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Poultry Management Strategies to Alleviate Heat Stress in Hot Climates: A Review

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ABSTRACT

Heat stress remains a major challenge affecting poultry production in sub-tropical and tropical environments; hence it continues to receive attention. The present study aimed to discuss heat stress and its effects on poultry production and suggests mitigation strategies to combat the effects of increased environmental temperature on poultry performance. Poultry raised in hot climates suffers from heat stress, which reduces meat and egg production, reproductive performance, feed intake, and feed conversion efficiency leading to poor growth rates. Reduced feed intake results in a reduction in meat quality, growth, egg yield, and quality. A decrease in feed utilization efficiency is the major cause of poor growth performance in hot environments. To counteract the negative impacts of high ambient temperatures on the performance of poultry, a wide range of management practices are widely used, including nutrient manipulations (particularly protein and energy), electrolyte and vitamin supplementation, feed form (especially particle size and moisture content), choice feeding, controlled feeding, time of feeding, wet feeding, water management, and use of new breeds that thrive well in hot environments. These management practices help lower heat load and facilitate evaporative cooling, all of which may positively impact poultry performance and health.

Keywords: Choice feeding, Feed conversion efficiency, Heat stress, Poultry production.

INTRODUCTION

There has been a significant increase in global average temperatures recently, which has affected the farming sector in the tropics (Barrett et al., 2019; Sohsuebngarm et al., 2019; Kennedy et al., 2022). High temperature above 32°C depresses feed intake, leading to poor performance in poultry (Cassuce et al., 2013; Sohsuebngarm et al., 2019). In addition, the increase in temperature results in the number of etiologically harmful microorganisms in the environment around the animals increasing. Due to an increase in parasites and microorganisms, climate change influences disease emergence and transmission (Ranjan et al., 2019). When the temperature in a living organism exceeds the threshold limit (i.e., thermo-neutral zone), it disrupts normal physiological functions and causes cell damage (Mack et al., 2013; Kennedy et al., 2022). High environmental temperatures typically cause stress-related issues such as output losses, metabolic alterations, poor development, and inefficiency (Dayyani and Bakhtiari, 2013; Afsal et al., 2018). At high temperatures, feed intake decreases while water intake increases (Mottet and Tempio, 2017).

Due to their insulating feathers, the absence of sweat glands on the skin, and the significantly high mass-to-body surface area ratio, broiler chicken strains are highly susceptible to rising temperatures (Scanes, 2015; Sejian et al., 2018; Bernabucci, 2019) compared to laying hens. In broiler chickens, for instance, rigorous genetic selection has enhanced metabolic activity in the pursuit of a higher development rate, further eroding the potential of a modern bird to withstand heat (Tamzil, 2014; Bohler et al., 2021). The broiler sector is confronted with heat stress, which raises production costs and degrades meat quality. This is attributable to the vulnerability of poultry to heat stress given the rapid metabolic and faster growth rates. In chickens, notably broilers, grown in hot climates, metabolic changes occur, resulting in a significant

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reduction in breast muscle growth (Safdar and Maghami, 2014).

Heat stress is divided into two types: acute heat stress (AHS), which is characterized by exposure to high temperatures for a short time, and chronic heat stress (CHS), which is characterized by exposure to high temperatures for a longer time (Lara and Rostagno, 2013; Pawar et al., 2016). In contrast to acute heat stress, chronic heat stress can increase fat content while destroying the muscles (Song and King, 2015; Adu-Asiamah et al., 2021). Besides the duration of excessive heat, the degree of heat stress influences the level of production (Adu-Asiamah et al., 2021). Both AHS and CHS have the potential to produce a significant decrease in poultry metabolism, which could lead to substantial issues with broiler growth performance and carcass characteristics which include meat color change, water holding capacity, muscular pH, and meat juiciness (Song and King, 2015; Gonzalez-Rivas et al., 2020).

Understanding the basic aspects underlying the causes, and impacts of heat stress, as well as, the approaches that can be used to mitigate or control such a widespread threat, will help solve worldwide food security challenges. Despite the ongoing debate in the literature on heat exposure, a synthesis of knowledge on such systems in terms of elevated ambient temperature exposure is still yet to be published. Therefore, this review aimed to discuss the management strategies that poultry producers can utilize to boost production in hot places around the world.

EFFECTS OF HEAT STRESS ON POULTRY

Heat stress (also referred to as hyperthermia) is a result of global warming and is considered one of the crucial factors that negatively influence poultry production (Vandana and Sejian, 2018). Excessive heat depresses feed intake, feed conversion efficiency, growth, meat and egg output, and reproductive function (Alverdy and Luo, 2017; Quinteiro-Filho et al., 2017; Rostagno, 2020). The reduced feed intake due to high temperatures has a negative effect on semen quality and fertility, thus leading to poor hatchability rates (Nawab et al., 2018; Nyoni et al., 2019). In addition, heat stress affects a poultry's production performance, digestive health, body temperature, immunological responses, hunger hormone modulation, and oxidative properties (Goel, 2021). Recently, Nawaz et al. (2021) observed that heat stress degrades meat quality by altering the pH, water-holding capacity, and drip loss in the meat leading to changes in the normal meat color, flavor, and texture of chicken meat. Moreover, the effects of heat stress on meat quality include a reduction in protein synthesis and an increase in unfavorable fat (Kadykalo et al., 2018). By adjusting to changing climatic conditions, poultry frequently sacrifices their production capacity (Slawinska et al., 2019; Smith et al., 2019). However, poultry breeds are more resilient to climate change which continues to influence egg and meat production (Farag and Alagawany, 2018; Liverpool-Tasie et al., 2019).

Overcrowding and high outside temperatures contribute to the development of heat stress. However, by increasing cooling options, which include using the fogging system, use of a wet pad system, and micro-sprinklers, the heat load may be reduced by lowering the heat production level or changing the pattern of thermal production throughout the day (Gicheha, 2021). Commercial broilers' growth rate and meat yield are known to be slowed by high ambient temperatures (Zhang et al., 2017). In addition to poorer weight gain, high mortality rate, and reduced feed consumption, high temperatures negatively affect intestinal development (Rostagno, 2020). Furthermore, high temperatures disrupt broilers' acid-base balance and increase respiratory rate which can contribute to respiratory alkalosis (Scanes, 2015).

Heat stress can have a substantial influence on layer flocks, but some precautions can be done to keep hens healthy and produce eggs. For instance, the lighting schedule should be changed to provide more light hours during the colder hours of the day to promote feed consumption during cooler times of the day. In addition, when it is hot outside, it is best to lower stocking density (Reddy and Ramya, 2015; Abbas et al., 2021). High stocking rates during the hot season can lead to inadequate ventilation. Early heat conditioning also appears to be an effective method for boosting the heat tolerance of some chicken breeds (Saeed et al., 2019). Layer flocks can be kept calm by starving or fasting during hot hours (Saeed et al., 2019; Bilal et al., 2021; Shakeri and Le, 2022). Therefore, egg producers must be prepared when summer temperatures rise as egg yield will decrease and flock mortality increases (Yahav, 2015; Sinha et al., 2018).

During the chicks' first few days of life, chickens cannot regulate its heat production in response to the environmental temperature, therefore a decrease in environmental temperature leads to a reduction in body temperature (Ranjan et al., 2019). However, after 21 days, chicks start to develop additional homeothermic traits, such as the capacity to match their heat production to the surrounding temperature, allowing them to endure the lowering effect that a decrease in ambient temperature has on their body temperature (Ranjan et al., 2019; Saeed et al., 2019). The normal body temperature of an adult chicken is 40.6-41.7°C (Ranjan et al., 2019). The comfortable ambient temperature for adult poultry is 18-24°C, whereas chicks require higher temperatures of around 32°C in their first week of life which decreases over time (Scanes, 2015). Above 32°C, poultry fails to maintain their normal internal body temperature, due to the absence of sweat glands and the presence of complete feather coverage of the body (Hu et al., 2016). When the ambient temperature rises above 24°C, the internal body temperature of the chicken also rises, which causes it to consume less feed (Cassuce et al., 2013). Heat stress, panting, and prostration results at a temperature above 35°C (Hu et al., 2016). When a chicken's core body temperature reaches a critical level of 47°C, sometimes known as the upper lethal temperature, chickens may die from heat prostration (Reddy and Ramya, 2015; Scanes, 2015). In laying hens, heat stress causes low egg production and an increased number of hatching egg rejects in breeder hens (Abbas et al., 2021). Heat stress is less likely similar to affect younger and lighter chicks than older and heavier chickens (Farag and Alagawany, 2018). Therefore, heat stress can be alleviated by modifying the macro and microenvironments in which chickens are kept. High humidity and high environmental temperatures adversely affect poultry production (Saeed et al., 2019; Yousaf et al., 2019).

POULTRY RESPONSES TO HEAT STRESS

The susceptibility of broiler chickens to heat stress increases as air relative humidity and ambient temperature values are above the thermal comfort zone (16-23°C and 50-70% relative humidity), making it hard for birds to release heat (Gamba et al., 2015). This results in their body temperature rising, which harms their growth performance. Hot weather causes poultry to perform poorly as it results in decreased feed intake and increased water intake (Saeed et al., 2019; Rahman and Hidayat, 2020). At high temperatures, laying hens lay fewer eggs, watery eggs, and eggs with thin shells or even shell-less eggs due to lack of calcium; grow slower; and are more likely to become sick due to their compromised nutritional requirement as protein digestibility is reduced up to 9.7% (Habashy et al., 2017; Nawaz et al., 2021). In broiler chickens, decreases in growth rates, feed efficiency, immunity, and carcass quality were observed at high ambient temperatures (Dayyani and Bakhtiyari, 2013). Aswathi et al. (2019) reported a reduction in fertility percentage (-7.22%) and hatchability of fertile egg sets (-2.51%) in breeders. Heat stress has a negative effect on not just feed intake and utilization, but also carcass quality (Rath et al., 2015, Aswathi et al., 2019; Rahman and Hidayat, 2020) due to the unfavorable partitioning of metabolizable energy consumed, with a large proportion of it being stored as fat and the remainder as muscle (Rahman and Hidayat, 2020). The signs of a heat-stressed chicken include panting, extending the wings, holding the wings slightly apart from the body, standing or lying down, and closing the eyes (Dayyani and Bakhtiyari, 2013). A study by Altan et al. (2003) reported that heat stress increases fearfulness, induces oxidative stress, and initiates significant physiological responses in broiler chickens. Birds can survive a gradual increase in temperature, but a rapid increase in temperature will result in higher mortality rates (Rostagno, 2020). Figure 1 illustrates the responses of chickens to heat stress.

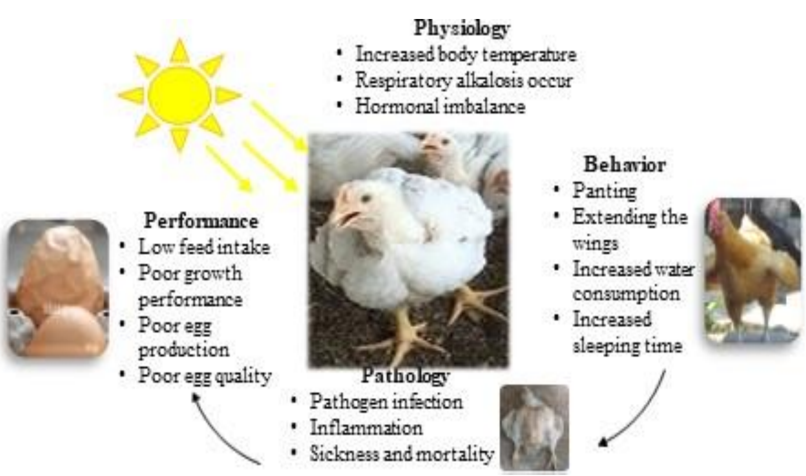

Figure 1. Poultry responses to heat stress

BIOLOGICAL CHANGES IN CHICKENS DUE TO HEAT STRESS

Heat stress in poultry results in several behavioral, physiological, and neuroendocrine changes that influence health and performance (Ahmad et al., 2022). The major physiological changes that occur in heat-stressed poultry are discussed briefly below.

Oxidative stress

Reactive oxygen species (ROS) are peroxyl radicals produced by cells during normal metabolism and are required for physiological functions such as ion transport, immunomodulation, and cytokine production (Wasti et al., 2020). Extra ROS is removed from cells through physiological detoxification processes. The Nrf2, a transcriptional factor when activated, under thermoneutral conditions, causes an increase in the production of a collection of antioxidant molecules that deal with the elevated ROS generated within the cell (Surai et al., 2019). Since the mitochondria create a significant amount of ROS, excessive mitochondrial ROS production may be a key factor in oxidative stress. Acute heat stress increases the formation of ROS from mitochondria, harming birds' skeletal muscles by oxidation (Akbarian et al., 2016). Acute heat stress causes an increase in the activity of the electron transport chain and mitochondrial substrate oxidation, which results in an excessive generation of superoxide (Akbarian et al., 2016).

Heat stress has been linked to cellular oxidative stress in chickens (Estévez, 2015; Surai et al., 2019). Down-regulation of chicken uncoupling protein exacerbates the oxidative stress situation during the later stages of acute heat stress, leading to mitochondrial malfunction and tissue damage (Mishra and Jha, 2019). Constant heat stress reduces the mitochondria's ability to create oxidative energy and consequently increases the chicken's uncoupling protein, this significantly alters the pattern of antioxidant enzyme activities, leading to the depletion of antioxidant reserves (Sahin et al., 2016). Oxidative stress has been linked to reduced growth rates, biological defects, loss of income, and severe health concerns in poultry (Estévez, 2015; Zaboli et al., 2019). While the chicken's physiology struggles to maintain thermal homeostasis, elevated ROS concentrations increase in stressful environmental situations (Sahin et al., 2016). In an effort to defend itself from the damaging effects of ROS on cells, the body undergoes an oxidative stress state and starts to manufacture and release heat shock proteins (HSP, Archana et al., 2017). Studies by Arnal and Lallès (2016) and Hao et al. (2017) have demonstrated that when exposed to heat stress, laying hens and broilers have higher *HSP70* levels.

Role of genes in heat stress

The global poultry industry has difficulty with genetic screening for high-temperature tolerant broilers (Zeferino et al. 2016). Therefore, crossing commercial chickens with strains that are highly tolerant to high temperatures can also be used to integrate heat stress resistance into the genome. The most common breeding approach for generating a commercial hybrid robust to tropical conditions and capable of producing a respectable amount of eggs and meat is a crossbreeding program between indigenous and foreign breeds (Duangjinda et al., 2017; Abd El-Hack et al., 2018).

The introduction of genetics from high-temperature tolerant strains into grandparental stock is a useful technique for speeding up the genetic advancement of commercial strains that can withstand heat stress. In chickens, heat-tolerant genes such as dwarfism (Vandana et al., 2021), naked-neck (Desta, 2021), slow/rapid feathering (Wells et al., 2012), and frizzle genes (Fathi et al., 2013; 2019), have been extensively studied. In every case, the chickens' appearance and performance indicators which include body weight gain, body weight, and feed conversion ratio (FCR), were influenced by their genes (Nawaz et al., 2021). Another downside of temperature control is immune inhibition (Goel et al., 2021). When exposed to high ambient temperature, differences in the levels of several immunological marker genes including interleukins (ILs), tumor necrosis factors (TNF), and toll-like receptors (TLRs) had a more pronounced increase in the spleen and intestine of chicks (Varasteh et al., 2015; Moraes et al., 2019).

The response of prokaryotic and eukaryotic cells to potentially harmful stimulations like heat stress induces the synthesis of stress proteins which are referred to as heat shock proteins (Efeoğlu, 2009). Many strategies, including the development of thermotolerance, modification of apoptotic and anti-apoptotic signaling pathways, and control of cellular redox conditions, are used by heat-shock proteins to provide protection against heat stress to cells (Shehaha et al., 2020). The *HSP70* and *HSP90* relate to families of HSP that are around 70 and 90 kilo Daltons, respectively (Datta et al., 2017). The *HSP70* gene is thought to protect the body from the harmful consequences of oxidative stress (Xie et al., 2015), whereas *HSP90* engages with client proteins during the last stages of folding and changes their shape (Kumbhar et al., 2018). The *HSP70* is a chaperone polypeptide that successfully protects a variety of proteins and cell components from stress (Habashy et al., 2017; Perin et al., 2021). In chickens, Cedraz et al. (2017) found a nucleotide polymorphism in the coding area of *HSP70*. Hyperthermia causes oxidative stress and promotes the formation of ROS, resulting in the stimulation of *HSP70* expression (Robert et al., 2017).

Acid-base balance

As the ambient temperature rises, birds must release heat through panting as thermoregulation is difficult (Wasti et al., 2020). Panting is a behavior in which chickens open their beaks to increase their rate of breathing such that the respiratory tract will provide the evaporative cooling effect (Park and Kim, 2016). When panting occurs, CO_2 is excreted faster than it is produced by the cells, causing the blood's regular bicarbonate buffer system to be disrupted. Carbonic acids (H_2CO_3) and hydrogen ions (H^+) concentrations decrease when CO_2 levels are reduced (Hamm et al., 2015). On the other hand, the concentration of H_2CO_3 is raised leading to an increase in the blood pH, and the blood becomes alkaline. To cope with this situation and maintain a normal blood pH, chickens will begin to expel more H_2CO_3 and retain H^+ from the kidneys (Saeed et al., 2019). The increased H^+ disrupts the acid-base balance, resulting in respiratory alkalosis and metabolic acidosis, as well as, a reduction in poultry production (Zaboli et al., 2017).

Suppressed immune-competence

Chickens pant to expel heat and reduce body temperature, but they frequently experience instabilities in their overall energy balance because of insufficient feed consumption under heat stress (Hirakawa et al., 2020). In broilers, the weights of the main organs such as the liver and pectoral muscle do not improve as expected under the heat stress situation, in addition to impairment of broiler growth performance (Piestun et al., 2017; Hirakawa et al., 2020; Tang et al., 2022). Decreased humoral immunity is one of the most common forms of immunodeficiency in heat-stressed chickens, which might increase the risks of secondary infections that restrict vaccination efficacy (Lara and Rostagno, 2013).

Bursa of Fabricius is a fundamental immunological tissue unique to birds that are connected to the cloaca and it is necessary for B cell development and antibody competence diversification brought on by gene conversion and V(D)J recombination that causes B cell exportation to the lower limbs (Ratcliffe et al., 2014; Monson et al., 2018). Continuing heat stress accelerates the rate of the bursa of Fabricius atrophy and adds to the atrophy of the other immune components in hens intensively selected for muscle yield and growth (Jahanian and Rasouli, 2015; Campbell et al., 2019). Reduced intestinal integrity, which increases exposure to pathogens and antigenic compounds such as lipopolysaccharides (LPS), or systemic stress responses such as circulatory cytokines and acute-phase proteins, could affect the bursa of Fabricius during heat stress (Nochi et al., 2018). These factors influence the formation, survival, and motility of the bursa of Fabricius (Calefi et al., 2016).

The hypothalamic-pituitary-adrenal and sympathetic adrenal medullar axis are the main mechanisms by which the body's immune response can be altered (Herman et al., 2016; Goel et al., 2021). Neuroendocrine products of both the hypothalamic-pituitary-adrenal and sympathetic adrenal medulla axes including cortisol and catecholamines have been shown to have receptors on monocytes, lymphocytes, and granulocytes, which might affect proliferation, cytokine production, cellular trafficking, cytolytic activity, and antibody production (Bohler et al., 2021). Heat stress affects the microbiome's makeup and abundance in addition to causing oxidative stress in the gut epithelium, which impairs permeability and increases susceptibility to infection and inflammation (Cao et al., 2021).

It has been shown that broilers that have been exposed to heat stress had decreased concentrations of free circulating antibodies and specific IgG and IgM, along with lower levels of general and humoral reactivity (Van Goor et al., 2017). The weights of the bursa, thymus, liver, and spleen were also observed to be drastically lowered. Similarly, Cantet et al. (2021) reported reduced bursa weight and lymphocyte numbers in the medulla and the cortex regions of the bursa in broilers exposed to heat stress. Faud et al. (2016) also reported that heat stress was associated with a decrease in spleen and thymus size in laying chickens. Heat stress has also been shown in recent research to change the number of circulating cells (Santos et al., 2015). Due to lower quantities of circulatory lymphocytes and greater concentrations of heterophils, heat stress leads to a significant increase in the heterophil: lymphocyte ratio which is an indication of chronic stress (Santos et al., 2015; McGregor et al., 2016). Consequent to this, communicable and infectious poultry diseases such as Newcastle and infectious bursal disease become more prevalent in tropical environments throughout the summer

(Badruzzaman et al., 2015; Saelao et al., 2021). In another study, Hirakawa et al. (2020) reported lowered levels of antibodies in heat-stressed birds (Hirakawa et al., 2020).

Neuroendocrine changes

During heat stress, the neuroendocrine system is critical for the maintenance of homeostasis and proper physiological functioning in poultry (Jessop et al., 2016). The sympathetic nerves detect a rise in ambient temperature and send an impulse to the adrenal medulla (Kumari and Nath, 2018), which enhances catecholamine secretion in response to stress (Ruuskanen et al., 2021), resulting in elevated blood glucose levels, exhaustion of liver glycogen, loss of muscle glycogen, accelerated respiration rate, peripheral blood vessel vasodilation, and heightened neurological responsiveness (Kumari and Nath, 2018; Beckford et al., 2020). In response to stress, the hypothalamus releases a corticotrophin-releasing hormone (CRH), which induces the pituitary to release adrenocorticotrophic hormone (ACTH, Wasti et al., 2020). Corticosteroids are produced and released by the adrenal glands in response to ACTH (Souza et al., 2016). Corticosteroids increase plasma glucose levels by stimulating gluconeogenesis (Kumari and Nath, 2018). The thyroid thyroxine and hormones triiodothyronine are also crucial in maintaining a consistent metabolic rate by playing a pivotal role in digestion, and heart and muscle function (Cioff et al., 2013; Wasti et al., 2020).

HEAT STRESS MITIGATION STRATEGIES

The strategies to combat heat stress are categorized broadly as genetic approach, managerial practices, and nutritional manipulation.

A genetic approach to mitigate heat stress

Current developments in genetics and biotechnology may pave the way for the investigation of changes to the chicken gene to assist reduce heat stress (Cedraz et al., 2017). The increased metabolic rate of improved broiler lines makes them more sensitive to heat stress. Therefore, improving the production qualities of these breeds in hot and arid environments may require creating poultry lines that incorporate some of the genes that reduce heat stress (Wasti et al., 2020).

A single dominant autosomal gene called "naked neck" enables chicken necks to have less plumage, which helps the neck to dissipate heat (Tóth et al., 2021). In heterozygous necked neck (*Na*/*na*) and homozygous necked neck (*Na*/*Na*), the naked neck gene reduces the neck plumage cover by 20% and 40%, respectively, in comparison to normal siblings (*na*/*na*, Rajkumar et al., 2010). In broilers, the *Na* gene is associated with an increase in body weight and breast muscle, a decrease in abdominal fat, and an increase in body temperature (Wang et al., 2018). It was found that the heterophil to lymphocyte (H/L) ratio and total plasma cholesterol levels of the naked-necked chickens were much lower throughout the hot season compared to normal chickens (Wasti et al., 2020). Under high temperatures, laying hens with the bare neck gene also demonstrated improvements in egg weight, number, and quality (Azhar et al., 2019). These experiments show that it is possible to use these genes to create a breed of chicken that can withstand heat stress.

The *frizzle* (*F*) gene enables the feather's edge to curve, which decreases the feather's weight, enhances heat radiation from the body, and improves the feather's ability to act as an insulator (Nawaz et al., 2021). Relative to heterozygous carriers and regular feathered hens, laying hens with the homozygous frizzle gene had increased egg production and quality features by enhancing the extent of heat dissipation (Kumari and Nath, 2018). Except for sexual development under heat stress, there is a positive interaction between the feathering genotype (*FF*) and ambient temperature for all reproductive variables, including egg production, hatchability, and chick production (Dong et al., 2018).

In poultry, a sex-linked recessive gene called the *dwarf* gene (*dw*) causes homozygous females and males to weigh about 30% and 40% less than normal, respectively (Zerjal et al., 2013). The benefit of the *dw* gene in heat-stressed laying hens has been the subject of some debate (Wasti et al., 2020). However, Fathi et al. (2022) recommended the development and commercialization of *frizzled* and *naked-necked,* and *dwarf* genes in poultry.

Managerial practices

Housing

In the tropics, poultry houses are predominantly naturally ventilated open-sided (Alchalabi, 2013). With rising air velocity, heat loss via radiation and convection can increase significantly (Saleeva et al., 2019; Elbaz et al., 2021). Therefore, it is best to allow natural airflow from the north and south sides while also shielding birds from direct sunlight throughout the day; thus, the shed's longitudinal direction should be from east to west (Oloyo and Ojerinde, 2019). To maintain their internal temperature, poultry houses should be designed with optimal insulation (Scanes, 2015).

The roof of the poultry shed should be at a 45° angle which will be able to maximize the distance of the poultry from the heat accumulated under the roof (Oloyo and Ojerinde, 2019). Furthermore, water sprinkling can keep the roof cool at high temperatures (Saeed et al., 2019). The heat that is gained or lost from the building is significantly influenced by the size, pitch, the roof's color, reflectivity, and direction, as well as, the structure's ventilation system (Wang et al., 2018). According to Saleeva et al. (2019), the reflectivity of the roof can be increased by adding an aluminum roof or painting it with metallic zinc. Evaporative cooling technologies with cooling pads and sprinklers inside the chicken house can be used in farms with extreme outside temperatures and low relative humidity (Saeed et al., 2019). Glass wool is currently used as an insulating material in the ceiling of environmentally controlled chicken houses (Alchalabi, 2013).

Stocking density is another factor that contributes to heat stress. A study by Moreki et al. (2020) in Botswana showed that the stocking density of 10-12 birds/m^2 was ideal for open-sided poultry sheds in summer. The authors concluded that broiler chicken growth performance was negatively impacted by stock densities of more than 12 birds/m^2. In another study, Gholami et al. (2020) reared broilers at four different stocking densities (10, 15, 17, and 20 birds/m^2) under hot and dry conditions and observed that the stocking density of 10 birds/m^2 resulted in lower FCR, higher body weights, weight gains, and feed intake compared to those reared at 15, 17 and 20 birds/m^2. The higher metabolic rate of chickens during the summer increases heat generation inside the poultry house and slows heat loss during hot and humid weather giving rise to an increase in the poultry house's total temperature (Nilsson et al., 2016; Donald, 2018).

The use of corrugated iron sheets and walls which are painted white to reflect heat is encouraged in sub-tropical and tropical regions (Oloyo and Ojerinde, 2019). Furthermore, grass can be used as a roofing material which can also serve as an insulation material. Sidewalls should have roll-down reinforced curtains that can be adjusted for use in cold weather and at night (Bhadauria, 2017). A sidewall's height should be between 25 and 70 cm high to allow natural airflow during the hot period as side wall curtains will be rolled down (Oloyo and Ojerinde, 2019). The open space between the sidewall and the roof gable will be closed with a 25 mm wire mesh (Alchalabi, 2013). However, as technology progresses, the use of a closed housing system for the intensification of agricultural operations has increased significantly (Donald, 2018). Climate-controlled housing systems (also referred to as closed buildings) with exhaust fans, air conditioning, cooling pads, and cool perches are beneficial in assisting chickens in dealing with the negative consequences of heat stress (Bhadauria, 2017). Closed buildings, on the other hand, are costly to construct and maintain (Glatz and Pym, 2013).

Feeding strategies

Only feeding methods can lessen heat exhaustion if the animal generates less heat or dissipates heat from the body through radiation during tunnel ventilation, where air velocity is higher. Lower heat production can be realized by a reduced heat increment, catabolism of fewer nutrients above requirements, or more efficient nutrient digestion (Barrett et al., 2019). Broiler chickens compared to laying hens appear to need more attention to feeding schedules. Many of the difficulties related to heat exhaustion in broilers can be alleviated simply by feeding at the right time (Syafwan et al., 2011; Kennedy et al., 2022). To address heat stress, coarser meals, diurnal feeding patterns, self-selection procedures, and wet feeding are all viable options. The feed should be well processed into mash, crumb, or pellets, and supplementary feeders should be available on hot days to increase appetite (Rahman and Hidayat, 2020).

The use of low-beam lights may also minimize activity, thus lessening the heat burden on the birds (Bhadauria et al., 2016). Lighting schedules are utilized for broiler chickens to control feed intake (Wu et al., 2022) and provide access to feed and water, especially during the cooler parts of the day (De Oliveira and Lara, 2016). The length of the photoperiod can be altered as an alternate strategy to enhance the well-being, immune response (Riber, 2015), and ultimately the performance of birds that are under heat stress (Parvin et al., 2014). Using low-intensity lighting when the temperature is high (for example 180 Lux) can prevent broilers from moving around and agitating, which can lead to them to be heavier (Mousa-Balabel et al., 2021; Wu et al., 2022). Mousa-Babel et al. (2021) compared the performance of broiler chickens reared at low-beam blue light intensity (5 Lux), medium blue light (20 Lux), and high blue light intensity (320 Lux) and found that broiler chickens raised under low-beam blue light intensity had significantly higher body weight, body weight gain, antibody titers against the Newcastle disease virus, and foot pad dermatitis compared to their counterparts in high blue light intensity. In addition, chickens on low-beam blue light intensity had lower activity levels and heterophil/lymphocyte ratios, and FCR.

Feeding time is a significant component in reducing the effects of heat stress on feed intake and utilization (Farghly et al., 2018, Kennedy et al., 2022). Therefore, during the time of low temperatures, for example, in the early hours of the day and late evening, a significant portion of the feed should be supplied to the poultry, with the remaining amount available *ad libitum*. According to Daghir (2009), chickens that are feed-starved produce less heat than those that are fed; hence removing feed on hot days has some ameliorating benefits on performance. Farghly et al. (2018) reported that feed withdrawal involves alterations in intestinal morphology and depletion of intestinal mucosa due to fasting which may damage the intestinal cells.

A study by Zaboli et al. (2019) reported that a rise in the room temperature from 21.1°C to 32.2°C leads to a decline in feed intake of around 9.5% /bird/day from 1 to 6 weeks of age. In another study, He et al. (2019) reported that a rise in environmental temperature from 32.2°C to 37.8°C results in a 9.9% decrease in feed intake per bird/day. It is, however, not recommended to allow birds to go for a long time without a feed as this will have an impact on growth and may increase skin scratches at feeding time resulting in downgraded carcasses (Suganya et al., 2015; Vandana et al., 2021).

The form in which the feed is presented to the birds affects the consumption of poultry exposed to high environmental temperatures. In warmer conditions, poultry, particularly broilers, prefer eating larger particles (Ranjan et al., 2019; Massuquetto et al., 2020). According to Smalling et al. (2019), when broilers are fed pelleted feed, the energy required for feeding is reduced by 67%, allowing that energy to be channeled toward more productive applications. Khalil et al. (2021) reported that feeding pellets to laying hens during high ambient temperatures contributes to higher feed efficiency, egg production, and water intake compared to mash feeding. The physical feature of the pellets enables the birds to ingest feed with less wasted energy, therefore the pellets' quality and durability are extremely important. The FCR can be altered by 0.01 points if the pelleted feed contains 10% fine particles (Ahmed and Abbas, 2013).

The quantity of coarse particles in droppings is adversely correlated to the water in the droppings. The higher retention duration of coarse particles inside the gastrointestinal tract (GIT) is responsible for this association (Smalling et al., 2019; Abdel-Moneim et al., 2021). In comparison to fine diets, coarse diets can enable more retention of water from GIT (Smalling et al., 2019) and this may aid to release the heat burden. More heat loss by evaporative cooling, on the other hand, emphasizes the importance of increased water intake in heat-stressed birds (Lara and Rostagno, 2013). Therefore, the provision of high-physical-quality feed will minimize energy expended and heat generated during feeding (Mir et al., 2018).

Choice feeding encourages chickens to select a meal and reduce the heat burden associated with the metabolic process in hot environments. It could also help the chickens to better match their nutrient intake to their needs. When given a choice of diet, chickens are reported to select a variety of food items to meet their nutrient needs (Sinha et al., 2018). It has been observed that chickens that are choice fed choose feed ingredients with lower heat increments to minimize excess heat during the harshest times of the day, thus enhancing their heat tolerance (Diarra et al., 2014). Suganya et al. (2015) reported that choice-fed broilers ingest less protein and much more energy at high temperatures than those feeding on a complete diet, presumably to limit body heat output from protein-high heat increment. Similarly, De Almeida et al. (2012) observed that when Japanese quails were kept at temperatures ranging from 20 to 35^{o}C, they chose to eat more calories and less protein when given a choice diet vs. a single complete diet.

Diet management changes, including rehydrating feed, have long been known to improve poultry performance (Rahman and Hidayat, 2020). Relative to broiler chickens consuming dry feed, this technique enhances weight gain, feed intake, FCR, and the weight of the gut in broilers at ordinary temperatures (Kaldhusdal et al., 2016; Rostagno., 2020). In another study, it was reported that even though the weight of the digesta across the entire digestive system of chickens was lower while the feed intake was higher, wet feeding has been associated with a quicker rate of passage through the gut (Calefi et al., 2016).

A previous study by Calefi et al. (2014) reported advancements in digestive efficiency which were assumed to be due to a higher empty weight, a longer gut length, and greater gut wall thickness in some areas of the digestive tract with wet feeding. Farghly et al. (2018) and Kadykalo et al. (2018) observed that wet feeding increased the ingesta's fluidity, possibly indicating a faster digesta transit rate. Additionally, a thicker intestinal wall could help with digestion. Farghly et al. (2018), compared rehydrating to dry feed and found that rehydrating feed lowers digesta fluidity to a similar degree and promotes pre-digestion and absorption, presumably due to faster digestion enzyme penetration into feed particles. This may result in increased nutrient digestibility. In addition, external enzyme inclusion in the wet feed may have an additional potential influence on absorption, since they may promote substrate accessibility for enzymes, hence, increasing nutrient absorption (Holtmann et al., 2017). Saleh et al. (2021) reported that wet feeding may improve performance because it increases dry matter (DM) intake at high temperatures. Egg weight and egg production could be boosted in this manner under high temperatures. Waiz et al. (2016) observed that compared to dry feeding, moistening laying hen’s feed at a 1:1 (feed: water) ratio in hot environments improves laying performance. High performance in hot conditions is predominantly caused by an increase in DM intake on wet feed, which enhances the intake of micronutrients (Afsharmanesh et al., 2016).

At high temperatures birds eat less, thus failing to meet their nutrient needs (Rath et al., 2015). Therefore, heat stress can be alleviated by increasing the nutrient density of the diet. During summer, especially for broiler hens, adding fat to the diet should be taken into consideration to keep their daily energy requirement in line with their needs for growth (Diarra and Tabuaciri, 2014; Teyssier et al., 2022). Due to fat's lower heat increment when compared to alternative energy sources like carbohydrates or proteins, the inclusion of fat in diets for broilers that are under heat stress improves their feed intake and performance (Rath et al., 2015; Pursey et al., 2017). However, to achieve a balanced meal and hence optimize utilization, the content of other nutrients, notably proteins, must be appropriately adjusted whenever the energy density is raised by added fat (Rahman and Hidayat, 2020). Heat-stressed chickens have a strong urge to reduce feed intake to lower their body temperature (Wasti et al., 2020). Low-digestible energy and protein-rich diets are favorable when heat stress is moderate (Lemme et al., 2019). In addition, it was reported that fat in the diet increases nutrient utilization by slowing feed passage through the GIT (Jha and Mishra, 2021).

According to a previous study, polyunsaturated fatty acid-rich fat sources, such as soybean oil, fish oil, canola oil, flaxseed oil, and walnuts must be avoided or be used in moderation, indicating that caution must be exercised when choosing a fat source to include in a diet (Seifi et al., 2020). According to Surai et al. (2019), such sources are deficient in antioxidants and are vulnerable to oxidative rancidity, which results in the degradation of vitamins A and E and the taste of poultry meat being altered. Moreover, soybean oil has a high concentration of polyunsaturated fatty acids that frequently result in the creation of excess visceral and breast intramuscular fat, which lowers the quality of the carcass (Abdel-Moneim et al., 2021). However, if the energy density of the diet is to be increased, the levels of all nutrients must be adjusted to maintain optimal intake (Pawar et al., 2016).

It was previously noted, poultry limit feed consumption in hot weather which results in nutrient deficiencies (Teyssier et al., 2022). Due to a reduction in consumption, there is a decrease in the intake of essential nutrients, such as protein, essential amino acids, minerals, and vitamins (Rath et al., 2015). In this case, it is preferable to improve and balance vital amino acids because increasing protein levels can increase heat production during protein metabolism (Teyssier et al., 2022). Bird performance is unaffected even if the diet is lacking in protein but contains a balanced amino acid content (Kumar et al., 2016). If protein levels must be increased, vegetable-derived proteins such as soy, sesame, and sunflower are excellent choices since animal-source proteins will produce more heat during metabolism (Tari et al., 2020). Vegetable proteins are rich in arginine, an essential amino acid required during heat stress. Dao et al. (2021) reported that the role of arginine aids in protein synthesis and immunity. At the macrophage level, arginine is transformed into nitric oxide (Rath et al., 2014), a mediating component in vasodilation and increased peripheral blood flow which are significant thermoregulatory responses to heat stress (Liu et al., 2019).

When feed intake is lowered due to heat stress, it was normally advised that dietary protein levels be raised to maintain a steady protein intake (Liu et al., 2019). However, studies conducted over time suggest that birds under heat stress may not always require more protein (Suganya et al., 2015). A recent study reported that feeding broilers high-protein diets at high environmental temperatures result in their growth being inhibited (Qaid and AlGaradi, 2021). It was indicated that hens' growth performance at 3 to 6 weeks of age under hot temperatures of 32^{o}C was not improved by raising protein content from 17 to 23% (Awad et al., 2019). This was primarily caused by the increased nitrogen excretion and reduced efficacy of the high-protein diet compared to the low-protein diet (Kidd et al., 2021). Previous investigations demonstrated that higher body heat generation due to increased feed intake contributed to poor performance (Diarra et al., 2014). The mentioned authors reported that birds on low-protein diets consumed more protein, possibly due to a physiological shift that allows them to use the protein more efficiently when it is scarce. On the other hand, prolonged heat-stress exposure affects the reaction of poultry to dietary protein levels, therefore lowering crude protein levels as a strategy for mitigating heat stress is not justified (Bohler et al., 2021).

In a separate study, it was found that using protein sources that provide the appropriate amounts and proportions of methionine and lysine can lower 2-4% of dietary protein without compromising weight increase or feed conversion (Attia et al., 2020). It was reported that adding 0.05% methionine to water boosted feed efficiency considerably in heat-stressed chickens (Cadirci and Koncagul, 2014). Any loss in amino acids will result in their insufficiency, making protein non-ideal irrespective of the protein amount (Kumar et al., 2016). Therefore, supplementing low-protein meals with essential amino acids has been shown to help heat-stressed chickens perform better (Lemme et al., 2019). Heat intensity and duration, breed, age of birds, the quantity of amino acid supplementation, and diet composition could all influence how heat-stressed chicken responds to low-protein diets. Under hyper thermoneutral conditions compared to thermoneutral conditions, the total sulfur amino acids (TSAA) demand would be higher (Babazadeh and Ahmadi, 2022). In addition, it takes more TSAA to attain optimal growth performance when broiler chicks are raised at high temperatures (Del Vesco et al., 2013; Zarghi et al., 2020). When adding methionine supplements, factors such as age and production parameters must be considered to mitigate the harmful effects of heat stress (de Freitas Dionizio et al., 2021). Supplementing with methionine is also useful for lowering immunological stress and can change how the immune system responds (Pacheco et al., 2018).

Feed as a source of calcium carbonate

Calcium is supplied to commercial breeders in many ways which include using grower diets that contain 0.9 to 1.0% calcium supplemented with up to 5% egg production or using classical pre-breeder diets that allow for the development of greater medullary bone reservoirs without using the diets that contain 2-2.5% calcium (Bryden et al., 2021). Heat stress causes poultry to consume less than 3.5 grams of calcium each day (Abbas et al., 2021). In addition, heat stress decreases the production of calbindin, a calcium-binding protein required for calcium absorption in the intestine (Ebeid et al., 2012). Ranjan et al. (2019) it is reported that feeding laying hens in the evening improves their laying rate and eggshell quality by increasing calcium intake. A decrease in egg production is directly linked to a reduction in calcium intake (Bryden et al., 2021).

During heat stress, reduced calcium intake and poor absorption result in lower plasma calcium levels, leading to less calcium being available for eggshell formation in laying hens. This results in lower egg output, smaller eggs, or thin-shelled eggs, and poor skeletal development, causing economic losses to producers (Allahverdi et al., 2013; Ventura and Matias da Silva, 2019). As poultry's DM intake is already low due to heat stress, adding large amounts of calcium supplements may not be viable. However, a larger particle-size calcium source including limestone or oyster shells is retained in the gizzard for a longer period and is released slowly into the duodenum for eventual absorption into circulation (Mir et al., 2018).

Electrolytes and vitamins

The main causes of poor performance in heat-stressed chickens have been identified by the alteration of the acid-base balance and lowered feed intake (Sugiharto et al., 2017). The minerals potassium (K), sodium (Na), and chlorine (Cl) are essential for maintaining the acid-base balance of bodily fluids (Popoola et al., 2019). As a result, adding minerals such as ammonium chloride (NH_4Cl), sodium bicarbonate ($NaHCO_3$), sodium chloride (NaCl), potassium chloride (KCl), and potassium sulfate (K_2SO_4) to the diet or drinking water of heat-stressed chickens will assist to mitigate the negative effects of heat stress (Diarra and Tabuaciri, 2014; Pawar et al., 2016).

At high ambient temperatures water intake increases while feed intake decreases. Chickens drink four times more at 38°C compared to 21°C (Orakpoghenor et al., 2020), indicating that water must be available all the time during this period. Increased water intake, which improves heat dissipation and cools down the body provides relief from the detrimental effects of heat exhaustion by supplementing the drinking water with Na+, K+, and Cl^- salts (Gamba et al., 2015). Bryden et al. (2021) found that heat-stressed laying hens treated with 0.5% hydrochloric acid in drinking water had significant gains in egg production and egg quality. Gamba et al. (2015) observed that excreta and litter moisture rise due to increased water intake caused by elevated Na^+ and K^+ levels.

In another study, Cherian (2015) found that supplementing drinking water with vitamins A, D, E, and B complex increased broiler performance and immune function. Additionally, supplementation of vitamin C (ascorbic acid) has been found to improve performance through improved feed consumption and nutritional intake in heat-stressed birds. Furthermore, Asensio et al. (2020) observed that supplementing broilers with ascorbic acid enhanced the weight and protein content of the carcass while lowering carcass fat content. Daghir (2009) recommended 1 g of vitamin C per liter of drinking water and 20 mg per liter of water for broilers and laying hens, respectively. A study by Wang et al. (2011) in laying hens found that vitamin C does not affect egg weight or egg production. However, Skřivan et al. (2013) reported that 50 and 100 mg/kg vitamin C supplementation significantly increased fertility and hen-day egg production of broiler breeders.

Since poultry cannot synthesize vitamin E, they must be supplemented (Attia et al., 2016). The hormone levels of catecholamine and corticosterone rise in response to stress, particularly heat stress, and lipid peroxidation in cell membranes begins (Abd El-Hack et al., 2018). Vitamin E has also been proven to safeguard macrophages, lymphocytes, and plasma cells from oxidative stress while also enhancing their viability, propagation, and functionality (Shakeri et al., 2020). Therefore, supplementing with vitamin E in the diet during times of stress improves the immunological response of poultry. According to new research, adding vitamin E at a dosage of 250 mg/kg to broiler chickens is a viable protective approach for reducing the severity of heat stress and it may result in optimal performance and enhanced meat quality (Saeed et al., 2019). For layers, however, the dosage is 125-250 mg/kg has been found to result in an improved immunological response, egg production, and feed utilization (Shakeri et al., 2020). Heat stress raises the levels of malondialdehyde in the blood and liver, whereas vitamin E inhibits the formation of malondialdehyde in the liver by preventing lipid peroxidation and cell damage (McDowell, 2012), resulting in improved chicken performance.

Supply of cool water

Water consumption and balance are linked to evaporative heat dissipation and calories dissipated every breath (Chikumba and Chimonyo, 2013; Abdel-Moneim et al., 2021). Reduced water temperature encourages water consumption, which increases evaporative cooling and heat dissipation for each breath (McCreery, 2015). Furthermore, a 20% water consumption increase can result in a 30% increase in heat loss in each breath, with a corresponding performance improvement (Abdel-Moneim et al., 2021).

Water temperature, height, and the shape of drinkers affect poultry performance during heat stress (Orakpoghenor et al., 2020). Water consumption is high in nipple drinkers that are slightly above chick eye than in lower nipple drinkers as chickens find it difficult to bend down and drink from lower nipples (Quilumba et al., 2015; Ranjan et al., 2019). Daghir (2009) recommended the use of wider and deeper drinkers during heat stress as they will permit immersion of not only the beak but the whole face and help dissipate more heat. Cool water at 10-12^{o}C is helpful to poultry, therefore, there is a need to protect water tanks and pipes from the direct sun because birds will not drink warm water (Park et al., 2015). Poultry should always have access to cool, clean water that is below 25^{o}C and has ice in it so that their body temperatures can remain steady during times of heat stress (Park et al., 2015).

Use of phytochemicals in mitigating heat stress

To reduce heat stress in poultry, various phytochemical supplements have been added to the diet.

Resveratrol

Natural bioactive polyphenols called resveratrol are mostly found in peanuts, grapes, turmeric, and berries (Saeed et al., 2017). Resveratrol supplementation (400 mg/kg of feed) has been found in previous studies to boost the antioxidant capacity in broilers under heat stress (Hu et al., 2019). In yellow-feather broilers under heat stress, resveratrol supplementation at 300 or 500 mg/kg of feed increased average daily growth, decreased rectal temperature, and decreased the levels of adrenocorticotropin hormone, malondialdehyde (MDA), corticosterone, and cholesterol (He et al., 2019). Resveratrol supplementation of 200 mg/kg of feed increased egg production in laying hens, whereas resveratrol supplementation of 400 mg/kg of feed decreased total blood cholesterol and triglycerides, decreased egg cholesterol content, increased antioxidant activity, and increased egg sensory scores (Zhang et al., 2017).

Lycopene

The carotenoid lycopene, which is mostly present in tomatoes and tomato-based products, is known to increase the synthesis of antioxidant enzymes by activating the DNA's antioxidant response element (Wasti et al., 2020). Heat-stressed broilers' total feed intake, weight gain, and FCR were all improved when lycopene (200 or 400 mg/kg of feed) was added (Sahin et al., 2016). Lycopene has been reported to increase the levels of antioxidant enzymes, such as superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) in broilers (Arain et al., 2018). Lycopene administration increased vitamin levels, improved oxidative stability, and the yolk color of eggs in laying hens (Sahin et al., 2016; Arain et al., 2018).

Epigallocatechin gallate

Green tea extract contains the polyphenol epigallocatechin gallate (EGCG), which has strong anti-inflammatory and antioxidant effects (Hu et al., 2019). When Luo et al. (2018) fed heat-stressed broiler birds at three EGCG dosages (0, 300, and 600 mg/kg), they observed a linear increase in feed intake, body weight, and levels of blood total protein, glucose, and alkaline phosphatase activity. In a related study, Xue et al. (2017) found that feeding EGCG improved body weight and antioxidant enzyme levels (catalase, GSH-Px, and SOD) in heat-stressed broiler chicks' liver and serum.

Curcumin

The main polyphenols extracted from turmeric are called curcumin, which has anti-inflammatory and antioxidant properties (Attia et al., 2017; Wasti et al., 2020). Even though curcumin is easily absorbed by animals, more recent studies have concentrated on its potential application as a compound to reduce heat stress in chickens (Wasti et al., 2020). It was reported that adding curcumin to feed at a rate of 100 mg/kg significantly increased broiler body weight during heat stress (Zhang et al., 2017). Furthermore, the inclusion of 150 mg/kg of curcumin in the diet of laying hens enhanced egg quality, laying efficiency, antioxidant enzyme activity, and immunological response to heat stress (Liu et al., 2020).

Mitigation of heat stress by use of probiotics and betaine

Betaine is widely distributed in plants, animals, microbes, and its rich food sources include fish, spinach, and wheat bran (Saeed et al., 2017). Betaine plays an essential role in sustaining the basic functions of poultry, including osmoregulation, fat distribution, methionine sparing, immunity, and the bird's ability to withstand heat stress (Attia et al., 2016; Saeed et al., 2019). The performance of chickens kept under heat stress can be greatly improved by including betaine in their diets (Hao et al., 2017; Saeed et al., 2017). In addition, betaine also functions as a methyl donor, which enables feed cost reductions by substituting methionine and choline supplements (Gholami et al., 2015). Betaine supports a variety of intestinal bacteria in their defense against osmotic changes, improving microbial fermentation activity (Abd El-Ghany and Babazadeh, 2022).

The term "probiotics" refers to feed additives that contain live beneficial microorganisms such as Bifidobacterium, Streptococci, and Lactobacillus, yeast cultures with Saccharomyces and candida strains, and fungi (*Aspergillus awamori*, *A. niger*, and *A. oryza*), which may improve poultry performance, intestinal microbiota, and immune system (Abd El-Hack, et al., 2018; El-Moneim et al., 2020). Probiotics have received a lot of attention lately for reducing the oxidative damage brought about by heat stress in chickens (Ahmad et al., 2022). It has been shown that the addition of probiotics to the diet of broilers increased their growth performance, FCR, and immunological response (Wang et al., 2018).

A symbiotic relationship occurs when prebiotics and probiotics are combined to have a positive effect on poultry raised in hot environments (Lara and Rostagno, 2013). It has been suggested that incorporating synbiotics in the diet may benefit chickens kept in areas that experience high levels of heat stress by minimizing the negative effects of heat and possibly improving their welfare and performance (Mohammed et al., 2018). Probiotic supplements have been shown to have favorable benefits on the health and productivity of chickens in tropical climates (Ahossi et al., 2016; Deraz, 2018). It was reported that the performance, intestinal morphology, and immunological response of heat-stressed chickens were all improved by consuming mannan-oligosaccharides, prebiotics, and a probiotic combination (Jahromi et al., 2015).

CONCLUSION

Heat stress has a negative impact on the health and productivity of poultry and is a significant challenge in poultry production in the tropics. Heat stress results from a combination of many factors including high ambient temperature, radiant heat, humidity, and airspeed. Due to heat stress many behavioral, neuroendocrinal, and physiological changes occur. Gene screening for higher growth rates to meet the ever-increasing food requirement has made poultry susceptible to heat stress. In birds raised for egg and meat production, an increase in the ambient temperature induces decreases in body weight gain, feed intake, eggshell weight, higher FCR, and increases in body temperature. These negative effects can be addressed by strategic managerial enhancements. Several approaches are used worldwide to combat the severe impacts of heat stress, including the selection of rearing systems with better ventilation, suitable housing conditions, and recommended correct stocking densities, all of which are crucial for enhancing performance at high temperatures.

Given that there is no single strategy for heat stress, a variety of strategies will help to reduce it. Further research on new innovative strategies which include utilizing heat tolerance genes and selecting genotypes with higher heat tolerance using genetic markers should be carried out.

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Authors' contributions

Shame Bhawa and John Cassius Moreki conceptualized this study. Shame Bhawa surveyed the literature, and drafted and revised the manuscript while John Moreki edited and suggested changes to the manuscript. James Butti Machete also surveyed and played a part in drafting the manuscript. All authors checked and approved the final version of the manuscript for publication in this journal.

Competing interests

The authors declare no existence of competing for interests.

Ethical considerations

The authors have examined ethical issues, such as plagiarism, permissions to publish, misconduct, and duplicate publishing.

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