2025, Scienceline Publication
World's Veterinary Journal
World Vet J, 15(4): 1130-1137.
ISSN 2322-4568

DOI: https://dx.doi.org/10.54203/scil.2025.wvj116
PII: S232245682500116-15

Effects of Heat Stress on Growth Performance, Egg Production, Egg Quality, and Potential Controlling Strategies in Layer Chicken: A Review

Eyayu Gobezie*, Ashenafi Timotiwos, and Getahun Simeneh

College of Agricultural and Environmental Conservation, Department of Animal Science, Debark University, P.O. Box 90, Debark, Ethiopia

*Corresponding author's Email: gobezieeyayu@gmail.com

REVIEW ARTICLE
Received: September 19, 2025
Revised: October 24, 2025
Accepted: November 21, 2025
Published: December 31, 2025

ABSTRACT

Egg production is a key indicator of laying hens' reproductive efficiency. High ambient temperatures cause heat stress in laying hens, which negatively impacts their health, behavior, blood chemistry, feed intake, egg production, and egg quality. The present study aimed to focus on the effects of heat stress on growth performance, egg production, egg quality, and potential controlling strategies for heat stress in layer chickens. Heat stress reduces body weight, feed efficiency, egg yield, and egg quality. Reduced feed intake is the main reason contributing to its negative impacts on production. The reduced feed intake and decreased nutrient digestibility have adverse effects on egg quality and production performance. Heat stress reduces egg production and impairs the behavior, welfare, and immunity of layer chickens, resulting in significant financial losses. Higher ambient temperatures (above 25°C) can lead to lower egg quality (soft shells or shell-less eggs), weakened skeletal integrity in hens, and fewer eggs. Poor hatchability results from reduced feed intake due to high temperatures, which adversely affects semen fertility and quality. Eggs produced under extreme heat stress had lower Haugh units, egg yolk color, and eggshell thickness and strength. Overcrowding, also known as high stocking density, adversely affects animal health by degrading their habitat and increasing competition for resources such as feed, which can ultimately lead to feather pecking and cannibalism. Due to a quicker metabolic rate, chickens produce more body heat and are more susceptible to heat stress. High stocking density and high ambient temperature increase the risk of heat stress. Reducing stocking density to prevent heat stress may limit the number of hens that can be raised in a given space. Heat stress significantly reduces egg production, egg quality, and egg weight in laying hens under hot conditions. The current findings highlighted the need for improved environmental management and methods to mitigate the harmful effects of heat stress in laying hens.

Keywords: Egg production, Egg quality, Egg weight, Heat stress, Laying chicken

INTRODUCTION

Climate change has become a significant global concern for the livestock industry, resulting from increasing weather patterns that lead to higher ambient temperatures and humidity (Nawab et al., 2018). According to Charles (2002), the ideal temperature range for the thermoneutral zone and performance is 19-22°C for laying hens and 18-22°C for broiler chickens; however, their usual body temperature is 41-42°C (Naga et al., 2018). Heat stress is caused by the interaction of several factors, such as high ambient temperature, high humidity, radiant heat, and airspeed (Lara and Rostagno, 2013). Chickens experience heat stress at any temperature above 25°C (Donkoh, 1989). Chickens have feathers all over their bodies and no sweat glands (Richards, 1970), which makes it more difficult for them to regulate body temperature, so when the outside temperature rises, they should actively dissipate heat via panting. When chickens experience heat stress, their body temperature rises because they are unable to dissipate extra heat into the surrounding environment (Sugiharto, 2020). Heat stress reduces the body weight, feed intake, egg production, fertility, and survivorship in laying hens (Mashaly et al., 2004; Barrett et al., 2019). According to the study conducted by Mashaly et al. (2004), 31-week-old laying hens exposed to heat stress for five weeks experienced a notable decrease in body weight, feed intake, egg production rate, and egg weight. In tropical and temperate nations, high environmental temperature is one of the most significant factors influencing laying hens' production performance (Tesakul et al., 2025). High ambient temperatures and humidity can cause heat stress in laying hens, greatly impacting their egg production, quality, feed intake, blood chemistry, health, and behavior (Tesakul et al., 2025). According to Sahin et al. (2007), the three main reasons for egg losses are reproductive failure (fewer eggs), poor egg quality (soft shells or shell-less eggs), and impaired hen skeletal integrity.

To cite this paper: Gobezie E, Timotiwos A, and Simeneh G (2025). Effects of Heat Stress on Growth Performance, Egg Production, Egg Quality, and Potential Controlling Strategies in Layer Chicken: A Review. *World Vet. J.*, 15(4): 1130-1137. DOI: https://dx.doi.org/10.54203/scil.2025.wvj116

Heat stress in poultry can be classified as acute, characterized by abrupt, short-duration exposures to extreme heat, or chronic, involving sustained exposure to elevated temperatures (Kpomasse et al., 2021). Depending on the length and severity of the stressor, there are two types of heat stress. While chronic heat stress occurs during a prolonged period of high temperature and humidity, acute heat stress is defined as an abrupt increase in temperature and humidity over a brief period. Heat stress in chickens can last 1 to 24 hours (acute), 7 days (moderate), or longer (chronic) at temperatures between 27°C and 38°C (Vandana et al., 2021). Acute or chronic heat stress may reduce egg production (Deng et al. 2012; Ebeid et al., 2012). Extreme weather conditions and chronic heat stress affect hen physiology, leading to lower egg production efficiency, poor health, and increased death rates (Saeed et al., 2019; Attia et al., 2024; Kim et al., 2024). Significant physiological problems, immune suppression, and gut microbial imbalance can result from both acute and chronic heat stress (Wasti et al., 2020). Serious physiological issues (elevated heart rate, increased body core temperature, and sweating), immunological suppression, and an imbalance in gut microbes can result from heat stress (Lara and Rostagno, 2013; Attia et al., 2018). The biggest concern for large economic losses in the poultry sector is stress, stemming from numerous types of stressors; heat stress is a prominent one (Safi et al., 2022). Moreover, reduced egg production directly affects the number of day-old chicks and increases production expenses (Lara and Rostagno, 2013). Thus, one of the most important challenges in raising chicken productivity and profitability during heat stress is increasing egg production (Radwan, 2020). Reduced egg production is a significant problem in the world's food shortage situation and directly impacts farmers' incomes (Pawar et al., 2016). According to a 2021 UN report (FAO, IFAD, UNICEF, WFP, and WHO), the prevalence of hunger in the world increased sharply in 2020. It was estimated that between 9.2% and 10.4% of the global population faced undernourishment that year, with a central estimate of 9.9% (FAO, 2021). In terms of egg quality, meat quality, growth, and egg output, heat stress affects the total performance of both layers and broiler chickens (Safi et al., 2022).

Poultry in the thermoneutral zone (19-22ºC for laying hens and 18-22ºC for growing broilers) do not experience heat stress because their body temperature is kept constant and they dissipate heat through routine behaviors (Charles, 2002). The production of body heat and heat loss cannot be balanced in chickens under heat stress (Lara and Rostagno, 2013). Laying hens exposed to severe heat stress at 33 °C had significantly reduced feed intake and lower egg production (Kim et al., 2024). Additionally, the laying hens' immediate environment contains more etiologically dangerous bacteria as the temperature rises. Climate change affects the emergence and spread of diseases by increasing the prevalence of parasitic and bacterial infections (Ranjan et al., 2019). Certain feeding practices have gained importance and are employed in commercial settings because heat stress negatively impacts the health, welfare, and laying performance of laying hens (Attia et al. 2016; Jahromi et al. 2016; Abdel-Moneim et al. 2021). Heat stress strategies include a variety of treatments, such as supplementing feed or water with natural antioxidants, organic acids, vitamins, minerals, electrolytes, prebiotics, probiotics, and Phytobiotics, rationing, feed restriction, dietary changes, and drinking cold water (Abd El-Ghany and Babazadeh, 2022).

Understanding the basics of heat stress's causes, detrimental effects, and methods for lowering or mitigating heat stress in the chicken industry is essential to resolving global food security challenges. The present study aimed to assess the effects of heat stress on growth performance, egg output, and egg quality, and to identify potential control strategies for heat stress in laying chickens.

GROWTH PERFORMANCE

As shown in Figure 1, heat stress results in a number of physiological alterations, including oxidative stress, acid-base imbalance, and inhibited immunocompetence. These alterations impact the quality of meat and eggs as well as increase mortality and decrease feed efficiency, body weight, feed intake, and egg production (Wasti et al., 2020). High temperatures can also increase panting under heat stress, leading to elevated carbon dioxide levels and higher blood pH (Lara and Rostagno, 2013). In hot weather, chickens use more water and less feed, and poultry perform badly (Saeed et al., 2019; Rahman and Hidayat, 2020). To maintain homeostasis and reduce heat production, chickens decrease their feed intake (Etches et al., 2008). Decreased feed intake is likely the main reason heat stress harms production, leading to losses in body weight, feed efficiency, egg yield, and egg quality (Barrett et al., 2019). Reduced feed intake and nutrient digestibility have negative impacts on production performance, meat, and egg quality (Song and King, 2015; Song et al., 2022). Deng et al. (2012) demonstrated that a 12-day heat stress exposure (34°C) in 60-week-old commercial hens (Hy-Line Brown) reduced egg production by 28.8% (from 79.5% to 50.7%). This was accompanied by a significant reduction in daily feed intake of 28.6 g per chicken. Additionally, in 24-week-old laying hens, exposure to 32°C heat stress for 22 days significantly reduced hen-day egg production by approximately 34% during the first week of exposure and slightly reduced average egg weight (~1%; Star et al. 2009). When ambient temperature increases from 21.1°C to 32.2°C, feed intake decreases by approximately 9.5% per bird per day during the post-hatch period up to 6 weeks of age. This reduction in feed consumption is associated with poorer feed conversion efficiency and lower daily weight gain in chickens exposed to heat stress (Syafwan et al., 2011). He et al. (2019) demonstrated that cyclic heat stress, exposure to 37 ± 2°C for 8 hours per day, reduces average daily feed intake by 15.8%. Weight loss may have resulted from the heat-stressed chickens eating less feed than the control group (Mashaly et al., 2004). Moreover, Zhang et al. (2017) indicated that in 21-day-old Cobb male broiler chickens, high ambient temperatures (33°C) reduce development rate and meat yield. Due to the reduced nutritional requirements in chickens, protein digestibility may decrease by as much as 9.7%. The growth rates, feed efficiency, immunity, and carcass quality in broiler chickens can decrease due to high ambient temperatures (Dayyani and Bakhtiyari, 2013). Consequently, layer chickens grow more slowly and are more susceptible to illnesses (Nawaz et al., 2021).

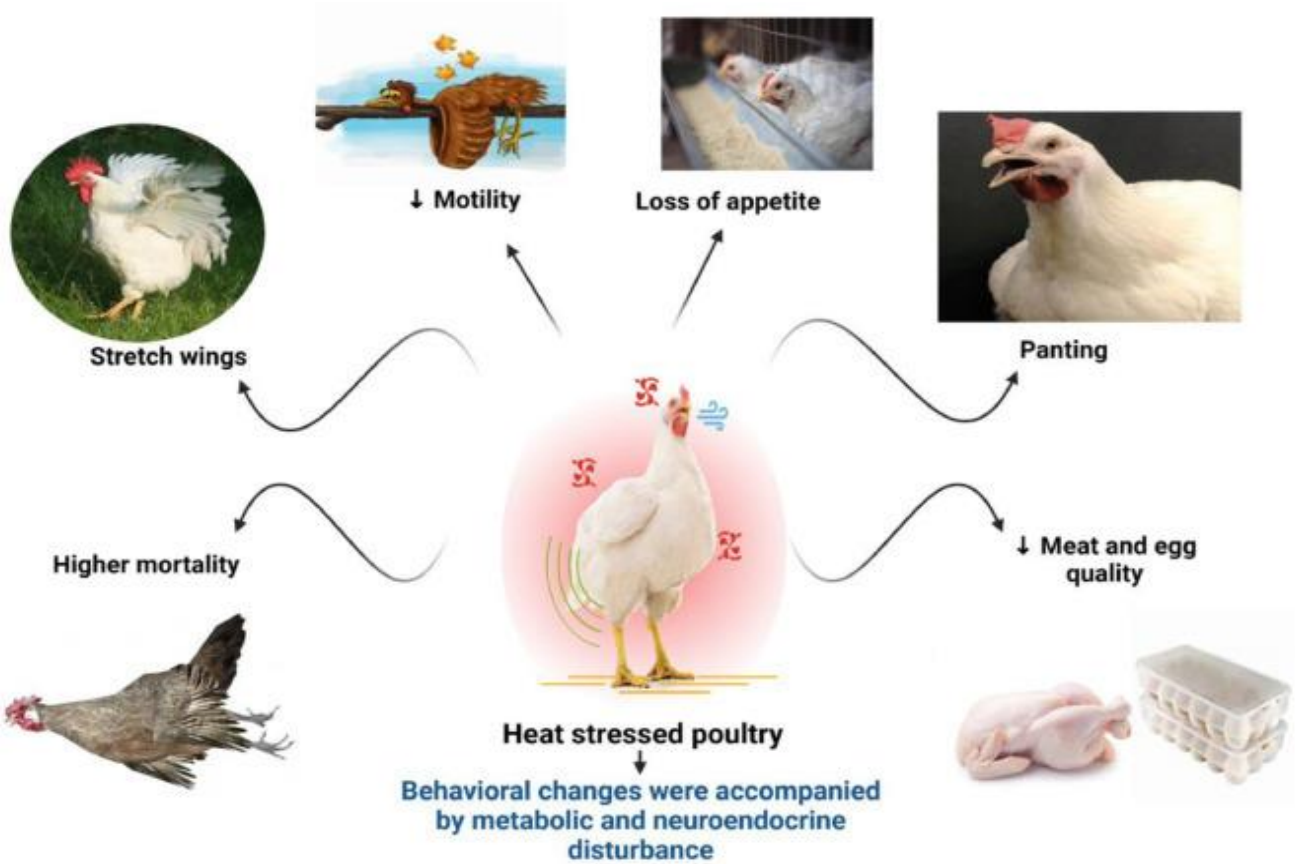

Figure 1. Effect of heat stress on the production performance in layer chickens. Source: Ahmed et al. (2024).

EGG PRODUCTION

Heat stress is the primary reason for the egg weight loss. The weight loss of egg albumen and yolk is likewise predominantly driven by high temperatures above 26°C (Smith, 1974). According to Ugurlu et al. (2001), hens exposed to heat had lower egg weights. Mashaly et al. (2004) found that high temperatures (35°C) can significantly reduce the shell thickness, as measured by a micrometer screw gauge, and specific gravity, in addition to the weights of the egg yolk, egg albumen, and shell.

The number of eggs produced by hens kept in a hot chamber (23.9 to 35 °C) differed significantly from those kept in regulated chambers (23.9°C), which were maintained for 5 weeks (Mashaly et al., 2004). This implied that egg production and surrounding temperature are inversely related. In a study by Rozenboim et al. (2007), 36 White Leghorn hens (31 weeks old) exposed to 42 ± 3°C for 12 hours daily developed hyperthermia and demonstrated a marked reduction in egg production and egg weight. These effects were accompanied by hormonal changes detectable just two days after heat exposure, compared to controls kept at 24-26°C. Yan et al. (2022) reported that Hy-Line Brown laying hens that were exposed to 32°C (heat stress for 14 days) compared to the hens in the control group (22°C), indicated an 18.75% drop in egg production on day 4 of heat exposure, from 90.63% in the control to 71.88% in the heat group. Additionally, Deng et al. (2012) found that during a 12-day heat stress phase in 96 commercial Hy-Line Brown hens at the age of 60 weeks, egg production decreased by 28.8%. In four genetically distinct strains, including Lohman Brown, Golden Sabathia (23.21%), Fayoumi (15.15%), and White Leghorn (28.57%) in Egypt, it was found that exposure to a temperature of 35 ± 1°C and 55 ± 5% relative humidity for six hours had detrimental effects on egg quality and production (Ghoname et al., 2022). Kim et al. (2024) indicated that hens exposed to 33°C and 66% relative humidity for 28 days experienced an 11% decrease in egg production rate. Furthermore, eggs produced by laying hens under extreme heat stress result in low-quality output, more broken eggs, and thinner eggshells (Lin et al., 2013). Moreover, heat stress has been shown to reduce eggshell weight (9.93%), thickness (1.2%), percentage (0.66%), and Egg weight (3.24%; Ebeid et al., 2012).

EGGSHELL QUALITY

Hereditary (genetic) factors, environmental factors (management, housing, stress), nutrition, and external components all contribute to eggshell quality flaws, including thin shell, softness, speckles, fractures, and translucency (Cheng and Ning, 2023). Laying hens can produce high-quality eggshells only when they are raised in optimal conditions with all essential components present and functioning in unison (Ketta and Tůmová, 2016). Eggshell development is disrupted by high ambient temperatures (over 32-35°C), which significantly reduces the eggshell's weight, thickness, and strength. A variety of issues, including low feed intake by hens, acid-base and mineral imbalances, physiological disorders in the endocrine system, and other organs involved in eggshell formation, are associated with the negative impact of high ambient temperatures on eggshell quality (Kavtarashvili and Buyarov, 2021). High ambient temperatures (above 32-35°C) disrupt shell formation, leading to lighter, thinner, and weaker shells (Kavtarashvili and Buyarov, 2021). A low-calcium diet significantly decreased hen-day egg production, eggshell weight, strength, and thickness. Calcium deficiency in hens leads to poor shell quality, which may be exacerbated under stressors (Li X et al., 2024). According to Elijah and Adedapo (2006), a drop in feed intake during high ambient temperatures (32.4-33.15 °C) compromised the quality of the eggshell, causing small egg size, low egg production, and eggshell cracking, using climatological data and data from poultry farmers over a period of five years (2000-2004).

SIGNS OF HEAT STRESS IN LAYER CHICKENS

As shown in Figure 1, the signs of heat stress in poultry include open-mouthed panting, lethargy, reduced feed intake, and decreased egg production and quality, as well as a rapid breathing rate, a characteristic posture of standing with wings outstretched, and an increased tendency for cannibalism, which can ultimately lead to prostration and death (Nardone et al., 2010). Additionally, a heat-stressed chicken would pant, spread its wings, hold them slightly apart from its body, stand or lie down, and close its eyes (Dayyani and Bakhtiyari, 2013). Providing cool drinking water to hens under heat stress (33°C) maintained egg production and significantly improved eggshell strength (Kim et al., 2025). Exposure of chickens to severe heat stress (≥ 40-42°C) can cause very high mortality, sometimes approaching 100% during acute heat waves, whereas moderate-to-severe heat stress typically results in mortality rates of about 5-50%, depending on duration, humidity, genotype, age, and management. Annual financial losses from heat stress in the US layer industry were estimated at 61.4 million USD (St-Pierre et al., 2003).

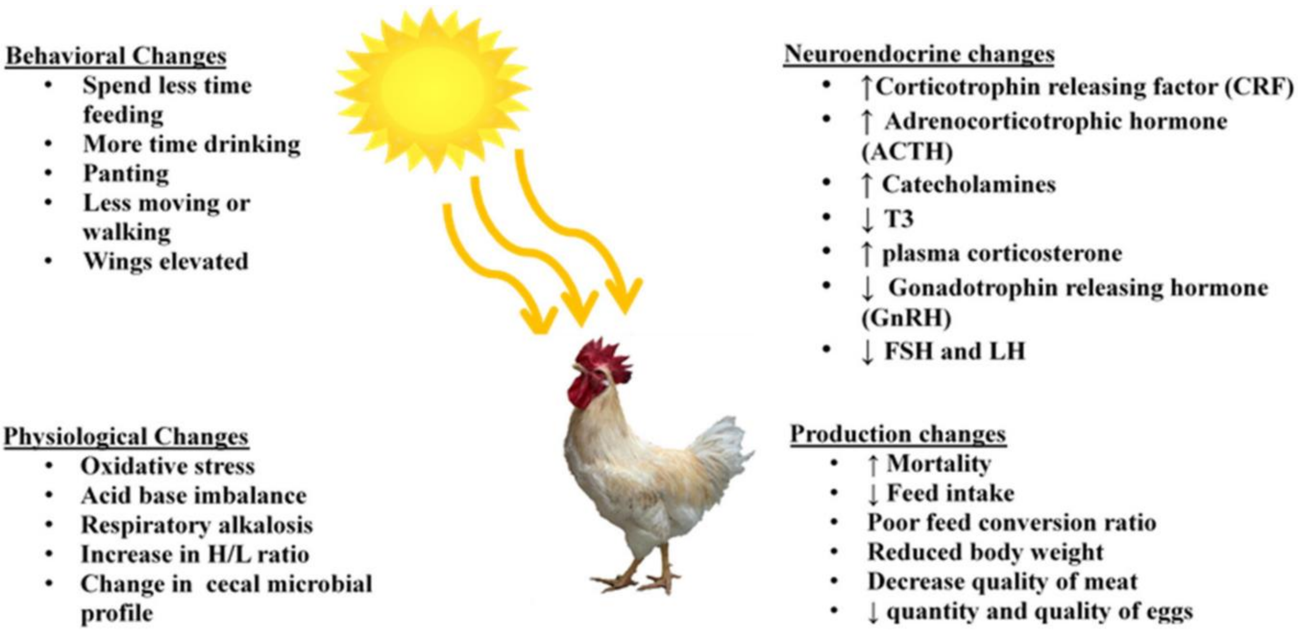

Figure 2. Layer chicken responds to heat stress. Source: Wasti et al. (2020).

To deal with heat stress, chickens try to control their body temperature by changing their normal behaviors (Figure 2). The chickens may rest to dissipate heat from activity, eat less feed, drink more water, lift their wings away from their bodies to reveal any patches of skin without feathers, move into air streams or against cooler surfaces such as brick walls, and move away from other chickens and breathe rapidly (Lara and Rostagno, 2013).

CONTROLLING STRATEGIES

The layout and design of the housing are essential factors in reducing heat stress in hens during hot weather. Therefore, it is necessary to ensure that air flows freely into and out of the layer chicken pens (Pawar et al., 2016; Nawab et al., 2018). Wet feeding, self-selection, diurnal feeding patterns, and coarser meals are all effective ways to combat heat stress (Rahman and Hidayat, 2020). To boost appetite on hot days, more feeders should be available, and the feed should be well-prepared into mash, crumbles, or pellets (Pawar et al., 2016). Open-style homes with adequate ventilation, shade, and water input are essential in hot and muggy climates. It is advised that houses be oriented east-west (Oloyo and Ojerinde, 2020).

When environmental temperatures exceed the thermoneutral zone (16-26°C), chickens should be managed to consume less feed and increase their water intake to aid in cooling (Diarra and Poasa, 2014). Sahin et al. (2002) reported that serum vitamin E levels decreased in poultry under heat stress, while supplemental vitamin E and vitamin A improved broiler performance, increased serum triiodothyronine (T_3), thyroxine (T_4), calcium, and phosphorus, and reduced adrenocorticotropic hormone (ACTH) and specific blood metabolites under heat stress (32°C). Dietary supplementation with vitamin E and organic selenium significantly improved growth performance (body weight gain and feed intake) and reduced heat-related mortality in broiler chickens exposed to heat stress (Çalik et al., 2022). Dehydration, the most intuitive panting-related disadvantage, usually results in higher water requirement and consumption (Wang et al., 2018). Providing chickens with cool drinking water aids cooling by absorbing body heat and helps maintain thermoregulation under high ambient temperatures (Kim et al., 2025), while adding electrolytes to the water helps restore essential minerals and balance blood pH levels disrupted by heat stress (Olayiwola and Adedokun, 2025).

To reduce the negative effects of heat stress on feed intake and utilization, managing feeding time is essential (Farghly et al., 2018). As a result, the hens should be fed a lot in the early morning and late evening when it is cold outside, and the rest of the feed can be provided at any time the layer chickens choose. Since feed-starved chickens produce less heat than fed ones, removing feed on hot days can improve performance traits such as egg production, feed efficiency, egg weight, and growth rate (Daghir, 2009).

Adequate ventilation is crucial because it helps to remove moisture, carbon dioxide, and ammonia that have accumulated in the poultry barns (Pawar et al., 2016; Nawab et al., 2018). Ventilation technology can reduce health issues associated with stress (Pawar et al., 2016; Nawab et al., 2018).

Heat stress is also influenced by stocking density. Excessive stocking density, or overcrowding, has detrimental effects on animal welfare by lowering the general quality of the habitat and making it more difficult for hens to compete for resources. However, lowering stocking density to reduce heat stress can also limit the number of hens that can be raised on a particular farm or in a specific home. Feather pecking and cannibalism are two problems that may arise from overcrowding (Shakeri et al., 2014). Low economic return may result from high stocking density, which generally has negative effects on health, and production performance (Pawar et al., 2016; Nawab et al., 2018).

CONCLUSION

Heat stress has detrimental effects on the health and productivity of hens, posing a major problem for tropical poultry farming. A drop in feed intake during high ambient temperatures compromised the quality of the egg shell, causing small egg size, low egg production, and eggshell cracking. Heat stress has impaired layer production performance by reducing eggshell thickness, increasing egg breakage, and decreasing egg weight and percentage. There are strategies worldwide to mitigate the negative effects of heat stress, including selecting rearing systems with enhanced ventilation, suitable housing conditions, and recommended optimal stocking densities, all of which are critical for enhancing performance at high temperatures. Therefore, exploring other strategies to reduce heat stress while maintaining stocking density without compromising the chickens' performance and well-being is necessary. It is important to conduct further studies on novel approaches that leverage heat-tolerance genes in chickens, as well as on genetic markers to identify chicken genotypes with enhanced heat tolerance.

DECLARATIONS

Acknowledgments

The authors would like to express their gratitude to the reviewers for their constructive criticisms, which have contributed to enhancing the quality of the present manuscript.

Authors' contributions

Eyayu Gobezie conceived and designed the review topic, conducted the comprehensive literature search, synthesized and critically analyzed the published data, and prepared the original draft of the manuscript. Ashenafi Timotiwos contributed to literature collection and organization, assisted in writing specific sections related to growth performance and egg quality, and participated in manuscript revision. Getahun Simeneh contributed to reviewing and editing the manuscript for scientific accuracy and clarity and provided intellectual input on mitigation strategies for heat stress in layer chickens. All authors checked and approved the last edition of the manuscript.

Funding

The current study received no funding.

Competing interests

The authors declared no conflict of interest.

Ethical considerations

The authors declared and confirmed that the manuscript is original, free from misconduct, and has not been previously published in another journal. It is confirmed to be a new contribution to this journal. All authors checked the originality of the data and sentences via a plagiarism checker. No AI tools were used during the writing and preparation of the present study.

Availability of data and materials

No new data were created or analyzed in this study. This article is a review of existing literature, and all referenced materials are cited in the reference list.

REFERENCES

Abd El-Ghany WA and Babazadeh D (2022). Betaine: A potential nutritional metabolite in the poultry industry. Animals, 12(19): 2624. DOI: https://www.doi.org/10.3390/ani12192624

Abdel-Moneim AME, Shehata AM, Mohamed NG, Elbaz AM, and Ibrahim N (2021). Synergistic effect of *Spirulina platensis* and selenium nanoparticles on growth performance, serum metabolites, immune responses, and antioxidant capacity of heat-stressed broiler chickens. Biological Trace Element Research, 200(2): 768-779. DOI: https://www.doi.org/10.1007/s12011-021-02662-w

Ahmed G, Samar T, Khalid M, Shatha G, Asmaa F, Norhan E, Mariusz J, Moustafa M, Alshaharni MO, and Algopish U (2024). Heat shock proteins as a key defense mechanism in poultry production under heat stress conditions. Poultry Science, 103(4): 103537. https://www.doi.org/10.1016/j.psj.2024.103537

Attia YA, Abd El-Hamid AEH, Abedalla AA, Berika MA, Al-Harthi MA, Kucuk O, Sahin K, and Abou-Shehema BM (2016). Laying performance, digestibility and plasma hormones in laying hens exposed to chronic heat stress as affected by betaine, vitamin C, and/or vitamin E supplementation. Springer Plus, 5: 1619. DOI: https://www.doi.org/10.1186/s40064-016-3304-0

Attia YA, Aldhalmi AK, Youssef IM, Bovera F, Tufarelli V, ElHack MEA, ElKholy KH, and Shukry M (2024). Climate change and its effects on poultry industry and sustainability. Discover Sustainability, 5(1): 397. DOI: https://www.doi.org/10.1007/s43621-024-00627-2

Attia YA, Al-Harthi MA, and Elnaggar SH (2018). Productive, physiological and immunological responses of two broiler strains fed different dietary regimens and exposed to heat stress. Italian Journal of Animal Science, 17(3): 686-697. DOI: https://www.doi.org/10.1080/1828051X.2017.1416961

Barrett NW, Rowland K, Schmidt CJ, Lamont SJ, Rothschild MF, and Ashwell CM (2019). Effects of acute and chronic heat stress on the performance, egg quality, body temperature, and blood gas parameters of laying hens. Poultry Science, 98(12): 6684-6692. DOI: https://www.doi.org/10.3382/ps/pez541

Çalik A, Emami N, White M, Walsh M, Romero L, and Dalloul R (2022). Influence of dietary vitamin E and selenium supplementation on broilers subjected to heat stress: Part I — Growth performance, body composition and intestinal nutrient transporters. Poultry Science, 101(6): 101857. https://www.doi.org/10.1016/j.psj.2022.101857

Charles DR (2002). Responses to the thermal environment. Poultry environment problems, a guide to solutions. Nottingham University Press., Nottingham, United Kingdom, pp. 1-16. DOI: https://www.doi.org/10.1093/ps/81.8.1257

Cheng X and Ning Z (2023). Research progress on bird eggshell quality defects: A review. Poultry Science, 102(1): 102283. DOI: https://www.doi.org/10.1016/j.psj.2022.102283

Daghir NJ (2008). Poultry production in hot climates, 2nd Edition. CAB International., Wallingford, Oxfordshire, UK, pp. xiii, 387. DOI: https://www.doi.org/10.1079/9781845932589.0000

Dayyani N and Bakhtiyari H (2013). Heat stress in poultry: Background and affective factors. International Journal of Advanced Biological and Biomedical Research, 1(11): 1409-1413. Available at: http://www.ijabbr.com/article_7968_f56af19891048da54f54040274e4cd73.pdf

Deng W, Dong XF, Tong JM, and Zhang Q (2012). The probiotic *Bacillus licheniformis* ameliorates heat stress-induced impairment of egg production, gut morphology, and intestinal mucosal immunity in laying hens. Poultry Science, 91(3): 575-582. DOI: https://www.doi.org/10.3382/ps.2010-01293

Diarra S and Poasa T (2014). Feeding management of poultry in high environmental temperatures, International Journal of Poultry Science, 13(11): 657-661. DOI: https://www.doi.org/10.3923/ijps.2014.657.661

Donkoh A (1989) Ambient temperature: A factor affecting performance and physiological response of broiler chickens. International Journal of Biometeorology, 33(4): 259-265. DOI. https://www.doi.org/10.1007/BF01051087

Ebeid TA, Suzuki T, and Sugiyama T (2012). High temperature influences eggshell quality and calbindin-D28k localization of eggshell gland and all intestinal segments of laying hens. Poultry Science, 91(9): 2282-2287. DOI: http://www.doi.org/10.3382/ps.2011-01898

Elijah OA and Adedapo A (2006). The effect of climate change on poultry productivity in Ilorin Kwara State, Nigeria. International Journal of Poultry Science, 5(11): 1061-1068. DOI: https://www.doi.org/10.3923/ijps.2006.1061.1068

Etches RJ, John TM, Verrinder, and Gibbins AM (2008). Behavioral, physiological, neuroendocrine and molecular responses to heat stress. In: N. J. Daghir, Editor, Poultry production in hot climates, 2nd Edition. CAB International., Wallingford (UK), pp. 48-79. DOI: https://www.doi.org/10.1079/9781845932589.0048

Farghly MF, Kh M, Mahrose AE, Galal RM, Ali EA, Ahmed M, Rehman Z, Ullah Z, and Ding C (2018). Implementation of different feed withdrawal times and water temperatures in managing turkeys during heat stress. Poultry Science, 97(9): 3076-3084. DOI: http://www.doi.org/10.3382/ps/pey173.

Food and agriculture organization of the United Nations (FAO) (2021). The state of food security and nutrition in the world. Available at: https://openknowledge.fao.org/server/api/core/bitstreams/1c38676f-f5f7-47cf-81b3-f4c9794eba8a/content

Ghoname M, Elnaggar A, Hassan S, and Habashy W (2022). Effect of acute heat stress on production performance and egg quality in four strains of chickens. South Africa Journal of Animal Science, 52(2): 168-176. DOI: https://www.doi.org/10.4314/sajas.v52i2.6

He S, Li S, Arowolo MA, Yu Q, Chen F, Hu R, and He J (2019). Effect of resveratrol on growth performance, rectal temperature, and serum parameters of yellow-feather broilers under heat stress. Animal Science Journal, 90(3): 401-411. DOI: https://www.doi.org/10.1111/asj.13161

Jahromi MF, Altaher YW, Shokryazdan P, Ebrahimi R, Ebrahimi M, Idrus Z, Tufarelli V, and Liang JB (2016). Dietary supplementation of a mixture of lactobacillus strains enhances performance of broiler chickens raised under heat stress conditions. International Journal of Biometeorology, 60(7): 1099- 1110. DOI: https://www.doi.org/10.1007/s00484-015-1103-x

Kavtarashvili A and Buyarov V (2021). The reasons for the deterioration of chicken eggshell quality at high temperatures: A review. E3S Web of Conferences, 247(2): 01015. DOI: https://www.doi.org/10.1051/e3sconf/202124701015

Ketta M and Tůmová E (2016). Eggshell structure, measurements, and quality-affecting factors in laying hens: A review. Czech Journal of Animal Science, 61(7): 299-309. DOI: https://www.doi.org/10.17221/46/2015-CJAS

Kim CH, Lee WD, Lim SJ, Yang KY, and Jeon JH (2025). Effects of cool water supply on laying performance, egg quality, rectal temperature and stress hormones in heat-stressed laying hens in open-type laying houses. Animals, 15(11): 1635. DOI: https://www.doi.org/10.3390/ani15111635

Kim HR, Ryu C, Lee SD, Cho JH, and Kang H (2024). Effects of heat stress on the laying performance, egg quality, and physiological response of laying hens. Animals, 14(7): 1076. DOI: https://www.doi.org/10.3390/ani14071076

Kpomasse CC, Emmanuel Oke O, Frédérick M, and Kokou T (2021). Broiler production challenges in the tropics: A review. Veterinary Medicine and Science, 7(3): 831-842. DOI: https://www.doi.org/10.1002/vms3.435

Lara L and Rostagno M (2013). Impact of heat stress on poultry production. Animals, 3(2): 356-369. DOI: https://www.doi.org/10.3390/ani3020356

Li X, Uyanga VA, Jiao H, Wang X, Zhao J, Zhou Y, Li H, and Lin H (2024). Effects of low dietary calcium and lipopolysaccharide challenges on production performance, eggshell quality, and bone metabolism of laying hens. Frontiers in Physiology, 15: 1396301. DOI: https://www.doi.org/10.3389/fphys.2024.1396301

Lin H, Mertens K, Kemps B, Govaerts T, De Ketelaere B, De Baerdemaeker J, Decuypere E, and Buyse J (2013). New approach of testing the effect of heat stress on eggshell quality: Mechanical and material properties of eggshell and membrane. British Poultry Science, 45(4): 476-482. DOI: https://www.doi.org/10.1080/00071660400001173

Mashaly MM, Hendricks GL, Kalama MA, Gehad AE, Abass AO, and Patterson PH (2004). Effects of heat stress on production parameters and immune response of commercial laying hens. Poultry Science, 83(6): 889-894. DOI: https://www.doi.org/10.1093/ps/83.6.889

Naga R, Kumari K, and Narendra D (2018). Ameliorative measures to counter heat stress in poultry. World's Poultry Science Journal, 74(1): 117-130. DOI: https://www.doi.org/10.1017/S0043933917001003

Nardone A, Ronchi B, Lacetera N, Ranieri MS, and Bernabucci U (2010). Effects of climate changes on animal production and sustainability of livestock systems. Livestock Science, 130(1-3): 57-69. DOI: https://www.doi.org/10.1016/j.livsci.2010.02.011

Nawab A, Ibtisham F, Li G, Kieser B, Wu J, Liu W, Zhao Y, Nawab Y, and Li K Xiao M (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. DOI: https://www.doi.org/10.1016/j.jtherbio.2018.08.010

Nawaz AH, Amoah K, Leng QY, Zheng JH, Zhang WL, and Zhang L (2021). Poultry response to heat stress: Its physiological, metabolic, and genetic implications on meat production and quality including strategies to improve broiler production in a warming world. Frontiers in Veterinary Science, 8: 699081. DOI: https://www.doi.org/10.3389/fvets.2021.699081

Olayiwola S and Adedokun S (2025). Heat stress in poultry: The role of nutritional supplements in alleviating heat stress and enhancing gut health in poultry. Frontiers in Veterinary Science, 12: 1691532. DOI: https://www.doi.org/10.3389/fvets.2025.1691532

Oloyo A and Ojerinde A (2020). Poultry housing and management. In: A. A. Kamboh (Editor), Poultry- An advanced learning. Intech Open, pp. 1-17. DOI: https://www.doi.org/10.5772/intechopen.83811

Pawar SS, Sajjanar B, Lonkar VD, Nitin KP, Kadam AS, Nirmale AV, Brahmane MP, and Bal SK (2016). Assessing and mitigating the impact of heat stress in poultry. Advances in Animal and Veterinary Sciences, 4(6): 332-341. DOI: http://www.doi.org/10.14737/journal.aavs/2016/4.6.332.341

Radwan LM (2020). Genetic improvement of egg laying traits in Fayoumi chickens bred under conditions of heat stress through selection and gene expression studies. Journal of Thermal Biology, 89: 102546. DOI: https://www.doi.org/10.1016/j.jtherbio.2020.102546

Rahman and Hidayat C (2020). Reducing the negative effect of heat stress in broiler through nutritional and feeding strategy. IOP Conference Series: Earth Environmental Science, 465(1): 012034. DOI: https://www.doi.org/10.1088/1755-1315/465/1/012034

Ranjan A, Sinha R, Devi I, Rahim A, and Tiwari S (2019). Effect of heat stress on poultry production and their management approaches. International Journal of Current Microbiology and Applied Sciences, 8(2): 1548-1555. DOI: https://www.doi.org/10.20546/ijcmas.2019.802.181

Richards SA (1970). Physiology of thermal panting in birds. Annales de Biologie Animale, Biochimie, Biophysique, 10(Hors-série 2): 151-168. DOI: https://www.doi.org/10.1051/rnd:19700614

Rozenboim I, Tako E, Gal-Garber O, Proudman JA, and Uni Z (2007). The effect of heat stress on ovarian function of laying hens. Poultry Science, 86(8): 1760-1765. DOI: https://www.doi.org/10.1093/ps/86.8.1760

Saeed M, Abbas G, Alagawany M, Kamboh AA, Abd El-Hack ME, Khafaga AF, and Chao S (2019). Heat stress management in poultry farms: A comprehensive overview. Journal of Thermal Biology, 84(2): 414-425. DOI: https://www.doi.org/10.1016/j.jtherbio.2019.07.025

Safi A, Imtiaz M, Ahsan HM T, Riaz A, Ali and S, and Uzair MD (2022). Effect of heat stress in poultry and its mitigation. Current Research in Agriculture and Farming, 3(6): 9-18. DOI: http://www.doi.org/10.18782/2582-7146.179

Sahin K, Küçük O, Miller D, and Sahin N (2002). Effects of vitamin E and vitamin A supplementation on lipid peroxidation and concentrations of some minerals in broilers reared under heat stress (32 °C). Poultry Science, 81(11): 1650-1657. DOI: https://www.doi.org/10.1093/ps/81.11.1650

Sahin N, Onderci M, Balci TA, Cikim G, Sahin K, and Kucuk O (2007). The effect of soy isoflavones on egg quality and bone mineralization during the late laying period of quail. British Poultry Science, 48(3): 363-369. DOI: https://www.doi.org/10.1080/00071660701341971

Shakeri M, Zulkifli I, Soleimani AF, O'Reilly EL, Eckersall PD, Anna AA, Kumari S, and Abdullah FFJ (2014). Response to dietary supplementation of L-glutamine and L-glutamate in broiler chickens reared at different stocking densities under hot, humid tropical conditions. Poultry Science, 93(11): 2700-2708. DOI: https://www.doi.org/10.3382/ps.2014-03910

Smith AJ (1974). Changes in the average weight and shell thickness of eggs produced by hens exposed to high environmental temperatures: A review. Tropical Animal Health and Production, 6(4): 237-244. DOI: https://www.doi.org/10.1007/BF02383283

Song D, Li A, Wang Y, Song G, Wang L, Lin K, Min Y, and Wang W (2022). Effects of symbiotic on growth, digestibility, immune and antioxidant performance in broilers. Animal, 16(4): 100497. DOI: https://www.doi.org/10.1016/j.animal.2022.100497

Song DJ and King AJ (2015). Effects of heat stress on broiler meat quality. World's Poultry Science Journal, 71(4): 701-709. DOI: https://www.doi.org/10.1017/S0043933915002421

Star L, Juul-Madsen, HR, Decuypere E, Nieuwland MGB, de Vries Reilingh G, van den Brand H, Kemp B, and Parmentier HK (2009). Effects of early life thermal conditioning and immune challenge on thermotolerance and humoral immune competence in adult laying hens. Poultry Science, 88(11): 2253-2261. DOI: https://www.doi.org/ 10.3382/ps.2008-00373

St-Pierre B, Cobanov, and Schnitkey G (2003). Economic losses from heat stress by us livestock industries. Journal of Dairy Science, 86(Suppl.): E52-E77. DOI: https://www.doi.org/10.3168/jds.S0022-0302(03)74040-5

Sugiharto S (2020). Alleviation of heat stress in broiler chicken using turmeric. A short review. Journal of Animal Behaviour Biometeorology, 8(3): 215-222. DOI: https://www.doi.org/10.31893/jabb.20028

Syafwan W, Kwakkel R, and Verstegen M (2011). Heat stress and feeding strategies in meat-type chickens. World's Poultry Science Journal, 67(4): 653-674. DOI: https://www.doi.org/10.1017/S0043933911000742

Tesakul S, Mitsuwan W, Morita Y, and Kitpipit W (2025). Effects of heat stress on egg performance in laying hens under hot and humid conditions. Veterinary World, 18(4): 851-858. DOI: DOI: https://www.doi.org/10.14202/vetworld.2025.851-858

Ugurlu N, Acar B, and Topak R (2001). Production performance of caged layers under different environmental temperatures. Archiv fur Geflugelkunde, 66(1): 43-46. Available at: https://acikerisim.selcuk.edu.tr/items/c92fd093-5167-4c6c-b51d-fdee1dcfd951

Vandana GD, Sejian V, Lees AM, Pragna P, Silpa MV, and Maloney SK (2021). Heat stress and poultry production: Impact and amelioration. International Journal of Biometeorology, 65(2): 163-179. DOI: https://www.doi.org/10.1007/s00484-020-02023-7

Wang W, Yan F, Hu J, Amen O, and Cheng H (2018). Supplementation of Bacillus subtilis-based probiotic reduces heat stress-related behaviors and inflammatory response in broiler chickens. Journal of Animal Science, 96(5): 1654-1666. DOI: https://www.doi.org/10.1093/jas/sky092

Wasti S, Sah N, and Mishra B (2020). Impact of heat stress on poultry health and performances, and potential mitigation strategies. Animals, 10(8): 1266. DOI: https://www.doi.org/10.3390/ani10081266

Yan L, Hu M, Gu L, Lei M, Chen Z, Zhu H, and Chen R (2022). Effect of heat stress on egg production, steroid hormone synthesis, and related gene expression in chicken preovulatory follicular granulosa cells. Animals, 12(11): 1467. DOI: https://www.doi.org/10.3390/ani12111467

Zhang C, Zhao XH, Yang L, Chen XY, Jiang RS, Jin SH, and Geng ZY (2017). Resveratrol alleviates heat stress-induced impairment of intestinal morphology, microflora, and barrier integrity in broilers. Poultry Science, 96(12): 4325-4332. DOI: https://www.doi.org/10.3382/ps/pex266