Review Article

Impact of heat stress on chicken performance, welfare, and probable mitigation strategies

.

ABSTRACT

The poultry industry has been necessary and helpful globally as it provides chicken meat and eggs which are the most important sources of protein among animal foods. The industry is grappling with the effect of climate change which causes heat stress and harms the performance and welfare of the chicken. Heat stress has been one of the most significant environmental stressors challenging the global poultry industry, as chickens only tolerate a narrow range of temperatures during heat stress. This review aims to assess the impact of heat stress on chicken performance, welfare, and probable mitigation strategies to ameliorate its hazard. The study review research papers of different authors and revealed that heat stress affects the performance, nutrition, and health of the chicken. Heat stress contributes to an increase in mortality as well as a reduction in feed efficiency, body weight, feed intake, and egg production of chicken. Some mitigation strategies that have been employed by farmers include modification of the environment like providing adequate ventilation and cooling systems and also adjusting their nutrition to help lower the body's metabolic heat output and keep electrolyte levels stable under high-stress, high-temperature circumstances. Therefore, there is a pressing need to study the extent of the resilience of native chicken breeds to the effects of climate change. Moreover, it is necessary to develop newer varieties of chicken especially heat-tolerant breed lines in response to climate change and the diverse need of the farmers and consumers.

Comment [A1]: Globally

Comment [A2]: delete

Keywords:*Climate change, Heat stress, Mitigation, Poultry production, Thermoneutral zone*

1. INTRODUCTION

The poultry industry has been essential and beneficial on a worldwide scale since it supplies chicken meat and eggs, the most significant sources of protein among animal diets [1,2]. In certain regions of the world, poultry farming has a greater impact on the livestock industry than other sectors [3,4]. The global output of chicken meat increased by 1.3% in 2018 to a total of 123.9 million tonnes, while global exports of poultry meat increased by 1.0% to a total of 13.3 million tonnes in 2018 [5]. The demand for greater chicken protein sources around the globe is increasing as a result of the fast growth of the global human population over the past two decades, during which the poultry industry has experienced significant growth [6,7]. Climate change is hurting chicken performance and welfare, and the industry is struggling to adapt [8,9]. Heat stress, in particular, appears to be very dangerous for poultry in hot climates [3,10]. Stress from the combination of high temperature and high humidity is particularly detrimental to birds and results in poor performance [11,12].

Heat stress is among the most significant environmental stresses impacting global poultry production [11,13]. Due to the low heat tolerance of chicken genotypes, heat stress significantly impacts the physiological, immunological, and gastrointestinal health of poultry birds, resulting in substantial economic losses for the poultry industry [3,14]. Poultry production can be negatively impacted by the birds' exposure to high temperatures, as this can reduce egg output, diminish egg quality, and reduce bird weight [15,16]. Heat stress is responsible for several alterations in the body's physiology, such as oxidative stress, acid-base imbalance, and diminished immune function [8,5,17]. These changes contribute to an increase in mortality, as well as a reduction in feed efficiency, body weight, feed intake, and egg production [7,18]. Heat stress can also affect the quality of meat and eggs [19,7,1]. This makes climate changes a big threat to the performance, health, and well-being of the chicken which may lead to a high economic loss for the poultry industry in the world [20,21]. Therefore, this review aims to assess the impact of heat stress on chicken performance, welfare, and probable mitigation strategies to ameliorate its hazard.

Comment [A3]: delete

UNDER PEER REVIEW

2. Thermoneutral zone of chicken and temperature tolerance range

Similar to mammals, poultry is homeothermic, which means that their exterior comfort zone (thermoneutral zone) ranges between l8^{o}C and 36^{o}C, but their interior environment (body temperature) remains generally constant [22]. The optimal temperature for the health and performance of chickens is within their thermoneutral zone [23]. The term "thermoneutral zone" describes the range of temperatures where birds can maintain a steady body temperature with the least amount of effort [24]. The chicken has the least amount of stress when the ambient temperature is in the thermoneutral zone [25,23]. When kept in this temperature range, birds don't have to work as hard to maintain a consistent body temperature [26]. Birds' normal behavior would vary when temperatures exceed their comfort zone, causing them to pant and shift their posture [27]. The lowest critical temperature (LCT) is the coldest point in the thermoneutral zone. Whenever the temperature drops below that threshold, the bird will begin to use its food as a source of heat. The highest critical temperature (HCT) is the highest temperature in the thermoneutral zone. The birds will perish if the temperature climbs above that point because their bodies will overheat [28,29]. Between 36^{o}C and 37^{o}C is the highest critical temperature for broilers [30].

When the ambient temperature is in the thermoneutral range, the chicken is most at ease and operates at its best; if the temperature is above or below their thermoneutral, they get anxious [31]. The condition known as heat stress occurs when an organism, whether it be a person, a plant, or an animal, absorbs an excessive amount of heat, which can lead to anxiety, disease, or even death [32]. An animal feels heat stress when the quantity of heat energy it creates exceeds the amount of heat energy it loses to its surroundings [11]. This energy imbalance is affected by environmental elements such as sunshine, thermal irradiation, air temperature, humidity, and stocking density, as well as animal-related parameters such as body mass, feather distribution, dehydration status, metabolic rate, and thermoregulatory processes [11,33]. When the environment is above the thermoneutral zone, animals employ their thermoregulatory systems to release heat through behavioral, biochemical, and physiological responses [34,35]. Acute and chronic heat stress are the two basic kinds of heat stress. Acute heat stress refers to a brief and rapid increase in environmental temperature (a few hours), whereas chronic heat stress is characterized by prolonged exposure to high temperatures (several days) [36,26]. Symptoms of heat stress include a high core body temperature, lack of perspiration, and the onset of neurological conditions like paralysis, headache, vertigo, and unconsciousness [32].

Comment [A4]: is within

During high ambient temperature of about 35.5^{o}C and relative humidity of 50-70%, the chicken starts to develop a panting mechanism to maintain homeothermy as this would allow a high rate of cooling from the respiratory tract through evaporation [30,22]. The animal dissipates heat mostly through conduction, convection, radiation, and evaporation [37]. The amount of heat a bird loses by radiation is proportional to its size of the chicken [38]. When the external temperature matches or exceeds the body temperature, evaporation is the principal method by which chickens can cool themselves [39]. When moisture evaporates away from the respiratory tract of chickens, evaporative cooling occurs [39,38]. Evaporative cooling to stabilize the body temperature of the chicken is required for efficient production [40].

UNDER PEER REVIEW

3. Effect of heat stress on the performance and health of the chicken

Chicken is highly vulnerable to climate change as a result of its low heat tolerance which affects behavioral and physiological activities [41]. Birds try to dissipate heat during extreme heat and try to conserve heat during freezing temperatures; however, in both cases, birds need to expend much energy to maintain their bodies within their comfort zone [42]. To keep its internal temperature from rising above its external temperature, a bird experiencing heat stress will lower its food intake [41,43]. Heat stress in the chickens leads to a decrease in their feed intake as a result of the birds being outside their comfort zone as the birds tend to adjust to the changes in the environment [44]. The most damaging consequences of heat stress on production are likely, to begin with, lower feed intake, which then results in decreased body weight, feed efficiency, egg output, and quality [45,42].

According to research by Lara and Rostagno [11], feed consumption drops by 5% for every 1^{o}C increase in temperature between 32^{o}C and 38^{o}C. When the ambient temperature increases to 34^{o}C, the mortality due to heat stress would be very high in broilers by 8.4% and the feed intake of the chicken decreases from 108.3g/bird/day at 31.6^{o}C to 68.9g/bird/day at 37.9^{o}C, the egg production would reduce by 6.4% [46].Feed intake in broilers is reduced by 16.4% when they are subjected to chronic heat stress, and body weight is lowered by 32.64% [47,46]. Laying hens exposed to heat stress during 8-14 days, 30-42 days and 43-56 days saw a decrease in egg production of 13.2%, 26.4%, and 57%, respectively [11]. Related research by Mashaly et al. [48] shows that laying hens exposed to chronic heat stress for five weeks have significant drops in egg production (28.8%), feed intake (34.7%), and body weight (19.3%). Deng et al. [45] found that after 12 days of heat stress, daily feed intake dropped by 28.58 g/bird, which led to a 28.8% drop in egg production. Heat stress in laying hens decreased feed conversion by 31.6%, egg production by 36.4%, and egg weight by 3.45%, as found by Star et al. [49]. According to a different set of researchers, Lin et al. [50], found that heat stress led to poorer production performance, thinner eggshells, and more egg breaking. Ebeid et al. [51] also found a drastic decrease in the egg weight (-3.24%), eggshell thickness (-1.2%), eggshell weight (-9.93%), and eggshell percent (-0.66%) when birds are exposed to high temperatures. As previously mentioned, Mack et al. [52] found that heat stress caused a reduction in egg output, egg weight, and eggshell thickness in laying hens. Since chickens drink more water and eat less feed when temperatures and sunshine are high, heat stress can hurt the quantity and quality of eggs and meat produced by chickens [53].

Comment [A5]: Kindly suggest the importance of Thyroxine hormone role in regulating feed intake. And its relationship with heat stress

UNDER PEER REVIEW

4. Interaction of heat stress with coccidiosis and necrotic enteritis

Climate change alters the global disease distribution and the emergence of poultry diseases [53,54]. Normally, birds reduce the intake of feed in hot environments to reduce heat production from metabolism but, reduced feed intake leads to watery droppings and diarrhea, which results in a significant reduction in body weight [11]. Heat stress affects the feed intake of the chicken and lowers the immune system of the chicken which makes the chicken vulnerable to many poultry diseases [55]. According to Calefi et al. [56], heat stress may especially reduce the release of corticosterone in hens used for commercial and industrial production, which would reduce the birds' resistance to other diseases like coccidia and put them at risk for necrotic enteritis. Both the quantity and activity of commensal bacteria may be altered as a result of decreased feed intake and weakened intestinal function [53]. Beneficial microbe populations can decrease under the stress of heat [46]. It can also promote the growth of latent pathogens and lead to dysbiosis, augmented intestinal penetrability, as well as immune and metabolic disorders [45]. Clostridia, Salmonella, and coliform bacteria populations rise in heat-stressed chicken, whereas populations of Lactobacilli and Bifidobacterial populations decrease [58,59]. Coccidiosis, hemorrhagic syndrome, fowl pox, and bronchitis are only some of the diseases that can spread rapidly in chicken flocks due to changes in temperature and humidity [60]. High winds can further disperse airborne diseases in poultry flocks [61].

Oviedo-Rondón et al. [62]reported that Intestinal health has a significant impact on poultry productivity, animal welfare, and food safety. Immunosuppression and damage to the gut microbiota, intestinal integrity, and villus shape are caused by heat stress, and consequently, digestion and absorption of feed decrease [63,34]. These variables enhance the likelihood of epidemics of necrotic enteritis which is one of the most troublesome bacterial infections in contemporary chicken farming [64]. In broilers challenged with C. perfringens, researchers Tsiouris et al. [65] discovered that cyclical acute heat stress enhanced the incidence and severity of necrotic enteritis and induced the disease in birds not exposed to the bacteria. Heat stress manifested itself in a variety of ways in the birds, including delayed development and a drop in the pH of the intestinal digesta [34,3]. Heat stress increases the need for antibiotics because it reduces feed digestibility, increases gut permeability, and decreases immunity, all of which increase the risk of gastrointestinal diseases such as dysbacteriosis and necrotic enteritis in animals [53,43,46].

Comment [A6]: Verify????
Usually during heat stress, corticosterone level increases and it is a stress hormone

Recheck?

UNDER PEER REVIEW

5. Stress response by chicken due to heat stress

Birds are homeothermic, meaning their internal temperatures stay within a rather constant range [38]. High temperatures reduce the bird's ability to disperse heat. It happens when heat is hard to evaporate quickly [66]. The optimum temperature range differs significantly among bird types and age ranges [67]. Observable differences can be attributed to natural factors and avian diversity [38,68]. The bird and its surroundings can undergo radiant heat transfer if the bird's surface temperature is different from that of the surface it is resting on or the ambient air temperature [38,68,67]. The comb, wattles, face, legs, toes, neck, torso, and wings all contribute to convection by radiating heat into the ambient air [38,67]. The comb and wattles contribute 34% of the total Sensible heat loss at 35°C [69]. Heat loss by convection and radiation can also rise dramatically with wind speed [38]. The skin is further exposed by the increased air velocity, which may enhance radiation losses [38,70]. Changes in heat dissipation from non-evaporation to increased evaporation occur as the surrounding temperature rises [70]. To a large extent, birds cool themselves by increasing their breath rate, a process known as panting; in fact, this form of enhanced respiration can account for as much as 60% of the total heat loss in some species [70,69]. Dehydration can develop due to the loss of water that occurs during the evaporation process. Thermo-tolerance at greater ambient temperatures is enhanced by drinking enough water, which aids in this sort of heat loss [38,67].

When temperatures soar, birds attempt thermoregulation by making adjustments to their behavior and physiological balance [71,72]. When faced with high environmental temperatures, animals employ a variety of strategies for thermoregulation and homeostasis, including enhancing radiative, convective, and evaporative heat loss through vasodilation and perspiration [11]. Most bird species respond equally to heat stress, while there is some individual disparity in the severity and length of responses [38,11]. Mack et al. [52] stated that birds in heat stress circumstances eat less, drink and pant more, stand still or rest with their wings raised more often, and move or walk less frequently. Air sacs are an additional means through which birds facilitate heat exchange with their surroundings [38]. During panting, air sacs are helpful because they increase the surface area exposed to air, which increases gas exchanges with the air and, in turn, increases the rate at which heat is lost by evaporation [73]. The local chicken displayed a behavioral coping mechanism during heat stress by moving into the shade [74,42]. Although this considerably reduces radiant heat load, actively seeking shade during the day may imply poor feed intake, especially for rural poultry which relies primarily on scavenging around homesteads [74].

UNDER PEER REVIEW

6. Effect of heat stress on the nutrition and physiology of the chickens

Given that different species have different thermal comfort zones, defining what constitutes a "high" environment temperature is a matter of degree [75]. An animal will feel heat stress if the environmental temperature is higher than its thermo-neutral zone [76,75]. When this occurs depends not just on the relative humidity and air speed but also the surrounding temperature [76]. As the birds' thermal stress rises at higher temperatures, their appetite and metabolism are negatively impacted, limiting the temperature range in which their output is at its peak [43]. Increased environmental heat causes changes in hydration and nutrition intake, metabolic rate, core temperature, heterophil/lymphocyte (H/L) ratio, and gastrointestinal tract (GIT) maturation. Some enzymes, for instance, wouldn't work as effectively in hotter temperatures, limiting birds' ability to eat and digest [53].

When the temperature increased from 32.2^{o}C to 37.8^{o}C, feed intake decreased by 9.9% per bird per day compared to the intake at 21.1^{o}C and the chicken will drink four times as much water at 38^{o}C as it does at 21^{o}C due to the higher ambient temperature [77]. Chickens drink roughly 7% more water for every degree over 21°C [78]. Increasing the bird's water intake may help it by increasing the efficiency of its cooling system, which relies on evaporation [69]. Thus, water plays a vital role in the metabolism of chickens by helping regulate body temperature, digestion, feed absorption, and nutrient delivery [79]. Heat stress is associated with a decrease in feed intake, which may lead to less overall body weight gain if water intake is also reduced [80]. Gains in weight were lower in the high-temperature group of chickens compared to the average-temperature group [80,79]. It has been found through extensive research that nutritional approaches, such as limiting the amount of feed that is consumed, wet or dual feeding, increasing the amount of fat in diets, and supplementing with vitamins, minerals, osmolytes, and phytochemicals, can ease the negative effects of heat stress [81].

7. Potential preventive measures of heat stress in chicken.

Climate change's impact on chicken production is just one more difficulty that poultry farmers face in an already challenging sector [82]. Heat stress can be reduced through several measures, including those related to environmental control, dietary modification, feed additive use, and electrolyte additions to drinking water [11,82]. In high-temperature stressful settings, it may be possible to lower metabolic heat generation and maintain electrolyte balance by modifying the chickens' surroundings with the addition of ventilation, cooling devices, and dietary changes [11]. In contrast, chicks can improve their thermo-tolerance

UNDER PEER REVIEW

and thus their survival rate under heat stress through early-age heat conditioning and regulated fasting in the first few days of life [3].

According to the research of Selvam et al. [83], Phytocee supplementation has an anti-stress impact on hens by bringing their serum corticosterone levels and thermoregulatory systems back to normal. Changes in energy-to-protein ratio, wet feeding, electrolyte supplementation, feeding time, drinker type, and height are only some of the feeding management methods shown to boost performance in the face of heat stress [84]. Based on their findings that heat stress can cause hyperthermia in poultry, Syafwan et al. [69] advise free-choice feeding with high-protein or high-energy diet options. The bird's free-choice food must contain a variety of particle sizes and/or shapes. Having a big particle size aids in the maturation of the GIT, particularly the gizzard and the caeca. The amount of heat generated by digestion could be reduced if birds had large gizzards, as this would allow for more efficient grinding and possibly better digestion further down the GIT [69,3]. The chicken may be able to self-select its diet in such a way that it optimizes the heat load associated with the metabolism of the nutrients it consumes [85,69].

The local poultry farmers employ traditional procedures, such as early stocking of birds, increased frequency of litter changes during the hot period, and the maintenance of native bird breeds [86,87]. Rajkumar et al. [87] suggested that the naked neck birds fared much better in terms of growth, carcass, and metabolic markers at high ambient temperatures. The lower feather bulk of the naked-necked birds allows for more efficient heat dissipation, making them more resistant to the effects of heat stress. Nyoni et al. [74] also stated that using genetics and adaptation, native breeds may do better than foreign ones in a warmer world.

Comment [A7]: Include about oxidative stress during heat stress

8. Conclusion

Heat stress is responsible for many physiological changes, including oxidative stress, acid-base imbalance, and suppressed immunocompetence. These changes contribute to an increase in mortality as well as a reduction in feed efficiency, body weight, feed intake, and egg production. Heat stress also has an impact on the quality of meat and eggs.

Rural poultry may have a higher level of heat tolerance than commercial breeds, but the extent of their tolerance threshold to temperature variation is unknown and requires urgent attention. Breeding projects to improve the climate resilience of native birds should also be promoted. Moreover, it is necessary to develop newer varieties of chicken especially heat-

UNDER PEER REVIEW

tolerant breed lines in response to climate change and the diverse need of the farmers and consumers. Finally, a well-planned and carried-out adaptation response system for the poultry industry will raise enough awareness and adaption to extreme climate circumstances.

REFERENCES

1. Ravindran V. Poultry feed availability and nutrition in developing countries. Poultry development review. 2013;2:60-63.
2. Sesay AR, Sesay AR, Kallon S. Analysis of Backyard Poultry Farmers' Awareness, Perceptions, and Adaptability to Climate Change in Tonkolili District, Sierra Leone. Asian Journal of Advances in Agricultural Research. 2022;8:6–17. https://doi.org/10.9734/ajaar/2022/v19i130235
3. Nawab A, Ibtisham F, Li G, Kieser B, Wu J, Liu W, An L. Heat stress in poultry production: Mitigation strategies to overcome the future challenges facing the global poultry industry. Journal of thermal biology. 2018;78:131-139.
4. Nkukwana TT. Global poultry production: Current impact and future outlook on the South African poultry industry. South African Journal of Animal Science. 2018;48(5):869-884.
5. Pozdniakova E, Pozdniakov V, Brench A. Development trends and risk factors of meat global exports. Ukrainian food journal. 2019;8(3):645-658.
6. Cao Y, Li D. Impact of increased demand for animal protein products in Asian countries: Implications on global food security. Animal frontiers. 2013;3(3):48-55.
7. Mottet A, Tempio G. Global poultry production: current state and future outlook and challenges. World's Poultry Science Journal. 2017;73(2):245-256.
8. Shields S, Orme-Evans G. The impacts of climate change mitigation strategies on animal welfare. Animals. 2015;5(2):361-394.
9. Hempel S, Menz C, Pinto S, Galán E, Janke D, Estellés F, Amon T. Heat stress risk in European dairy cattle husbandry under different climate change scenarios–uncertainties and potential impacts. Earth System Dynamics. 2019;10(4):859-884.
10. Abdel-Moneim AME, Shehata AM, Khidr RE, Paswan VK, Ibrahim NS, El-Ghoul AA, Ebeid TA. Nutritional manipulation to combat heat stress in poultry–A comprehensive review. Journal of Thermal Biology. 2021;98:102915.
11. Lara LJ, Rostagno MH. Impact of heat stress on poultry production. Animals. 2013;3(2): 356-369.

12. Tawfeek SS, Hassanin KMA, Youssef IMI. The effect of dietary supplementation of some antioxidants on performance, oxidative stress, and blood parameters in broilers under natural summer conditions. Journal of World's Poultry Research. 2014;4(1):10-19.
13. Zaboli G, Huang X, Feng X, Ahn DU. How can heat stress affect chicken meat quality?–a review. Poultry science. 2019;98(3):1551-1556.
14. Biswal J, Vijayalakshmy K, Bhattacharya TK, Rahman H. Impact of heat stress on poultry production. World's Poultry Science Journal. 2022;78(1):179-196.
15. He SP, Arowolo MA, Medrano RF, Li S, Yu QF, Chen JY, He JH. Impact of heat stress and nutritional interventions on poultry production. World's Poultry Science Journal. 2018;74(4):647-664.
16. Popoola OO, Monde N, Yusuf SFG. Climate change: perception and adaptation responses of poultry smallholder farmers in Amathole District Municipality, Eastern Cape Province of South Africa. South African Journal of Agricultural Extension. 2019;47(3):108-119.
17. Kennedy GM, Lichoti JK, Ommeh SC. Heat stress and poultry: adaptation to climate change, challenges and opportunities for genetic breeding in Kenya. Journal of Agriculture, Science and Technology. 2022;21(1):49-61.
18. Soliman A, Safwat AM. Climate change impact on immune status and productivity of poultry as well as the quality of meat and egg products. In Climate Change Impacts on Agriculture and Food Security in Egypt. Springer, Cham. 2020;(pp. 481-498).
19. Fouad AM, Chen W, Ruan D, Wang S, Xia WG, Zheng CT. Impact of heat stress on meat, egg quality, immunity and fertility in poultry and nutritional factors that overcome these effects: A review. International Journal of Poultry Science. 2016;15(3):81.
20. Skuce PJ, Morgan ER, VanDijk J, Mitchell M. Animal health aspects of adaptation to climate change: beating the heat and parasites in a warming Europe. Animal. 2013;7(s2):333-345.
21. Narayan E, Barreto M, Hantzopoulou GC, Tilbrook A. A retrospective literature evaluation of the integration of stress physiology indices, animal welfare and climate change assessment of livestock. Animals. 2021;11(5):1287.
22. Chaiyabutr N. Physiological reactions of poultry to heat stress and methods to reduce its effects on poultry production. The Thai Journal of Veterinary Medicine. 2004;34(2):17-30.
23. Ribeiro BPVB, Junior TY, de Oliveira DD, de Lima RR, Zangeronimo MG. Thermoneutral zone for laying hens based on environmental conditions, enthalpy and thermal comfort indexes. Journal of Thermal Biology. 2020;93:102-678.

24. Song S, Beissinger SR. Environmental determinants of total evaporative water loss in birds at multiple temperatures. The Auk. 2020;137(1):ukz069.
25. Yosi F, Widjastuti T, Setiyatwan H. Performance and physiological responses of broiler chickens supplemented with potassium chloride in drinking water under environmental heat stress. Asian Journal of Poultry Science. 2017;11(1):31-37.
26. Akbarian A, Michiels J, Degroote J, Majdeddin M, Golian A, De Smet S. Association between heat stress and oxidative stress in poultry; mitochondrial dysfunction and dietary interventions with phytochemicals. Journal of animal science and biotechnology. 2016;7(1):1-14.
27. Dos Santos VM, Dallago BS, Racanicci AM, Santana ÂP, Cue RI, Bernal FE. Effect of transportation distances, seasons and crate microclimate on broiler chicken production losses. PLoS One. 2020;15(4):e0232004.
28. Toro-Velasquez PA, Bícego KC, Mortola JP. Chicken hatchlings prefer ambient temperatures lower than their thermoneutral zone. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology. 2014;176:13-19.
29. Branco T, Moura DJ, Nääs IA, Oliveira SR. Detection of broiler heat stress by using the generalised sequential pattern algorithm. Biosystems engineering. 2020;199:121-126.
30. Van Der Hel W, Verstegen MWA, Henken AM, Brandsma HA. The upper critical ambient temperature in neonatal chicks. Poultry Science. 1991;70(9):1882-1887.
31. Qaid MM, Al-Garadi MA. Protein and amino acid metabolism in poultry during and after heat stress: A review. Animals. 2021;11(4):1167.
32. Bekele G. Review on the Effect of Heat Stress on Poultry Production and Productivities. Food Science & Nutrition Technology. 2021;6(2):1–9. https://doi.org/10.23880/fsnt16000260
33. Saeed M, Abbas G, Alagawany M, Kamboh AA, Abd El-Hack ME, Khafaga AF, Chao S. Heat stress management in poultry farms: A comprehensive overview. Journal of thermal biology. 2019;84:414-425.
34. Santos, R. R., Awati, A., Roubos-van den Hil, P. J., Tersteeg-Zijderveld, M. H., Koolmees, P. A., & Fink-Gremmels, J. (2015). Quantitative histo-morphometric analysis of heat-stress-related damage in the small intestines of broiler chickens. *Avian Pathology*, *44*(1), 19-22.
35. Farag MR, Alagawany M. Physiological alterations of poultry to the high environmental temperature. Journal of thermal biology. 2018;76:101-106.
36. Azad KM, Kikusato M, Hoque AM, Toyomizu M. Effect of chronic heat stress on performance and oxidative damage in different strains of chickens. The journal of poultry science. 2010;47(4):333-337.

37. Mutaf S, SeberKahraman N, Firat MZ. Intermittent partial surface wetting and its effect on body-surface temperatures and egg production of white and brown domestic laying hens in Antalya (Turkey). British poultry science. 2009;50(1):33-38.
38. Yahav S, Shinder D, Tanny J, Cohen S. Sensible heat loss: the broiler's paradox. World's Poultry Science Journal. 2005;61(3):419-434.
39. Aerts JM, Berckmans D. A virtual chicken for climate control design: static and dynamic simulations of heat losses. Transactions of the ASAE. 2004;47(5):1765.
40. Sossidou EN, Tsiplakou E, Zervas G. Options for managing livestock production systems to adapt to climate change. Journal of Earth Science and Engineering. 2014;4(1):15-427.
41. Gaughan J, Cawdell-Smith AJ. Impact of climate change on livestock production and reproduction. In Climate change Impact on livestock: adaptation and mitigation. 2015;(pp. 51-60). Springer, New Delhi.
42. Vandana GD, Sejian V, Lees AM, Pragna P, Silpa MV, Maloney SK. Heat stress and poultry production: impact and amelioration. International Journal of Biometeorology. 2021;65(2):163-179.
43. Pawar SS, Sajjanar B, Lonkar VD, Kurade NP, Kadam AS, Nirmal AV, Bal SK. Assessing and mitigating the impact of heat stress in poultry. Adv. Anim. Vet. Sci. 2016;4(6):332-341.
44. Osti R, Bhattarai D, Zhou D. Climatic variation: Effects on stress levels, feed intake, and bodyweight of broilers. Brazilian Journal of Poultry Science. 2017;19(3):489-496.
45. Deng W, Dong XF, Tong JM, Zhang Q. The probiotic Bacillus licheniformis ameliorates heat stress-induced impairment of egg production, gut morphology, and intestinal mucosal immunity in laying hens. Poultry science. 2012;91(3):575-582.
46. Ahaotu EO, De los Ríos P, Ibe LC, Singh RR. Climate change in poultry production system—A review. Acta Scientific Agriculture. 2019;3(9):113-117.
47. Sohail MU, Hume ME, Byrd JA, Nisbet DJ, Ijaz A, Sohail A, Rehman H. Effect of supplementation of prebiotic mannan-oligosaccharides and probiotic mixture on growth performance of broilers subjected to chronic heat stress. *Poultry science*. 2012;*91*(9):2235-2240.
48. Mashaly MM, Hendricks 3rd GL, Kalama MA, Gehad AE, Abbas AO, Patterson PH. Effect of heat stress on production parameters and immune responses of commercial laying hens. Poultry science. 2004;83(6):889-894.
49. Star L, Juul-Madsen HR, Decuypere E, Nieuwland MGB, de VriesReilingh G, Van Den Brand H, Parmentier HK. Effect of early life thermal conditioning and immune

UNDER PEER REVIEW

challenge on thermotolerance and humoral immune competence in adult laying hens. Poultry science. 2009;88(11):2253-2261.

50. Lin H, Mertens K, Kemps B, Govaerts T, De Ketelaere B, De Baerdemaeker J, Buyse J. New approach of testing the effect of heat stress on eggshell quality: mechanical and material properties of eggshell and membrane. British poultry science. 2004;45(4):476-482.

51. Ebeid TA. Vitamin E and organic selenium enhances the antioxidative status and quality of chicken semen under high ambient temperature. British Poultry Science. 2012;53(5):708-714.

52. Mack LA, Felver-Gant JN, Dennis RL, Cheng HW. Genetic variations alter production and behavioral responses following heat stress in 2 strains of laying hens. Poultry science. 2013;92(2):285-294.

53. Adesiji YO, Deekshit VK, Karunasagar I. Antimicrobial-resistant genes associated with Salmonella spp. isolated from human, poultry, and seafood sources. Food science & nutrition. 2014;2(4):436-442.

54. Jones BA, Grace D, Kock R, Alonso S, Rushton J, Said MY, Pfeiffer DU. Zoonosis emergence linked to agricultural intensification and environmental change. Proceedings of the National Academy of Sciences. 1013;110(21):8399-8404.

55. Mengesha M. Climate Change and the Preference of Rearing Poultry for the. Asian Journal of Poultry Science. 2011:5(4):135-143.

56. Calefi AS, Honda BTB, Costola-de-Souza C, de Siqueira A, Namazu LB, Quinteiro-Filho WM, Palermo-Neto J. Effects of long-term heat stress in an experimental model of avian necrotic enteritis. Poultry science. 2014;93(6):1344-1353.

57. Shi D, Bai L, Qu Q, Zhou S, Yang M, Guo S, Liu C. Impact of gut microbiota structure in heat-stressed broilers. Poultry science. 2019;98(6):2405-2413.

58. Burkholder KM, Thompson KL, Einstein ME, Applegate TJ, Patterson JA. Influence of stressors on normal intestinal microbiota, intestinal morphology, and susceptibility to Salmonella enteritidis colonization in broilers. Poultry Science. 2008;87(9):1734-1741.

59. Rostagno MH. Effects of heat stress on the gut health of poultry. Journal of Animal Science. 2020;98(4):skaa090.

60. Alade OA, Ademola AO. Perceived effect of climate variation on poultry production in Oke Ogun area of Oyo State. Journal of Agricultural Science. 2013;5(10):176-182.

61. Chah JM, Odo E, Asadu AN, Enwelu IA. Poultry farmers' adaptation to climate change in Enugu north agricultural zone of Enugu state. Nigeria. Journal of Agricultural Extension. 2013;17(1):100-114.

UNDER PEER REVIEW

62. Oviedo-Rondón EO. Holistic view of intestinal health in poultry. Animal Feed Science and Technology. 2019;250:1-8.
63. Quinteiro-Filho WM, Rodrigues MV, Ribeiro A, Ferraz-de-Paula V, Pinheiro ML, Sá L, Palermo-Neto J. Acute heat stress impairs performance parameters and induces mild intestinal enteritis in broiler chickens: role of acute hypothalamic-pituitary-adrenal axis activation. Journal of animal science. 2012;90(6):1986-1994.
64. Lian P, Braber S, Garssen J, Wichers HJ, Folkerts G, Fink-Gremmels J, Varasteh S. Beyond heat stress: intestinal integrity disruption and mechanism-based intervention strategies. Nutrients. 2020;12(3):734.
65. Tsiouris V, Georgopoulou I, Batzios C, Pappaioannou N, Ducatelle R, Fortomaris P. Heat stress as a predisposing factor for necrotic enteritis in broiler chicks. Avian Pathology. 2018;47(6):616-624.
66. Gerson AR, Smith EK, Smit B, McKechnie AE, Wolf BO. The impact of humidity on evaporative cooling in small desert birds exposed to high air temperatures. Physiological and Biochemical Zoology. 2014;87(6):782-795.
67. Smith EK, O'Neill J, Gerson AR, Wolf BO. Avian thermoregulation in the heat: resting metabolism, evaporative cooling and heat tolerance in Sonoran Desert doves and quail. Journal of Experimental Biology. 2015;218(22):3636-3646.
68. Greenberg R, Cadena V, Danner RM, Tattersall G. Heat loss may explain bill size differences between birds occupying different habitats. PloS one. 2012;7(7):e40933.
69. Syafwan S, Kwakkel RP, Verstegen MWA. Heat stress and feeding strategies in meat-type chickens. World's Poultry Science Journal. 2011;67(4):653-674.
70. Etches RJ, John TM, Gibbins AV. Behavioural, physiological, neuroendocrine and molecular responses to heat stress. Poultry production in hot climates. 2008;31-66.
71. Cunningham SJ, Gardner JL, Martin RO. Opportunity costs and the response of birds and mammals to climate warming. Frontiers in Ecology and the Environment. 2021;19(5):300-307.
72. Sesay AR, Sesay AR, Kallon S. Livestock farmers' perception, perceived impacts, and adaptations to climate change in Koinadugu district, Sierra Leone. Journal of Applied and Advanced Research. 2022;25–34. https://doi.org/10.21839/jaar.2022.v7.7675
73. Fedde MR. Relationship of structure and function of the avian respiratory system to disease susceptibility. Poultry Science. 1998;77(8):1130-1138.
74. Nyoni NMB, Grab S, Archer ER. Heat stress and chickens: climate risk effects on rural poultry farming in low-income countries. Climate and Development. 2019;11(1):83-90.

75. Mirrahimi S, Mohamed MF, Haw LC, Ibrahim NLN, Yusoff WFM, Aflaki A. The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot–humid climate. Renewable and Sustainable Energy Reviews. 2016;53:508-1519.
76. Veldkamp T, Kwakkel RP, Ferket PR, Verstegen MWA. Impact of ambient temperature and age on dietary lysine and energy in turkey production. World's Poultry Science Journal. 2002;58(4):475-491.
77. North MO, Bell D. Commercial Poultry Production manual. 1990;pp800-820. Chapman and Hall, London.
78. National Research Council. Nutrient requirements of poultry. 1994. National Academies Press.
79. Pearlin BV, Muthuvel S, Govidasamy P, Villavan M, Alagawany M, RagabFarag M, Gopi M. Role of acidifiers in livestock nutrition and health: A review. Journal of animal physiology and animal nutrition. 2020;104(2):558-569.
80. Ferket PR, Gernat AG. Factors that affect feed intake of meat birds: A review. Int. J. Poult. Sci. 2006;5(10):905-911.
81. Wasti, S., Sah, N., & Mishra, B. (2020). Impact of Heat Stress on Poultry Health and Performances, and Potential Mitigation Strategies. Animals. 2020;10(8):12-66.
82. Thaxton YV, Christensen KD, Mench JA, Rumley ER, Daugherty C, Feinberg B, Scanes CG. Symposium: Animal welfare challenges for today and tomorrow. Poultry science. 2016;95(9):2198-2207.
83. Selvam R, Suresh S, Saravanakumar M, Chandrasekaran CV, Prashanth DS. Alleviation of heat stress by a polyherbal formulation, Phytocee™: impact on zootechnical parameters, cloacal temperature, and stress markers. Pharmacognosy research. 2018;10(1):1.
84. Diarra SS, Tabuaciri P. Feeding management of poultry in high environmental temperatures. International journal of poultry science 2014;13(11):657-661.
85. Balnave, D. (2004). Challenges of accurately defining the nutrient requirements of heat-stressed poultry. Poultry science. 2004;83(1):5-14.
86. Liverpool-Tasie LSO, Sanou A, Tambo JA. Climate change adaptation among poultry farmers: evidence from Nigeria. Climatic Change. 2019;157(3):527-544.
87. Rajkumar U, Reddy MR, Rao SV, Radhika K, Shanmugam M. Evaluation of growth, carcass, immune response and stress parameters in naked neck chicken and their normal siblings under tropical winter and summer temperatures. Asian-Australasian Journal of Animal Sciences. 2011;24(4):509-516.

UNDER PEER REVIEW