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Heat stress management in poultry farms: A comprehensive overview

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A R T I C L E I N F O

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A B S T R A C T

Heat stress causes significant economic losses in poultry production, especially in tropical and arid regions of the world. Several studies have investigated the effects of heat stress on the welfare and productivity of poultry. The harmful impacts of heat stress on different poultry types include decreased growth rates, appetites, feed utilization and laying and impaired meat and egg qualities. Recent studies have focused on the deleterious influences of heat stress on bird behaviour, welfare and reproduction. The primary strategies for mitigating heat stress in poultry farms have included feed supplements and management, but the results have not been consistent. This review article discusses the physiological effects of heat stress on poultry health and production and various management and nutritional approaches to cope with it.

1. Introduction

Animals are divided into two groups: cold-blooded (heterothermic) and warm-blooded (homeothermic; Nagy, 2004). Birds are homeothermic, as they have the ability to maintain their body temperature throughout the year (Pickering, 2000; Donald and William, 2002); however, the thermoregulatory mechanisms are efficient only in thermoneutral zones, i.e., 27.5–37.7 °C (Van Kampen et al., 1979; Scanes, 2015). General features of thermoregulation in Aves are similar to those of other animals; however, birds also use plumage, fat insulation and salt glands (Abbas et al., 2012; Scanes, 2015). In addition, birds, as endotherms, can regulate body temperature using heat generated in their bodies. Heat is produced in the body of birds as a result of metabolism (glycolysis, the Krebs cycle, the pentose phosphate shunt pathway) and muscular activity (Stewart et al., 2010; Cooke, 2011; Little and Seebacher, 2013; Rowland et al., 2015). The concentrations of enzymes, vitamins, and hormones; physical activities; oxygen consumption; ambient temperature; and circadian rhythms affect the amount of heat production in the bodies of chickens (Scanes, 2015; Alagawany et al., 2017; El Kholy et al., 2018). To maintain body temperature and avoid overheating, excess heat is dissipated to the surrounding environment through cellular conduction and vascular convection (Donald and William, 2002; Scanes, 2015).

2. Heat balance

Poultry farmers should be conscious and vigilant about maintaining environmental temperatures according to the requirements of the birds, especially during the summer (Scanes, 2015). The internal body temperature of birds is more variable than that of mammals, and birds have no absolute body temperature. The adult chicken body temperature varies between 40.5 °C (Donald and William, 2002), whereas the body temperature of a newly hatched chick is approximately 103.5 °F (39.7 °C), and it increases daily until it reaches a stable level at approximately 3 weeks (Dawson and Whittow, 2000). For maximum production performance in poultry, the bird body temperature must remain at approximately 106 °F (Scanes, 2015).

Variations within and beyond this temperature range may be due to certain physiological conditions, such as sex (male birds have a higher body temperature than females because of an increased metabolic rate and increased muscular activity), physiological activity (increased mobility increases the body temperature), breed (smaller breeds have

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higher body temperatures than larger breeds), age, body weight, moulting period (moulting birds have a higher body temperature than fully feathered birds), broodiness (broody hens have an increased body temperature), feeding status (body temperature increases during digestion of feed) and external environment (more light increases the body temperature) (Holik, 2010; Farag and Alagawany, 2018).

In chickens, the thermoneutral zone depends on body weight; amount of plumage; amount, shape and distribution of feathers on the body; acclimatization; and dehydration status (Dawson and Whittow, 2000; Donald and William, 2002). When the equilibrium between body heat production and heat loss is disturbed, heat loss is decreased, and heat production is increased within the body of the bird, resulting in the onset of heat stress (Donald and William, 2002). The core body temperature increases when the ambient temperature increases or decreases above or below the thermoneutral zone (Scanes, 2015). When heat production by birds is greater than heat lost, the core body temperature rises (Etches et al., 2008). When the core body temperature reaches a critical point (116.8 °F or 47 °C), which is called the upper lethal temperature, birds can die from heat prostration (Scanes, 2015). On the other hand, when the temperature drops below 16 °C, heat production inside the body initially increases by physical means (shivering, huddling, fat/plumage insulation), then the thyroid gland is activated, and energy production increases until the carbohydrates (CH_2O) and fats in the body become severely depleted (Donald and William, 2002; Sturkie, 1976). Body temperature decreases when the body temperature is below the normal range (Mount, 1979), which also causes mortality within the flock (Donald and William, 2002). At relatively low temperatures, heat is transferred from the body through conduction, convection and radiation (Yahav et al., 2005) in the following ways.

2.1. Conduction

Conduction is the loss of heat by direct body contact with cooler surrounding surfaces, such as the floor, litter, slats, sidewalls and cage wires, inside the poultry house (Holik, 2010). The contact area for conduction is always small; therefore, only minute heat loss occurs through conduction. Heat travels from one molecule to another, and the rate of transfer via conduction depends upon the thickness of the superimposed tissues (Donald and William, 2002).

2.2. Convection

Temperature loss by convection occurs when heat from the comb, wattles, face, legs, toes, neck, body and wings is lost to the surrounding air as air circulates inside the poultry house (Cengel, 2002; Yahav et al., 2005). When the temperature of the surrounding air is higher than the temperature of the body, heat loss through convection is substantially reduced (Donald and William, 2002), and at higher temperatures, heat loss may be not occur at all (Donald and William, 2002; Scanes, 2015).

2.3. Radiation

Radiation involves heat loss from the body of bird to the environment through variations in body temperature and environmental conditions (Scanes, 2015; Donald and William, 2002). When the temperature of a bird's body surface is greater than that of the surrounding environment, heat is transferred from the bird's body surface to the environment through electromagnetic radiation (Scanes, 2015). Higher the temperature difference more will be the heat lost from the surface of the body (Donald and William, 2002). Heat loss through radiation accounts for only approximately 5% of the total heat loss (Blair and Walsberg, 2000).

2.4. Evaporative heat loss/gular fluttering/latent heat loss

In mammals sweat glands responsible for sweating resulting in a greater heat loss (Scanes, 2015). However, chickens lack sweat glands; therefore, most of the heat loss occurs through the respiratory route (Donald and William, 2002) through a process of evaporative cooling by the vaporization of moisture from the damp lining of the respiratory tract (lungs and air sacs) (Gupta, 2011). Evaporative cooling causes major heat loss from the deep lining of the respiratory tract of birds when the ambient temperature is high (Etches et al., 2008). Gular fluttering produces heat loss by forming vapour in the respiratory tract (Scanes, 2015). The vapours exit through the mouth of the bird and evaporate along with excess heat, lowering the body temperature of chickens (Scanes, 2015). Gular fluttering is the major method of heat loss at high temperatures (Ahmad and Sarwar, 2006; Abbas et al., 2008). Birds lose 540 kcal of energy for every 1 ml of water evaporation, and this energy loss may cause a significant decline in production (Holik, 2010). However, increased levels of humidity in the atmosphere decrease the efficiency of latent heat loss (Donald and William, 2002), increasing the internal body temperature (Speakman, 2004).

2.5. Faecal heat loss and heat loss through egg production

Some body heat is also lost through faecal excretion and egg expulsion (Donald and William, 2002; Scanes, 2015). Heat lost from the body must be equal to the heat produced; the heat balance is expressed as follows: $Hm = conv + K + R + S$. If the amount of heat produced by a bird is greater than the amount of heat lost, the bird's body temperature will increased (Dawson and Whittow, 2000; Donald and William, 2002).

3. Heat stress

It is well established that an increase in the energy cost of maintenance results in heat stress in poultry flocks (Scanes, 2015; Abbas et al., 2017; Abdelnour et al., 2018). Heat stress adversely affects the productive performance, reproductive performance, economic traits and welfare of poultry (Daghir, 2008; Oguntunji and Alabi 2010; Yousaf et al., 2019). A 10–20 times increase in the respiration rate of birds causes increased CO_2 loss through the lungs. This loss results in an increase in the blood pH and ultimately disrupts the acid-base balance (Abbas et al., 2012; Toyomizu et al., 2005) that deteriorate the health as well as performance of birds. Heat stress can be chronic or acute. Sudden and short periods of extremely high ambient temperatures and humidity can result in acute heat stress (Kettlewell et al., 1993). An extended period of elevated ambient temperatures along with increased humidity results in chronic heat stress (Scanes, 2015).

3.1. Effect of heat stress on the performance of birds

The normal body temperature of a chicken is approximately 41 °C (106 °F); if the body temperature rises more than 4 °C, the bird will die (Scanes, 2015). Summer weather and high environmental temperatures are among the factors responsible for heat stress in poultry flocks (Scanes, 2015). Birds are 'heat stressed' if they have difficulty achieving a balance between body heat production and body heat loss (Abbas et al., 2012). Heat stress can occur at all ages and in all types of poultry (Donald and William, 2002). Birds feel comfortable at 75 °F (Donald and William, 2002) and function normally up to 80 °F . Above 80 °F (up to 85 °F), feed consumption drops, while water intake increases (Donald and William, 2002). Feed conversion ratios (FCRs) and weight gain decrease in broiler birds, and egg production decreases in layer and breeder flocks (Donald and William, 2002). During the summer season, chickens should be housed and managed to provide a comfortable environment (thermoneutral zone) so that the birds can adequately dissipate body heat to the external environment and maintain a thermal

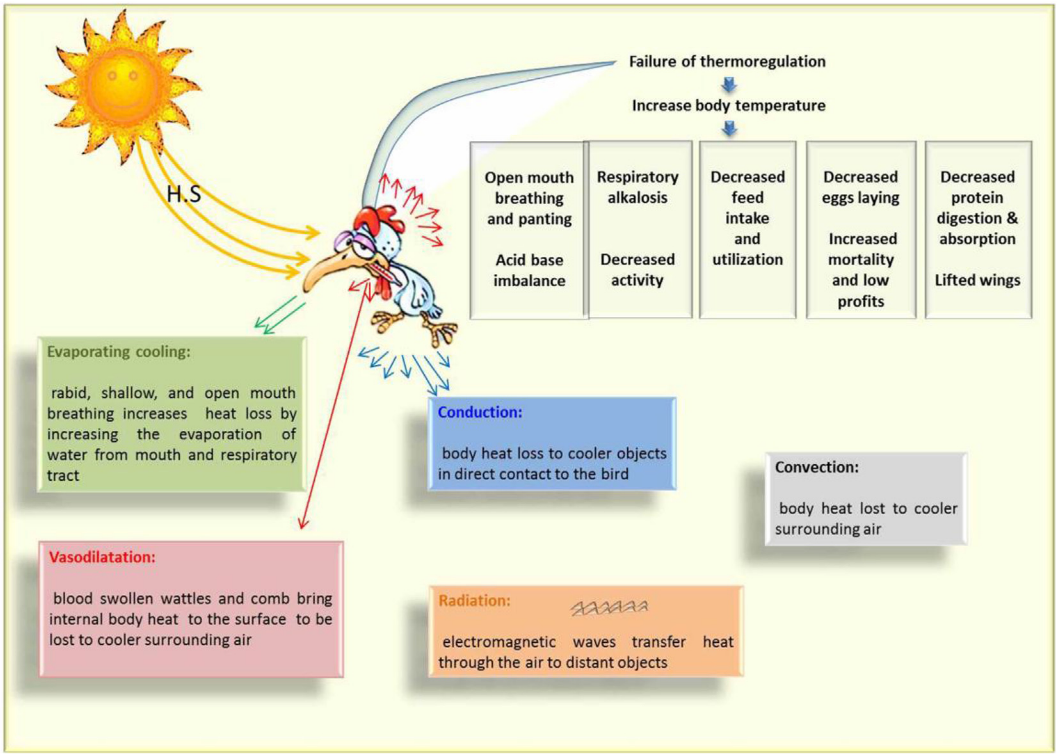

Fig. 1. Responses of the chicken to heat stress.

balance (Abbas et al., 2012). At 86–95 °F, a significant decline in egg production and egg shell quality is observed (Holik, 2010; Oguntunji and Alabi, 2010). In layers, the FCR on the basis of egg mass and the FCR per dozen eggs increases as ambient temperatures increase. When the temperature exceeds 96–100 °F, birds attempt to reduce body heat through severe gular fluttering; however, temperatures in this range result in some degree of mortality . Additionally, marked depression, nervous behaviours and symptoms such as trembling, staggering, and convulsions can also be seen.

Increased temperature with increased relative humidity (RH, %), however, is more devastating. At 95 °F and 40% RH, birds can dissipate 80% of their total heat through evaporative heat loss (gular fluttering), whereas at 95 °F and 50% RH, heat loss dissipation is reduced to 50%. At 95 °F and 100% RH, heat cannot be lost from the body, resulting in severe stress, shock and high mortality. A temperature above 101 °F is lethal; at this temperature, mortality risk increases and emergency measures are needed (Dawson and Whittow, 2000).

Feed consumption and FCR are affected by high temperature (Abbas et al., 2012; Sohail et al., 2012). Body weight gain (Cahaner and Leenstra, 1992; Sahin et al., 2001), egg production (Melesse, 2011; Abbas et al., 2017), egg size, egg quality (Oguntunji and Alabi, 2010; Abbas et al., 2017), hatchability (Lin et al., 2006; Yousaf et al., 2017) and fertility (Banks et al., 2005; Oguntunji and Alabi, 2010) are decreased in breeder flocks exposed to heat stress. Heat stress has been shown to decrease feed intake (from 3947.87 to 3678.23 g/bird), weight gain (2098.87–1786.77 g/bird), and dressing percentage (61.78%–57.22%) and increase water consumption (9636.55–12330.1 ml/bird) and the FCR (1.88–2.05) in broilers (Jahejo et al., 2016). A recent study also showed a 15.8% and 31.9% reduction in average daily feed intake and average daily gain, respectively, under high-temperature conditions (37 ± 2 °C) compared to thermoneutral conditions (27 ± 2 °C); a 23.2% increase in the feed-to-gain ratio under the high-temperature treatment was reported (He et al., 2019). Likewise, a layer study reported a significant decrease in feed intake, egg production, egg weight, eggshell thickness, eggshell weight, Haugh unit, eggshell strength, and serum K and Na concentrations and an increase in serum cholesterol and glucose concentrations (Sahin et al., 2018). The birds appeared lethargic and extended their feathers outwards (Donald and William, 2002) for maximum exposure of the skin surface to the external environment for heat dissipation (Etches et al., 2008). The birds seemed to seek out 'comfort zones' inside the house (Donald and William, 2002) and made body contact with cooler objects (Mack et al., 2013). Birds took shelter under feeders, pressed against drinking water troughs and containers, pressed against the walls of the sheds, sat on litter, stretched their necks high and tried to bathe in the litter (Scanes, 2015). Under high-temperature conditions, birds exhibit restricted movement, or birds may show no movement with symptoms of depression (Habib et al., 2001).

3.2. Effect of heat stress on the physiological parameters of birds

Heat stress causes a pronounced effect on the physiological potential of birds (Mashaly et al., 2004; Ayo et al., 2010). Stress develops when maintenance energy costs increase (Abbas et al., 2012); for example, gular fluttering requires muscle activity in birds, resulting in excessive heat production inside the body. Gular fluttering increases the respiration rate up to 10 times (Brown-Brandl et al., 1997) and causes increased CO_2 loss from the body (Abbas et al., 2012), resulting in an increase in the pH of blood plasma; additionally, the pH within the cells increases, resulting in respiratory alkalosis (Borges et al., 2007; Abbas et al., 2012). Increased gular fluttering causes increased loss of bicarbonate (HCO3) as well as urine output, ultimately increased the loss of electrolytes (Borges et al., 2003, 2004; Sahin et al., 2001). Moreover, the electrolyte intake from feed is also reduced because there is no intake of feed (Scanes, 2015). Furthermore, stress hormones appear in the blood, and heat shock proteins are activated (Kamboh et al., 2013). Gene function may be disrupted, and birds become vulnerable to different diseases (Scanes, 2015). Fig. 1 shows the responses of chickens to heat stress.

Heat stress causes an increase in the concentrations of sodium (Na^+) and chloride (Cl^-) ions in the blood (Abbas et al., 2012), whereas the concentrations of potassium (K^+) and phosphate (PO_4^{++})

Table 1
Summary of different studies showing the mitigating heat stress in poultry.

Type	Strategy	Methodology	Outcome/Mechanism	Reference
Mechanical techniques	Housing and thermal conditioning	Trees and lawns. Direction and design of the house. Roof insulation; also cleaning and painting the surface with metallic zinc paint or by installing an aluminum roof. Increasing floor space etc. Controlled environmental conditions including increased ventilation by fans, sprinklers, roof sprinklers. Foggers, or pad cooling. Fewer afternoon light hours. Avoid overcrowding. Provide shade to overhead water tanks and pipe system.	Reduce summer stress	Scanes (2015); Donald and William (2002); Tumová and Gous, 2012
Nutritional strategies				
	Restricted feeding and watering strategies	Restricted feeding and/or intermittent feeding. Feed withdrawal from 9am to 4.30 p.m. and provide cool water during this time. Increased water consumption.	Effective in reducing heat stress mortality. Metabolic heat production is 20–70% less in starved birds than in fed birds.	Suganya et al. (2015); Macleod et al. (1993); Yalcin et al., (2001); Ahmad et al. (2006); Farghly et al., 2018a; North and Bell (1990)
	Feeding strategies	Wet mash feeding. Pellet or crumble form of feed. Whole grain feeding. Increasing calcium contents of diets with choice calcium. Frequent feeding and stirring of feed in the feeder. Addition of molasses.	Reduce mortality related to heat stress	Lin et al. (2006); Awojobi et al. (2009); Afsharmanesh et al. (2010); Khoa (2007); Leeson and Summers, 2001
	Phytochemicals	Use of phytochemicals such as lycopene, Anthocyanins, Gamma-Glutamylethylamide etc. found in papaya, guava, apricots, pink grapefruit, watermelon, tomatoes etc.	Ameliorate heat stress and improve the performance	Saeed et al., 2017a, b; Arain et al. (2018)
	Electrolytes	Use of potassium bicarbonate, potassium chloride, sodium bicarbonate, sodium chloride and ammonium chloride in water and/or feed	Mitigate heat stress	Khattak et al., 2012
	Vitamin C	Inclusion of Vit. C at 150–400 g/ton of feed.	Helps to regulate body temperature. Reduce corticosterone levels, oxidative stress and carcass grade	Khattak et al., 2012; Attia et al. (2009);.Attia et al. (2016); Abidin and Khatoon, 2013
	Vitamin E	Supplementation of Vit. E at a dose of 100–150 mg/kg of feed.	Acts as antioxidants and protects against oxidative damages. Reduces metabolic heat production, improve performance and stimulates immune responses.	Traber, 2007; Attia et al. (2016)
	Virginiamycin	Use of virginiamycin 15–20 mg/kg of feed	Reduces metabolic heat production, alleviates heat stress and stimulates immune responses.	Zulkifli et al., 2006
	$NaHCO_3$ (Baking Soda)	Supplementation of $NaHCO_3$ at dose of 0.5% in broiler ration and at rate of 1% in layer ration.	Helps to reduce panting and to normalize the blood chemistry during heat stress. Also helps to improve egg quality and digestibility of nutrients.	Abbas et al., 2017
	Betain	Addition of betain at the rate of 0.5–1 g/ton feed.	Acts as osmolyte helps in maintaining water balance in the body cells	Saeed et al., 2017a, b; Attia et al. (2016)
	Prebiotic/probiotics	Use of prebiotic and probiotics.	Modify intestinal microflora, improve health status and performance in summer season	Silva et al. (2010); Sohail et al. (2010), 2011
	Crude protein	Reduce Crude Protein level, also prefer vegetable source of protein in feed.	Maintain protein levels, crucial amino acids may be increased to compensate for reduced feed intake.	Donald and William (2002)
	Fats	Increase by 3–5% at the cost of carbohydrates without changing ME.	Give better cooling effect in body because of higher metabolic water production, also fat stimulates feed consumption	Ghazalah et al. (2008)
	Synthetic amino acids	Increase the digestible amino acids about 5–10 per cent higher than normally used.	Improve performance in summer weather.	Suganya et al. (2015)
Other management	Activities at farm	Do not disturb the birds for transportation, debeaking, dubbing, etc., during peak heat period. Do these practices during cool hours of the day.	Reduce mortality in summer season.	Andersson et al. (2001)
	Early heat conditioning	Induce heat resistance	Increase in adaptation against hot-dry conditions.	Minka and Ayo (2007); Yahav (2000)
	Litter Management	Litter should be kept dry and not be much wet.	Helps in reducing litter temperature and mitigating heat stress.	Bessei (2006); Abreu and Abreu (2004)

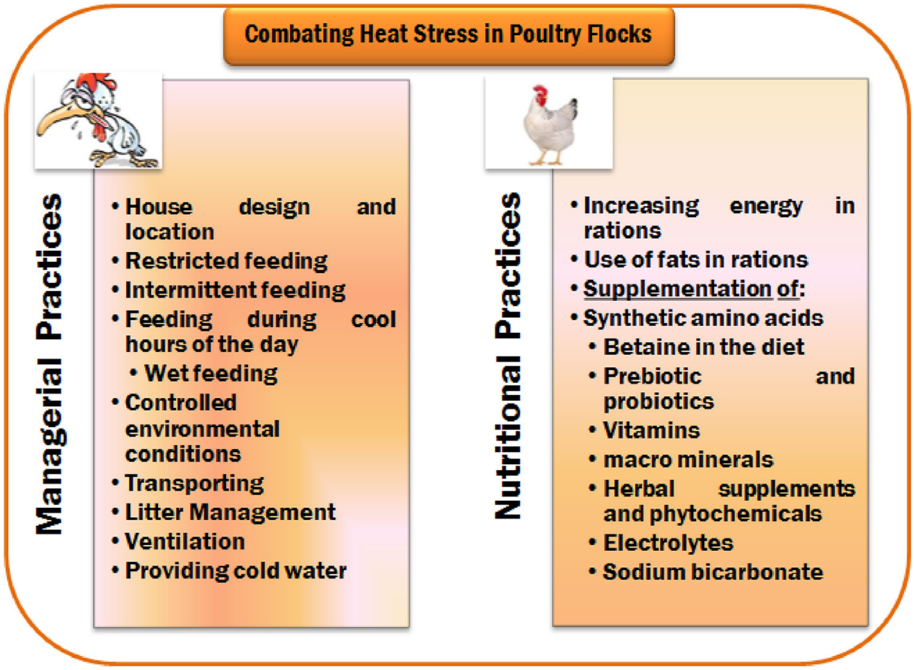

Fig. 2. Combating heat stress in poultry flocks.

is reduced (Yosi et al., 2017). Serum cortisol levels increase (Abbas et al., 2017), whereas serum concentrations of triiodothyronine (T3) and thyroxine (T4), which are important growth-promoter hormones, are adversely affected (Sahin et al., 2001; Abbas et al., 2017).

3.3. *Effect of heat stress on poultry health*

Above 20 °C, with a 1 °C increase in temperature, there is a 1.5% decrease in feed intake, but water intake remains normal. The water requirement increases (LOTT, 1991; May et al., 1997; Lara and Rostagno, 2013) above 30 °C and leads to diarrhoea because of reduced feed intake (Scanes, 2015). With a 1 °C increase in body temperature, the metabolic rate increases by 20%–30%; thus, heat production increases, and the temperature of birds increases above normal (Yahav, 2000; De Basilio et al., 2003; Abbas et al., 2008; Zuidhof et al., 2010).

At this stage, water consumption and the metabolic rate of the body substantially increase (Abbas et al., 2008), but reduced feed intake leads to watery droppings and diarrhoea, which result in a significant reduction in body weight (North and Bell, 1990; Cheng et al., 1997; Lara and Rostagno, 2013). Naturally, birds decrease the intake of feed in hot environments to reduce heat production from metabolism (May and Lott, 1992; Abbas et al., 2008). Decreased feed intake leads to reduced egg production (Abd-Ellah, 1995; Lara and Rostagno, 2013) and the production of thin-shelled, cracked and poor-quality eggs (Mahmoud et al., 1996; Farnell et al., 2001; Lin et al., 2004; Jones, 2006; Lara and Rostagno, 2013). Other contributing factors to thin eggshells are a reduced intake of calcium and an increased loss of phosphorus as feed consumption decreases (Lara and Rostagno, 2013).

Heat production is a genetic factor, especially in meat-type birds (Scanes, 2015). Birds in the production stage are already under stress and easily become susceptible to heat stress (Buys et al., 1999). In the production stage, respiration increases, gular fluttering increases and CO_2 levels increase, ultimately affecting the central nervous system (CNS), resulting in convulsions and death. Heat-stressed birds show increased heterophil/lymphocyte ratios (Gross and Siegel, 1983; Al-murrani et al., 2006; Kamboh et al., 2013) and liver enzymes in serum (Abbas et al., 2017), which could be correlated with higher mortality levels. Heat stress reduces lymphoid organ weight and lowers antibody concentrations in serum (Lara and Rostagno, 2013; Habibian et al., 2014).

Heat stress negatively affects the digestive tract (Mitchell and Carlisle, 1992; Garriga et al., 2006; Ahmed et al., 2015) and may reduce the digestibility of carbohydrates, proteins and fats (Andersson et al., 2001; Abu-Dieyeh, 2006; Lara and Rostagno, 2013). It negatively affects intestinal development (Mitchell and Carlisle, 1992; Garriga et al., 2006), which may lead to diarrhoea or watery droppings (Lara and Rostagno, 2013). A reduction in carcass quality and tibial dyschondroplasia can also occur (Scanes, 2015). Increased mortality (Lara and Rostagno, 2013) with post-mortem changes, such as dry and sticky muscles with a cooked appearance, viscous blood, and shrivelled and dry legs, can also occur inside the poultry shed. Petechial, striated, and ecchymotic-type haemorrhages may be present on the posterior surface of breast muscles (Mitchell and Sandercock, 1995; Kranen et al., 2000; Sandercock et al., 2001). Haemorrhages may also be found on the abdominal fat, liver, heart, skin and mucous membranes. Hyperaemia and congestion of the respiratory tract along with muscle myopathy and congestion of the lungs, blood vessels and brain can be seen (Mitchell and Carlisle, 1992). Glue-like contents can be seen in the intestine, and crops and gizzards may be empty. Dilatation of the right side of the heart is also observed. Ascites increases rigor mortis, which sets early, and the putrefaction of dead birds is rapid.

4. Combating heat stress in poultry flocks

Commercial poultry farming is a very profitable business; however, heat stress during the summer season drastically reduces the profitability of poultry farming (McNadabb and King, 1993; Kamboh et al., 2013; Ranjan et al., 2019). Solutions for the protection from heat stress require multifactorial strategies that may involve housing (Donald and William, 2002; Yahav et al., 2004), genetics (Gowe and Fairfull, 2008), thermal conditioning (Yahav and Mcmurtry, 2001) and feeding and nutrition (Balnave and Abdoellah, 1990; Uni et al., 2001; Moritz et al., 2001; De Basilio et al., 2003; Balnave and Brake, 2005; Shariatmadari and Forbes, 2005; Ahmad and Sarwar, 2006; Khoa, 2007; Daghir, 2008; Ghazalah et al., 2008; Afsharmanesh et al., 2010; Lara and Rostagno, 2013) (Table 1). Lin et al. (2006) reviewed potential ways to combat high ambient temperature, including thermal conditioning and the provision of some micronutrients, such as minerals and vitamins.

Table 2
Summary of managerial practices for whole day during summer season.

Time of Day	Stockman Actions	Flock Response
Early morning	Ventilation on full to lower core body temperature Normal duties – inspections	Eating and drinking normally, noise and activity normal.
Mid morning	Option to withdraw feed and to switch off lights.	Birds begin to pant – Eating and drinking normally – noise and activity normal.
Late morning to noon	–	Birds panting – feed consumption reduced, drinking against dehydration. Activity reduced – more birds sitting.
Noon to early afternoon	–	Birds panting heavily – feed after consumption negligible – Some drinking – Limited activity.
	Slow flock walking to release heat – up and down a line only, not across.	Birds should readily move away from stockman's feet.
Early to late afternoon	–	Birds panting heavily – No activity – drinking stopped – birds sitting, heads up into air stream – Alarm calls may be heard. A welfare problem probably exists about this time.
	Slow flock walking may still be possible – only if birds can still move. Can flick on lights or jump the feed motors for similar response.	Birds should still be able to ripple away from the stockman's feet.
Late afternoon to early evening – falling temperature, but elevated humidity	Flock walking not recommended	Birds panting heavily – No activity – drinking stopped – birds sitting –flock quiet and heads can start to drop – mortality often worse at this time.
Evening to dusk	Flock walking not recommended.	Birds panting heavily – No activity – drinking stopped – birds sitting and heat and physical exhaustion probable – flock still quiet – mortality still probable.
Dusk to temperatures fall	Watching for all birds to be drinking – Birds may require low light.	Birds start to drink again – takes time.
	Ensure birds are fully rested and fill feed lines before reintroducing	Birds recover and begin to feed or look for feed if removed.

Moreover, the resistance of cocks to hot climates through early heat exposure (heat acclimation) is a new focus of research on heat stress mitigation (Rizk et al., 2018). Fig. 2 gives an overview of combating heat stress in poultry flocks.

4.1. Managerial practices

A summary of managerial practices for whole day has been summarized in Table 2.

4.1.1. House design

Poultry houses should be designed to avoid the penetration of heat from the outside environment (Donald and William, 2002). Poultry houses should also be designed with maximum insulation to maintain their internal temperature (Scanes, 2015). The direction of the poultry sheds should be from east to west in length and north to south in width in hot areas (Donald and William, 2002). It is advisable to promote natural air flow from the north and south sides and to shield birds from maximum sunlight during the day; therefore the longitudinal direction of the shed should be from east to west (Donald and William, 2002). Insulation of the roof is extremely important, as 60% of the external heat penetrates through the ceiling into the house (Donald and William, 2002). The roof of the poultry shed should be steep and high. Furthermore, water sprinkling can keep the roof cool in high temperatures (Donald and William, 2002). The building design; ventilation system; roof colour, reflectivity, pitch and orientation; and site also have significant effects on heat loss or gain from the building (Donald and William, 2002). The type and R-values of construction materials and whether the building is in the shade should also be considered. Furthermore, the reflectivity of the roof can be increased by installing an aluminium roof or by painting the surface with metallic zinc paint (Donald and William, 2002). Evaporative cooling systems can be used with cooling pads inside the shed, and sprinklers can be used in farms where environmental temperatures are high and humidity levels are low (Donald and William, 2002). Excessive heat is lost during water evaporation, and cool air is produced inside the shed; however, the resultant humidity produced should be monitored carefully (Attia et al., 2006; Tumová and Gous, 2012). RH increases approximately 4.5% for every 1 °C decrease in temperature through evaporative cooling.

Strong air flow is essential for heat stress relief (Nilipour, 2000). The loss of heat by radiation plus convection can increase considerably with increasing air velocity (Yahav et al., 2004). In extreme conditions of very high humidity and very high temperature, the use of cooling systems might be detrimental or ineffective (Donald and William, 2002; Attia et al., 2006; Tumová and Gous, 2012). Stagnant air inside the shed can be circulated to maximize heat loss by convection (Donald and William, 2002). Exhaust fans can also be used for the expulsion of hot air from the poultry house (Donald and William, 2002). The distance between the sheds should be adjusted such that the flow of wind across the sheds is not interrupted and fresh air is available to the flocks (Mitchell, 1985; Lott et al., 1998; Simmons et al., 2003). To achieve maximum air flow, the house should be open with internal recirculation fans (Donald and William, 2002) positioned in a tunnel ventilation arrangement (Lacy and Czarick, 1992).

A high stocking density will result in ventilation failure. The increased metabolic rate of birds during the summer increases heat production inside the poultry house, and the decreased loss of heat during hot and humid weather will increase the overall temperature of the poultry house (Donald and William, 2002). The stocking densities should be adjusted according to temperature and humidity conditions in the respective area (Donald and William, 2002).

4.1.2. Feeding management

Intermittent feeding programmes have been investigated in some broiler operations. These methods could have possible applications in high-temperature regions where birds are minimally active during the dark hours, consequently reducing the production of heat. Fasting broilers prior to or during peak hot periods of the day lessens the heat load and enhances survival. Feeding should be conducted during the cool hours of the day, i.e., during the early hours in the morning and during late hours in the evening (Farghly et al., 2018a). An advantage of interrupting feeding is a reduction in metabolic heat output. Extra consumed feed during the hot hours of the day will increase the heat load and probably result in additional mortality. Fasting reduces heat production from the digestion, absorption and metabolism of nutrients (Richards and Proszkowiec-Weglarz, 2007). Fasting also has a calming effect. Movement in animals occurs through muscle contraction, which generates heat. In hot environments, this heat production only adds to the heat load. Therefore, to lessen the heat load, broilers should be kept as calm as possible (Macleod et al., 1993). This is especially important during the hottest parts of the day. Once the hottest periods are over and ambient temperature starts to decrease, the broilers usually begin consuming feed again (Macleod et al., 1993). The reduction in feed consumption results in a reduction in the daily intake of nutrients responsible for growth (Suganya et al., 2015). Thus, even though growth is slowed, the chickens can more easily cope with the heat due to the lessened need for the dissipation of heat (Gous and Morris, 2005).

Wet feeding has been found to be beneficial for heat stress in the rainy season in tropical environments (Awojobi and Meshioye, 2001; Lin et al., 2006; Awojobi et al., 2009). Wet feeding improves feed consumption, which results in a better FCR in meat-type strains (Yasar and Forbes, 2000; Moritz et al., 2001; Shariatmadari and Forbes, 2005; Khoa, 2007; Afsharmanesh et al., 2010). Lin et al. (2006) reported that wet feeding improves the performance in layer birds. Moreover, wet feeding increases the passage rate of digesta (Yasar and Forbes, 2000; Farghly et al., 2018b) through the gastrointestinal tract.

4.1.3. Water management

Heat stress causes birds to consume less feed and ingest more water. This increased water consumption helps to reduce the body temperature of birds (North and Bell, 1990; Lara and Rostagno, 2013). The water:feed intake ratio at 15 °C is 1.82:1. However, when the temperature rises to 30–35 °C, the ratio increases to 4.9:1 (Holik, 2010). On average, for each 1 g of feed intake, birds consume 2–3 ml of drinking water during the winter and 4–5 mL during the summer. To keep the body temperature of birds stable, clean and cool water below 25 °C should be provided *ad libitum* and with ice added to the water. The number of drinkers and space should be increased, and the water supply should be ensured to prevent dehydration in birds (Abbas et al., 2008). The use of water troughs in place of nipple or bell-type drinkers can increase water intake in birds. Water tanks should be placed in the shade and insulated. Drinkers should have sufficient water flow (> 70 ml/min/nipple) and chlorination should be discontinued on extremely hot days; H_2O_2 should be used for flushing water lines (Donald and William, 2002).

4.1.4. Litter management

The litter temperature increases during hot weather. To reduce the litter temperature, litter should be kept moderately wet (Abreu and Abreu, 2004; Bessei, 2006). Dry litter can result in excessive heat and decreased humidity, and wet litter during the summer is indicative of increased humidity inside the poultry house (Donald and William, 2002). After drying, the wet litter forms cakes and sticks to the floor. Wet litter will produce a bad smell and ammonia inside the house that can hamper the growth rate, attract flies and increase stress in birds (Donald and William, 2002).

4.1.5. Health management

The overall general health conditions of poultry should be maintained. High ambient temperature induces unfavourable alterations in indigenous bacterial populations in the gut. Probiotic supplementation may enrich the microbiota diversity in the jejunum and caecum of birds, restoring the microbial balance and maintaining natural stability. The timely diagnosis of diseases and prompt treatment of diseased birds should be ensured (Donald and William, 2002). Layer and breeder flocks should be regularly screened for mycoplasmosis, salmonellosis, avian influenza (A.I.) and Newcastle disease (ND) with serological examinations.

4.2. Nutritional manipulation

Heat production in the body normally increases with an increase in the level of proteins (Macleod and Dabutha, 1997). Excess protein metabolism increases the heat load in poultry and exacerbates ionic imbalance (Donald and William, 2002). Under heat stress conditions, lower protein rations supplemented with some essential amino acids, such as methionine, lysine, threonine and tryptophan, will result in better outcomes than higher protein rations (Donald and William, 2002).

4.2.1. Use of fats in rations

Increasing the metabolizable energy content in the diet by adding fat is a common practice during the summer (Donald and William, 2002). Adding fat increases the intake of energy and reduces the specific dynamic action of the feed (Bonnet et al., 1997; Lara and Rostagno, 2013), allowing birds to cope with high temperature more effectively (Abbas et al., 2008). Because fat has a lower heat increment than either carbohydrates and/or protein, a higher fat content (up to 5%) in the diet helps mitigate the negative effects of heat stress in poultry raised at higher ambient temperature (Daghir, 2008; Ghazalah et al., 2008). The inclusion of fat in the diet also decreases the passage rate of digesta (Donald and William, 2002; Nelson and Cox, 2000) through the gastrointestinal tract, thus increasing nutrient uptake and retention (Daghir, 2008). Therefore, the supplementation of fat in the diet helps to increase the energy value of other feed ingredients (Daghir, 2008). Protein metabolism produces more heat production than fat and carbohydrate metabolism (Nelson and Cox, 2000). The protein-to-energy ratio should be readjusted, and up to 5% oil can be included in the diet. An additional advantage of adding oil is the presence of linoleic acid, which improves the production and weight of eggs (Leeson and Summers, 2001).

4.2.2. Use of synthetic amino acids

In addition to energy, consideration must be given to the balance of amino acids in the diet during the summer season (Bonnet et al., 1997). Usually, minimizing excess amino acids enhances feed consumption (Leeson and Summers, 2001). Critical amino acid levels should be approximately 5–10% higher than those normally used with the same level of protein (Suganya et al., 2015). Feed should be formulated with up to 100% of digestible amino acids targets established by the National Research Council and should not contain a high crude protein minimum (Cheng et al., 1999; Moughan and Fuller, 2003; Adzona and Banga-Mboko, 2017). Maintaining an adequate amount of essential amino acids, especially lysine (Corzo et al., 2003) or arginine and lysine (Mendes et al., 1997), or adding 2-hydroxy-4-(methylthio) butanoic acid (HMB) to the diet may be beneficial (Chen et al., 2003). The digestible lysine-to-energy ratio should be increased by 5%–10% during heat stress.

4.2.3. Use of feed additives

Including betaine in poultry diets can significantly benefit (Wang et al., 2004) the production performance in poultry kept under heat stress conditions (Khattak et al., 2012; Attia et al., 2016; Saeed et al., 2017a). Betaine has a specific role in maintaining poultry biological processes such as osmoregulation (Honarbakhsh et al., 2007; Lever and Slow, 2010) cellular water and ion balance (Leeson and Summers, 2001), methionine-sparing, fat distribution (Attia et al., 2005; Hassan et al., 2005) and immunity (Graham, 2002) and improves the bird's capacity to resist heat stress (Wang et al., 2004 > ; Attia et al., 2009; Attia et al., 2016). Betaine also acts as a methyl donor (Nelson and Cox, 2000), allowing feed cost savings through the replacement of some of the added dietary methionine and choline (Graham, 2002; Attia et al., 2009). Experiments conducted under controlled heat stress conditions demonstrated the positive impact of betaine on the performance of broilers (Graham, 2002; Türker et al., 2004; Farooqi et al., 2005; Attia et al., 2009) and layers (Attia et al., 2009; Gholami et al., 2015; Attia et al., 2016; Hao et al., 2017). The research results regarding performance, physiological response, immune response, hormone concentration, digestibility and liveability suggest that betaine supplementation in the diet of poultry during heat stress should be considered (Klasing et al., 2002; Wang et al., 2004; Akhavansalamat and Ghasemi, 2016; Attia et al., 2016; Hao et al., 2017), and DL-methionine should be replaced with a methionine hydroxyl analogue and betaine.

The combination of prebiotics and probiotics to produce a synergistic effect is referred to as a synbiotic. The dietary addition of synbiotics has also been suggested to be beneficial in mitigating the negative effects of heat stress and potentially improving the welfare and performance of birds kept under heat stress (Mohammed et al., 2018). In tropical areas, probiotic supplementation has exhibited several positive effects on poultry health and production (Ahossi et al., 2016; Deraz, 2018). Sohail et al. (2012) reported a positive effect of the dietary addition of mannan-oligosaccharides, prebiotics and a probiotic mixture on performance, intestinal microarchitecture, and immune response of heat-stressed poultry. Similarly, Silva et al. (2010), Sohail et al. (2010) and Sohail et al. (2011) observed significant improvements in performance, intestinal microarchitecture, and immune function in birds subjected to heat stress.

4.2.4. Supplementation of vitamins

The vitamin requirement of poultry increases during hot weather; therefore, vitamins should be added to feed (Abd El-Hack et al., 2017a, Abd El-Hack et al., 2018). Vitamin C can be given in the feed or in water to help regulate the body temperatures of birds (Khattak et al., 2012; Attia et al., 2016). The addition of vitamin C to drinking water or feed helps to reduce corticosterone levels during heat stress (Farooqi et al., 2005; Attia et al., 2009). Vitamin C is a white crystalline compound (Nelson and Cox, 2000) primarily synthesized by the kidneys in chickens (Leeson and Summers, 2001); however, during the hot and humid season (July to August), endogenous vitamin C becomes insufficient to fulfil the bird's requirements (Abidin and Khatoon, 2013). Vitamin C combats heat stress (Attia et al., 2009) and improves the immune response (Kutlu and Forbes, 1993), feed consumption, body weight gain, rectal and body temperature, fertility, hatchability of fertile eggs, oxidative stress, carcass grade, carcass yield and weight in birds (Khattak et al., 2012; Abidin and Khatoon, 2013; Attia et al., 2016; Orayaga et al., 2016).

Vitamin E provides cellular protection and scavenges free radicals (Khan et al., 2011; Attia et al., 2016). The dietary addition of vitamin E decreases the adverse effect of stress hormones (Metwally, 2003). Vitamin E protects lymphocytes, macrophages and plasma cells against oxidative damage and improves the immune response (Khan et al., 2012b; Attia et al., 2016; Abd El-Hack et al., 2017b). The dietary supplementation of vitamin C and vitamin E can improve production performance, nutrient digestibility, egg quality, physiological performance and organ weights under heat stress (Attia et al., 2016; Kumbhar et al., 2018).

4.2.5. Supplementation of minerals

Many studies have shown the positive effects of trace mineral (such as selenium, chromium, zinc, etc.) supplementation in tropical chicken farming. Studies have suggested the significant effects of minerals on the improvement of performance parameters and reduction in heat shock proteins and lipid peroxidation in birds reared in tropical climates (Rao et al., 2016; Rajkumar et al., 2018). The phosphorous requirement increases during heat stress (Leeson and Summers, 2001), and the Ca requirement increases during hot weather due to reduced feed intake (Leeson and Summers, 2001). The dietary supplementation of chromium to Japanese quail chicks exposed to heat stress beneficially affects the carcass and growth rate and modulates the biochemical blood indices (El Kholy et al., 2017).

4.2.6. Use of herbal supplements and phytochemicals

Supplementation with additives such as photobiotics can also help to attenuate heat stress (Leeson and Summers, 2001; Liu and Kim, 2017). Plant polyphenols like anthocyanins are phyto-pigments that have a positive effects on the health of poultry. Anthocyanins may function as antioxidant, anti-inflammatory, immunomodulatory, anti-diabetic, anti-obesity, neuroprotective and anticancer biochemical agents; therefore, the dietary addition of anthocyanins can produce several health benefits in heat-stressed birds (Hu et al., 2019; Saeed et al., 2017b).

Heat stress poses serious challenges, such as reduced production performance, increased morbidity and mortality and increased quality losses, leading to an economic burden (Mujahid et al., 2005, 2007; Gu et al., 2012; Ghazi et al., 2012). To mitigate heat stress, the use of plant derivatives, such as phytochemicals, in poultry diets is gaining popularity due to their potential antioxidant activities. Lycopene is a powerful antioxidant that can be metabolized by animals (Srivastava and Srivastava, 2015; Arain et al., 2018); lycopene improves cell growth and the immune response (Blokhina et al., 2003; Martinez et al., 2008; Palozza et al., 2012) and mediates gene transcription (Palozza et al., 2012). This beneficial phytochemical compound is abundant in vegetables and fruits, such as papaya, guava, apricots, pink grapefruit, watermelon and tomatoes (Tanaka et al., 2012). Previous research has revealed that lycopene is one of the powerful natural anti-stressor and antioxidants that can alleviate adverse impacts of heat stress (Zhang et al., 2014; Sun et al., 2015; Sahin et al., 2016). Supplementation of *Solanum lycopersicum* (tomato) in the diet of heat stressed birds have shown anti-oxidant (Sahin et al., 2011, 2013; Zhang et al., 2014; Sun et al., 2014, 2015), anti-inflammatory, immune-booster effect (Selim et al., 2013) and numerous others health promising beneficial effects like better performance and improved meat quality parameters and egg quality characteristics (Arain et al., 2018).

Gamma-Glutamylethylamide (L-theanine) is non-proteinous, water-soluble most abundant (50% of total amino acids of green tea) amino acid of green tea leaves (Kojima and Yoshida, 2008; Saeed et al., 2018). L-theanine offers unique health benefits like immune boosting (Yin et al., 2011; Li et al., 2016), antioxidant, antidepressant (Takeda et al., 2012) and stress/fatigue-relieving effects (Tian et al., 2013). L-theanine has also been found to increase the production of anti-inflammatory cytokines (Hwang et al., 2008). Additionally, Liu et al. (2013) concluded the beneficial effect of dietary supplementation of resveratrol (200, 400, or 600 mg/kg of diet) on growth index of immune organ, performance parameters, oxidative markers, and expressed levels of heat shock proteins of 42-d-old female black-boned chickens exposed to heat stress; these results suggested the antioxidant potential of resveratrol via increasing the level of serum growth hormone and alerting of heat shock genes in the immune system (Khafaga et al., 2019).

4.2.7. Supplementation of electrolytes

Electrolyte therapy should be done to balance salts (Leeson and Summers, 2001). Imbalances in acid-base balance occur in heat stressed birds (Leeson and Summers, 2001). Therefore, inclusion of various compounds in the diet or water is a common practice to alleviate the adverse effects of heat stress (Kamboh et al., 2015). Addition of potassium chloride at 0.2–0.5% is helpful to maintain osmotic and acid base balance and increase water consumption. However, potassium requirement increases with increase in temperature (0.6% - 0.7%). Dietary requirements were 0.20–0.25% sodium and 0.30% chloride (Mushlag et al., 2007). Supplementation of diet with salts such as potassium bicarbonate, sodium chloride, potassium chloride, and ammonium chloride increased the water consumption in heat stressed birds (Khattak et al., 2012).

4.2.8. Dietary inclusion of sodium bicarbonate

To combat the heat stress, sodium bicarbonate is also being widely used in poultry feed industry (Ahmad et al., 2006). Sodium bicarbonate is an antacid (buffering agent) and is the source of CO_2 for heat stressed animals (Ahmad et al., 2006). To combat the heat stress in commercial layer flock, Abbas et al. (2017) provided the layers diets containing different levels of sodium bicarbonate. The layer birds received the diet having 1% sodium bicarbonate outperformed as compared to the control group. Dietary inclusion of sodium bicarbonate at 1%, in layer diets during summer, may also be recommended to improve the efficiency of egg production, immune response against Newcastle disease and digestibility of nutrients, in the birds (Abbas et al., 2012). Replace 40–50 percent of any salt in the diet with sodium bicarbonate to help maintain egg shell quality. Use of sodium zeolite and aspirin are also proven to alleviate heat stress.

The primary objective of heat stress management is to ensure maximum heat loss from the house in order to lower the temperature of the house. For this purpose, following points can be kept in mind during running a poultry flock. Efficient heat stress management during summer season in poultry flocks can increase profitability of poultry business. The increased egg and poultry meat production during summer season can be helpful in fulfilling the protein requirement of the general public. Increased egg and meat production can also overcome the crisis of food shortage in developing country.

5. Other practices

- Avoid using anticoccidial drugs during heat stress.
- Thermostats should be checked for accuracy. An efficient stand-by generator must be installed in case of electricity shortage during summer.
- Genetic selection tools should be used for adaptation of heat tolerance genes in commercial chicken.
- Early heat conditioning also appeared to be one of the promising methods to induce heat resistance and adaptation of poultry breeds to the hot-dry conditions (Yahav, 2000; Minka and Ayo, 2007).

6. Conclusion and recommendations

Heat stress has emerged as a major concern to poultry keepers because of reducing heat tolerance in modern poultry genotypes in addition to the dramatic increase in global temperature. Heat burden causes many harmful impacts on poultry growth, meat quantity and quality, laying rate and egg quality criteria. These effects cause several economic losses to poultry production. Studies on heat stress in poultry farms, generally focus on exploring the strategies to maintain the conditions which cause heat stress. Specifically, in opened poultry houses, it is important to ensure that the outdoor air can flow smoothly into and out of poultry house. Furthermore, feeding at cooler times, wet feeding, feed withdrawl before an expected period of heat stress and dimming lights during feeding could be good strategies to cope with heat stress. In addition, maintaining good ventilation, increasing energy level in poultry rations and supplementing diets and drinking water with vitamins, antioxidants, probiotics and minerals can help in heat stress mitigation. Moreover, keeping in view the future protein demands it is advisable to explore the novel mitigation strategies in terms of farming practices, nutritional manipulation and genetic selection to reduce the deleterious effects of heat stress on production.

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