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Climatic Changes Have a Pronounced Impact on Productive and Reproductive Performance of Poultry

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Abstract

In order to optimize the performance of poultry in hot climate, we must bear in mind all factors that can affect their genetic potential such as environmental factors, nutrient requirements and managerial and hygienic practices. The modern strains of broiler chickens and laying hens have higher rates of growth and egg production than the early developed ones. This necessitate a reevaluation of their nutrient requirements periodically both under thermoneutral and heat stress conditions. Both acute and chronic heat stress have a detrimental impact on growth performance, carcass characteristic, meat quality and mortality of broiler chickens. Also, heat stress has dramatic harmful effects on egg production, egg quality, mortality and reproduction in adult poultry. Therefore, nutritionists and physiologists, and also poultry producers, must be aware at managerial procedures and nutritional strategies that can be applied to alleviate the adverse effects of heat stress on growth and performance of different classes of poultry. Some of these nutritional strategies are summarized herein in this report.

Keywords: Climatic changes, heat stress, broiler and laying productivity.

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1. Introduction

Undoubtedly, aviculture, as a subsector of animal agriculture, plays an important role in providing animal protein (meat and eggs) for human beings all over the world. As per [1], poultry are highly-efficient in converting their feeds into meat and eggs within a short period of time. Global warming is a critical phenomenon of climatic changes which can adversely affect all facets of human life. There is a viewpoint that global warming will be in a continuous ascending during the coming years, and this imposes a challenge on poultry industry and other agricultural systems [2]. The ambient temperature and relative humidity are critical components of the climatic system. They have an obvious impact on growth performance and productivity of different classes of poultry [3]. Additionally, seasonal fluctuations have been reported to interfere with the broilers comfort and can suppress their productive performance criteria [4]. Furthermore, [5] have reported that climatic changes caused dramatic reductions in meat and egg production, egg weight and egg quality of poultry along with significant increases in mortality rates and feeding costs. Recently, [6] stated that poultry exposure to high ambient temperatures leads to creation of physiological, behavioral and immunological responses which have direct or indirect adverse effects on their productive performance. They also reviewed that the adverse effects of high ambient temperature on poultry include decreases in growth rate, egg production, egg size, egg, meat and semen quality, fertility and hatchability, which lead to high monetary losses to the poultry industry.

The present review article will focus on the impacts of climatic changes, particularly heat stress, on the productive and reproductive performance of poultry and suggested nutritional strategies that can be used to alleviate the deleterious effects of heat stress on them.

1.1. Effects of Climatic Changes on Poultry Production

1.1.1. Direct effects

Climatic changes may occur in the form of extreme climatic situations in terms of elevated temperature, flood or drought, and water scarcity [7]. Common among these is increased global temperature. According to [8], extreme weather conditions can produce considerable losses in poultry production (reduced growth rate, lowered egg production, and increased morbidity and mortality). In this regard, [9] concluded that poultry farmers were aware of climate variations in household poultry production because they observed their effects on egg and meat production, water and feed intakes, outbreak of pests and diseases as well as the profitability of production. The following diagram (Fig. 1) illustrates the direct effects of climatic changes on the productive and reproductive performance of poultry, their health status and immunity, and some adaptation responses.

1.1.2. Indirect effects

Climatic changes may have indirect effects on the availability of feed components, drinking water and outbreak of diseases. Climate obviously affects yield and quality of different cereal grains and oil-seeds crops. Such cereal grains and oil-seeds and their byproducts are main components of poultry diets worldwide. Meanwhile, the availability of adequate amounts of good quality water is essential to sustainability of poultry production. Climatic changes, especially global warming, can reduce the amounts of water in the ponds, streams, rivers, and seas due to increased rate of evaporation [11]. Water shortage adversely affects body weight and lymphoid organs of broiler chickens [12]. The existing pattern of pests and disease invasion is expected to change due to different climatic changes. This will affect productivity of poultry as to morbidity, mortality, and the cost of vaccinations and medications.

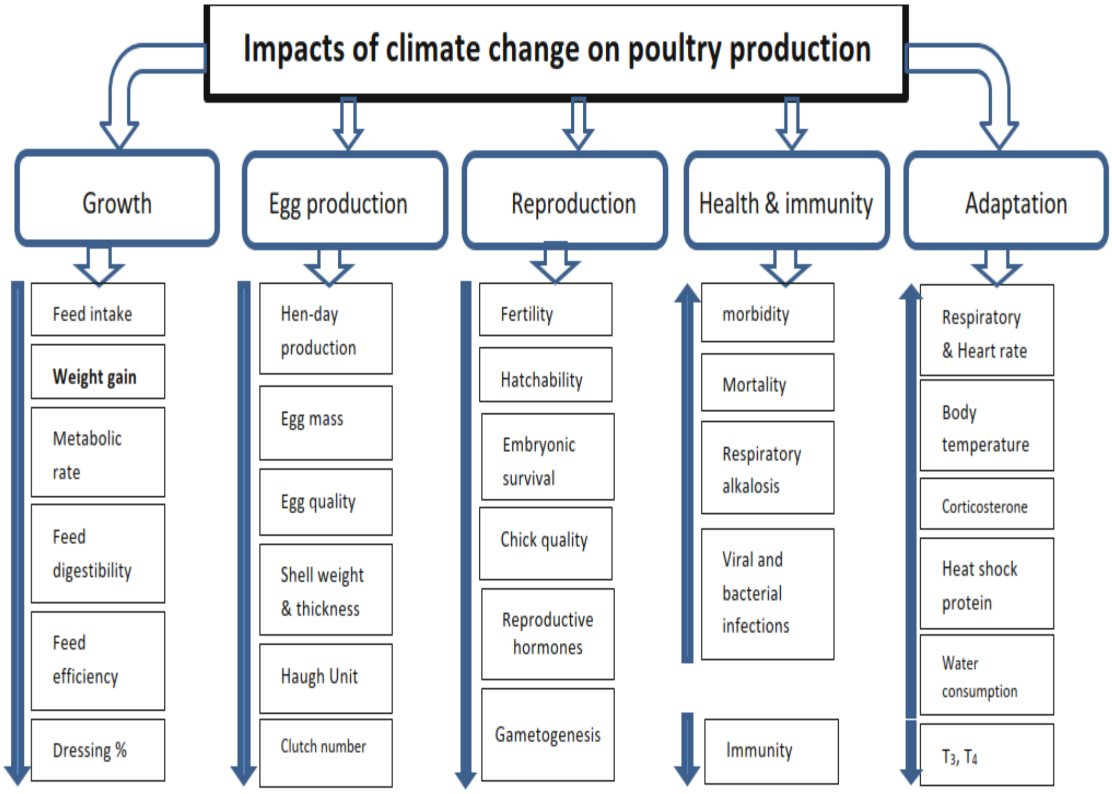

Figure 1: Direct impact of climatic changes on poultry production [10]

1.1.3. Effect of heat stress on poultry performance

Productive and reproductive performance of poultry can be affected by various factors such as, feeding strategies, management procedures, disease outbreak, stocking density, housing system, environmental factors and hatching process circumstances. Again, climatic changes can produce a great challenge to poultry industry to sustain their levels of productivity. The severe adverse effects of such climatic changes occur in tropical countries where poultry are raised in traditional open-sided houses. It is well known that birds of different ages, genders, breeds, strains and physiological status respond differently to climatic variations or fluctuations. It is highly desirable that data on such effects in different flocks of poultry should be collected and analyzed to develop strategies to deal with such adverse effects of the climatic changes.

Since poultry have no sweat glands they dissipate less heat from their skin but they can practice evaporative cooling via the panting process [13,14,15]. Heat stress is a critical facet of the climatic changes which negatively affects the growth performance of different classes of poultry [16,17,18,19]. For optimal performance, the ambient temperature has been reported to be in the range of 18 to 22°C for broiler chickens and 19 to 22°C for laying hens [20,21]. Exposure of poultry to high ambient temperature leads to generation of physiological, behavioral and immunological responses which directly or indirectly have adverse effects on their performance [22,19]. Such harmful effects of heat stress on poultry include impaired feed intake, high mortality, poor growth rate and meat quality in broiler chickens, and depressed egg production rate, egg weight, egg quality, semen quality, fertility and hatchability in laying hens [23,24,25,26,27,19]. In this regard, [28] reviewed that heat stress produces several physiological responses such as oxidative stress, acid-base imbalance, and suppressed immuno-competence which lead to less feed intake, increased mortality and poor efficiency of feed utilization, body weight, egg production, and meat and egg quality.

Heat stress has also been reported to depress feed intake, growth performance of chickens and turkeys and lead to hypoxia, and high mortality [29,30]. Compared with other animals, poultry are more sensitive to heat stress, which impairs their immunity and makes them more vulnerable to infection by pathogens, leading to poor growth performance [31,32,33]. Hot climate can exert a severe impact on poultry performance thus resulting to huge economic losses as a result of depressed growth, egg production, egg quality and higher mortality [28,34]. Fortunately, various nutritional and managerial strategies have been adopted to alleviate the effects of heat stress on the performance of broiler chickens and laying hens by maintaining feed intake, electrolytic and water balance or by dietary supplementation with micronutrients such as vitamins (ascorbic acid, vitamin E, vitamin A) and minerals (e.g. zinc, chromium and selenium) [21,28]. On the other hand, because heat stress adversely affect feed intake of poultry, some investigators advocated feeding diets with high concentrations of nutrients in an attempt to compensate for the reduction feed consumption and associated depression in poultry performance. In this respect, [35] demonstrated that increasing dietary nutrient density up to 110% of the recommended requirements of Bovans White laying hens does not improve their productive performance under Egyptian summer conditions but positively affected percent albumen, shell thickness, yolk index and Haugh units of eggs.

1.1.3.1. Effect of heat stress on meat yield and quality

Several reports in the scientific literature have indicated negative effects of heat stress on meat yield and quality of chickens. According to [36], exposure of broiler chickens to acute heat stress (AHS) led to alterations in breast muscle glycolytic metabolism as indicated by lower muscle pH immediately postslaughter, increased water loss, and increased incidence of breast muscle hemorrhages. Similarly, marked reductions were reported in meat quality and a change in breast muscle color of chickens subjected to AHS [37,38,39,40,41,34].

On the other hand, [42] observed that chronic heat stress (CHS) increased breast meat lightness and drip loss of Arbor Acres broilers. They also reported that CHE negatively affects fat deposition and meat quality in broilers, in a breed-dependent manner. CHS (at 30°C for 10 days) may deteriorate the meat quality of broiler chickens but its effects on meat quality were most significant in the toughness of broiler breast meat, and dietary supplementation with vitamin E proved to be effective in preventing the deterioration in meat quality caused by CHS [43]. The broiler chickens kept under chronic heat stress (CHS) displayed significantly lower body weight gain and increased levels of meat lipids and liver leakage marker aspartate aminotransferase than those of the thermo-neutral group; but feeding a high protein and energy-diet (22% CP and 13.81 MJ ME/kg) alleviated the adverse effects of CHS on broiler performance and meat lipids [44]. In addition, The exposure of broiler chickens to CHS (at 32°C for 14 days) led to an increase in the intramuscular fat (lipid contents), lightness and drip loss and a reduction in the pH and the shear force of the breast meat [45]. They also concluded that CHS impairs meat quality by causing mitochondria to malfunction and affecting energy-substance aerobic metabolism, resulting in increased glycolysis and intramuscular fat deposition. The observed reductions in body protein content and protein gain and retention in broiler chickens subjected to CHS have been attributed to changes in protein metabolic pathways (low rate of protein synthesis and high catabolic rate of protein in muscles) induced by rearing under high ambient temperatures [46,47,48,49].

Heat stress has also been reported to increase lactic acid accumulation in the broiler muscles which reduces their pH value via enhancing the glycolysis process in the meat; thus can deteriorate their meat quality by accelerating the production of reactive oxygen species, leading to increased rates of protein catabolism [49,50,51]. Again, the AHS and CHS could produce cause a sharp decline in the metabolism of birds, which in turn will stimulate serious complications regarding the growth and performance of the broilers, such as a change in color, the decline in muscle pH, water-holding capacity, and juiciness of chicken meat [52,53]. Recently, the detrimental effects of heat stress on broiler meat production and quality include a depression in growth and a deterioration in meat quality because it decreases water-holding capacity, pH and increases drip loss in meat; thereby, changing the normal color, taste and texture of chicken meat [54]. They also stated that heat stress causes poor meat quality by impairing protein synthesis and augmenting undesirable fat in meat. Also, the deterioration in meat quality traits of broiler chickens due to heat stress occurs mainly in accordance with the associated higher rate of lipid peroxidation and the altered electrolyte balance [55].

1.1.3.2. Effect of hest stress on egg production and egg quality

Because today's chickens have higher genetic potential for egg production and efficiency of feed utilization than do their old ones the former are more susceptible to heat stress than the latter [21]. It has been reported that the optimal ambient temperature for laying hens is between 19 and 22°C [20,21]. Several studies have indicated that exposure of laying hens to high ambient temperature depresses egg production rate [56,57], egg weight [58], egg shell thickness [59,56,57], which leads to an increased percentage of egg shell breakage and huge economic losses.

According to [24] egg production during moderate heat stress can be improved by increasing the intake of protein relative to energy but energy requirements will likely increase in severe heat stress. The egg yolk density of hens subjected to high ambient temperature (HAT) was significantly smaller at 27 and 31 than at 23°C [60]. They suggested that HAT negatively influences both the lipoprotein and steroid hormones and consequently reduces egg production, but the reduction in feed intake is not the only reason for a decline in egg quality in laying hens. With laying hens, [61] observed that acute elevation of temperature-humidity index has more severe effects on mortality than gradual changes even at similar temperature and humidity conditions.

1.1.3.3. Effect of hest stress on immunity and reproduction in poultry

Heat stress was reported to affect the intestinal colonization of pathogens in poultry, leading to enhancing the horizontal transmission of pathogens between birds [62]. Exposure of poultry to heat stress depresses their immune response resulting in an increased susceptibility to infectious diseases which greatly affects the productive performance and welfare of poultry [63]. Under heat stress conditions, lower concentrations of total circulating antibodies and immuno-globulins (IgM and IgG) were recorded in broiler chickens [64].

The CHS (continuous exposure to 34.5±0.5°C of 22-day broiler chickens for 14 days) severely damaged the morphology of the thymic cortex and bursal follicles, where the functional maturation of cells in the thymus (T) and bursa of Fabricius (B) occur [65]. Their results indicate that hest stress causes multiple immune abnormalities in broiler chickens by impairing the developmental process and functional maturation of T and B cells in both primary and secondary lymphoid tissues. In addition, heat stress has been reported to act as immunosuppressant on broiler chickens and laying hens as evidenced by reduced relative weights of thymus and spleen [64,32,66], and lower liver weights in laying hens [67]. The reductions in the weight of bursa of Fabricius and in the lymphocyte counts in the cortex and medulla of bursa in broiler chickens subjected to heat stress [68]. Furthermore, there is a general viewpoint among most nutritionists and physiologists that immunocompetence of poultry subjected to heat stress is affected as a result of decreased antibody production the immunized antigens [56,69,70,71]. In such heat stress conditions, birds tend to alter some physiological and behavioral responses in order to maintain their body thermoregulation; thus, decreasing body temperature [72,73,74].

Concerning the effects of heat stress on reproduction in poultry, [16] found that high ambient temperatures together with high humidity reduce the fertility and hatchability percentages in poultry breeders. Exposure of male broiler breeders to high ambient temperature (32°C) caused a great reduction (42%) in their fertility and the in vivo sperm-ovum penetration reduced to 52% compared with those roosters kept at 21°C [5]. Heat stress has been reported to evoke infertility in farm animals and also in domestic chickens [76]. Such detrimental effects of heat stress impair the secretion of the gonadotropin-releasing hormones (follicle stimulating hormone and luteinizing hormone; FSH and LH) in the laying hens, thereby disturbing their reproductive performance [77]. Working with in heat-stressed male ostriches, [78] found a deterioration in their semen characteristics coincided with heat-associated infertility. Reduced spermatozoa motility due to depreciating qualitative and quantitative seminal characteristics, thereby resulting in infertility [79].

2. Nutritional strategies to overcome the negative effects of heat stress

2.1. Dietary protein level

The effects of stress on protein requirements are not fully understood. Early reports indicated that temperature changes neither increase nor decrease the protein requirement per unit gain. In later studies, the protein synthesis decreases but protein catabolism increases when poultry are kept under heat stress condition [21]. In this regard, the decrease in protein synthesis in birds reared under heat stress cannot be restored by increasing the dietary protein level [80]. Feeding low-protein but high energy diets was advocated as a means of protecting poultry against heat stress [81,82]. Working with laying hens, [83] adopted decreasing dietary crude protein (CP) levels from 16.5% to 12.0% and enriching the diets with the essential amino acids for improving the stress response and maintaining the production performance under heat stress conditions. However, [84] suggested reducing dietary CP for broilers when they are exposed to moderate but not chronic heat stress conditions.

2.2. Dietary fat supplementation

Looking through the scientific literature on the nutrient requirements of poultry reared in hot climate may dictate that higher energy diets were effective in partially mitigating the negative effects of heat stress on poultry performance. During metabolism, fat produces lower heat increment as compared to protein and carbohydrates [85]. So, dietary supplementation of fat has become a common practice in the hot countries in order to increase the dietary energy level and minimize harmful effects of heat stress. Supplementation of fat in the poultry diet not only helps to increase the nutrient utilization in the digestive tract by lowering the rate of food passage [86] but also helps to improve the energy value of the other feed ingredients [86,87]. Interestingly, adding fat at the level of 5% to the diet of heat-stressed laying hens has been reported to increase feed consumption by 17% [88]. Similarly, a significant improvement in the broiler performance when fed on a diet containing 5% fat under hot summer conditions [89]. [87] also reported that increasing the oil supplementation in the higher protein concentration diet relieved the negative effects of chronic heat stress on broiler performance, meat lipids, and physiological and immunological traits. Along with these benefits, the addition of fat to diets of broilers and broiler breeders reduces the specific dynamic effect of the diet, helping the birds to deal with heat stress [90].

2.3. Dietary supplementation with electrolytes

Dietary electrolyte balance (acid base balance: ABB), which is expressed by the formula by the formula of Na + K – Cl as mEq/kg of diet, is not only affected by the amount and proportion of electrolytes in the diet, but also by endogenous carbonic acid production and rate of renal clearance [88]. Panting (evaporative cooling) is a behavioral phenomenon that heat-stressed birds have to perform to maintain body homeostasis and regulate their normal body temperature. This panting alters the blood ABB and ultimately leads to respiratory alkalosis. Such respiratory alkalosis suppresses the growth of broiler chickens and impairs eggshell quality of laying hens [21]. This acid-base imbalance can be restored by dietary supplementation of electrolytes such as NH_4Cl, $NaHCO_3$, and KCl [21,88,28]. During respiratory alkalosis, birds excrete a higher amount of bicarbonate ions from the kidney to recover normal blood pH [28]. These bicarbonates ions are further coupled with Na+ and K+ ions before being excreted through the kidney; ultimately, the loss of ions results in an acid-base imbalance [91]. A dietary ABB of 200–300 mEq/kg was suggested to be effective in alleviating the harmful effects of heat stress in poultry [92]. Dietary supplementation of $NaHCO_3$ for heat-stressed laying hens could improve eggshell quality [93]. The feeding KCl-supplemented diets during the heat stress period produced significantly higher egg production rate, lower mortality and superior quality eggs than their control counterparts [94]. In another study, the dietary supplementation with KCl (1.6%), vitamin E (300 mg/kg), either separately or in combination, can be used as an effective tool for alleviating the adverse effects of heat stress on the physiological status of laying hens [95]. Several studies have shown sodium bicarbonate ($NaHCO_3$) as the salt of choice during heat stress as it contains Na^+ and HCO_3 [92]. In addition, supplementation of electrolytes (e.g. NH_4Cl, KCl, and $NaHCO_3$) in drinking water proved to be effective in improving the performance of the heat-stressed broiler chickens [21].

2.4. Dietary supplementation with vitamins

The decreased feed intake of heat-stressed birds is associated with a reduction in nutrient intake and has a reflection on the intake of vitamins and other micronutrients which plays an important role on performance and immune function of poultry [21,28]. Dietary supplementation of vitamin E for laying hens exposed to heat stress has been found to improve egg production egg quality characteristics [96,97]. The beneficial effect of supplemental vitamin E on egg production of hens at high ambient temperatures is associated with an increase in feed intake and yolk and albumen solids [98], and increased plasma levels of vitellogenin and very-low-density lioprotein due to the enhanced release of vitellogenin from the liver [96]. Additionally, the vitamin E helps to improve the egg production by preventing liver damage in the heat-stressed hens [99]. Similarly, heat-stressed broiler chickens enriched with vitamin E displayed lower levels of liver and serum malondialdehyde, and higher levels of serum and liver vitamin E and A [100]. The combined dietary inclusion of vitamin E, vitamin C and probiotics was found to be more effective to attenuate negative effects of heat stress in broilers kept at under CHS [101].

Ascorbic acid (vitamin C) is a water-soluble vitamin that poultry can synthesize it under normal environmental temperatures, but its rate of biosynthesis is depressed at heat stress condition [102]. It is well known that ascorbic acid C improve immunity by enhancing the differentiation and proliferation of T and B cells [03]. Thus, dietary supplementation of vitamin C is an effective strategy to reduce the harmful effects of heat stress in poultry. Added dietary ascorbic acid (250 mg/kg) improved growth rate, nutrient utilization, egg production, and quality, immune response, and antioxidant status in heat-stressed birds [102]. Working with heat-stressed Japanese quail, [104] feeding diets fortified with ascorbic acid decreased the serum concentrations of malondialdehyde, homocysteine, and adrenal corticotrophin hormone. In broilers, dietary supplementation of 200 mg ascorbic acid per kg of feed improved body weight gain and feed conversion ratio [105]. In addition, feeding diets enriched with vitamin C under high temperature is suggested as an effective feeding strategy to reduce the mortality rates in both broiler chickens and laying hens [105,106].

Vitamin A is associated with antibody production and T cell proliferation [107]. Dietary supplementation with vitamin A was found to have a beneficial effect on the egg production and egg quality in laying hens reared under heat stress condition [108,109]. The feeding diets enriched with high concentrations of vitamin A caused a positive effect on egg weight and laying rate of heat-stressed laying hens [109]. They also reported that hens exposed to heat stress immediately after vaccination against Newcastle disease virus require a higher amount of vitamin A for producing adequate amounts of antibodies. In heat-stressed broilers, added dietary vitamin A was found to improve the body weight gain and efficiency of feed utilization, and decrease the serum concentration of malondialdehyde [110].

2.5. Dietary supplementation with minerals

At high ambient temperatures, poultry exhibit higher excretion rates of minerals from the body and lower mineral concentrations in liver and serum [111]. So, dietary supplementation of minerals is of great importance to improve growth and minimize mortality in poultry reared under heat stress conditions. The importance of enriching diets of poultry reared under heat stress with minerals such as zinc, chromium and selenium, as a beneficial nutritional strategy [28,34]. Dietary supplementation of zinc improved live weight gain, feed efficiency, and carcass traits of heat-stressed broiler chickens [110]. They also observed a beneficial effect for the concurrent supplementation of zinc and vitamin A in preventing the heat-stress-related depression in performance of broilers.

With broiler chicks exposed to heat stress, [112] reported that feeding diets enriched with incremental levels of chromium, as chromium picolinate, (200, 400, 800 or 1200 µg Cr/kg) produced an increase in body weight, feed intake, and carcass characteristics and improved feed efficiency. They also observed a significant reduction in serum corticosterone concentration and significant increases in serum levels of insulin, triiodothyronine (T3) and thyroxine (T4) with increasing dietary Cr level. The dietary chromium methionine supplementation could alleviate heat-stress-induced growth retardation in broiler chicks [113]. They also observed that supplemental chromium methionine could modulate the suppressive effects of heat stress on cellular and humeral immune responses of broilers. Added dietary chromium picolinate and chromium nanoparticles proved to be effective in improving performance and antibody titers against avian influenza and infectious bronchitis under heat stress conditions in broiler chickens [114]. The effect of supplemental dietary chromium picolinate (1200 μg/kg) on heat-stressed broiler chickens and found that supplemental Cr was effective to overcome the deleterious effects of heat stress on broiler performance [115]. In laying hens exposed to heat stress, dietary Cr supplementation (as chromium picolinate) improved immune response, egg quality, Haugh unit [116], and reduced serum glucose, cholesterol, and triglyceride concentration [117]

During heat stress, added dietary Se has been reported to improve the body weight gain and feed conversion ratio of broilers during heat stress [118]. In laying quails, there was a linear increase in feed intake, body weight, and egg production; and improvement in feed efficiency upon selenium supplementation (as sodium selenite or seleno-methionine) under heat stress [119] They reported that Haugh units and eggshell weights were also increased upon supplementation of both organic and inorganic selenium.

2. Conclusion

Climate change has a close direct and indirect effect on livestock and poultry production. Change in temperature affects all aspects of poultry production. Heat stress adversely affect commercial poultry production by reducing feed intake, body weight gain, reduced egg production and increased mortality rate. However, to reduce the effect of climatic change on poultry performance, improved animal breeding and genetic techniques should be looked into to produce birds that are genetically adaptable to the heat stress in the tropics and can still perform optimally, together with application of the managerial procedures and nutritional strategies that can be applied to alleviate the adverse effects of heat stress on growth and performance of different classes of poultry.

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References

[1] E.O. Ahaotu, W. Onuoha, G. Uwaleke & E.A. Agiang. (2019). Sustainability of black Nera laying birds on pig dung meal based diets. Sustainability, Agri, Food and Environmental Research, 7(1): 1-17. doi.org/10.7770/safer-V0N0-art1657

[2] A. Moorhead. (2009). Climate, Agriculture and Food Security: A Strategy for Change. A Technical Guidance.

[3] J.M. Chah, E. Odo, A. N. Asadu & I. A. Enwelu. (2013). Poultry farmers' adaptation to climate change in Enugu north agricultural zone of Enugu state, Nigeria. J. Agric. Ext., 17(1):100-114. Doi:10.4314/jae.v17i1.10

[4] S. Okonkwo & E. O. Ahaotu. (2019). Management of laying birds in deep litter and battery cage systems in Orlu local government area of Imo-state, Nigeria: a comparative study. International Journal of Research in Agriculture and Forestry, 6(3): 21-29.

[5] M. Kumar, P. Ratwan, S. P. Dahiya & A. K. Nehra. (2021). Climate change and heat stress: Impact on production, reproduction and growth performance of poultry and its mitigation using genetic strategies. Journal of Thermal Biology, 97: 102867. https://doi.org/10.1016/j.jtherbio.2021.102867

[6] O.O. Popoola, N. Monde & S.F.G. Yusuf. (2019). Climate change: perception and adaptation responses of poultry smallholder farmers in Amathole District Municipality, Eastern Cape Province of South Africa. South African J. Agric. Exten., 47 (3): 108-119. http://dx.doi.org/10.17159/2413-3221/2019/v47n3a519

[7] S. Tiruneh & F. Tegene. (2018). Impacts of climate change on livestock production and productivity and different adaptation strategies in Ethiopia. J. Appl. Adv. Res., 3(3): 52–58. DOI: https://doi.org/10.21839/jaar.2018.v3i3.150

[8] Y.A. Attia, R.A. Hassan. A.E. Tag El-Din & B.M. Abou-Shehema. (2011). Effect of ascorbic acid or increasing metabolizable energy level with or without supplementation of some essential amino acids on productive and physiological traits of slow-growing chicks exposed to chronic heat stress. J. Anim. Physiol. Anim. Nutr., 95(6): 744–755. https://doi.org/10.1111/j.1439-0396.2010.01104.x

[9] M.O. Oniah, V.N. Meremeku & F.B. Agiopu. (2018). Influence of climate variation on household poultry production in South-South, Nigeria. International Journal of Agricultural Economics and Management, 8(1): 9-19.

[10] M.O. Abioja & J.A. Abiona. (2021). Impacts of climate change to poultry production in Africa: Adaptation options for broiler chickens. Chapter 16 in: African Handbook of Climate Change Adaptation. Edited by Filho, W.L., N. Oguge, D. Ayal, L. Adeleke and I. da Silva, published by Springer Nature Switzerland AG, Switzerland, pp. 275-296. doi.org/10.1007/978-3-030-45106-6_111

[11] A. Alemayehu & W. Bewket. (2017). Smallholder farmers’ coping and adaptation strategies to climate change and variability in the central highlands of Ethiopia. Local Environ., 22(7):825–839. https://doi.org/10.1080/13549839.2017.1290058

[12] Y.S. Mustafa, A.Q.K. Sulehria, M.A. Muneer & R. Munir. (2010). Effect of water restriction on the lymphoid organs and production of broilers. Biologia (Pakistan) 56(1&2): 63–68.

[13] V. Pech-Waffenschmidt, E. Bogin, Y. Avidar & P. Horst. (1995). Metabolic and biochemical changes during heat stress in relation to the feathering degree of the domestic hen. Avian Pathol., 24(1): 33–44. https://doi.org/10.1080/03079459508419047

[14] L. Babinszky, M. Horváth, J. Remenyik & M.W.A. Verstege. (2019). The adverse effects of heat stress on the antioxidant status and performance of pigs and poultry and reducing these effects with nutritional tools. Chapter 8 In: Poultry and Pig Nutrition: Challenges of the 21st century. Edited by Hendriks, W.H., M.W.A. Verstegen and L. Babinszky, Wageningen Academic Publishers, Netherlands, pp.187-208. https://doi.org/10.3920/978-90-8686-884-1

[15] R. Hu, Y. He, M.A. Arowolo, S. Wu & J. He. (2019). Polyphenols as potential attenuators of heat stress in poultry production. Antioxidants (Basel), 8(3): 67 https://doi.org/10.3390/antiox8030067

[16] P. Bhadauria, J.M. Kataria, S. Majumdar, S.K.B. Divya & G. Kolluri. (2014). Impact of hot climate on poultry production system-A review. J. Poult. Sci. Technol., 2(4): 56–63.

[17] M. Alagawany, M.R. Farag, M.E. Abd EL-Hack & A. Patra. (2017). Heat stress: Effects on productive and reproductive performance of quail. World's Poult. Sci. J., 73(4): 747–756. DOI: https://doi.org/10.1017/S0043933917000782

[18] M.S. El-Kholy, M.M. El-Hindawy, M. Alagawany, M.E. Abd El-Hack & S.A.A. El-Sayed. (2017). Dietary supplementation of chromium can alleviate negative impacts of heat stress on performance, carcass yield, and some blood hematology and chemistry indices of growing Japanese quail. Biol. Trace Elem. Res., 179(1): 148–157.

[19] G. D. Vandana, V. Sejian, A. M. Lees, P. Pragna, M. V. Silpa & Shane K. Maloney. (2021). Heat stress and poultry production: impact and amelioration.

[20] D.R. Charles (2002). Responses to the thermal environment. In: Poultry Environment Problems: A guide to solutions. Edited by D.A. Charles and A.W. Walker, Nottingham University Press, Nottingham, United Kingdom, pp. 1-16.

[21] H. Lin, H.C. Jiao, J. Buyse & E. Decuypere. (2006). Strategies for preventing heat stress in poultry. World's Poultry Science Journal, 62(1): 71-85. DOI: https://doi.org/10.1079/WPS200585

[22] B. Mishra & R. Jha. (2019). Oxidative stress in the poultry gut: potential challenges and interventions. Frontiers in Veterinary Science, 6: 60. https://doi.org/10.3389/fvets.2019.00060

[23] S. Yahav (2000). Domestic fowl-strategies of confront environmental conditions. Avian and Poultry Biology Reviews, 11(2): 81-95.

[24] D. Balnave & J. Brake. (2005). Nutrition and management of heat-stressed pullets and laying hens. World's Poultry Science Journal, 61(3):399-406. https://doi.org/10.1079/WPS200565

[25] W. Deng, X.F. Dong, J.M. Tong & Q. Zhang. (2012). The probiotic Bacillus licheniformis ameliorates heat stress-induced impairment of egg production, gut morphology, and intestinal mucosal immunity in laying hens. Poult. Sci., 91(3): 575–582. https://doi.org/10.3382/ps.2010-01293

[26] F. Vercese, E.A. Garcia, J.R. Sartori, A. De P Silva, A.B.G. Faitarone, D.A. Berto, A.D.B. Molino & K. Pelicia. (2012). Performance and egg quality of Japanese quail submitted to cyclic heat stress. Brazilian J. Poult. Sci., 14(1): 37–41. https://doi.org/10.1590/S1516-635X2012000100007

[27] G. Abbas, S. Mahmood & H. Nawaz (2017). Effect of dietary inclusion of sodium bicarbonate on blood profile of caged layers during summer. Pakistan J. Agric. Sci., 54 (2): 443-450. DOI: 10.21162/PAKJAS/17.5014

[28] S. Wasti, N. Sah & B. Mishra. (2020). Impact of heat stress on poultry health and performances, and potential mitigation strategies. Animals (Basel), 10(8): 1-20 (Article 1266). https://doi.org/10.3390/ani10081266

[29] S. Yahav, S. Goldfeld, I. Plavnik & S. Hurwitz. (1995). Physiological responses of chickens and turkeys to relative humidity during exposure to high ambient temperature. J. Therm. Biol., 20(3): 245–253.

[30] A. Mujahid, Y. Akiba, & M. Toyomizu. (2007). Acute heat stress induces oxidative stress and decreases adaptation in young White Leghorn cockerels by downregulation of avian uncoupling protein. Poult. Sci., 86(2): 364-371. https://doi.org/10.1093/ps/86.2.364

[31] H. Lin, H.F. Zhang, R. Du, R.; X.H. Gu, Z.Y. Zhang, J. Buyse & E. Decuypere. (2005). Thermoregulation responses of broiler chickens to

humidity at different ambient temperatures. II. Four weeks of age. Poult. Sci., 84(8): 1173–1178. https://doi.org/10.1093/ps/84.8.1173

[32] J. Biswal, V. Kennady, T.K. Bhattacharya & H. Rahmana. (2022). Impact of heat stress on poultry production. World's Poultry Science Journal, 78(1): 179-196. https://doi.org/10.1080/00439339.2022.2003168

[33] W.M. Quinteiro-Filho, A.V.S. Gomes, M.L. Pinheiro, A. Ribeiro, V. Ferraz-de-Paula, C.S. Astolfi-Ferreira, A.J.P. Ferreira & J. Palermo-Neto. (2012). Heat stress impairs performance and induces intestinal inflammation in broiler chickens infected with Salmonella Enteritidis. Avian Pathol., 41(5): 421–427. https://doi.org/10.1080/03079457.2012.709315.

[34] J. Biswal, V. Kennady, T.K. Bhattacharya & H. Rahmana. (2022). Impact of heat stress on poultry production. World's Poultry Science Journal, 78(1): 179-196.

[35] F.S.A. Ismail, Hayam M.A. Abo El-Maaty, M.H. Rabie & A.Q. Aswad. (2015). Productive performance of Bovans White laying hens fed high nutrient density diets under Egyptian summer conditions. Asian Journal of Animal and Veterinary Advances, 10(12): 865-874. DOI: 10.3923/ajava.2015.865.874

[36] D.A. Sandercock, R.R. Hunter, G.R. Nute, M.A. Mitchell & P.M. Hocking. (2001). acute heat stress-induced alterations in blood acid-base status and skeletal muscle membrane integrity in broiler chickens at two ages: Implications for meat quality. Poultry Science, 80(4): 418–425. https://doi.org/10.1093/ps/80.4.418

[37] M. Petracci, M. Betti, M. Bianchi & C. Cavani. (2004). Color variation and characterization of broiler breast meat during processing in Italy. Poultry Science, 83(12): 2086–2092. https://doi.org/10.1093/ps/83.12.2086

[38] M. Akşit, S. Yalçin, S. Özkan, K. Metin & D. Özdemir. (2006). Effects of temperature during rearing and crating on stress parameters and meat quality of broilers. Poultry Science, 85(11): 1867–1874. https://doi.org/10.1093/ps/85.11.1867

[39] Z.Y. Zhang, G.Q. Jia, J.J. Zuo, Y. Zhang, J. Lei, L. Ren & D.Y. Feng. (2012). Effects of constant and cyclic heat stress on muscle metabolism and meat quality of broiler breast fillet and thigh meat. Poultry Science, 91(11): 2931-2937. https://doi.org/10.3382/ps.2012-02255

[40] A.M. Fouad, W. Chen, D. Ruan, S. Wang, W.G. Xia & C.T. Zheng. (2016). 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, 15(3): 81–95.

[41] R.H. Wang, R.R. Liang, H. Lin, L.X. Zhu, Y.M. Zhang, Y.W. Mao, P.C. Dong, L.B. Niu, M.H. Zhang & X. Luo. (2017). Effect of acute heat stress and slaughter processing on poultry meat quality and postmortem carbohydrate metabolism. Poultry Science, 96(3): 738–746. https://doi.org/10.3382/ps/pew329

[42] Q.W. Lu, J. Wen & H. Zhang. (2007). Effect of chronic heat exposure on fat deposition and meat quality in two genetic types of chicken. Poultry Science, 86(6): 1059–1064. https://doi.org/10.1093/ps/86.6.1059

[43] Y. Hashizawa, M. Kubota, M. Kadowaki & S. Fujimura. (2013). Effect of dietary vitamin E on broiler meat qualities, color, water-holding capacity and shear force value, under heat stress conditions. Anim. Sci. J., 84(11): 732–736. https://doi.org/10.1111/asj.12079

[44] Y.A. Attia & S.S. Hassan. (2017). Broiler tolerance to heat stress at various dietary protein/energy levels. European Poultry Science., 81: 1-15. DOI: 10.1399/eps.2017.171

[45] Z. Lu, X. He, B. Ma, L. Zhang, J. Li, Y. Jiang, G. Zhou & F. Gao. (2017). Chronic heat stress impairs the quality of breast-muscle meat in broilers by affecting redox status and energy-substance metabolism. Journal of Agricultural and Food Chemistry, 65(51): 11251–11258. DOI: 10.1021/acs.jafc.7b04428

[46] P.A. Geraert, J.C. Padilha & S. Guillaumin. (1996). Metabolic and endocrine changes induced by chronic heat exposure in broiler chickens: Growth performance, body composition and energy retention. British Journal of Nutrition, 75(2): 195–204. DOI: https://doi.org/10.1017/BJN19960124

[47] V.D. Yunianto, K. Hayashit, S. Kaiwda, A. Ohtsuka & Y. Tomita. (1997). Effect of environmental temperature on muscle protein turnover and heat production in tube-fed broiler chickens. British Journal of Nutrition. 77(6): 897–909. DOI: https://doi.org/10.1079/BJN19970088

[48] S. Temim, A.M. Chagneau, R. Peresson & S. Tesseraud. (2000). Chronic heat exposure alters protein turnover of three different skeletal muscles in finishing broiler chickens fed 20 or 25% protein diets. Journal of Nutrition, 130(4): 813–819. https://doi.org/10.1093/jn/130.4.813

[49] I. O. Popoola, O. R. Popoola, A. A. Adeyemi, O. M. Ojeniyi, I. F. Olaleru, F. J. Oluwadele & E. O. Akinwumi. (2020). Overall Performance, Carcass Yield, Meat Safety Potentials and Economic Value of Heat-Stressed Broilers Fed Diets with Balanced Electrolytes. Food and Nutrition Sciences. Vol.11 No.7,

[50] [50] M. Estévez (2011). Protein carbonyls in meat systems: A Review. Meat Science, 89(3): 259–279. https://doi.org/10.1016/j.meatsci.2011.04.025

[51] G. Zaboli, X. Huang, X. Feng & D. U. Ahn. (2019). "How can heat stress affect chicken meat quality? A Review. Poultry Science, 98(3): 1551–1556. https://doi.org/10.3382/ps/pey399

[52] D.J. Song & A.J. King. (2015). Effects of heat stress on broiler meat quality. Worlds Poultry Science Journal, 71(4): 701–709. https://doi.org/10.1017/S0043933915002421

[53] P.A. Gonzalez-Rivas, S.S. Chauhan, M. Ha, N. Fegan, F.R. Dunshea and R.D. Warner (2020). Effects of heat stress on animal physiology, metabolism, and meat quality: A review. Meat Sci., 162: 1-13 (Article 108025). https://doi.org/10.1016/j.meatsci.2019.108025

[54] A.H. Nawaz, K. Amoah, Q.Y. Leng, J.H. Zheng, W.L. Zhang & L. Zhang. (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. Front. Vet. Sci., 8: 1-16 (Article 699081). https://doi.org/10.3389/fvets.2021.699081

[55] L. Babinszky, V. Halas & M.W.A. Verstegen. (2011). Impacts of climate change on animal production and quality of animal food products. Chapter 10 In: Climate Change – Socioeconomic Effects. pp. 165-190. Edited by Kheradmand, H. ISBN: 978-953-307-411-5.

[56] M.M. Mashaly, G.L. Hendricks, M.A. Kalama III, A.E. Gehad, A.O. Abbas & P.H. Patterson. (2004). Effect of heat stress on production parameters and immune responses of commercial laying hens. Poultry Science, 83(6): 889-894. https://doi.org/10.1093/ps/83.6.889

[57] I. Rozenboim, E. Tako, O. Gal-Garber, J.A. Proudman & Z. Uni. (2007) The effect of heat stress on ovarian function of laying hens. Poult. Sci., 86(8):1760–1765. https://doi.org/10.1093/ps/86.8.1760

[58] T.A. Scott & D. Blanave. (1988). Comparison between concentrated complete diets and self-selection for feeding sexually maturing pullets at hot and cold temperatures. British Poultry Science, 29(3): 613-626. https://doi.org/10.1080/00071668808417088

[59] K.Z. Mahmoud, M.M. Beck, S.E. Scheideler, M.F. Forman, K.P. Anderson & S.D. Kachman. (1996). Acute high environmental temperature and calcium-estrogen relationships in the hen. Poult. Sci., 75(12): 1555–1562 https://doi.org/10.3382/ps.0751555

[60] N. Yoshida, M. Fujita, M. Nakahara, T. Kuwahara, S.I. Kawakami & T. Bungo. (2011). Effect of high environmental temperature on egg production, serum lipoproteins and follicle steroid hormones in laying hens. J. Poult. Sci., 48(3): 207-211. https://doi.org/10.2141/jpsa.010126

[61] S. Kang, D.H. Kim, S. Lee, T. Lee, K.W. Lee, H.H. Chang, B. Moon, T. Ayasan & Y.H. Choi. (2020). An acute, rather than progressive, increase in temperature-humidity index has severe effects on mortality in laying hens. Front. Vet. Sci., 7: Article 568093. https://doi.org/10.3389/fvets.2020.568093

[62] A. V. S. Gomes, W. M. Quinteiro-Filho, A. Ribeiro, V. Ferraz-de-Paula, M. L. Pinheiro, E. Baskeville, A. T. Akamine, C. S. Astolfi-Ferreira, A. J. P. Ferreira & J. Palermo-Neto. (2014). Overcrowding stress decreases macrophage activity and increases Salmonella Enteritidis invasion in broiler chickens, Avian Pathology, 43:1, 82-90, DOI: 10.1080/03079457.2013.874006

[63] M.S. Monson, A.G. Van Goor, C.M. Ashwell, M.E. Persia, M.F. Rothschild, C.J. Schmidt & S.J. Lamont. (2018). Immunomodulatory effects of heat stress and lipopolysaccharide on the bursal transcriptome in two distinct chicken lines." BMC Genomics, 19(1): 1-15 (Article 643). https://doi.org/10.1186/s12864-018-5033-y

[64] J.R. Bartlett & M.O. Smith. (2003). Effects of different levels of zinc on the performance and immunocompetence of broilers under heat stress. Poultry Science, 82(10): 1580–1588. https://doi.org/10.1093/ps/82.10.1580

[65] R. Hirakawa, S. Nurjanah, K. Furukawa, A. Murai, M. Kikusato, T. Nochi & M. Toyomizu. (2020). Heat stress causes immune abnormalities via massive damage to effect proliferation and differentiation of lymphocytes in broiler chickens. Front. Vet. Sci., 7: 1-13 (Article 46). https://doi.org/10.3389/fvets.2020.00046

[66] Sh. Ghazi, M. Habibian, M.M. Moeini & A.R. Abdolmohammadi. (2012). Effects of different levels of organic and inorganic chromium on growth performance and immuno-competence of broilers under heat stress. Biological Trace Element Research, 146(3): 309-317. DOI 10.1007/s12011-011-9260-1

[67] J.N. Felver-Gant, L.A. Mack, R.L. Dennis, S.D. Eicher & H.W. Cheng. (2012). Genetic variations alter physiological responses following heat stress in 2 strains of laying hens. Poult. Sci., 91(7): 1542-1551. https://doi.org/10.3382/ps.2011-01988

[68] W. Aengwanich. (2008). Pathological changes and the effects of ascorbic acid on lesion scores of bursa of Fabricius in broilers under chronic heat stress. Res. J. Vet. Sci., 1(1): 62-66.

[69] M. Habibian, S. Ghazi, M.M. Moeini & A. Abdolmohammadi. (2014). Effects of dietary selenium and vitamin E on immune response and biological blood parameters of broilers reared under thermoneutral or heat stress conditions. International Journal of Biometeorology, 58(5): 741–752. DOI 10.1007/s00484-013-0654-y

[70] R. Jahanian & E. Rasouli. (2015). Dietary chromium methionine supplementation could

alleviate immunosuppressive effects of heat stress in broiler chicks. J. Anim. Sci., 93(7): 3355–3363. https://doi.org/10.2527/jas.2014-8807

[71] F. Hajializadeh, H. Ghahri & A. Talebi. (2017). Effects of supplemental chromium picolinate and chromium nanoparticles on performance and antibody titers of infectious bronchitis and avian influenza of broiler chickens under heat stress condition. Vet. Res. Forum, 8(3): 259–264.

[72] L.A. Mack, J.N. Felver-Gant, R.L. Dennis & H.W. Cheng. (2013). Genetic variation alters production and behavioral responses following heat stress in 2 strains of laying hens. Poultry Science, 92(2): 285-294. https://doi.org/10.3382/ps.2012-02589

[73] M.R. Farag & M. Alagawany. (2018). Physiological alterations of poultry to the high environmental temperature. Journal of Thermal Biology, 76: 101–106. https://doi.org/10.1016/j.jtherbio.2018.07.012

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

[75] C.D. McDaniel, R.K. Bramwell & B. Howarth. (1996). The male contribution to broiler breeder heat induced infertility as determine by sperm-egg storage within hen's oviduct. Poultry Science, 75(12): 1546–1554. https://doi.org/10.3382/ps.0751546

[76] A. Nawab, F. Ibtisham, G. Li, B. Kieser, J. Wu, W. Liu, Y. Zhao, Y. Nawab, K. Li, M. Xei & L. An. (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

[77] J.O. Ayo, J.A. Obidi & P.I. Rekwot. (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

[78] M. Bonato, I.A. Malecki, P.K. Rybnik-Trzaskowska, C.K. Cornwallis & S.W.P. Cloete. (2014). Predicting ejaculate quality and libido in male ostriches: Effect of season and age. Animal Reproduction Science, 151(1–2): 49–55. https://doi.org/10.1016/j.anireprosci.2014.09.015

[79] S.A. Ameen, O.S. Opayemi, J.A. Ajayi & M.A. Adediwura. (2014). Evaluation of semen quality of five different cockerel breed used in poultry industry in Nigeria. Journal of Environmental Issues and Agriculture, 6(1): 30–36.

[80] R.L. Furlan, D.E. de Faria Filho; P.S. Rosa & M. Macari. (2004). Does Low-Protein Diet Improve Broiler Performance under Heat Stress Conditions? Brazilian Journal of Poultry Science. vol. 6 (2), pp. 71-79.

[81] V. Laudadio, A. Dambrosio, G. Normanno, R. U. Khan, S. Naz, E. Rowghani & V. Tufarelli (2012). Effect of reducing dietary protein level on performance responses and some microbiological aspects of broiler chickens under summer environmental conditions. Avian Biology Research, 5(2): 88–92. https://doi.org/10.3184/175815512X13350180713553

[82] A. Ratriyanto, R. Indreswari & A. Nuhriawangsa. (2017). Effects of dietary protein level and betaine supplementation on nutrient digestibility and performance of Japanese quails. Brazilian Journal of Poultry Science, 19(3): 445–454. https://doi.org/10.1590/1806-9061-2016-0442

[83] M. Torki, A. Mohebbifar, H.A. Ghasemi & A. Zardast. (2015). Response of laying hens to feeding low-protein amino acid-supplemented diets under high ambient temperature: performance, egg quality, leukocyte profile, blood lipids, and excreta pH. International Journal of Biometeorology, 59(5): 575–584. DOI 10.1007/s00484-014-0870-0

[84] E.A. Awad, I. Zulkifli, A.F. Soleimani, F.L. Law, S.K. Ramiah, I.M. Mohamed-Yousif, E.A. Hussein & E.S. Khalil. (2019). Response of broilers to reduced-protein diets under heat stress conditions. World's Poultry Science Journal, 75(4): 583–598. https://doi.org/10.1017/S0043933919000576

[85] N.A. Musharaf & J.D. Latshaw. (1999). Heat increment as affected by protein and amino acid nutrition. World's Poult. Sci. J., 55(3): 233–240. DOI: https://doi.org/10.1079/WPS19990017

[86] G.G. Mateos. & J.L. Sell. (1981). Influence of fat and carbohydrate source on rate of food passage of semi-purified diets for laying hens. Poult. Sci., 60(9): 2114–2119. https://doi.org/10.3382/ps.0602114

[87] Y.A. Attia, M.A. Al-Harthi & A. Sh. Elnaggar. (2018). Productive, physiological and immunological responses of two broiler strains fed different dietary regimens and exposed to heat stress. Ital. J. Anim. Sci., 17(3): 686–697. https://doi.org/10.1080/1828051X.2017.1416961

[88] N.J. Daghir. (2008). Poultry Production in Hot Climates, Second Edition, CABI: Wallingford, Oxfordshire, UK. https://doi.org/10.1079/9781845932589.0000

[89] A.A. Ghazalah, M.O. Abd-Elsamee & A.M. Ali. (2008). Influence of dietary energy and poultry fat on the response of broiler chicks to heat therm. Int. J. Poult. Sci., 7(4): 355–359.

[90] N.J. Daghir. (2009). Nutritional strategies to reduce heat stress in broilers and broiler breeders. Lohmann Information, 44(1): 6–15.

[91] T. Ahmad, T. Khalid, T. Mushtaq, M.A. Mirza, A. Nadeem, M.E. Babar & G. Ahmad. (2008). Effect of potassium chloride supplementation in drinking water on broiler performance under heat stress conditions. Poult. Sci., 87(7): 1276–1280. https://doi.org/10.3382/ps.2007-00299

[92] M.M.H. Mushtaq, T.N. Pasha, T. Mushtaq & R. Parvin. (2013). Electrolytes, dietary electrolyte balance and salts in broilers: An updated review on growth performance, water intake and litter quality. World's Poult. Sci. J., 69(4): 789–802. DOI: https://doi.org/10.1017/S0043933913000810

[93] D. Balnave, & S.K. Muheereza. (1997). Improving eggshell quality at high temperatures with dietary sodium bicarbonate. Poult. Sci., 76(4): 588–593. https://doi.org/10.1093/ps/76.4.588

[94] A.H. Raya, T.M. Dorra, Kh. El. Sherif, M.H. Rabie & Z.M. Kalaba. (2007). The use of dietary vitamin e and potassium chloride to alleviate the effects of heat stress on the performance of laying hens. J. Agric. Sci. (Mansoura Univ.), 32 (12): 9897 - 9915, 2007.

[95] A.H. Raya, T.M. Dorra, Kh. El. Sherif, M.H. Rabie & Z.M. Kalaba. (2008). The alleviation of the harmful effects of heat stress on nutrient digestibility and some blood constituents in laying hens by dietary potassium chloride and vitamin E. J. Agric. Sci. (Mansoura Univ.), 33(8): 5651- 5670. DOI: 10.21608/jappmu.2008.218908.

[96] S. Bollengier-Lee, M.A. Mitchell, D.B. Utomo, P.E. Williams & C.C. Whitehead. (1998). Influence of high dietary vitamin E supplementation on egg production and plasma characteristics in hens subjected to heat stress. Br. Poult. Sci., 39(1): 106–112. https://doi.org/10.1080/00071669889466

[97] R.U. Khan, S. Naz, Z. Nikousefat, V. Tufarelli, M. Javdani, N. Rana & V. Laudadio (2011). Effect of vitamin E in heat-stressed poultry. World's Poult. Sci. J., 67(3): 469–478. DOI: https://doi.org/10.1017/S0043933911000511

[98] D.F.K. Kirunda, S.E. Scheideler & S.R. McKee. (2001). The Efficacy of vitamin E (DL-α-tocopheryl acetate) supplementation in hen diets to alleviate egg quality deterioration associated with high temperature exposure. Poultry Science, 80(9): 1378-1383. https://doi.org/10.1093/ps/80.9.1378

[99] H. Yardibi, & G. Turkay. (2008). The effects of vitamin E on the antioxidant system, egg production, and egg quality in heat stressed laying hens. Turk. J. Vet. Anim. Sci., 32(5): 319–325.

[100] K. Sahin, N. Sahin, M. Ondereci, S. Yaralioglu & O. Kucuk. (2001). Protective role of supplemental vitamin E on lipid peroxidation, vitamins E, A and some mineral concentrations of broilers reared under heat stress. Vet. Med. (Czech), 46(5): 140-144. DOI:10.17221/7870-VETMED

[101] Y.A. Attia, M.A. Al-Harthi, A.S. El-Shafey, Y.A. Rehab & W.K. Kim. (2017). Enhancing tolerance of broiler chickens to heat stress by supplementation with vitamin E, vitamin C and/or probiotics. Ann. Anim. Sci.,17(4): 1155–1169. DOI: https://doi.org/10.1515/aoas-2017-0012

[102] R.U. Khan, S. Naz, Z. Nikousefat, M. Selvaggi, V. Laudadio & V. Tufarelli. (2012). Effect of ascorbic acid in heat-stressed poultry. World's Poult. Sci. J., 68(3): 477–490. DOI: https://doi.org/10.1017/S004393391200058X

[103] A.C. Carr, & S. Maggini. (2017). Vitamin C and immune function. Nutrients, 9(11): Article 1211. https://doi.org/10.3390/nu9111211

[104] K. Sahin, M. Onderci, N. Sahin, M.F. Gursu & O. Kucuk. (2003). Dietary vitamin C and folic acid supplementation ameliorates the detrimental effects of heat stress in Japanese quail. J. Nutr., 133(6): 1882–1886. https://doi.org/10.1093/jn/133.6.1882

[105] P.C. Njoku, (1986). Effect of dietary ascorbic acid (vitamin C) supplementation on the performance of broiler chickens in a tropical environment. Anim. Feed Sci. Technol., 16(1-2): 17–24. https://doi.org/10.1016/0377-8401(86)90046-5

[106] T. Ahmad, M. Sarwar, M.U Nisa, A.U. Haq & Z.U. Hasan. (2005). Influence of varying sources of dietary electrolytes on the performance of broiler reared in a high temperature environment. Animal Feed Sci. and Technol., 120(3-4): 277-298. https://doi.org/10.1016/j.anifeedsci.2005.02.028

[107] D. Sklan, D. Melamed & A. Friedman. (1994). The effect of varying levels of dietary vitamin A on immune response in the chick. Poult. Sci., 73(6): 843–847. https://doi.org/10.3382/ps.0730843

[108] D. F. Kirunda & S. R. McKee. (2000). Relating quality characteristics of aged eggs and fresh eggs to vitelline membrane strength as determined by a texture analyzer. Poultry Sci. 79:1189–1193. https://doi.org/10.1093/ps/79.8.1189

[109] H. Lin, L.F. Wang, J.L. Song, Y.M. Xie & Q.M. Yang. (2002). Effect of dietary supplemental levels of Vitamin A on the egg production and immune responses of heat-stressed laying hens. Poultry Science, 81(4): 458–465. https://doi.org/10.1093/ps/81.4.458

[110] O. Kucuk, N. Sahin & K. Sahin. (2003). Supplemental zinc and vitamin A can alleviate negative effects of heat stress in broiler chickens. Biological Trace Element Research, 94(3): 225–235.

[111] K. Sahin, N. Sahin, O. Kucuk, A. Hayirli & A.S. Prasad. (2009). Role of dietary zinc in heat stressed poultry: A Review. Poultry Science, 88(10): 2176–2183. https://doi.org/10.3382/ps.2008-00560

[112] K. Sahin, N. Sahin, M. Onderci, F. Gursu & G. Cikim. (2002b). Optimal dietary concentration of chromium for alleviating the effect of heat stress on

growth, carcass qualities, and some serum metabolites of broiler chickens. Biol. Trace Elem. Res., 89(1): 53–64.

[113] C.E. Benton, D. Balnave, J.B. Pas, L.J. Boyd & M.A. Brown. (1998). The use of dietary minerals during heat stress in broilers. Prof. Anim. Sci. 1998, 14, 193–196. https://doi.org/10.15232/S1080-7446(15)31828-3

[114] S. Bollengier-Lee. (1999). Optimal dietary concentration of vitamin E for alleviating the effect of heat stress on egg production in laying hens. Br. Poult. Sci., 40(1): 102–107. https://doi.org/10.1080/00071669987917

[115] W. Ezzat, E.A. Abdallah, A.M. Rizk, M.M.M. Ouda & R. E. Abd El-Krim. (2017). Impact of chromium picolinate supplementation on productive performance, immune response and heat shock proteins of broiler chickens under heat-stress condition. Egypt. Poult. Sci., 37(II): 559-583.

[116] K. Sahin, O. Ozbey, M. Onderci, G. Cikim & M.H. Aysondu. (2002a). Chromium supplementation can alleviate negative effects of heat stress on egg production, egg quality and some serum metabolites of laying Japanese quail. J. Nutr., 132(6): 1265–1268. https://doi.org/10.1093/jn/132.6.1265

[117] M. Torki, S. Zangeneh & M. Habibian. (2014). Performance, egg quality traits, and serum metabolite concentrations of laying hens affected by dietary supplemental chromium picolinate and vitamin C under a heat-stress condition. Biol. Trace Elem. Res., 157(2): 120–129. DOI 10.1007/s12011-013-9872-8

[118] S. Rahimi, D. Farhadi & A.R. Valipouri. (2011). Effect of organic and inorganic selenium sources and vitamin E on broiler performance and carcass characteristics in heat stress condition. Vet. J., 24(2): 25–35. Doi:10.22092/VJ.2011.101097

[119] N. Sahin, M. Onderci, K. Sahin & O. Kucuk. (2008). Supplementation with organic or inorganic selenium in heat-distressed quail. Biol. Trace Elem. Res., 122(3): 229–237. DOI 10.1007/s12011-007-8075-6.