addressing water scarcity and quality issues requires proactive water management strategies, including efficient irrigation practices, water recycling systems, and regular testing and treatment of water sources. Findings by (Soliman & Safwat, 2020) revealed that, Heat stress in poultry due to climate change impacts production, reproduction, and product quality. High temperatures and humidity hinder broiler chicks and laying hens, especially in open systems. Large poultry groups are more vulnerable, leading to high mortality, reduced production, poor feed conversion, weakened immunity, and lower egg quality. Addressing these issues involves improved nutritional and managerial practices. By prioritizing water availability and quality, poultry producers can enhance the resilience of their operations and mitigate the adverse effects of climate change on chicken production.

Feed supply and costs

The feed supply and its associated costs are profoundly influenced by climate change, particularly through their impact on crop production. Variability in temperature and precipitation patterns can lead to fluctuations in yields of key feed crops such as corn and soybeans, disrupting supply chains and driving up costs(Morton, 2007). Reduced crop yields may result from extreme weather events, prolonged droughts, or increased pest and disease pressures, exacerbating feed shortages and price volatility. This makes the feed staff for chicken to be scarce and highly costing to farmers(Acevedo et al., 2020; Vernooy, 2022). For the finsings have shown that, Small-scale farmers adopt climate-resilient crops primarily to address drought, heat, flooding, and salinity, with adoption influenced by extension services, education, access to inputs, socio-economic status, and social factors such as sex, age, and ethnicity(Acevedo et al., 2020). Furthermore, climate change can alter the nutritional quality of feed ingredients, affecting their protein, fiber, and energy content. A study by (Vernooy, 2022)revealed that, Human activities significantly increase atmospheric CO_2 and temperature, accelerating effects on crops. Elevated CO_2 may boost C3 crop yields and water efficiency for C3 and C4 crops but is offset by higher temperatures and altered precipitation. Changes in feed composition may necessitate adjustments in formulations to maintain optimal nutrition for chickens, potentially increasing production costs. To mitigate the impacts of climate change on feed supply and costs, poultry producers must adopt adaptive strategies such as diversifying feed sources, improving crop resilience, and implementing efficient resource management practices to ensure a stable and affordable supply of nutritious feed for their flocks. For example, a student in ruminant animals on assessing the alternative sources of feed, showed that, the competition between feed, fuel, and environmental pollution are major threats to ruminant-based food production. Potential solutions include innovative resources such as food industry by-products, vegetable and fruit waste, camelina expeller, grain legumes, and agroforestry, as well as sustainable feed production (Halmemies-Beauchet-Filleau et al., 2018). In the long-term, microalgae, duckweed, and wood industry by-products may become competitive feed options (Halmemies-Beauchet-Filleau et al., 2018).

Disease prevalence and patterns

The prevalence and patterns of disease in poultry production systems are changing due to climate change, which presents serious risks to the health and wellbeing of chickens. A study has revealed that, Heat stress brought on by climate change impairs chicken immunity by increasing corticosterone levels, decreasing feed intake, slowing growth, inflicting damage to the intestines, and weakening immunological responses(Hamdy, 2020). This results in a decrease in the generation of antibodies, white blood cells, lymphocytes, spleen weight, macrophage activity, and spleen weight, which increases the susceptibility of chickens to infections and lowers overall productivity (Hamdy, 2020). On another hand, Pathogens, such as viruses, bacteria, and fungi, can proliferate and spread in conditions that are conducive to their growth due to variables including elevated temperatures, increased humidity, and altered precipitation patterns (Elad & Pertot, 2014; Hamdy, 2020). This suggest that, new diseases that pose new risks to chicken populations are brought about by changing weather patterns. Poultry producers may suffer financial losses and high death rates as a result of these newly discovered diseases' potentially disastrous outbreaks(Ngongolo & Chota, 2022). A study in Dodoma Tanzania, has revealed that, Disease-related chicken mortality has a major effect on hens, chicks, and cocks. Control measures effectively lower mortality, particularly when they combine preventive and treatment. 400 chicken-keeper households in the Dodoma region lost over Tsh. 119.9 million (52,146.96 USD) in total as a result of high mortality, low productivity, and higher disease control expenses(Ngongolo & Chota, 2022). Furthermore, the distribution and prevalence of parasites that compromise the health of chickens are impacted by climate change.

Temperature and humidity variations affect the life cycle and geographic range of parasites like worms, ticks, and mites, which raises the danger of infestation and disease transmission in flocks of chickens. Animal health and productivity are significantly impacted by climate change because of its effects on temperature conditions and extreme occurrences(Skuce et al., 2013). Forecasts indicate that these consequences will intensify, necessitating new approaches to adaptation at every level of society. Conventional adaptations won't be adequate, so scientifically based strategies will be needed to address decreased output, higher losses, and animal welfare issues(Skuce et al., 2013). It is imperative to comprehend and track these shifts in disease prevalence and trends in order to put into practice efficient disease management plans and protect chicken production from health hazards associated with climate change.

Housing and infrastructure

Important elements of chicken production systems that are greatly impacted by climate change are housing and infrastructure. The frequency and severity of heatwaves and increasing temperatures necessitate the development of better ventilation and cooling systems.

Maintaining ideal climatic conditions within poultry houses, reducing heat stress, and protecting the health and wellbeing of hens all depend on effective cooling and ventilation systems. The unique requirements of stressed poultry cannot be met by dietary approaches such as early feed restriction, electrolyte, vitamin, and mineral balancing, or environmental adjustments such as early heat conditioning, open sheds, and cooling systems (Nawab et al., 2018; Renaudeau et al., 2012). Additionally, the infrastructure and shelter for chickens are at risk from extreme weather events like hurricanes, floods, and storms. These occurrences have the potential to harm infrastructure, machinery, and buildings, which could interrupt business as usual and jeopardize avian safety. Reduce risks and ensure the resilience of poultry production systems in the face of climate change by strengthening poultry housing against extreme weather events through structural enhancements, such as reinforced roofing and siding, and putting disaster preparedness plans into action.

Production efficiency

Through a number of factors, production efficiency in chicken farming is impacted by climate change. High temperatures and heat stress can reduce feed conversion efficiency, stunt development rates, and affect hens' ability to reproduce. Particularly in tropical areas, heat stress has a detrimental effect on the growth, reproduction, and egg production of chickens (Nawab et al., 2018; Vandana et al., 2021). Genetic, management, and nutritional techniques—such as heat-tolerant breeds, better ventilation and shelter, well-balanced feeds, and effective water and disease control—are examples of mitigation solutions (Vandana et al., 2021). Because heat stress interferes with metabolic functions, growth rates are slowed and food uptake is decreased. Furthermore, reproductive cycles may be disturbed by heat-induced stress, which would lower egg production and hatchability(Nawab et al., 2018; Vandana et al., 2021). On the other hand, cold stress in some areas can also affect the efficiency of production by requiring more energy to produce heat and rerouting resources away from growth and reproduction.

Through a number of factors, production efficiency in chicken farming is impacted by climate change. High temperatures and heat stress can reduce feed conversion efficiency, stunt development rates, and affect hens' ability to reproduce. Because heat stress interferes with metabolic functions, growth rates are slowed and food uptake is decreased. Heat stress in poultry causes physiological changes, increasing mortality and reducing feed efficiency, body weight, feed intake, and egg production(Wasti et al., 2020). Furthermore, reproductive cycles may be disturbed by heat-induced stress, which would lower egg production and hatchability(Ayo et al., 2011). On the other hand, cold stress in some areas can also affect the efficiency of production by requiring more energy to produce heat and rerouting resources away from growth and reproduction.

Economic impacts

The production of chickens is significantly impacted economically by climate change, which shows up as higher operating costs and unstable markets. Findings have shown that, Climate change causes economic loss in chicken production by impacting feed efficiency, growth, and reproduction(Escarcha et al., 2018; Wasti et al., 2020). Poultry producers' production costs rise as a result of investments in infrastructure upgrades, cooling systems, and disease management strategies brought on by extreme weather events and rising temperatures (Nawab et al., 2018; Renaudeau et al., 2012). Costs may also increase if supply systems for food are disrupted by climate-related issues. Furthermore, changes in agricultural production and food availability brought on by climate change may have an impact on the pricing of poultry goods on the market.

The market can be volatile and uncertain due to variations in supply and demand as well as consumer preferences for eco-friendly and climate-resilient products. For instance, a study in Nigeria has revealed that, Climate change contributes to economic issues such as increasing food prices, affecting marketing and pricing (Erdogan et al., 2024). In Nigeria, rising temperatures and agricultural difficulties elevate food prices, demonstrating "heatflation." Stabilizing prices necessitates policies that address environmental, agricultural, and monetary factors for economic development and social cohesion (Erdogan et al., 2024). As a result, predicting profitability and modifying production levels to satisfy fluctuating market demands may be difficult for chicken farmers. Strategic planning, investments in robust infrastructure, and income stream diversification are necessary to adapt to these economic difficulties, reduce risks, and guarantee the long-term viability of chicken production businesses.

Vulnerabilities and resilience of poultry

Poultry production systems vary in their vulnerability and resilience to climate change (Mteiye MALAWI, 2019). Backyard systems, though highly vulnerable, show resilience through native breeds (Table 1). Semi-intensive systems, while more adaptable, still face challenges related to resources and climate change. Intensive systems, despite their advanced technology, struggle with heat and energy issues (Abioja & Abiona, 2021; Elson, 2015). Free-range systems offer adaptability but come with inherent risks (Gentile et al., 2024). Organic systems emphasize sustainability, yet they face difficulties in managing feed and diseases. Integrated systems promote sustainability and resilience but are not without their own related risks.

Intensive and semi-intensive poultry systems are prevalent in developed nations, benefiting from advanced technology and financial resources for climate adaptation(Rocchi et al., 2019). However, they remain vulnerable due to their dependence on imported feed and energy. In contrast, developing nations primarily use

Table 1. Comparative Analysis of Poultry Production Systems: Vulnerabilities and Resilience Factors

s/n	Production System	Vulnerability	Resilience Factors	References
1	Backyard or Small-Scale Production	This system relies on traditional practices with limited technology. It is vulnerable to climate change, extreme weather, and disease.	Backyard systems show resilience through indigenous breeds adapted to local environments, supported by local knowledge and practices.	(Adesiji et al., n.d.; Egbeyale et al., 2021; Gentile et al., 2024; Rehman et al., n.d.; Rocchi et al., 2019)
2	Semi-Intensive Systems	Semi-intensive systems share vulnerabilities with small-scale but adapt better. Temperature fluctuations, droughts, and diseases are major challenges. Access to climate mitigation technologies depends on economic resources.	These systems allow better feeding and housing control, enabling climate adaptation through ventilation and selective breeding.	(Abioja & Abiona, 2021; Egbeyale et al., 2021; Rehman et al., n.d.)
3	Intensive Systems	Intensive systems are technologically advanced but sensitive to heat stress. They rely heavily on energy, making them vulnerable to shortages.	Developed economies' intensive systems have more financial and technological resources. They implement climate-controlled housing, advanced feed management, and biosecurity protocols.	(Abioja & Abiona, 2021; Adesiji et al., n.d.; Elson, 2015; Mteiye MALAWI, 2019)
4	Free-Range Systems	Free-range poultry is more vulnerable due to outdoor exposure. Extreme weather impacts bird health, food availability, and shelter. Disease risks rise with contact with wildlife or contaminated water.	Free-range systems allow birds to engage in natural behaviors. They are adaptable with proper infrastructure like mobile shade.	(Adesiji et al., n.d.; Mengesha, 2011; Rehman et al., n.d.)
5	Organic Systems	Organic poultry systems face challenges sourcing feed during droughts and floods. Limited chemical interventions make managing diseases more difficult in stress.	Organic systems focus on sustainability and biodiversity, enhancing resilience. Crop rotation and diverse farming reduce feed production's climate vulnerability.	(Abioja & Abiona, 2021; Boggia et al., 2010; Castellini et al., 2006)
6	Integrated Systems	Integrated systems combining poultry with activities like agroforestry face weather vulnerabilities. Interconnectedness means disruptions in one area, like water shortages, affect everything.	The diversity in integrated systems enhances resilience by distributing risks. Poultry waste can fertilize crops or feed fish, improving sustainability.	(Abioja & Abiona, 2021; Castellini et al., 2006; Rehman et al., n.d.; Turnpenny et al., 2001)

backyard and semi-intensive systems, which are limited by financial and technological constraints(Elson, 2015; Gentile et al., 2024). These systems face challenges such as inadequate cooling, veterinary care, and reliable feed sources, yet they exhibit some adaptability to climate change through indigenous knowledge and diverse farming practices (Table 1).

Climate-smart poultry production: enhancing resilience and sustainability production systems to climate change

Climate-smart poultry production involves a variety of techniques and technologies aimed at reducing the environmental impact of poultry operations while enhancing their resilience to climate change(Iyiola-Tunji, 2021). This approach includes integrating renewable energy sources to reduce reliance on fossil fuels, optimizing feed efficiency to minimize waste, and implementing effective waste management systems to lower greenhouse gas emissions. These strategies not only maintain productivity but also mitigate environmental impacts, thereby enhancing the overall sustainability of poultry production (Iyiola-Tunji, 2021; Singh et al., 2024). By adopting climate-smart technologies, poultry enterprises can better adapt to changing climate conditions and support environmental sustainability.

Poultry production systems must be adapted to the changing climate through various approaches, each tailored to specific needs and vulnerabilities. Intensive systems, which often rely on advanced technology, benefit from climate-controlled housing and sophisticated feed management to manage heat stress and energy use(Egbeyale et al., 2021; Rehman et al., n.d.; Singh et al., 2024). Semi-intensive systems can improve resilience with enhanced ventilation, selective breeding, and better housing control to address temperature fluctuations and disease. Free-range systems, while benefiting from natural behaviors, can increase resilience through movable shade and appropriate infrastructure. Organic systems focus on sustainability through practices like crop rotation and diverse farming techniques, which help reduce feed production's vulnerability to climate change. Each adaptation strategy aims to address the unique challenges faced by different poultry production systems.

Vulnerable poultry production systems, such as small-scale and backyard operations, face significant challenges due to limited financial and technological resources. These systems often struggle with inadequate cooling technologies, insufficient veterinary care, and unreliable feed sources, making them particularly susceptible to climate change impacts (Gentile et al., 2024). Addressing these vulnerabilities requires targeted solutions that leverage local knowledge and adaptable farming practices. By focusing on these vulnerable systems, the review will highlight specific adaptations and strategies that can enhance their resilience, bridge knowledge gaps, and promote more effective climate-smart practices across all poultry production systems (Castellini et al., 2006; Iyiola-Tunji, 2021; Singh et al., 2024).

Mitigation and adaptation strategies

Improved housing

Improved housing is essential for mitigating the effects of climate change on chicken production. Design innovations focused on temperature control include the implementation of insulated structures and advanced ventilation systems. Findings by (Li et al., 2022) showed that, focus on establishing renewable energy systems, increasing the energy efficiency of active systems, and lowering direct energy demand through structural design in order to mitigate climate change in the chicken industry. For effective alterations, prioritize HVAC systems and take into account the physiological needs of chickens as well as the local climate (Li et al., 2022). Energy-efficient cooling mechanisms, such as evaporative cooling pads and tunnel ventilation, help maintain optimal temperatures inside poultry houses, reducing heat stress and improving bird welfare. This is because Muscle glycogen is depleted by prolonged heat stress, producing black, hard, dry meat with a high pH and water-holding capacity (Gonzalez-Rivas et al., 2020). Additionally, it shortens shelf life, increases oxidative stress, and compromises food safety by encouraging bacterial development.

These innovations not only enhance environmental sustainability but also contribute to better productivity and profitability for poultry producers(Li et al., 2022). By investing in modern housing technologies, farmers can create more resilient production systems capable of withstanding the challenges posed by a changing climate(Li et al., 2022).

Water management

Water management is critical for sustainable chicken production amid climate change. Implementing efficient water use practices involves optimizing irrigation methods and minimizing water waste within poultry operations. This challenge can be addressed by utilizing or finding new alternative sources of water, such as water harvesting and groundwater drilling. Alternative water sources like water harvesting and groundwater drilling are essential amidst climate change to address decreasing freshwater resources and ensure water security, supporting agriculture and mitigating impacts from reduced rainfall and increased droughts.(Misra, 2014). Additionally, adopting water recycling and purification technologies enables the reuse of wastewater for non-potable purposes, reducing overall water consumption and environmental impact(Levy et al., 2010). These strategies not only conserve precious water resources but also help mitigate the risks associated with fluctuating water availability due to changing climate patterns. By prioritizing effective water management, poultry producers can enhance the resilience and long-term viability of their operations in a water-constrained future.

Feed innovation

Feed innovation is crucial for adapting poultry production to the challenges of climate change. It has reported that, for animal husbandry to have a smaller environmental impact, creative feed production and manure management are essential. To minimize environmental consequences and improve sustainability in the production of livestock such as pig, chicken, it is advised to increase efficiency, minimize input use, and implement advanced manure management procedures(Ndue & Pál, 2022). Developing resilient feed formulations involves optimizing nutrient content to support chicken health and performance under varying environmental conditions. This may include adjusting protein, energy, and micronutrient levels to mitigate the impacts of heat stress and changing dietary needs. Additionally, exploring alternative feed sources such as insect protein, algae, and by-products from food processing offers opportunities to diversify feed ingredients and reduce reliance on traditional crops vulnerable to climate-related disruptions. For instance, according to research, broiler performance can be maintained when using crude soybean lecithin (L) in place of soybean oil or monounsaturated vegetable acid oil. Blends that work best for grower-finisher and starter diets increase the digestion of fatty acids and feed energy content (Viñado et al., 2019). An investigation of the volatile profile of chicken meat from diets containing alternative proteins (algae or insects) was conducted at the University of Göttingen's Department of Animal Sciences(Gkarane et al., 2020). *Hermetia illucens* larvae or *Arthrospira platensis* larvae were substituted for soybean meal in the diets of broiler chickens. According to volatile analysis, HI-fed hens had lower levels of lipid-derived chemicals, which may indicate lower levels of polyunsaturated fatty acids. Taste compound levels were significantly impacted by dietary interventions(Gkarane et al., 2020). These innovations not only enhance the nutritional quality of chicken feed but also contribute to resource efficiency and sustainability in poultry farming. By embracing feed innovation, poultry producers can enhance the resilience of their operations and ensure consistent performance in the face of evolving climate challenges.

Disease management

Effective disease management is essential for safeguarding poultry production in the context of climate change. Enhanced biosecurity measures, such as strict sanitation protocols and controlled access to poultry facilities, help prevent the introduction and spread of pathogens. For example, severe NDV-caused Newcastle disease impacts the neurological, gastrointestinal, respiratory, and reproductive systems of chickens. Strict biosecurity and appropriate immunization are necessary for effective control. Maintaining the cold chain, vaccinating free-roaming birds, and applying vaccines unevenly are among the challenges. Immunization efficacy may be lowered by maternal antibodies(Dimitrov et al., 2017). Implementing biosecurity practices reduces the risk of disease outbreaks and minimizes economic losses associated with illness(Ngongolo & Chota, 2022). Furthermore, proactive monitoring and control of emerging diseases and parasites are crucial for early detection and containment efforts. This involves regular surveillance, diagnostic testing, and targeted treatment or vaccination programs to mitigate disease risks. By prioritizing disease management strategies, poultry producers can maintain flock health, optimize productivity, and sustain profitability amidst changing environmental conditions(Bouzoubaa et al., 1989; Chota et al., 2021; Ngongolo, Kitojo, et al., 2020; Tadele et al., 2014). Investing in robust biosecurity measures and disease surveillance systems is paramount to ensuring the resilience and long-term viability of poultry operations in a dynamic and challenging climate landscape.

Genetic selection

Genetic selection plays a vital role in enhancing the resilience of chicken production systems to the impacts of climate change. Breeding programs focused on heat tolerance and disease resistance aim to develop poultry strains capable of thriving in challenging environmental conditions. Strategies to mitigate heat stress in livestock include increasing ventilation in chicken housing, increasing feed intake, enhancing heat-loss capacities, and genetic selection for heat (Renaudeau et al., 2012; Vandana et al., 2021) Adjusting diet composition, feeding times, and environmental conditions can improve performance. Genetic tools and molecular biotechnologies offer potential for selecting heat-tolerant breeds, though further research is needed to optimize these methods (Renaudeau et al., 2012). Selecting for traits such as efficient heat dissipation mechanisms and robust immune responses helps mitigate the negative effects of temperature extremes and disease pressures. Additionally, the development of resilient chicken breeds involves incorporating genetic traits that confer adaptability and durability in the face of changing climatic conditions. By prioritizing genetic selection for heat tolerance and disease resistance, poultry breeders can produce strains better suited to withstand the challenges posed by climate change. Through the creation of an appropriate breeding program using marker-assisted selection, new strains of poultry birds with increased thermotolerance may be developed with the use of sophisticated biotechnological methods for identifying relevant genetic markers in the birds. In the context of a changing environment, these tactics might aid in maximizing and maintaining chicken output(Vandana et al., 2021). These efforts contribute to the sustainability and resilience of poultry farming, ensuring continued productivity and profitability in a dynamic and uncertain climate landscape.

Sustainable practices

Adopting sustainable practices is imperative for promoting the long-term viability of chicken production amidst climate change. This involves implementing farming techniques that minimize environmental impact while maximizing resource efficiency. The global livestock business needs to strike a balance between enhancing environmental sustainability and supplying enough food derived from animal sources. Increased productivity in the dairy and cattle industries has lowered emissions and resource consumption, however opinions on whether intensification is socially acceptable differ (Capper & Bauman, 2013). To evaluate the sustainability of ruminant products based on their nutritional value and environmental impact, more research is required. Sustainable practices encompass a range of strategies, including soil conservation, crop rotation, and integrated pest management, which help maintain ecosystem health and resilience(Capper & Bauman, 2013; Conti et al., 2021; Hobbs et al., 2008; Koohafkan & Altieri, 2016; Lizotte et al., 2014; Niesenbaum, 2019). Additionally, strategies for reducing the environmental footprint of poultry farming focus on minimizing waste generation, optimizing resource use, and mitigating pollution. This may involve investing in renewable energy sources, optimizing water and feed efficiency, and adopting waste management practices such as composting and recycling(Capper & Bauman, 2013). By embracing sustainable practices, poultry producers can minimize their environmental footprint, enhance ecosystem health, and ensure the continued viability of their operations in the face of climate change. These efforts contribute to the overall resilience and sustainability of chicken production systems, benefiting both the industry and the environment.

Future directions and research needs

Moving forward, there are several critical areas in chicken production research that warrant further exploration and innovation. Firstly, there is a need to identify and address gaps in current research, particularly regarding the long-term impacts of climate change on poultry health, productivity, and welfare. Additionally, research should focus on developing more resilient chicken breeds through genetic selection to withstand temperature stress, disease outbreaks, and other climate-related challenges.

Further investigation is also needed to evaluate the effectiveness of adaptation strategies, such as improved housing, water management, feed innovation, and disease control, in mitigating the impacts of climate change on chicken production. Moreover, there is a pressing need for interdisciplinary research that integrates agronomy, animal science, environmental science, and policy analysis to develop holistic solutions to climate-related challenges in chicken production.

Policy and industry collaboration are crucial in addressing climate impacts on chicken production. Policymakers should prioritize initiatives that support sustainable farming practices, incentivize innovation in climate-resilient technologies, and promote knowledge-sharing among stakeholders. Industry collaboration can facilitate the adoption of best practices, promote research translation, and ensure the scalability and affordability of climate adaptation measures. By working together, policymakers, industry stakeholders, and researchers can effectively mitigate the impacts of climate change on chicken production, ensuring food security, economic stability, and environmental sustainability in the poultry sector.

Conclusion

In conclusion, this review underscores the significant impacts of climate change on chicken production, including temperature stress, water scarcity, feed supply disruptions, disease prevalence, and economic challenges. Proactive measures such as improved housing, water management, feed innovation, disease control, and genetic selection are essential for enhancing the resilience of poultry farming systems. Industry stakeholders, researchers, and policymakers must collaborate to implement these strategies effectively, safeguarding food security, economic stability, and environmental sustainability. By prioritizing adaptation and mitigation efforts, we can mitigate the adverse effects of climate change on chicken production, ensuring continued productivity and profitability in a changing climate. It is imperative that stakeholders across the poultry industry take decisive action to address these challenges, fostering innovation, sustainability, and resilience in chicken production systems worldwide.

References

Abioja, M. O., & Abiona, J. A. (2021). Impacts of Climate Change to Poultry Production in Africa: Adaptation Options for Broiler Chickens. In *African Handbook of Climate Change Adaptation: With 610 Figures and 361 Tables* (pp. 275–296). Springer International Publishing. https://doi.org/10.1007/978-3-030-45106-6_111

Acevedo, M., Pixley, K., Zinyengere, N., Meng, S., Tufan, H., Cichy, K., Bizikova, L., Isaacs, K., Ghezzi-Kopel, K., & Porciello, J. (2020). A scoping review of adoption of climate-resilient crops by small-scale producers in low- and middle-income countries. *Nature Plants*, *6*(10), 1231–1241. https://doi.org/10.1038/s41477-020-00783-z

Adesiji, G. B., Baba, S. T., & Tyabo, I. S. (n.d.). EFFECTS OF CLIMATE CHANGE ON POULTRY PRODUCTION IN ONDO STATE, NIGERIA. In *Russian Journal of Agricultural and Socio-Economic Sciences* (Vol. 2, Issue 14).

Ayo, J. O., Obidi, J. A., & Rekwot, P. I. (2011). Effects of Heat Stress on the Well-Being, Fertility, and Hatchability of Chickens in the Northern Guinea Savannah Zone of Nigeria: A Review. *ISRN Veterinary Science*, *2011*, 1–10. https://doi.org/10.5402/2011/838606

Boggia, A., Paolotti, L., & Castellini, C. (2010). Environmental impact evaluation of conventional, organic and organic-plus poultry production systems using life cycle assessment. *World's Poultry Science Journal*, *66*(1), 95–114. https://doi.org/10.1017/S0043933910000103

Bouzoubaa, K., Nagaraja, K. V., Kabbai, F. Z., Newman, J. A., & Pomeroy, B. S. (1989). Feasibility of Using Proteins from Salmonella gallinarum vs. 9R Live Vaccine for the Prevention of Fowl Typhoid in Chickens. *Avian Diseases*, *33*(3), 385. https://doi.org/10.2307/1591094

Capper, J. L., & Bauman, D. E. (2013). The Role of Productivity in Improving the Environmental Sustainability of Ruminant Production Systems. *Annual Review of Animal Biosciences*, *1*(1), 469–489. https://doi.org/10.1146/annurev-animal-031412-103727

Castellini, C., Bastianoni, S., Granai, C., Bosco, A. D., & Brunetti, M. (2006). Sustainability of poultry production using the emergy approach: Comparison of conventional and organic rearing systems. *Agriculture, Ecosystems & Environment*, *114*(2–4), 343–350. https://doi.org/10.1016/j.agee.2005.11.014

Chota, A., Kitojo, O., & Ngongolo, K. (2021). Knowledge on diseases, practices, and threats of drugs residues in chicken food chains in selected districts of Dodoma region, Tanzania. *Journal of Applied Poultry Research*, *30*(4), 100186. https://doi.org/https://doi.org/10.1016/j.japr. 2021.100186

Classen, A. T., Sundqvist, M. K., Henning, J. A., Newman, G. S., Moore, J. A. M., Cregger, M. A., Moorhead, L. C., & Patterson, C. M. (2015). Direct and indirect effects of climate change on soil microbial and soil microbial-plant interactions: What lies ahead? *Ecosphere*, *6*(8), 1–21. https://doi.org/10.1890/ES15-00217.1

Conti, M. V., Kalmpourtzidou, A., Lambiase, S., De Giuseppe, R., & Cena, H. (2021). Novel Foods and Sustainability as Means to

Counteract Malnutrition in Madagascar. *Molecules (Basel, Switzerland)*, *26*(8). https://doi.org/10.3390/molecules26082142

Demissu, H., Gebeyehu, G., Berhan, T., & Gemeda, D. (2018). Assessment on rural poultry production and marketing system of Horro chicken ecotypes in Western Ethiopia. Journal of Agricultural Extension and Rural Development, 11(12), 248-259. *Journal of Agricultural Extension and Rural Development*, *11*(12), 248–259.

Dimitrov, K. M., Afonso, C. L., Yu, Q., & Miller, P. J. (2017). Newcastle disease vaccines—A solved problem or a continuous challenge? *Veterinary Microbiology*, *206*, 126–136. https://doi.org/10.1016/j.vetmic.2016.12.019

Egbeyale, L. T., Olaniran, O. J., Ademakin, A. O., & Onagbesan, O. M. (2021). Effect of intensive and semi –intensive systems of management on egg and meat quality of layer chickens. *Nigerian Journal of Animal Production*, *41*(2), 86–94. https://doi.org/10.51791/njap.v41i2.784

Elad, Y., & Pertot, I. (2014). Climate Change Impacts on Plant Pathogens and Plant Diseases. *Journal of Crop Improvement*, *28*(1), 99–139. https://doi.org/10.1080/15427528.2014.865412

Elson, H. A. (2015). Poultry welfare in intensive and extensive production systems. *World's Poultry Science Journal*, *71*(3), 449–460. https://doi.org/10.1017/S0043933915002172

Erdogan, S., Kartal, M. T., & Pata, U. K. (2024). Does Climate Change Cause an Upsurge in Food Prices? *Foods*, *13*(1), 154. https://doi.org/10.3390/foods13010154

Escarcha, J., Lassa, J., & Zander, K. (2018). Livestock Under Climate Change: A Systematic Review of Impacts and Adaptation. *Climate*, *6*(3), 54. https://doi.org/10.3390/cli6030054

Escobedo del Bosque, C. I., Risius, A., Spiller, A., & Busch, G. (2021). Consumers' Opinions and Expectations of an "Ideal Chicken Farm" and Their Willingness to Purchase a Whole Chicken From This Farm. *Frontiers in Animal Science*, *2*. https://doi.org/10.3389/fanim.2021.682477

Gentile, N., Carrasquer, F., Marco-Fuertes, A., & Marin, C. (2024). Backyard poultry: exploring non-intensive production systems. *Poultry Science*, *103*(2), 103284. https://doi.org/10.1016/j.psj.2023.103284

Gkarane, V., Ciulu, M., Altmann, B. A., Schmitt, A. O., & Mörlein, D. (2020). The Effect of Algae or Insect Supplementation as Alternative Protein Sources on the Volatile Profile of Chicken Meat. *Foods*, *9*(9), 1235. https://doi.org/10.3390/foods9091235

Gonzalez-Rivas, P. A., Chauhan, S. S., Ha, M., Fegan, N., Dunshea, F. R., & Warner, R. D. (2020). Effects of heat stress on animal physiology, metabolism, and meat quality: A review. *Meat Science*, *162*, 108025. https://doi.org/10.1016/j.meatsci.2019.108025

Halmemies-Beauchet-Filleau, A., Rinne, M., Lamminen, M., Mapato, C., Ampapon, T., Wanapat, M., & Vanhatalo, A. (2018). Review: Alternative and novel feeds for ruminants: nutritive value, product quality and environmental aspects. *Animal*, *12*, s295–s309. https://doi.org/10.1017/S1751731118002252

Hamdy, A. M. M. (2020). *Climatic Change and Chicken Immunity* (pp. 499–521). https://doi.org/10.1007/978-3-030-41629-4_21

Hobbs, P. R., Sayre, K., & Gupta, R. (2008). The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 543–555. https://doi.org/10.1098/rstb.2007.2169

Iyiola-Tunji, A. O. (2021). Climate-smart livestock production: options for Nigerian farmers. *Nigerian Journal of Animal Production*, *48*(4), 136–148. https://doi.org/10.51791/njap.v48i4.3005

Kahn, M. E., Mohaddes, K., Ng, R. N. C., Pesaran, M. H., Raissi, M., & Yang, J.-C. (2021). Long-term macroeconomic effects of climate change: A cross-country analysis. *Energy Economics*, *104*, 105624. https://doi.org/10.1016/j.eneco.2021.105624

Kondratyev, K. Ya., & Varotsos, C. (1995). Atmospheric greenhouse effect in the context of global climate change. *Il Nuovo Cimento C*, *18*(2), 123–151. https://doi.org/10.1007/BF02512015

Koohafkan, P., & Altieri, M. A. (2016). *Forgotten agricultural heritage: Reconnecting food systems and sustainable development*. Taylor & Francis.

Kpomasse, C. C., Oke, O. E., Houndonougbo, F. M., & Tona, K. (2021). Broiler production challenges in the tropics: A review. *Veterinary Medicine and Science*, *7*(3), 831–842. https://doi.org/10.1002/vms3.435

Kumar, A. (2018). Global Warming, Climate Change and Greenhouse Gas Mitigation. In *Biofuels: Greenhouse Gas Mitigation and Global Warming* (pp. 1–16). Springer India. https://doi.org/10.1007/978-81-322-3763-1_1

Levy, G. J., Fine, P., & Bar-Tal, A. (Eds.). (2010). *Treated Wastewater in Agriculture*. Wiley. https://doi.org/10.1002/9781444328561

Li, Y., Arulnathan, V., Heidari, M. D., & Pelletier, N. (2022). Design considerations for net zero energy buildings for intensive, confined poultry production: A review of current insights, knowledge gaps, and future directions. *Renewable and Sustainable Energy Reviews*, *154*, 111874. https://doi.org/10.1016/j.rser.2021.111874

Lizotte, R., Knight, S., Locke, M., & Bingner, R. (2014). Influence of integrated watershed-scale agricultural conservation practices on lake water quality. *Journal of Soil and Water Conservation*, *69*, 160–170.

Loo, Y. Y., Billa, L., & Singh, A. (2015). Effect of climate change on seasonal monsoon in Asia and its impact on the variability of monsoon rainfall in Southeast Asia. *Geoscience Frontiers*, *6*(6), 817–823. https://doi.org/10.1016/j.gsf.2014.02.009

Malhi, G. S., Kaur, M., & Kaushik, P. (2021). Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review. *Sustainability*, *13*(3), 1318. https://doi.org/10.3390/su13031318

Mengesha, M. (2011). Climate change and the preference of rearing poultry for the demands of protein foods. *Asian Journal of Poultry Science*, *5*(4), 135–143. https://doi.org/10.3923/ajpsaj.2011.135.143

Misra, A. K. (2014). Climate change and challenges of water and food security. *International Journal of Sustainable Built Environment*, *3*(1), 153–165. https://doi.org/10.1016/j.ijsbe.2014.04.006

Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the National Academy of Sciences*, *104*(50), 19680–19685. https://doi.org/10.1073/pnas.0701855104

Mramba, P. R. (2023). The role of feeds in the transmission of chicken pathogens in Dodoma Urban District, Tanzania. *Poultry Science*, *102*(4), 102558.

Mteiye MALAWI, A. (2019). EDITOR-IN-CHIEF CLIMATE CHANGE IN POULTRY PRODUCTION SYSTEM-A REVIEW. In *INTERNATIONAL JOURNAL-ASD* (Vol. 10, Issue 2).

Mujyambere, V., Adomako, K., Olympio, S. O., Ntawubizi, M., Nyinawamwiza, L., Mahoro, J., & Conroy, A. (2022). Local chickens in East African region: their production and potential. *Poultry Science*, *101*(1), 101547. https://doi.org/10.1016/j.psj.2021.101547

Nawab, A., Ibtisham, F., Li, G., Kieser, B., Wu, J., Liu, W., Zhao, Y., Nawab, Y., Li, K., Xiao, M., & An, L. (2018). Heat stress in poultry production: Mitigation strategies to overcome the future challenges facing the global poultry industry. *Journal of Thermal Biology*, *78*, 131–139. https://doi.org/10.1016/j.jtherbio.2018.08.010

Ndue, K., & Pál, G. (2022). Life Cycle Assessment Perspective for Sectoral Adaptation to Climate Change: Environmental Impact Assessment of Pig Production. *Land*, *11*(6), 827. https://doi.org/10.3390/land11060827

Ngongolo, K., & Chota, A. (2021). Chicken production, flock size, management systems, and challenges in the Dodoma region in Tanzania. *Poultry Science*, *100*(6), 101136. https://doi.org/https://doi.org/10.101 6/j.psj.2021.101136

Ngongolo, K., & Chota, A. (2022). Effect of sex, age, diseases, and control intervention on chickens' mortality and its financial implications in Dodoma, Tanzania. *Poultry Science*, *101*(5), 101785. https://doi.org/10.1016/j.psj.2022.101785

Ngongolo, K., Kitojo, O., & Chota, A. (2020). Drug used in controlling chickens diseases, the withdrawal periods, and the threats of drugs residues in food chain. A review. *Berkala Penelitian Hayati*, *26*(1), 39–44. https://doi.org/https://doi.org/10.23869/bphjbr.26.1.20207

Ngongolo, K., Kitojo, O., & Chota, A. (2021). Social-economic impact of chicken production on resource-constrained communities in Dodoma, Tanzania. *Poultry Science*, *100*(3), 100921.

Ngongolo, K., Omary, K., & Andrew, C. (2020). Drug used in controlling chickens diseases, the withdrawal periods, and the threats of drugs residues in food chain. A review. *Berkala Penelitian Hayati*, *26*(1), 39–44. https://doi.org/10.23869/bphjbr.26.1.20207

Niesenbaum, R. A. (2019). The Integration of Conservation, Biodiversity, and Sustainability. *Sustainability*, *11*(17), 4676. https://doi.org/Doi: 10.3390/su11174676

Nyoni, N. M. B., Grab, S., & Archer, E. R. M. (2019). Heat stress and chickens: climate risk effects on rural poultry farming in low-income countries. *Climate and Development*, *11*(1), 83–90. https://doi.org/10.1080/17565529.2018.1442792

Passarelli, S., Abdelmenan, S., Tewahido, D., Demmu, Y. M., Abreham, H., Ambikapathi, R., Gunaratna, N. S., Berhane, Y., & Fawzi, W.

(2022). Nutrition-sensitive chicken production in Ethiopia: a qualitative evaluation. *Agriculture & Food Security*, *11*(1), 23. https://doi.org/10.1186/s40066-022-00363-8

Rabie, T. S. K. M. (2020). *Potential Climate Change Impacts on Livestock and Food Security Nexus in Egypt* (pp. 423–450). https://doi.org/10.1007/978-3-030-41629-4_17

Ramanathan, V., & Feng, Y. (2009). Air pollution, greenhouse gases and climate change: Global and regional perspectives. *Atmospheric Environment*, *43*(1), 37–50. https://doi.org/10.1016/j.atmosenv.2008.09.063

Raupach, T. H., Martius, O., Allen, J. T., Kunz, M., Lasher-Trapp, S., Mohr, S., Rasmussen, K. L., Trapp, R. J., & Zhang, Q. (2021). The effects of climate change on hailstorms. *Nature Reviews Earth & Environment*, *2*(3), 213–226. https://doi.org/10.1038/s43017-020-00133-9

Rehman, M. S., Mahmud, A., Mehmood, S., Pasha, T. N., Javed, K., Hussain, J., & Khan, M. T. (n.d.). PRODUCTION PERFORMANCE OF ASEEL CHICKEN UNDER FREE RANGE, SEMI-INTENSIVE AND CONFINEMENT REARING SYSTEMS. In *The J. Anim. Plant Sci* (Vol. 26, Issue 6).

Renaudeau, D., Collin, A., Yahav, S., de Basilio, V., Gourdine, J. L., & Collier, R. J. (2012). Adaptation to hot climate and strategies to alleviate heat stress in livestock production. *Animal*, *6*(5), 707–728. https://doi.org/10.1017/S1751731111002448

Rocchi, L., Paolotti, L., Rosati, A., Boggia, A., & Castellini, C. (2019). Assessing the sustainability of different poultry production systems: A multicriteria approach. *Journal of Cleaner Production*, *211*, 103–114. https://doi.org/10.1016/j.jclepro.2018.11.013

Rosinger, A. Y. (2023). Extreme climatic events and human biology and health: A primer and opportunities for future research. *American Journal of Human Biology*, *35*(1). https://doi.org/10.1002/ajhb.23843

Singh, B., Singh, A., Jadoun, Y. S., Bhadauria, P., & Kour, G. (2024). Strategies for Sustainable Climate Smart Livestock Farming. In *Adapting to Climate Change in Agriculture-Theories and Practices* (pp. 341–359). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-28142-6_16

Skuce, P. J., Morgan, E. R., van Dijk, J., & Mitchell, M. (2013). Animal health aspects of adaptation to climate change: beating the heat and parasites in a warming Europe. *Animal*, *7*, 333–345. https://doi.org/10.1017/S175173111300075X

Soliman, A., & Safwat, A. M. (2020). *Climate Change Impact on Immune Status and Productivity of Poultry as Well as the Quality of Meat and Egg Products* (pp. 481–498). https://doi.org/10.1007/978-3-030-41629-4_20

Tadele, G., Asrade, B., Bayleyegn, G., & Ali, M. S. (2014). Typhoid and pullorum disease from apparently healthy chickens in eastern. *Ethiopia. J. Vet. Sci. Technol*, *5*(2), 156.

Thornton, P. K., van de Steeg, J., Notenbaert, A., & Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems*, *101*(3), 113–127. https://doi.org/10.1016/j.agsy.2009.05.002

Turnpenny, J. R., Parsons, D. J., Armstrong, A. C., Clark, J. A., Cooper, K., & Matthews, A. M. (2001). Integrated models of livestock systems for climate change studies. 2. Intensive systems. *Global Change Biology*, *7*(2), 163–170. https://doi.org/10.1046/j.1365-2486.2001.00401.x

Vandana, G. D., Sejian, V., Lees, A. M., Pragna, P., Silpa, M. V., & Maloney, S. K. (2021). Heat stress and poultry production: impact and amelioration. *International Journal of Biometeorology*, *65*(2), 163–179. https://doi.org/10.1007/s00484-020-02023-7

Vernooy, R. (2022). Does crop diversification lead to climate-related resilience? Improving the theory through insights on practice. *Agroecology and Sustainable Food Systems*, *46*(6), 877–901. https://doi.org/10.1080/21683565.2022.2076184

Vieira, F. M. C., Groff, P. M., Silva, I. J. O., Nazareno, A. C., Godoy, T. F., Coutinho, L. L., Vieira, A. M. C., & Silva-Miranda, K. O. (2019). Impact of exposure time to harsh environments on physiology, mortality, and thermal comfort of day-old chickens in a simulated condition of transport. *International Journal of Biometeorology*, *63*(6), 777–785. https://doi.org/10.1007/s00484-019-01691-4

Viñado, A., Castillejos, L., Rodriguez-Sanchez, R., & Barroeta, A. C. (2019). Crude soybean lecithin as alternative energy source for broiler chicken diets. *Poultry Science*, *98*(11), 5601–5612. https://doi.org/10.3382/ps/pez318

Wasti, S., Sah, N., & Mishra, B. (2020). Impact of Heat Stress on Poultry Health and Performances, and Potential Mitigation Strategies. *Animals*, *10*(8), 1266. https://doi.org/10.3390/ani10081266