Heat stress in broilers

Contents

Summary

Increasingly frequent heatwaves represent a major environmental challenge globally, leading to heat stress in farm animals as they struggle to cope with elevated temperatures. In broiler chickens, heat stress refers to the adverse physiological and behavioural changes that result from exposure to elevated environmental temperatures. Broiler chickens suffering from heat stress experience significant physiological challenges with profound welfare and productivity implications that can significantly compromise their quality of life.

Physiologically, heat stress disrupts the normal functioning of broiler chickens' bodies, leading to imbalances in electrolytes, impaired calcium metabolism, and alterations in thyroid hormone levels. These disruptions can result in weakened bones, skeletal deformities, muscle weakness, lethargy, and cardiac abnormalities. The physiological strain imposed by heat stress can cause immense suffering and distress to the birds, leading to compromised welfare.

Moreover, heat stress interferes with broilers' behavioural repertoire, limiting their ability to engage in natural behaviours essential for their well-being. Broilers respond to heat stress by exhibiting thermoregulatory behaviours such as panting, increased resting and seeking shade. While these behaviours are adaptive mechanisms to cope with the heat, prolonged exposure to high temperatures restricts the birds' ability to perform other vital behaviours such as foraging, socialising, and exploring. As a result, heat-stressed birds may become bored and frustrated, further compromising their welfare.

Heat stress also has important implications for productivity, as it adversely affects broilers' feeding behaviour and growth performance. In particular, high ambient temperatures reduce feed intake, leading to weight loss, slower growth rates, and poorer feed conversion efficiency. The resulting decrease in energy consumption exacerbates the birds' physical weakness and fatigue, further compromising their welfare. Additionally, heat-stressed broilers may experience increased susceptibility to diseases and reduced immune function, exacerbating welfare issues.

Addressing the welfare impacts of heat stress requires holistic management approaches that prioritise the birds' physical and psychological well-being. The only sustainable approach to mitigating the risk of heat stress is to adopt higher welfare systems that provide adequate ventilation, access to outdoor areas with shade, and reduced stocking densities to allow the birds the space and freedom to move. Additionally, selecting breeds with slower growth rates is critical in ensuring that the broilers are more robust, produce less metabolic heat, and have the physical ability to spread themselves out and perform thermoregulatory strategies such as seeking shade. The European Chicken Commitment (ECC) criteria have the potential to reduce the risk of heat stress by requiring lower stocking densities and the use of slower-growing breeds, while substantially improving the welfare of billions of chickens worldwide.

1. What is heat stress?

Heat stress in broiler chickens refers to the adverse physiological and behavioural changes that result from exposure to elevated environmental temperatures[1]. Broiler chickens are homeothermic, which means, like mammals, they can internally regulate their temperature within a small range, regardless of external temperatures[2]. Broilers have a range of thermoregulatory mechanisms, including physical adaptions and behavioural strategies (see Figure 1 and section 3.2). High environmental temperatures can also stimulate the bird's hypothalamic-pituitary-adrenal axis to release more corticosterone[3,4]. This stress hormone helps the body cope with heat stress by regulating metabolism, immune function, and inflammation[4]. However, as broilers do not have any sweat glands and are covered in insulating feathers, they are particularly susceptible to heat stress[5]. Furthermore, if the external temperature exceeds the birds' thermoneutral zone of 18-22°C (range of temperatures where they can maintain their body temperature without expending extra energy) or is prolonged, these behavioural and physiological mechanisms can become overwhelmed, resulting in heat stress. Relative humidity levels also play a significant role, as high humidity levels can inhibit the bird's ability to dissipate heat through evaporative cooling[6].

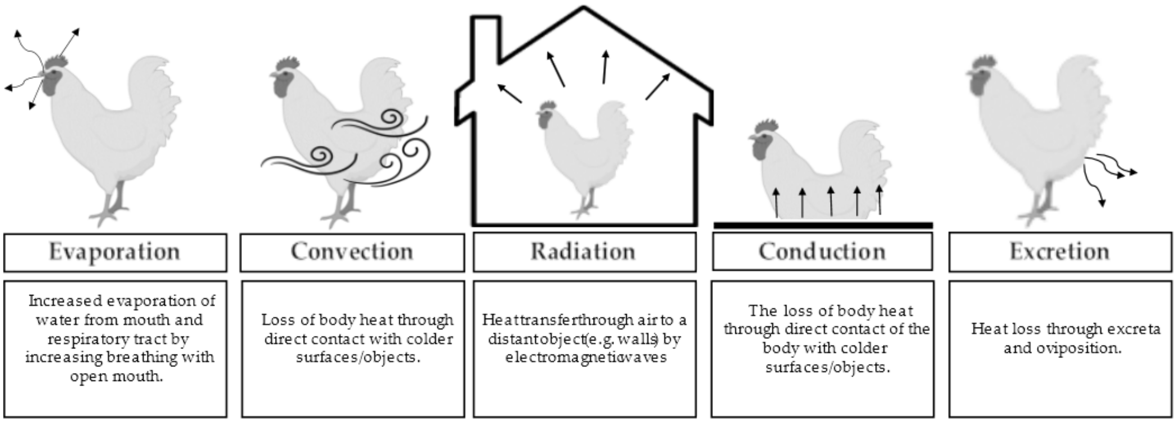

Figure 1. Broiler chickens have five main thermoregulation mechanisms for reducing body heat. (From Fernandes et al., 2023)[7].

Heat stress in poultry can be classified as acute, moderate, or chronic[3]. Acute heat stress occurs when the birds are exposed to sudden rises in temperature and humidity for short periods (i.e., 27-38°C for 1-24 hours. Moderate heat stress also occurs at temperatures between 27-38°C but for longer periods (7 days or more). Chronic heat stress refers to higher temperatures of 38-50°C for a prolonged period of 7 days or more[3].

2. What causes heat stress?

Both animal-based and environmental factors can influence the environmental temperature in a broiler system[1,2,8]. Animal-based factors include, for example, the age or metabolic rate. Environmental factors include anything from the outside temperature to the design of the poultry house. The cause of heat stress is often multifaceted, and the compounding effect of the factors involved makes it a complex issue to tackle[5].

2.1. Environmental factors

2.1.1 The impact of climate change

According to the Intergovernmental Panel on Climate Change (IPCC)[9], global warming will likely reach 1.5°C between 2030 and 2052. Furthermore, these global trends will be accompanied by more significant changes in local climates, which can adversely affect animal production[10]. Broiler production in tropical and subtropical areas has increased over the past few decades, and the increasing average temperatures in these regions have introduced significant challenges[10,11]. However, increases in global temperatures will also impact temperate countries as adverse weather patterns become more common and summer temperatures rise[7,10]. For example, during the summer of 2022, an estimated 18,500 chickens died from heat stress during transport amid a severe heatwave in the UK. Additionally, millions were reported to have died in industrial sheds, where ambient temperatures reached as high as 45°C[12]Therefore, the impact of climate change on broiler farming is widespread and significant[7].

2.1.2. Broiler housing in conventional systems

The internal temperature within a broiler house is impacted by numerous factors, including the design of the house itself and the external climate[13]. For instance, when the outside temperature is hot, the building surfaces and other mechanical equipment heat up and radiate heat within the building[14,15]. The orientation of a poultry house can also have an impact in warmer climates as the roof can become a significant contributor to heat generation when it is exposed to solar radiation[2,14]. Direct sun exposure may also be a factor for barns with open sides, especially if the birds cannot move freely between outside and inside areas, as broilers may cluster together to escape the direct sunlight, further reducing convection cooling[14].

Ventilation is critical in broiler houses, although management strategies can vary due to different ventilation methods, including natural ventilation from open-sided barns, tunnels, and cross-mechanical ventilation, where fans facilitate airflow[13,16,17]. Additional features, such as evaporative cooling systems, may also be used but are not always efficient and can be costly and wasteful[1,18]. Furthermore, some systems, such as foggers, can increase relative humidity, which may introduce additional issues, such as the growth of microorganisms[14]. However, even state-of-the-art ventilation systems may be unable to cope with the heat produced within the system, especially when the outside temperature rises[16].

2.2. Animal-based factors

Even with the most well-designed broiler house, the system will still have to tackle the heat generated by the birds themselves, which can be a considerable and major challenge.

2.2.1.High stocking density

High bird densities can cause ventilation failure, as the systems cannot cope with the increasing heat produced from within the broiler house[2].Conventionally high stocking densities in broiler houses impede airflow and evaporative cooling at the bird level, further increasing the ambient temperature[19–21].

2.2.2. Selecting for fast growth

The natural heat produced by the broilers puts considerable pressure on the ventilation systems utilised in conventional systems[22]. Broilers produce considerable body heat, and the selection for fast growth has played a considerable and detrimental role in regard to heat stress[8,23]. The fast growth seen in modern broiler strains has resulted in increased metabolic rates and higher heat production[24,25]. Metabolic heat also increases linearly as the birds age and grow, which is further compounded by increasing stocking densities and degrading litter quality[27]. As a result, metabolic heat is a significant contributor to the microclimate within the poultry house[6,19,20]Therefore, heat stress is now an inherent part of rearing fast-growing broilers and causes considerable suffering and distress for the birds involved[13,27].

2.2.3. Litter quality

Conventional broiler systems typically operate an all-in, all-out system, where the birds are raised on the same litter till slaughter, resulting in an accumulation of faeces[28]. As the faeces decompose, further heat is released into the environment, which, although minimal compared with the contribution of metabolic body heat, still has a notable effect, especially in large-scale conventional broiler houses[14]. Furthermore, at high densities, the moisture content of the litter increases, promoting microbial activity that generates more heat and has significant health and behavioural impacts on the birds[21].

3. Impacts and indicators of heat stress in broilers

3.1. Health and Production

Heat stress has a range of health implications for broilers, many of which also negatively impact production. Furthermore, many of the health concerns associated with heat stress also increase the risk of mortality. In fact, a meta-analysis of six studies found that heat stress significantly increased mortality rates in broilers compared with control groups[4]. The following sections discuss some of the key health concerns and physiological complications caused by or exacerbated by heat stress, which can result in considerably impaired welfare or even mortality.

3.1.1. Immunosuppression

Numerous studies have demonstrated the immunosuppressive effects of heat stress on broilers[29–32]. Heat stress compromises the effectiveness of specific immune cells, such as intraepithelial lymphocytes and immunoglobulin A-producing cells, thereby reducing their effectiveness[3,33]. Additionally, it diminishes the antibiotic response and phagocytic activity of macrophages while inducing harmful oxidative changes in cell membranes[29,34,35]. Consequently, the broilers' immune system faces increased pressure, promoting the growth and colonisation of harmful bacteria in the gut, leading to dysbiosis[36]. This dysbiosis triggers morphological alterations in the intestinal tract, negatively impacting gut health and immune function[3]. These effects alter broilers' immune responses to pathogens by modifying pathogen recognition receptors and increasing the production of inflammatory molecules[1,37]. Overall, heat stress significantly compromises broilers' immune systems, rendering them vulnerable to infections and compromising their overall health and welfare.

3.1.2. Intestinal health

The intestine plays a crucial role in nutrient digestion and absorption in broilers. Heat stress significantly disrupts the microbial composition and function of the intestinal microbiota, impairing nutrient breakdown and absorption[1,3]. Moreover, it reduces feed intake, increases water intake, accelerates intestinal motility, and diminishes the production of digestive enzymes[2,3]. These changes lead to oxidative stress, inflammation, and dysbiosis, characterised by a transition from beneficial to pathogenic bacteria, compromising digestibility and nutrient uptake[1,3,36].

Furthermore, heat stress induces morphological changes in the intestine and alters the expression of key genes, predisposing broilers to conditions such as leaky gut syndrome (see Figure 2)[1,38]. This syndrome facilitates the translocation of pathogenic bacteria, including *Coliforms* and *Clostridium*, into the bloodstream, potentially resulting in health complications such as septicaemia[3,38]. Moreover, the influx of pathogens triggers an inflammatory response characterised by the activation of pro-inflammatory cytokines, which, when excessive or prolonged, exacerbate the development of various diseases, negatively impacting broiler health[39].

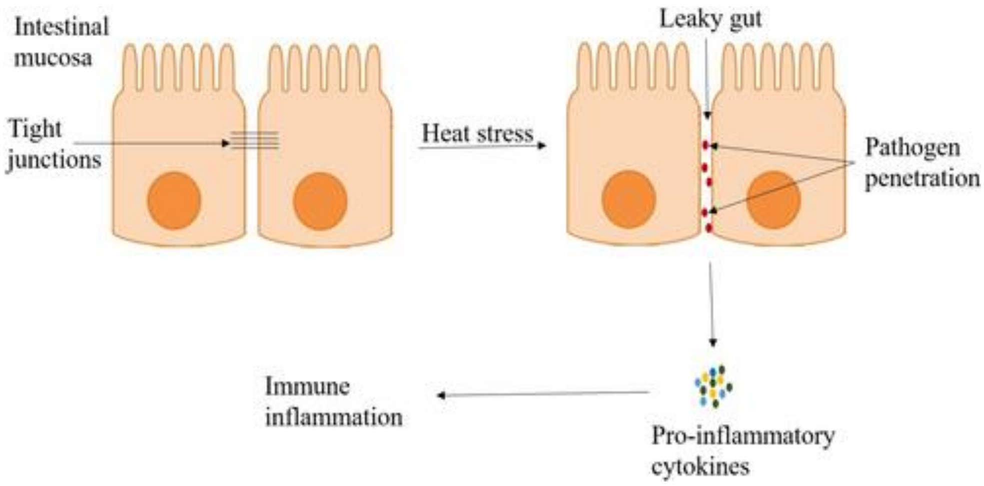

Figure 2. Effect of heat stress on intestinal health and immune system (From Goel, 2021)[1].

3.1.3. Respiratory alkalosis and metabolic acidosis

Another negative health consequence of heat stress in broilers is respiratory alkalosis[15]. In response to heat stress, broilers typically pant and breathe more rapidly to dissipate their body heat through evaporative cooling[13]. The heightened respiration rate leads to a higher exhalation of carbon dioxide (CO_2), decreasing the partial pressure of CO_2 in the blood[40]. When these effects are prolonged, the blood becomes more alkaline. The resulting condition, respiratory alkalosis, can lead to electrolyte imbalances, such as hypokalaemia (low potassium levels) or hypocalcaemia (low calcium levels), negatively impacting enzyme activity, protein structure and cell function[5,40]. It can also contribute to reduced feed intake, impaired growth, and greater susceptibility of broilers to other stressors and diseases[3,5,40]. Furthermore, it also triggers the kidneys to excrete bicarbonate ions (HCO_3^-) and retain more hydrogen ions (H^+) to restore the acid-base balance[5]. However, the elevated hydrogen ions can then lead to metabolic acidosis, an altered acid-base balance[41].

In the short term, metabolic acidosis can restore the acid-base balance, but it can have negative health consequences for broilers when prolonged. For instance, acidosis can impair the immune system in broilers and negatively affect calcium metabolism and bone health, resulting in weakened bones and skeletal deformities[3]. The disruption of electrolyte balance can cause issues such as muscle weakness, lethargy, and cardiac abnormalities[40,42,43].

3.1.4. Impacts on thyroid glands

Thyroid hormones play a key role in broiler growth and thermoregulation. Continuously high temperatures cause marked reductions in the activity of the thyrotrophic axis, which results in a decrease in plasma tri-iodothyronine (T3) concentration[41]. T3 plays a critical role in metabolic processes, and the resulting metabolic imbalance can lead to a reduced metabolic rate, impaired growth and development, including skeletal growth and maturation, as well as negatively impacting the birds' thermoregulatory capacities and immune responses[3,41,44].

3.1.5. Impacts on feed intake and growth rate

Modern broiler chickens have been genetically selected to grow quickly, and to do so, they need to maintain high feed intake to support their rapid growth[4]. However, when subjected to heat stress, broilers spend less time feeding than birds kept in optimal temperatures to reduce heat production by reducing feed metabolism[3,45]. For example, in one study, where two breeds of fast-growing broilers (Cobb 500 and Ross 308) were kept at the high ambient temperature of 34°C for 6hr a day from day 22 to 35, the birds responded by reducing their feed intake by around 8-9%[30]. Other studies have also reported significantly lower feed intakes in heat-stressed birds (e.g., -12% in [46], -14.90% in [47], and -16.4% in [36]). Heat stress is thought to stimulate appetite-related hormones such as Cholecystokinin, which triggers anorexic tendencies in the broilers[48].

When prolonged, feed reduction can have detrimental effects on both welfare and productivity, as the birds soon become depressed and lethargic, have poorer body weight gain and poor feed conversion ratios due to the reduced energy consumption[3]. For instance, in one study, heat-stressed birds had 17% lower body weight gain than control birds, and the feed conversion ratio increased by around 9-10%[30]. Similarly, Sohail et al.[36]reported a 32.6% reduction in body weight and a 25.6% increase in the feed conversion ratio at 42-day-old broilers.

3.1.6. Meat quality

From a production perspective, the impact of heat stress on meat quality is important and substantial. Chronic heat stress in broilers can negatively impact meat quality in broilers through various physiological and biochemical pathways, which in turn affects consumer acceptability and the processing quality of the meat[49].

pH is widely accepted as a significant factor affecting meat quality[50]. Heat stress can lead to a rapid drop in broilers' muscle pH during and after slaughter due to the conversion of glycogen to lactic acid[49]. This rapid drop in pH, which is exacerbated by high muscle temperatures, can result in the denaturation of sarcoplasmic proteins[49]. This can reduce meat quality by lowering the water-holding capacity of the muscle[51]. Lower water-holding capacity in meat makes it more prone to moisture loss during processing, storage and cooking, which can negatively impact consumer acceptability[52].

The increased concentration of corticosteroids circulating in heat-stressed broilers also impacts meat quality. In particular, the high levels of circulating corticosterone increase fat accumulation in abdominal, cervical, and thigh adipose tissues[40,53], whilst stimulating the proteins in skeletal muscle to degrade and break down[54]. Furthermore, as heat-stressed birds have reduced basal metabolic and physical activities, the additional energy is also stored as abdominal and subcutaneous fats[49].

Corticosteroid hormones can also accelerate the production of reactive oxygen species (ROS)[49]. These are highly reactive molecules that are naturally produced during normal metabolism. However, when broilers are heat stressed, ROS production increases, resulting in conditions such as pale, soft, and exudative meat, which is undesirable from a meat quality perspective[49]. In particular, ROS can affect the protein structure of the meat, leading to increased drip loss during storage and cooking, reduced marinade uptake, lower protein solubility, higher shear force values, and lower cooking yields[55,56]. These changes result in meat that is more susceptible to drying out, with poorer texture, tenderness, and flavour, reducing consumer acceptability.

3.2. Behaviour

In general, broilers all perform the same reactions to heat stress, although there are individual variations regarding the intensity and duration of their responses[27]. Broilers kept at higher temperatures will spend more time resting, drinking and panting than at optimal temperatures[8,45]. Furthermore, they keep their wings drooped and lifted from the body slightly or stretched out to maximise heat loss, and they will ruffle their feathers to promote peripheral vasodilation[3,8,57]. Unfortunately, broilers are badly equipped for thermoregulation, as not only do their insulating feathers make heat dissipation more challenging, but a high basal metabolic rate (a result of the selection for fast growth) increase their vulnerability to heat stress[3,58]. Therefore, panting is a vital thermoregulatory behaviour for broilers[3].

Although these thermoregulatory behaviours are a natural and useful response to increased temperatures, when their performance is prolonged due to sustained high temperatures, they can negatively affect the broiler's overall behavioural repertoire[8,57]. In particular, as heat-stressed birds need to rest more, they cannot engage in other natural behaviours, including foraging[57]. Foraging is important for feed consumption, but its performance also helps mitigate boredom and frustration, as it is a highly motivated and natural behaviour for chickens[59]. Broilers, especially as they approach slaughter weight, are already limited in their mobility due to their size and fast growth[60], so the increased need to rest when heat-stressed further restricts their already limited exercise capacity, which can have both physical and mental impacts[23].

Heat-stressed broilers consume less feed than normal, leading to weight loss and slower growth when prolonged[30] . Although the birds are not thought to be hungry due to the appetite-suppressive processes involved in thermoregulation[48], consuming insufficient calories may make them feel weak and fatigued, exacerbating their already limited drive to exercise and engage in natural behaviours[3,41]. Furthermore, the reduction in activity levels means that heat-stressed broilers are also less likely to engage in behaviours that could elicit positive emotions, such as socialisation, play, and exploration, further impacting their welfare[60].

4. How can heat stress in broilers be mitigated or, better still, prevented?

Because of the considerable implications of heat stress upon production, including significant economic, welfare and productivity impacts, there has been much focus on mitigating heat stress in broilers[1,5,31]. Strategies for mitigating the effects of heat stress fall under three main categories: 1) breeding more heat-tolerant birds, 2) altering the birds' environment or system and 3) feeding strategies, including supplementing their diet with substances known to have positive effects.[31]. However, these strategies tend only to seek to address the symptoms rather than the root cause of the issue, which is often the pressures placed on the birds by conventional systems, including the selection of fast-growth strains and high stocking densities[1,5]. Dietary supplements, for example, can help the birds physically cope with heat stress in some way but do not alleviate all the physical and mental effects caused by heat stress[2,5]. Therefore, approaches that address the root cause of the issue are far more sustainable and effective in the long term. Moreover, tackling the root cause of heat stress through adopting higher-welfare approaches — such as using more resilient, slower-growing breeds — has important and widespread health and welfare benefits for the broilers [1,5,8,23,27,61].

4.1. Breeding strategies

4.1.1. Selecting heat-tolerant birds

There have been many attempts to breed heat-tolerant broilers, especially in tropical areas[7,13]. However, given the growing impact of climate change and the susceptibility of conventional broilers to heat stress, the need to examine the importance of genetics upon welfare is a pressing and widespread issue[7]. As with many of the strategies used to mitigate the effects of heat stress, genetically heat-tolerant birds do not necessarily experience better welfare, especially as the focus is often on production outcomes rather than the bird's welfare.

One breeding strategy that has been explored is to breed broilers with the Naked Neck gene (Na) to reduce neck feathers in the birds and promote improved heat dissipation (see Figure 3)[5,62]. In particular, the Na gene can reduce feather cover by 20% in heterozygous and 40% in homozygous birds[63]. As a result of the reduction in feather insulation, birds with the Na gene show reduced body temperature[64] and increased body weight[65] in high environmental temperatures, compared with those without it[7,13]. Broilers from the Na genotype are, therefore, better suited to extensive systems, as they are more tolerant of high temperatures, and they are also more morphologically adapted and resistant to diseases[7]. However, there are concerns with the genotype's effect on meat quality and egg hatchability, which can have financial implications[7].

The Frizzle gene (F) has also been explored (see Figure 4), as it reduces the intensity of feathers by producing more curled and delicate feathers[66]. The F gene reduces the insulator effect of the feathers and aids heat dissipation[67]. It also works well in combination with the Na gene, producing more reliable results in terms of productivity[62]. As a result, breeding broilers with the F gene is considered to be another viable strategy for mitigating the risk of heat stress in tropical areas[66].

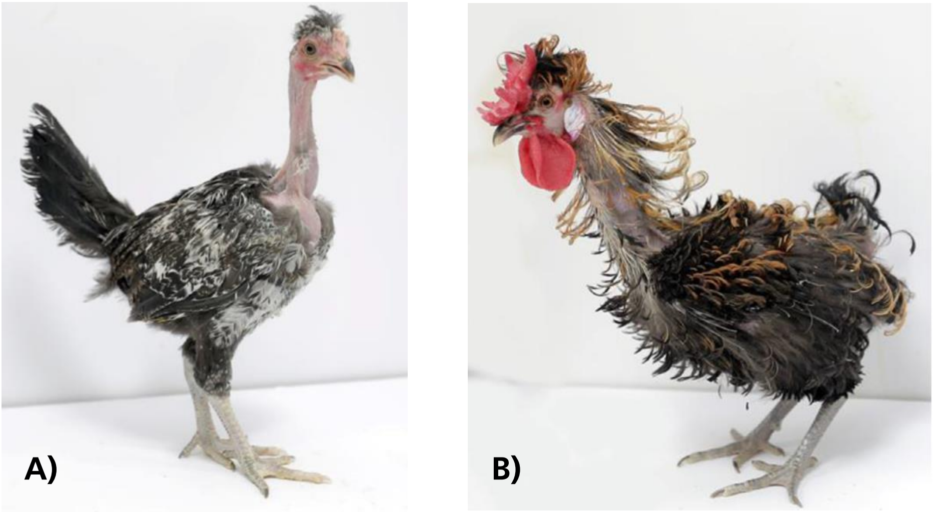

Figure 3 A) Homozygous phenotype for the Naked neck gene (NaNa); B) Homozygous phenotype for the Frizzled gene (FF) (From Fathi et al. 2022)[66]

4.1.2. Breeding for slower growth

Despite the somewhat positive effects Na and F genes have on the ability of broilers to withstand higher temperatures, the birds still experience symptoms of heat stress and specifically show poorer success on productive traits as a result[7,62,75]. A key factor in this is the continued selection for fast growth rates in broilers, as by their very nature, fast-growing broilers produce considerable body heat, which is further exacerbated by the high stocking densities they are typically kept in[1]. As a result, many studies have found that slower-growing genotypes are better able to cope with hotter temperatures and are less susceptible to the negative impacts of heat stress[62,68,69].

Lu et al. (2007), for instance, found no significant differences between the performance of slower-growing broilers reared in a constant high ambient temperature of 34°C compared with those kept at an optimum temperature of 21°C. In particular, the heat treatment had no significant effect on body weight gain, drop loss, initial pH, breast proportion, or shear force of breast meat in the slow-growing broilers[69]. Conversely, the fast-growing broilers showed considerable differences in these measures, with the heat-treated birds having poorer productivity overall. The mortality rates were also higher in the commercial fast-growing birds, compared with 0% in the local, slow-growing breeds[69]. Similarly, Cahaner and Leenstra[68] also found that broilers with fast-growing genotypes were less able to cope with heat stress, showing poorer growth, protein gain, and feed efficiency compared with slow-growing genotypes[68].

Whereas the previous studies used a static ambient temperature, Settar et al.[70] compared the results from a range of fast-growing broiler genotypes reared in Turkey during the spring (temperate) and summer (hot). They found considerable variation in heat tolerance in the birds and a significant interaction between genotype and environment. Specifically, the genotypes that showed the most weight gain under temperate conditions tended to gain the least weight in the hot summer. Their results showed clear differences between broiler genotypes, highlighting that broilers reared for fast growth in temperate climates do not adapt well to higher temperatures[70].

4.2. Housing and management

Housing features and management measures to mitigate heat stress in chickens focus on optimizing the thermal environment.

4.2.1.Housing features

Key strategies include ensuring adequate ventilation to promote air exchange and heat dissipation, and maintaining low relative humidity to enhance evaporative cooling.

The utilisation of insulated roofing helps limit solar heat gain. Additionally, in order to provide natural light, solar tubes can be used to provide natural light in locations with hotter climates that do not allow for windows[71].

Since litter can retain and generate heat, the use of elevated wire platforms or perches allows birds to distance themselves from warm surfaces, thereby decreasing heat exposure. Additionally, cooling perches, that have cool water (~10°C) flowing through the perching bars, can be use to encourage more chickens to perch during higher temperatures. More chickens perching during hotter conditions benefits the entire flock by opening up space on the floor level and improving air flow[72,73].

For mobile houses used in free-range systems, the choice of location is very important: mobile houses should be placed in the shade during summer. The orientation of the side of the entrance (preferably towards the west) and the exit will play an important role to have a lower temperature in the house[74].

4.2.2. Outdoor access

Providing broilers with outdoor space has many welfare benefits and can be a key strategy for preventing heat stress[75,76]. Outdoor ranges that are well-designed with plenty of cover, shade, and enrichment stimulate ranging behaviour in broilers and give them the confidence to remain outdoors and not cluster together[21,75]. This allows the birds to perform useful thermoregulatory behaviours, such as seeking shade, and the increased space and natural ventilation also facilitate improved airflow and reduce the likelihood of heat stress in the first place[21,76,74].

Providing sufficient shaded areas is crucial in preventing heat stress in broilers[14,25]. Broilers will naturally seek out shaded, cooler areas when the temperature is high, and so unless sufficient shade is provided, they may cluster together, which can exacerbate the issue further[14,21]. The type of shade also has important implications for broilers. For example, artificial shelters' efficiency depends on the materials used for cover and their ability to intercept solar radiation. In particular, one study found that both PVC and a material made from vegetable fibre and bitumen and then painted white were the most successful shelters for broilers as they significantly reduced both the internal and external surface temperature and provided sufficient shading[15]. Others have found that hedgerows can benefit broilers, as they provide a suitable shaded range, reduce the likelihood of heat stress, and introduce more foraging opportunities for the birds[75]. In regenerative systems such as agroforestry, trees not only provide natural shade but also enhance biodiversity, improve soil health, and create a cooler microclimate that benefits broiler welfare.

4.2.3. Reducing stocking density

Reducing stocking density allows to minimize metabolic heat accumulation from the birds. Providing outdoor access alone is not enough to reduce the likelihood of heat stress, as stocking densities also play a significant role[1,5,27]. For instance, even when given outdoor access, broilers at high indoor stocking densities display more signs of heat stress (e.g., panting and wing stretching) than broilers kept at lower densities[77]. This is because high stocking densities increase heat production in broiler houses, hinder heat dissipation, and constitute a significant stressor for broilers[26,27,77]. In addition, high stocking densities can also negatively affect movement in the system and access to the range. For instance, high stocking densities may mean that some birds cannot reach the openings, and crowding around the openings can exacerbate heat stress[26].

When combined with the stress of high ambient temperatures, high densities can have a compounding negative effect on broiler welfare[78]. For instance, broilers kept at very high stocking densities (23 and 26 birds/m^2) in continuous high ambient temperatures of 33°C for seven days show significant physical and endocrinological impacts, including decreased body weight and increased corticosterone levels[79]. Whereas, birds kept at lower stocking densities (e.g., 16 birds/m^2) appear to be better able to mitigate the oxidative stress caused by high temperatures, partly because of reduced stress levels[80]. The lower densities also mean that the birds can move more freely, improving access to feed and water[22] and positively affecting meat quality measures, such as meat shear force[81]. Therefore, providing broilers with more space to move has significant welfare benefits and is critical in mitigating the risk of heat stress[74].

4.3. Modifying feed and feeding practices

4.3.1. Dietary supplements

Various dietary supplements have been explored to mitigate the negative effects of heat stress in broilers, although they are typically only successful in reducing the adversity of the birds' symptoms[3]. Consequently, the birds may still experience distress and other symptoms deemed irrelevant from a production perspective, such as panting and increased resting[3].

Various supplements have been explored in broilers, including vitamins, minerals, probiotics, and plant extracts. For example, vitamin E has improved various factors in heat-stressed broilers, including feed intake and efficiency, fatty acid composition, and oxidative stability of thigh muscle[82,83]. Vitamins A and C and minerals such as zinc also positively affect the productivity of heat-stressed birds, including increasing live weight gain, growth, and feed efficiency[5,84,85].

Other supplements, including probiotics[36], Betaine[86], aspirin[87,88], rosemary extract[89], and Noni[90,91], have also improved broiler performance and reduced some of the most detrimental effects of heat stress[1]. In particular, probiotic products are often considered the most effective supplement[1,3] as they improve the feed's nutritional value and can positively impact gut health and digestion[3]. Consequently, studies using probiotics have seen improvements in feed intake, body weight, feed conversion rate and liveability in heat-stressed broilers[33,92,93]. However, supplements can only be considered effective when combined with proper management to address the root causes of heat stress[3].

Citrullus colocynthis (CC) seeds have also been found to positively affect heat stress symptoms[29]. Specifically, CC seeds have been shown to enhance the immune response in heat-stressed broilers by increasing their total white blood cell count and stimulating the indices of T and B lymphocytes[29]. Therefore, supplementing the diet of broilers with CC seeds can positively affect their immune system, reducing the likelihood of them suffering from disease[29]. However, CC seeds, like other dietary supplements, do not alleviate all of the aversive symptoms associated with heat stress nor address the root cause.

Supplementing broiler diets with fat is another strategy to help mitigate the effects of heat stress and has become a general practice in hot climates[5]. Fat metabolism produces less heat than protein and carbohydrates[94] while increasing the birds' energy levels[5]. Therefore, adding fat to a high-protein diet for heat-stressed broilers has been found to reduce some of the negative impacts of chronic heat stress upon production parameters (i.e., feed conversion ratio and body weight gain), although not to normal levels[95]. Despite the positive findings, chronically heat-stressed birds still present with aversive symptoms, albeit reduced[95], so it is unclear to what extent the supplemented diet improves the birds' experience in higher temperatures.

4.3.2. Feeding practices

In addition to supplementing the diet of broilers, feed withdrawal may also be practised, typically during the hottest hours of the day[5,41]. Feed restriction reduces the metabolic rate of the birds, reducing heat production by as much as 23% [96], which can minimise mortality in heat-stressed broilers[97]. Furthermore, feed restriction may also improve feed efficiency and reduce fearfulness in broilers[97]. However, as the approach is also associated with a reduced growth rate and a delayed marketing age, it is not widely performed[5,97–99]. Furthermore, as broilers are highly motivated to feed due to their fast growth, withdrawing feed may cause considerable stress and frustration in the birds, negatively impacting their welfare[100]. In fact, according to Wasti et al.[5], broilers typically rush to feeders at re-feeding times, which can cause overcrowding and mortalities.

Due to the issues with feed restriction, the application of dual feeding regimes has also been explored[5]. This is where a protein-rich diet is given during cooler hours, and a carbohydrate-rich diet is given during the warmer hours[41]. The consumption of protein results in higher metabolic heat than carbohydrates, so limiting broilers to carbohydrates during the day can reduce their body temperature[101,102] and lower mortality rates[96]. However, as with feed-restriction regimes, growth rates and feed efficiency are negatively affected[97], so it is not thought to be commonly practised[5,41].

Wet feeding is another practice known to reduce the effects of heat stress but is not commonly practised due to the associated risk of fungal growth and mycotoxicosis[5]. Wet feeding involves adding water to the feed to aid water intake and speed up the feed's passage in the gut[5]. In heat-stressed birds, it can improve feed intake and body weight, thereby mitigating some of the issues associated with heat stress[103,104]. However, as with other measures, it does not improve the physical experience of exposure to high ambient temperatures in the bird, only improving specific production outputs.

Conclusion and Recommendations

Heat stress in broiler chickens is an increasing welfare concern due to rising global temperatures, aggravated by the continued selection for fast-growing birds and higher stocking densities. Despite attempts to mitigate the symptoms through supplementing diets or breeding more heat-resistant birds, important welfare concerns remain. Heat stress mitigation requires housing systems that enable natural thermoregulatory behaviours in broilers (such as seeking cooler, shaded areas), through lower stocking densities, smaller flock sizes, outdoor access, and the use of slower-growing breeds with better mobility and slower metabolism. Higher-welfare systems such as European Chicken Commitment compliant indoor systems, free-range, organic or regenerative and agroforestry systems offer the most effective long-term solution to tackle heat stress in broilers.

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