Technical Bulletin

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in poultry production system

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FOREWORD

It is a moment of great pleasure for me that ICAR-ATARI, Zone-1 Ludhiana has come out with a publication titled "**Management of heat stress in poultry production system".** In India, as poultry plays an important economic, nutritional and socio-cultural role in the livelihood of poor rural households. But looking at the present scenario, climate change is one of the most important environmental stressors challenging poultry production worldwide. This bulletin has been published for brushing up and updating the knowledge of Scientists, Subject Matter Specialists, Extension professional, Farmers and other stakeholders as ready reference.

I am happy that the authors have done a commendable job in compiling immensely useful information in this bulletin. I earnestly hope that the readers will find this publication useful to them. I extend my heartiest congratulation to all the team members in bringing out this bulletin.

March, 2016
Ludhiana

(Rajbir Singh)
DIRECTOR

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PREFACE

Inspite of the tremendous growth and baffling figures of poultry production in Indian, farmers are facing numerous risks among which temperature-associated environmental challenges, especially hot climate imposes severe stress on birds and leads to reduced performance.

Heat stress is expected to disproportionately affect various poultry species; however, there is limited information on their overall vulnerability and adaptation needs. Therefore, reviewing the impacts of heat stress on poultry productions or its reciprocal effects seems to be the priority concern in the present scenario. Transmitting information regarding all the available facts related to physiology of the birds with respect to hot climate, its detrimental effects on poultry production system and managemental strategies to alleviate the same to various researchers, extension workers and other stakeholder on poultry production has been a key objective of this publication.

Authors

The Indian poultry sector is characterized by its industrialization, faster growth in consumption and trade than any other major agricultural sectors in the world. Today, India is the third largest egg producer in the world and the nineteenth largest broiler producer. India's contribution to world's egg and chicken meat production is nearly 5.3% and 2.53%, respectively (FAO, 2010), whereas poultry sector contributes about 1% to national GDP and 11% of total livestock GDP in India. The estimated rate of growth in layers is 6-7% per annum and 10-15% for chicken meat. Thus, poultry development in the country has shown steady progress over the years. Along with this, poultry plays an important economic, nutritional and socio-cultural role in the livelihood of poor rural households in many developing countries, including India. Poultry are birds that includes fowl, turkey, duck, goose, ostrich, guinea fowl etc which render not only economic services but contribute significantly to human food as a primary supplier of meat, egg, raw materials to industries (feathers, waste products) source of income and employment to people compared to other domestic animals (Avila,1985; Demeke, 2004). Agriculturists and nutritionists have generally agreed that developing the poultry industry of India is the fastest means of bridging the protein deficiency gap presently prevailing in the country (Wit, 1996; Amos, 2006). Based on the poultry industry's development during the last two decades and the need for increased animal protein sources in the hot regions of the world, there is general agreement that these areas are going to witness further expansion in the current decade. Although the need for more eggs and poultry meat is obvious and the availability of these products can go a long way to meet the protein needs of several populations in hot regions, there are several constraints to the future development of the poultry industry. The most obvious constraint on poultry production is the climate. Poultry seems to be particularly sensitive to temperature-associated environmental challenges, especially heat stress. High temperature, especially when coupled with high humidity, imposes severe stress on birds and leads to reduced performance. It has been suggested that modern poultry genotypes produce more body heat, due to their greater metabolic activity (Settar, 1999 and Deeb and Cahaner, 2002). Understanding and controlling environmental conditions is crucial to successful poultry production and welfare. Therefore, reviewing the impacts of climate changes on poultry productions or its reciprocal effects is seems to be the priority research area. Both of the climate change and poultry productions have always negative impacts one over the other. The purpose of this bulletin is to review some of the effects of heat stress on poultry and to look at methods that can be used by the poultry producer to partially alleviate some of the detrimental effects of heat stress on the poultry productivity.

Present scenario of poultry production with respect to higher environmental temperature

Animal productions, particularly the ruminants contributed around 18% of negative impact of climate change. However, poultry has low global warming potentials and its product is cheap and nutritious and is also without taboos of all livestock meats. Seo and Mendelsohn (2006) reported that global warming will be harmful to commercial poultry owners and warming causes the net revenue from all animals to fall. Pant (2011) reported also that farmers have to bear direct cost of climate change that involves reductions of yield in poultry and indirect costs of adaptation. However, Costa (2009) reported that the poultry industry has a natural advantage over other livestock industries because of its low global warming potential. On the other hand, they are particularly more vulnerable to because birds can only tolerate narrow temperature ranges (Costa, 2009). Moreover, according to FAO (2010b) reports, compared with cattle, chickens emit no methane and emit less phosphate and carbon dioxide than other meat-producing animals. Grimes (2009) reported also that the desire for poultry meat and eggs and the relative ease in establishing poultry as an industry (compared with other animal agriculture) is driving this movement. Thus, FAO (2010b) reported that chicken is usually the cheapest of all domestic livestock meats, particularly for Asian countries. According to Costa (2009) reports, the red meat industries have been pro-active in addressing environmental concerns. ILRI (2006) reported that the genetic diversity in fowl is much higher than other livestock species that most of the indigenous breeds have a good adaptability for climate and disease. Thus, Ivo (2009) reported that the possibilities of village poultry as a viable sector to boost protein deficiencies via sustainable village poultry. Poultry farmers need to consider making adaptations now to help reduce cost, risk and concern in the future. Furthermore, exceeding to preferring animal species production that best fits to the scenarios of climate change and protein food demands, types of implementing production systems will be also another issue that needs emphasis. According to FAO reports, advances in technology favor the intensification of poultry production in developing countries and if their by-product isn't managed or recycled properly, it will be the concern of environment. According to FAO (2010b) reports, recent research suggests, contrary to widespread belief, that intensive poultry production may have a lesser impact on the environment and global warming than organic or free-range production. This organic poultry has higher feed conversion efficiency (FCR) and a longer growing period for the heavier chickens that are produced.

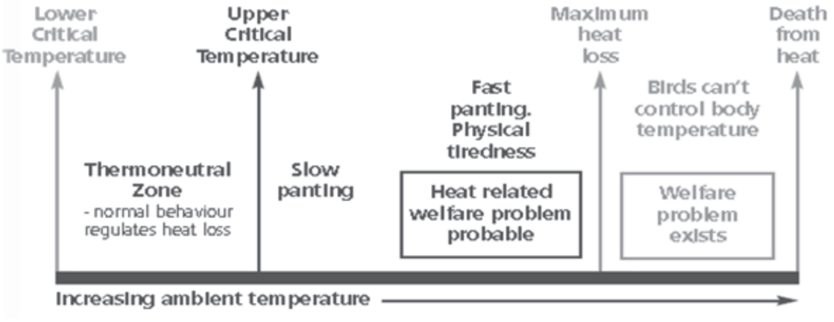
Thermoregulatory mechanism of poultry

The internal body temperature of domesticated gallinaceous birds (chickens) at 41.2°C to 42.2°C is measurably higher than that of mammalian livestock and humans (36°C to 39°C). The upper temperature limit beyond which living cells and tissues progressively fail to operate is governed by the temperature at which enzymes (enzymic proteins) are denatured (destroyed) by loss of configuration (shape) and chemical activity. This starts to occur in the region of 46°C and thus poultry have considerably less leeway than other animals when suffering from heat stress and quickly succumb to higher temperature. In comparison, actual body temperature of poultry may fall as much as 20°C below the normal range with birds still making full recovery if carefully re-warmed. Poultry are not well adapted and disposed to high ambient air temperatures. They lack sweat glands in the skin and are therefore unable to gain much from natural evaporative cooling, although there is some direct diffusion of water through the skin tissue. Only the head appendages (e.g. comb) are very rich in blood vessels and able to act as sites for direct loss of heat, so poultry appears to have few limited options for heat loss in warm conditions. Domestic poultry is clearly less tolerant of heat than cold and much more likely to die from heat stress (hyperthermia) than succumb to stress associated with low temperature (hypothermia).

Table 1 General guide to the reaction of adult poultry to various temperatures

55° to 75° F	Thermal neutral zone. The temperature range in which the bird does not need to alter its basic metabolic rate or behavior to maintain its body temperature.
65° to 75° F	Ideal temperature range.
75° to 85° F	A slight reduction in feed consumption can be expected, but if nutrient intake is adequate, production efficiency is good. Egg size may be reduced and shell quality may suffer as temperatures reach the top of this range.
85° to 90° F	Feed consumption falls further. Weight gains are lower. Egg size and shell quality deteriorate. Egg production usually suffers. Cooling procedures should be started before this temperature range is reached.
90° to 95° F	Feed consumption continues to drop. There is some danger of heat prostration among layers, especially the heavier birds and those in full production. At these temperatures, cooling procedures must be carried out.
95° to 100° F	Heat prostration is probable. Emergency measures may be needed. Egg production and feed consumption are severely reduced. Water consumption is very high.
Over 100° F	Emergency measures are needed to cool birds. Survival is the concern at these temperatures.

Fig. 1. Diagram of Thermoneutral Zone



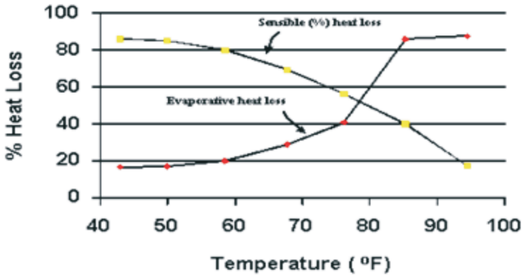
Methods of heat loss

During the summer months, when daily temperatures reach at their extremes, it becomes critical for the birds to dissipate body heat to the surrounding environment. Poultry do not sweat and therefore must dissipate heat in other ways to maintain their body temperature at approximately 105°F. Body heat is dissipated to the surrounding environment through radiation, conduction, convection, and evaporation (Table 2). The first three avenues are known as sensible heat loss; these methods are effective when the environmental temperature is below or within the thermal neutral zone of the bird (55° to 75°F). The proportion of heat lost through radiation, conduction, and convection depends upon the temperature difference between the bird and its environment. The bird loses heat from surfaces such as wattles, shanks, and unfeathered areas under wings. To maintain body temperature by sensible heat loss, the bird does not need to drastically alter its normal behavioral patterns, feed intake, or metabolism. The purpose of poultry house ventilation is to maintain a high enough air velocity or a low enough temperature in the house that the birds can maintain body temperature by sensible heat loss. Once the environmental temperature reaches approximately 77°F, the method of heat loss begins shifting from sensible to evaporative heat loss (Figure 2). Dissipation of body heat by the evaporative process requires the bird to expend energy by panting (hyperventilation), which begins to occur at about 80°F. Panting removes heat by the evaporation of water from the moist lining of the respiratory tract. However, panting itself generates body heat, and it causes poultry to eliminate water from the body. It can induce respiratory alkalosis, which occurs because the bird "blows off" excessive carbon dioxide (CO_2) when it pants. As a result, body fluids become more alkaline, causing the kidneys to excrete excessive amounts of several electrolytes. As the shift in body fluid pH occurs, feed intake is increasingly depressed, adversely affecting growth, production, and overall performance of the bird. During the hot summer months, evaporative heat loss typically becomes the primary method by which birds regulate their body temperature unless proper ventilation is provided and other steps are taken to reduce heat stress.

Table 2 Methods of sensible and latent body heat loss in poultry

Heat Loss Method	Direction of Heat Flow
Sensible Heat Loss Methods	
Radiation Flow of thermal energy without the aid of a material medium between two surfaces	All surfaces radiate heat and receive radiation back; the net radiation heat flow is from higher to lower temperature surfaces.
Conduction Thermal energy flow through a medium or between objects in physical contact.	Direction of energy transfer depends on a temperature gradient; heat moves from areas of higher to lower temperature.
Convection Heat flow through a fluid medium such as air; thermal energy moves by conduction between a solid surface and the layer of air next to the surface, and the thermal energy is carried away by the flow of air over the surface.	Energy transfer to the air depends on temperature and movement of air across the skin surface; heat is transferred to air moving across the skin surface if the air is at a lower temperature than the skin.
Latent Heat Loss Method	
Evaporation The transfer of heat when a liquid is converted to a gas; when water is converted from a liquid to a vapor, heat is utilized.	Energy transfer is influenced by the relative humidity, temperature, and air movement; heat is transferred from the animal's body to water, turning it to water vapor.

Fig. 2. Method of heat loss from birds as temperature changes.



Heat stress is a worldwide problem in poultry production, especially in broiler and layer lines. Heat stress begins when the ambient temperature climbs above 80°F and is readily apparent above 85°F. When a bird begins to pant, physiological changes have already started within its body to dissipate excess heat. Even before the bird reaches this point, anything that you do to help birds remain comfortable will help maintain optimum growth rates, hatchability, egg size, egg shell quality, and egg production. High ambient temperatures can be devastating to commercial broilers; coupled with high humidity they can have an even more harmful effect. Heat stress interferes with the broilers comfort and suppresses productive efficiency, growth rate, feed conversion and live weight gain (Etches *et al*., 1995;Yalcin *et al*., 1997). In poultry production, heat stress can be described as acute or chronic. Acute heat stress refers to short and sudden periods of extremely high temperature, whereas chronic heat stress refers to extended periods of elevated temperature. Chronic stress has deleterious effects on birds reared in open-sided houses mainly through reducing feed consumption and increasing water consumption. Most of the reduction in feed consumption is due to reduced maintenance requirement. In broilers, growth rates, feed efficiency and carcass quality are negatively affected. Again, prolonged periods of elevated ambient temperature increase the broilers time to reach market weight and increase mortality. In laying hens, heat stress leads to a decline in egg production and egg quality, as well as, shelf life of eggs is shortened. In breeders, high ambient temperature coupled with high humidity decreases fertility resulting in low hatchability. During the heat stress period the increase in body temperature has a negative effect on gamete formation and the fertilization process. During periods of heat stress the hens have to make major thermo-regulatory adaptations to prevent death from heat exhaustion. As a result, the full genetic potential of the layer is often not achieved.

Clinical signs and symptoms of heat stress

Poultry subject to high environmental temperatures exhibit many behavioral and physiological changes which allow them to re-establish heat balance with their surroundings. As ambient temperature increases above comfort zone, chicken spend less time in feeding, more time in drinking and panting, as well as more time with their wings elevated, less time moving or walking and more time in resting (Mack, *et al*., 2013). Usually, their wings are spread away from the body to promote cooling by reducing body insulation and they splash water on their combs and wattles in order to increase evaporative cooling from these surfaces (Fedde, 1998). Heat stressed birds also spend relatively less time engaging in social behaviour and in changing posture.

In a natural environment, birds will look for a shady and cool area. Within the bird, blood flow is diverted from certain internal body organs such as the liver, kidneys and intestines to dilated blood vessels of the peripheral tissue (skin) in order to facilitate heat loss (Mustaf *et al*., 2009).

Effect of heat stress on poultry production system

As previously seen, exposure of birds to high environmental temperature generates behavioral, physiological and immunological responses, which impose detrimental consequences to their performance and productivity (bhadauria *et al.*, 2015). Hot climate can have a severe impact on poultry performance. It inflicts heavy economic losses on poultry production as a result of stunted growth (Sahin *et al*., 2001), decrease in hen-day production (Njoku. 1989; Khan *et al*., 2003; Ayo *et al*., 2011), increased cost of production, high rate of mortality due to depressed immunity, and reproductive failure (Morsy, 1998; Obidi *et al*. 2008; Ayo *et al*., 2011).

Growth and production efficiency

Heat stress depresses growth rate and production as a result of a down-turn in voluntary feed intake in birds (Sahin *et al.*, 2001). It is apparent that the inhibition of growth and production in heat-stressed broiler birds is mediated via the stress hormones, especially the corticosteroids. Sahin *et al.* (2001) also showed that body weight in heat-stressed broilers was signiflcantly lower than in birds administered with antioxidant vitamins A and E.

Plasma triiodothyronine and thyroxine, which are important growth promoters in animals, were adversely affected in heat-stressed broiler chickens. Heat stress results in decreased feed consumption and increased water consumption. As temperature rises, the bird has to maintain the balance between heat production and heat loss and so will reduce its feed consumption to reduce heat from metabolism. Research demonstrated that feed consumption is reduced by 5% for every 1 ^{o}C rise in temperature between 32-38^{o}C. In a recent study (Sohail *et al*., 2012), broilers subjected to chronic heat stress had significantly reduced feed intake (16.4%), lower body weight (32.6%) and higher feed conversion ratio (+25.6%) at 42 days of age. Many additional studies have shown impaired growth performance in broilers subjected to heat stress (Niu, *et al*., 2009; Attia *et al*., 201; Imik *et al*., 2012). However, in addition to decreased feed intake, it has been shown that heat stress leads to reduced dietary digestibility and decreased plasma protein and calcium levels (Bonnet *et al*., 1997; Zhou *et al*., 1998).

Reproductive performance

Heat stress causes decreased production performance, as well as reduced egg shell thickness and increased egg breakage (Lin *et al*., 2004). Additionally, heat stress has been shown to cause a significant reduction of egg weight (3.24%), egg shell thickness (1.2%), egg shell weight (9.93%) and egg shell percent (0.66%) (Ebeid *et al*., 2012). Heat stress affects all phases of semen production in breeder cocks (Banks *et al*., 2005). Although limited high temperature stimulates testicular growth in the early phase and promotes increased semen volume and concentration, a subsequent rise suppresses reproductive capacity as a result of a decrease in seminiferous epithelial cell differentiation, which is manifested in decreased semen quality and quantity with time (Obidi *et al*. 2008; McDaniel *et al*. 1996; Edens, 2009). McDaniel *et al*. (1996) showed that the broiler male broiler breeder was exposed to a temperature of 32°C, male fertility declined to 42% and in vivo sperm-egg penetration declined to 52%, compared to values obtained from males that were maintained at 21°C, it may be concluded that heat stress has deleterious multiple effects on testicular function through inhibition of intracellular ion exchange. Report of McDaniel *et al*., (1996) showed that semen characteristics such as consistency, spermatozoa concentration, and seminal volume were depressed by environmental temperatures outside the zone of thermal comfort. In the study in which breeder hens were inseminated in the morning hours had a significantly higher fertility and hatchability than those obtained in inseminated hens during the afternoon hours (Obidi *et al*. 2008).

Embryonic development

The incidence of adverse effects of heat stress on embryonic growth has been reported by various workers. Yalcin and Siegel (2003) showed that over-heating fertile eggs during incubation resulted in differential tissue growth at different stages of incubation. The finding further showed asymmetries in skeletal development during the early and late stages of embryo development. Heat-stressed embryos, showed shorter face length and low lung weight, resulting in weaker chicks with high incidence of culled-out birds due to unsteady gait. A greater number of culled chicks as a result of unthrifty behaviour. All the anomalies were due to heat stress suffered by embryo during the incubation process, induced by poorly controlled machine and environmental temperature due to frequent incubator electrical power failure. Findings of Deeming and Ferguson (1991)and Lourens *et al.* (2001 and 2007), showed that retarded embryonic and post hatch chick developments are due to consistent heat stress.

Immunity

In poultry, several studies have investigated the effects of hot climate on the immune response in recent years. In general, all studies show an immunosuppressing effect of heat stress on broilers and laying hens. For instance, lower relative weights of thymus and spleen has been found in laying hens subjected to heat stress (Ghazi *et al*., 2012); reduced lymphoid organ weights have also been reported in broilers under heat stress conditions (Bartlett and Smith, 2003; Niu *et al*., 2009). Additionally, Felver-Gant *et al*. (2012) observed reduced liver weights in laying hens subjected to chronic heat stress conditions. Bartlett and Smith (2003) observed that broilers subjected to heat stress had lower levels of total circulating antibodies, as well as lower specific IgM and IgG levels.

Meat quality

Climate change could affect meat quality in two ways. First, there are direct effects on organ and muscle metabolism during heat exposure which can persist after slaughter. For example heat stress can increase the risks of pale-soft-exudative meat in turkeys, heat shortening in broilers and dehydration in most species. Second, changes in poultry management practices in response to hazards that stem from climate change could indirectly lead to changes in meat quality. Also, pre-conditioning broilers to heat stress to encourage better survival during transport could lead to more variable breast meat pH. The impacts that short term climate change could have will vary between regions (Gregory, 2010). It has been reported that chronic heat exposure negatively affects fat deposition and meat quality in broilers, in a breed-dependent manner (Lu *et al*., 2007). In fact, recent studies demonstrated that heat stress is associated with depression of meat chemical composition and quality in broilers (Dai *et al*., 2012 and Imik *et al*., 2012). Another recent study (Zhang *et al*., 2012) demonstrated that chronic heat stress decreased the proportion of breast muscle, while increasing the proportion of thigh muscle in broilers. Moreover, the study also showed that protein content was lower and fat deposition higher in birds subjected to hot climate.

Disease incidence

According to Guis *et al*. (2011) reports, climate change will alter global disease distribution. These climate changes have tremendous effect on prevalence of zoonotic diseases as well. The changes in climate may increase the insect vectors, prolong transmission cycles or increase the importation of vectors or animal reservoirs. It may also have an adverse effect on biodiversity, distribution and migratory pattern of birds which may lead to emergence of disease outbreaks. Climate change would almost certainly alter bird migration, influence the avian influenza (AI) virus transmission cycle and directly affect virus survival outside the host. In domestic poultry, too little is known about the direct effect of environmental factors on highly pathogenic avian influenza transmission and persistence to allow inference about the possible effect of climate change. However, possible indirect links through changes in the distribution of duck-crop farming are there, as reported by Gilbert *et al*. (2008).

Measures to alleviate heat stress in poultry

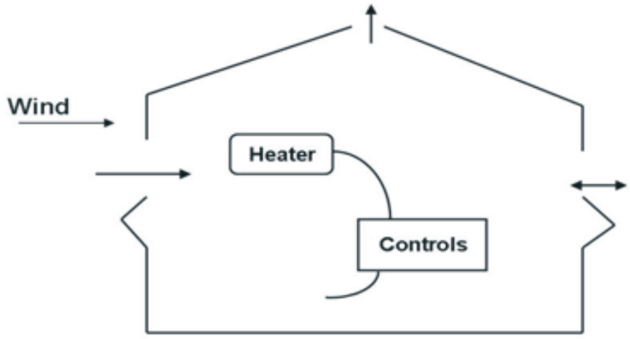
Housing Management

Housing design

The design of the building and its ventilation system, the siting of new buildings and construction materials, will all have an effect. Roof colour, reflectivity, pitch and orientation, and whether the building is in the shade or not, is also factors which will have a small bearing on solar heat gain. Expert advice should be sought at the design stage. The house and ventilation system must complement each other to achieve maximum benefit. Traditionally poultry producers have found that natural ventilation tends to be most effective in houses which are 12 m in width or less, although the houses can be of any convenient length. Recommended design spacing D = 0.4 x H x (L) 0.5 where, H and L are height and length of obstructing building or not less than 10-12 meters. All naturally ventilated houses must be equipped with some type of adjustable side-wall curtains to control the flow of air into the house. Properly designed roof overhang helps to reduce the possibility of both direct and indirect sunlight entering a house during hot weather. To minimize heat-stress-related problems during hot weather, it is always beneficial to insulate poultry-house roofs/ceilings. A typical minimum level of ceiling insulation for a naturally ventilated house is R-value 1.25 m^2 C/W. Whereas houses that have high temperatures above 40°C or temperatures below 0°C typically require ceiling R-values of 2.25 m^2 C/W or more. There are a variety of methods of insulating a poultry-house ceiling dropped ceiling, rigid board insulation, spray polyurethane insulation, reflective insulation etc. Similarly, reflective roof paints have been shown to reduce roof temperature from 5°C to 32°C, thus dramatically reducing heatgain through roof surfaces (Bucklin *et al*., 1993).

Air movement

Increasing the amount of air movement over a bird is one of the most effective methods that producers can use to increase heat removal from birds. Air movement provides a number of benefits that help to cool the birds during hot weather. First, it increases convective heat loss from the birds in a house, thereby lowering the effective air temperature. Second, it helps to remove trapped heat from between the birds as well as from cages. Last, but not least, it lessens the adverse effects of high-humidity environments. High air speed is essential in heat stress relief. In systems with lower stocking rates, the effects are greater. As air speed increases, the amount of heat removal increases and the bird cooling is enhanced. The effect of this is to transfer the bird heat loss from latent heat loss (heat loss through panting) to sensible heat loss (convective heat loss), so as wind speed increases more sensible heat loss occurs than latent heat loss (Mitchell, 1985; Simmons *et al*., 1997).



Schematic of a naturally ventilated building and its components

Recommended air speed

All poultry producers should aim for between 1 m/s and 3 m/s for relief against extreme heat. 1m/s should be an absolute minimum for commercially stocked houses. 1.0 -1.5 m/s should be within the abilities of most conventional powered ventilation systems, especially after minor upgrades. (1m/s = 200 ft/min). To achieve 1.5 – 3 m/s, the house would usually need to be operating in a tunnel ventilation format. Low stocking rate systems, such as breeders, pullets and layers should aim for at least 0.7 m/s. In these systems, high volumes of air can, to some extent, make up for an inlet system that cannot deliver high air speeds over birds. But good air speed and good air change rate is the ideal.

Ventilation

During the summer when the temperature and humidity are high, proper poultry house ventilation is vital to ensure the necessary removal of heat and the continued productivity of the flock. Poultry house ventilation systems have a number of components. These include curtains, fans, fogging nozzles, evaporative cooling pads, timers, static pressure controllers, thermostats etc. Most ventilation systems can provide an adequate indoor environment when properly managed.

Natural ventilation

One of the keys to minimizing heat stress in naturally ventilated poultry houses during hot weather is making sure that outside air can easily flow into and out of the house. The easier it is for outside air to flow through a house the less likely there will be a detrimental build-up of heat within the house, minimizing inside to outside temperature differentials. Furthermore, increased air-exchange rates tend to result in increased air movement over the birds within the house, thus maximizing heat loss due to convection. Factors which affect heat build-up in a naturally ventilated house include house width, house length, side-wall openings, local obstructions, ridge openings, house orientation, roof overhang, roof slope, roof insulation, side-wall and end-wall insulations, roof coatings, roof sprinkling and circulation fans. The first four factors are the primary factors that determine the ease with which outside air moves through a house. All naturally ventilated poultry houses should always be orientated in an east–west direction, so that the roof line runs from east to west. This orientation will keep direct summer sunlight from coming through the sidewall and causing heat to build up within the house. These houses work best when they are located away from obstructions such as other buildings or trees that can block natural air currents. To avoid total reliance on natural air movement, circulation fans can also be to increase air movement and promote the loss of body heat from the birds. These fans should be spaced and positioned to maintain air movement between fans and to direct their flow in a way that will increase the turbulent air movement around the birds. Spacing of the fans depends somewhat on their size, but they are generally spaced about 25 to 30 feet apart in curtain layer houses and 40 to 50 feet apart in broiler houses. Adequate insulation in the ceiling and sidewalls will pay dividends by reducing the amount of the sun's radiant heat energy that reaches the interior. Installing insulation to the end of a 24-inch roof overhang will prevent solar radiation from penetration the sidewalls. Insulation also reduces heating costs during winter months.

Forced ventilation

Inforced ventilation systems, all air movement is produced by fans in the building walls. Houses that use this type of ventilation are also referred to as controlled environment systems. Power ventilation houses can provide good, uniform airflow patterns under hot summer conditions if correct static pressure is maintained and airflow obstructions are avoided. It is very important to determine how much air should be moved through the building. This can be accomplished in two ways. Approximate values for the minimum volume of air required per pound of poultry body weight are given in Table 3. These values can be used to determine the total fan capacity required for the house. However, that the rates shown are minimum

Table 3. Recommended minimum ventilation rates based on body weight

Body weight (pounds)	Airflow per pound of body weight (cubic feet per minute)
1 to 6	1.0
6 to 15	0.8
15 to 30	0.7

Negative pressure systems use exhaust fans to provide air movement. Stale air is expelled from the house by fans at a slightly higher rate than air is allowed to enter through the vents. This creates a partial vacuum, causing the air to enter the house at a high velocity. The increased velocity creates more turbulent air movement. Negative pressure systems are designed to operate best with a static pressure drop of 0.03 to 0.08 inch of water. This pressure difference induces the air to travel from inlets along the ceiling until it meets a stream from inlets on the opposite side of the house. The location and orientation of the inlets is the single most important factor influencing the airflow pattern inside the building. Positive pressure systems use fans to blow fresh air into the building, creating a slightly higher pressure inside the house. Stale air is allowed to escape through strategically placed exhaust vents. Air movement is controlled by automatic environmental control mechanisms.

Tunnel ventilation

A new arrangement for ventilating poultry houses in the summer is tunnel ventilation. This method involves moving air along the building axis from inlets to exhaust fans, providing high airflow velocities. This rapid air movement increases convective heat loss, reducing the effective temperature experienced by the birds (Lacy and Czarick, 1992). Most of the benefits of tunnel ventilation occur at an air velocity of 350 feet per minute. This velocity should be considered the minimum for most house designs. Tunnel ventilation systems do not operate on a static pressure difference. In fact, they work best when there is no pressure difference between the inlets and the fans.

Evaporative cooling

An evaporative cooling system is an essential component of any hot-weather ventilation system. As house temperatures rise, the temperature difference between a bird's body and the ambient air decreases, which results in a decrease in heat loss from a bird. There are basically two types of evaporative cooling systems used in poultry houses: fogging systems and pad systems. While pad systems can only be installed in a power-ventilated house, fogging systems can be used in either power-ventilated or naturally ventilated housing to lower house temperatures during hot weather. A third system, sprinkling, has limited usage except in very dry climates.

Foggers

Foggers reduces air temperature in the house on hot days (90 o to 95^0 F) when humidity is low, especially during mid-day when humidity levels are lowest and temperature is highest. The foggers inject fine water particles into the warm inside air. As the water vaporizes, heat is absorbed from the air, lowering its effective temperature. When foggers are used, they should be operated intermittently or designed to avoid excessive water flow into the environment. If too much water flows through the foggers, humidity levels may increase to the point where birds can no longer cool themselves by evaporation. Fogging systems in naturally ventilated house are typically designed for a water flow rate of 50 to 100 gallons per hour. Fogging systems have also been used successfully in environmentally controlled poultry houses. Fogging systems that provide a reliable fine mist and that have water filters (to keep nozzles from clogging) and also have a positive shutoff to prevent dripping can provide successful cooling without causing wet litter. The water pressure should be at least 100 pounds per square inch (psi) to achieve a fine mist; a pressure 200 psi is preferred. The volume of water that goes through the fogging system and the number and placement of the nozzles are critical design considerations. A total flow rate of up to 1 gallon per hour per thousand cubic feet per minute (cfm) of ventilation can be used in tunnel-ventilated houses. Fogging nozzles and evaporative cooling pads are also used in combination with power ventilation systems and especially with tunnel ventilation. Evaporative cooling uses heat from the air to vaporize water, increasing humidity but lowering air temperatures. Evaporative cooling pads operate on the same cooling principle as foggers, except that the air is cooled when it passes through the wet pads as it enters the house. This method avoids the problem of wet litter sometimes encountered with foggers, allowing evaporative cooling pads to be used on a continuous basis. Aspen fiber and corrugated cellulose are two materials widely used as cooling pads. Similarly, sprinkling systems primarily act by bird surface wetting. Air flowing over the birds' body surfaces evaporates water off their bodies, producing cooling. Since the primary method of cooling is through bird wetting it is important that nozzles are spread out evenly throughout a house, so that all birds within the house are wetted when the nozzles are used. Sprinkler systems should operate off a 5 or 10-min interval timer to keep moisture levels within a house from becoming excessive.

Sprinkling systems are generally best suited for drier climates, where excess moisture added to the house quickly evaporates.

Stocking density

Heat loss often depends on the difference between the body temperature of birds and the ambient temperature. If stocking density is high, the radiant heat between the birds accumulates and the temperature increases. Birds in high density stocked barns tend to absorb each other's radiant heat load, which makes heat management more difficult for the birds. Therefore, the birds cannot lose body temperature. Reducing the bird density in the summer will give more floor space per bird and allow more heat to escape from underneath their bodies and from the litter. Also, less crowded barns allow birds to move more freely to nearby water lines. Where possible, and in particular in older broiler houses with less efficient ventilation equipment, it is sound practice to reduce stocking densities in the summer. It is possible to calculate the maximum stocking density that any particular poultry house can support in hot weather using known facts about the house and its ventilation efficiency.

Table 4. Minimum floor area recommendations for typical broiler weight categories.

Mature Bird Weight Kg	Recommended Minimum Density	
	m^2/Bird	Kg/m^2
1.7	0.06	27.80
2.0	0.07	27.80
2.2	0.08	27.80
2.5	0.09	27.80
3.5	0.13	27.80

Nutritional Management

Any management technique that increases nutrient intake during heat stress will minimize the drop in production efficiency. Three easy ways to increase nutrient consumption are to increase nutrient density, take advantage of natural increases in feed consumption at certain times of the day, and adjust ventilation fans to provide more cooling during the evening. A second alternative is to feed the birds at the time of day when feed consumption is highest. If birds are fed during the cool part of the day, feed consumption will be higher. Birds should not be fed during the afternoon in periods of hot weather since this will increase the amount of body heat that they must dissipate and thus increase the potential for heat prostration. Abrupt changes in feeding times should be avoided. A third technique is to cool the birds as much as possible during the evening hours. Hens or meat birds tend to build up body heat during extended periods of hot weather. If their body temperature can be reduced during the evening, the birds will be able to consume more feed in the early morning. The house can be cooled in the evening by setting the fan thermostats so that the fans will continue to run until the internal house temperature reaches 75°F (65°F for mature birds).

Drinking water

During heat stress, the bird tries to maintain its body temperature by increased respiration, i.e. evaporation of metabolic water, which may considerably increase the water requirement. Cool water (at 10-120C) should be supplied continuously to birds. Watering space should be doubled. Over head tanks and pipe system should be properly covered to keep the water cool. Birds reject warm water and that accentuates heat stress. Providing fresh cool water in noon time is very effective for internal cooling of body (heat sinks) and reducing symptoms of stress. Panting is accompanied by an increase in water loss so more water has to be consumed by birds during hot, dry weather in order to prevent dehydration. Drinking water cooler than body temperature will absorb body heat, which will help with cooling the bird. Adding an electrolyte to the drinking water will replenish vital nutrients that will help balance blood pH levels. Offering a night-time feeding program will encourage birds to eat during cooler periods and help maintain their performance during hot weather.

Preventive treatment for heat stress through drinking water:

a) In moderate hot weather

Ascorbic acid (Vit C) ....62.5 mg/litre
+ Acetylsalicylic acid 62.5 mg/litre
+ Sodium bi carbonates 75 mg/litre
+ Potassium chloride(KCl) 125 mg/Litre

b) In heat stress

Ascorbic acid (Vit C) …… 400 mg/ L
+ Electrolytes
+ Acetyl salicylic acid (Disprin 1 tablet/5 L)
+ Sodium bicarbonate 1gr/Litre

Feeding time

Feeding at the right time of the day is very important to help the birds cope with heat stress. During late afternoon a significant rise in body temperature can be observed, which, in severe cases, can cause bird mortality. This is not the hottest time of the day, but it is the peak time of digestion if the birds have been fed in the early/mid morning. A good strategy to take an unnecessary heat load off the birds is to withdraw feed 8 hours prior to the anticipated time of peak temperature. One third of the daily feed ration should be given in the morning and two thirds in the late afternoon. An additional advantage is the availability of calcium in the digestive system during s hell formation at night and in the early hours of the morning. This will improve shell quality and prevent the birds from depleting bone calcium. So-called 'midnight snacks' are a good tool to give hens extra feeding time in the cooler parts of the night. This does not necessarily need to be done at midnight, but rather 3 hours of darkness before and after the extra 1-2 hours of light is essential to avoid disturbing the lighting programme.

Feed stimulation

Low feed intake is the main cause of poor performance at high temperatures. The following practices can help to raise feed consumption and stimulate feed intake may be worthwhile considering:

- Wet mash feeding
- Pellet or crumble form of feed
- Low-calcium diets with choice feeding of calcium sources
- Frequent feeding and stirring of feed in the feeder
- Addition of fat or molasses so to increase feed palatability
- Run the feeder chains more frequently
- Empty them to avoid overflow if need be
- Feeders should run empty at least once a day to enhance the appetite and to ensure that the fine particles of the feed (premixes, vitamins etc.) are consumed
- The feed texture should not be too fine. Oil can be used to avoid “dusty” feed.

Nutrient requirement

In summer, a very direct way to ensure optimum nutrient intake despite decreases in feed consumption is to increase the nutrient density of the ration. Feed should be made denser with nutrients, vitamins and minerals to compensate for reduced intake. Thus as the hot season progresses it may be necessary to fine tune feed formula again in mid-summer. In addition following features, which have bearing on heat stress control, should be included in summer feed formula.

Energy

Energy intake is the most important nutrient limiting bird performance at high temperatures. The energy requirement for maintenance decreases by about 30kcal/day with increase in environmental temperature above 21 °C. Although the energy requirement for maintenance is lower at higher temperatures, most of the energy is wasted in heat dissipation so the absolute energy requirement is not affected by heat stress. The feed energy concentration should be adjusted to allow for the reduction in feed intake at higher temperatures. The concentration of energy should be increased by 10% during heat stress, whilst the concentration of other nutrients should be increased by 25%. Feed intake changes about 1.72% for every 1°C variation in ambient temperature between 18 and 32°C. However, the decline is much faster (5% for each 1°C) when the temperature rises to 32-38°C.

Fat/oil

Measures to increase feed intake include the inclusion of fat in the diet. Fats are good in summer because their heat increment value is lowest give better cooling effect in body because of higher water content and fat stimulates feed consumption. Digestion of fat produces less heat than the digestion of carbohydrates and proteins. Oil binds the fine particles in the feed and stimulates feed intake. In addition, fat offers an extra calorific value by decreasing the rate of passage of digest a, thereby increasing the utilization of nutrients. Fats or oils with more saturated fatty acids are preferred in hot humid climates. Additionally, it increases the energy level in the feed, which is very important to compensate the reduced energy intake due to less feed intake during the hotter periods. An additional advantage of oil is the content of linoleic acid, which improves the production and weight of the eggs. Fat has also been shown to slow down feed passage through the gastro-intestinal tract, and therefore increases nutrient utilization. Fat should be increased by 2 to 3% (Up to 5% oil can also be used) at the cost of carbohydrates without changing ME. Including oil in the diet has long proved to be beneficiary in hot climates and shows better effects than in moderate climates. For example, the inclusion of oil increased feed intake by 17.2% at 31°C compared to only 4.5% at temperatures of 10-18°C. Feed consumption increased up to 17% by 5% fat supplementation in heat stressed birds because fat improves palatability.

Protein

The requirements for protein and amino acids are independent of environmental temperature so heat stress does not affect bird performance as long as the protein requirement is met. Whether protein levels should be increased or decreased in diets to minimize heat stress and maintain production has been studied with different results. However, heat stress reduces feed intake and the levels of protein/amino acids need to be increased with the environmental temperature up to 30°C. At even higher temperatures, heat stress has a direct effect on production and there is no benefit in raising the protein level. Crude protein level in feed should not be increased and protein from only vegetable source should be used. Proteins in general and those from animal sources in particular have higher heat increment values i.e. produce more internal heat in the body. Secondly vegetable proteins (Soya, Sesame, Sun flower) are rich in Arginine. Under heat stress arginine absorption is low and those results in plasma aminoacid imbalance, leading to increased catabolism of amino acids adding to body heat. Hence vegetable proteins are preferred in summer. Consensus appears to be that the key to good nutrition is to focus on daily intake of essential amino acids while reducing total digestible protein intake within the constraints of available raw materials. The correct amino acid balance in the diet minimizes fat deposition in the liver, thereby increasing the survival of birds under heat stress. So, a low protein diet with balanced critical amino acids (methionine and lysine) is more beneficial than a diet high in total protein during hot periods. The oxidation of excess protein or amino acids generates metabolic heat.

Vitamins

Vitamins are unarguably very important components of a chicken's diet. Vitamin C and E are used in the poultry diet because of their anti-stress effects and because their levels is reduced during the heat stress (Njoku, 1986 and Richards, 1997). Vitamin C is thought to support the birds in handling heat stress, but the effects are not yet fully understood. Some birds may not be able to synthesise sufficient ascorbic acid to replace the severe loss of vitamins during heat stress. Because of the release of corticosteroids in heat stress, there is increased demand for Vit C by adrenal glands for controlled production of hormones needed for gluconeogenesis. (Kutlu and Forbes, 1993) reported that ascorbic acid reduces the synthesis of corticosteroid hormones in birds. By decreasing synthesis and secretion of corticosteroids, vitamin C alleviates the negative effects of stress.

The optimal effect was shown by adding 250-400 mg ascorbic acid/kg. Due to the lower feed intake at high temperatures, a sufficient supply of vitamins has to be guaranteed. Inclusion of Vit C at 150 - 200-400 Gr/ton of feed is recommended in summer months. If included in feed, there is no need to give; in water again. Many studies have indicated benefit of dietary vitamin E supplementation to laying hens during heat stress (Edens and Siegel, 1975). Vitamin C and vitamin E are primary antioxidants in biological systems and break the chain of lipid peroxidation in cell membranes. Regarding antioxidant property, there is a positive synergistic effect of vitamins C and E on the immune response (Siegel, 1995 and Bendich *et al.*,1984)

Minerals

During hot periods, mineral excretion is usually increased. It is therefore advisable to increase the mineral level in the formula. Since it is difficult to react fast enough through dietary changes, application via drinking water is recommended. Heat stress reduces calcium intake and the conversion of vitamin D3 to its metabolically active form, 1, 25(OH) 2D3, which is essential for the absorption and utilization of calcium. In effect, the calcium requirement of layers, particularly older birds, is increased at high environmental temperatures. To overcome this effect, extra calcium should be provided at the rate of 1g/bird in the summer months in the form of oyster shell grit or limestone chips can be offered. The optimum particle size is the one that supplies the required calcium at the time of shell formation. The minimum size to improve gizzard retention is about 1mm. Supplementation should be made over the normal dietary calcium level (3.75g/bird/d) recommended for layers. However, excessive levels of calcium reduce feed intake due to the physiological limit of calcium appetite and also reduced palatability Instead of increasing the diet specification, the calcium should be offered separately as a choice feed. Better results are obtained by offering the calcium source in the afternoon. The phosphorus level in diet must not be forgotten as excessive phosphorus inhibits the release of bone calcium and the formation of calcium carbonate in shell gland, thereby reducing the shell quality.

Electrolytes

The electrolyte balance in birds is altered during heat stress due to panting. Panting increases carbon dioxide loss in the bird, which reduces the bird's ideal water intake. By adding electrolytes to the feed or water, birds increase their water intake. This aids in keeping a constant body temperature, and also maintains an effective system of evaporative cooling. It has positive effect of increasing water intake, and also reducing systemic acidosis. The body weight gain can be increased up to 9% by addition of these chemicals in the feed of heat-stressed broilers. To compensate for the reduced feed intake under heat stress, dietary allowances for electrolytes (sodium, potassium and chloride) may be increased by 1.5% for each 1°C rise in temperature above 20°C. Electrolyte can also be given through feed instead of through drinking water. Supplementing the diet with 0.5% sodium bicarbonate or 0.3-1.0% ammonium chloride or sodium zeolites can alleviate the alkalosis caused by heat stress. Sodium bicarbonate stimulates feed and water intake at high environmental temperature. The excretion of potassium through urine is significantly higher at 35°C than at 24°C. The potassium requirement increases from 0.4-0.6% with a rise in temperature from 25 to 38°C. A daily potassium intake of 1.8-2.3g potassium is needed by each bird for maximum weight gain under hot conditions. Potassium chloride can be added to the drinking water (to give 0.24-0.30% K) but care must be taken to avoid imbalances.

e) Other recommendations

- Virginiamycin 15 to 20 ppm in feed apart from being growth promoter, reduces metabolic heat production, alleviates heat stress and stimulates immune responses.
- Anticoccidials: Nicarbazine and Monensin are contraindicated in summer. The former decreases tolerance to heat and the latter depresses water intake.
- Biotin supplementation at 150 micrograms / Kg feed is recommended.
- Vit K supplementation is recommended particularly at time of debeaking or if there is threat of coccidiosis because in heat stress blood clotting time is prolonged.
- Toxin binders: In wet summer, there is rapid growth and toxin formation in feed. Good quality toxin binders at higher dose should be used in feed.

Breeding Management

Selection for heat tolerance trait by using major genes

The breeder has many approaches possible. Selection can be directed at the quantitative genes responsible for heat resistance by challenging under controlled conditions or natural conditions. There are several genes that affect heat tolerance, such as the dominant gene for naked neck (Na), affect the trait directly by reducing feather cover, while the sex-linked recessive gene for dwarfism (dw), reduce body size and thereby reduce metabolic heat output, and the frizzle (F) gene causes the contour feathers to curve outward away from the body. In egg-type birds tested at higher temperatures where the Na gene improves heat tolerance, as indicated by higher egg production, better feed efficiency, earlier sexual maturity, larger eggs with possibly fewer cracks, and lower mortality (Merat, 1990). Similarly, frizzle (F) gene will reduce the insulating properties of the feather cover (reduces feather weight) and make it easier for the bird to radiate heat from the body. Horst (1988) also credited the slow feathering (K) gene with the indirect effects: (i) reduced protein requirement; (ii) reduced fat deposit during juvenile life; and (iii) increased heat loss during early growth, all of which may assist the bird in resisting heat stress. It has been suggested by Horst (1988, 1989) that several other genes may be useful in making fowl tolerant of tropical conditions. The recessive gene for silky (*h*), which affects the barbules on the feathers, may improve the ability to dissipate heat. The dominant gene for peacomb (*P*) reduced feather tract width, reduced comb size and changed skin structure. These may improve the ability to dissipate heat. The recessive, sex-linked, multiple-allelic locus for dermal melanin (*id*) may improve radiation from the skin. However, to date very few investigations have been reported on the use of these genes to develop heat tolerance in commercial-type birds.

Another way to exploit the heat tolerance trait possessed by native or indigenous chickens breeds or strains of tropical conditions (Horst, 1989; Mukherjee, 1992). Many of these indigenous village chickens could be upgraded by mating them to males from improved strains of indigenous stock, or by crossing them to exotic stock that have higher productivity and possibly one or two major genes for heat tolerance (Horst, 1989). The adaptability genes of the indigenous stock would be selected for along with the performance genes of the commercial stocks in the composite if selection is carried out under tropical conditions. The addition of major genes such as *Na* or *F* into these composites (if not already there) might help ensure there is greater heat tolerance as well as general adaptability. Such new strains developed from synthetic strains might then be useful in crosses to be used under tropical conditions.

Acclimatization or thermal conditioning of eggs and chicken to hot climate

In order to decrease the effect of heat stress on broilers, methods such as thermal conditioning are implemented (Mazzi, 2002, Yalcin *et al*., 1997). According to Yahav and McMurtry (2001), the main idea behind the thermal conditioning process is to incorporate thermoregulatory threshold response changes that enable chickens to cope, within certain limits, with acute exposure to unexpected heat spells. Since the technique of temperature conditioning takes advantage of the immaturity of the temperature regulation mechanism in the young chick (Dunnington and Siegel, 1984), it is hypothesised that a potentially better thermotolerance could be induced in the developing mechanism of thermoregulation by early conditioning during incubation or through a combination of this pre-hatch conditioning with early post-hatch conditioning. It has been shown that conditioning of posthatched chicks by exposure to moderate heat stress increase survival of adult chickens at high ambient temperature (Arjona *et al*., 1988, 1990; Yahav and Hurwitz, 1996).Yalcin *et al*. (2005) examined the effects of conditioning during and after incubation on thermal resistance, live weight, physiological response and proportional asymmetry in young and old broiler, and they stated that conditioning might help in overcoming heat stress during rearing and parent age is an important factor in this mechanism. It may be considered that there may be a relation between Hsp70 and resistance to higher temperatures as a result of the increase in Hsp70 quantity from high incubation temperature suggested that broilers gained stress experience in advance by being exposed to high temperature in incubation and no increase was observed in Hsp70 level when they exposed to heat stress later in life. A report by Wang and Edens (1993) showed that conditioning of chickens by daily exposure to high ambient temperature for 1 improved induction of HSP70 mRNA upon further exposure to a heat challenge. This report raised the expectation that improved HSP response could be a part of the mechanism that leads to acquisition of improved thermo-tolerance.

Conclusion

Both of the climate change and poultry productions have always negative impacts one over the other. Climate change is one of the most important environmental stressors challenging poultry production worldwide. The negative effects of heat stress on broilers and laying hens range from reduced growth and egg production to decreased poultry and egg quality and safety. However, a major concern should be the negative impact of heat stress on poultry welfare. Finally, it is important to mention that intervention strategies to deal with heat stress conditions have been the focus of many published studies, which apply different approaches, including environmental management (such as facilities design, ventilation, sprinkling, shading, etc.), nutritional manipulation (i.e., diet formulation according to the metabolic condition of the birds), as well as inclusion of feed additives in the diet (e.g., antioxidants, vitamins, minerals, probiotics, prebiotics, essential oils, etc.) and water supplementation with electrolytes. Nevertheless, effectiveness of most of the interventions has been variable or inconsistent. More recently, two innovative approaches have been explored, including early-life conditioning (i.e., perinatal heat acclimation) and genetic selection of breeds with increased capacity of coping with heat stress conditions (i.e., increased heat tolerance). However, these potential opportunities, although promising (particularly, for poultry production in hot climatic regions) still require further research and development.

References

Arjona, A.A., Denbow, D.M. and Weaver, W.D. Jr. 1988. Effect of heat stress early in life on mortality of broilers exposed to high environmental temperatures just prior to marketing. Poultry Sci. 67,226–231.

Attia, Y.A., Hassan, R.A., Tag El-Din, A.E., Abou-Shehema, B.M. 2011. Effect of ascorbic acid or increasing metabolizable energy level with or without supplementation of some essential amino acids on productive and physiological traits of slow-growing chicks exposed to chronic heat stress. J. Anim. Physiol. Anim. Nutr. 95, 744–755.

Avila, M. 1985. Intra and inter-household decision making in the Mangwende and Chivi Communal Areas: Preliminary results, Farming System Research Unit, Harare.

Ayo, J.O and Oladele, S.B. 1998. Stress and its adverse effects on modern poultry production. Student Veterinarian, 17, 6–10.

Ayo, J.O., Obidi, J.A and Rekwot, P.I. 2011. mSeasonal variations in feed consumption, hen-day, mortality and culls of Bovans Black chickens in Proceedings of the 35th Annual Conference of the Nigerian Society for Animal Production, pp. 415–418,University of Ibadan.

Banks, S., King, S.A., Irvine D.S and Saunders, P.T.K. 2005. Impact of a mild scrotal heat stress on DNA integrity in murine spermatozoa. Reproduction, 129(4), 505–514.

Bartlett, J.R and Smith, M.O. 2003. Effects of different levels of zinc on the performance and immunocompetence of broilers under heat stress. Poult. Sci. 82, 1580–1588.

Bendich, A., Apolito, P.D., Gabriel, E and Machlin, L.J. 1984. Interaction of dietary vitamin C and E on guinea pig immune responses to mitogens. J. Nutr. 114, 1588-1593.

Bhadauria Pragya., Kataria J.M., Majumdar, S., Bhanja, S.K., Divya and Kolluri, G. 2015. Impact of hot climate on poultry production system-A Review. Journal of Poultry Science and Technology. 2(4)56-63.

Bonnet, S., Geraert, P.A., Lessire, M., Carre, B and Guillaumin, S. 1997. Effect of high ambient temperature on feed digestibility in broilers. Poult. Sci. 76, 857–863.

Bucklin, R.A., Bottcher, R.W., VanWicklen, G.L and Czarick, M. 1993. Reflective roof coatings for heat stress relief in livestock and poultry housing. Applied Engineering in Agriculture 9(1), 123–129.

Costa, N.D. 2009. Climate change: Implications for water utilization in animal agriculture and poultry, in particular. Proceedings of the 20th Annual Australian Poultry Science Symposium, February 9-11, 2009, University of Sydney, Australia.

Dai, S.F., Gao, F., Xu, X.L., Zhang, W.H., Song, S.X and Zhou, G.H. 2012. Effects of dietary glutamine and gamma-aminobutyric acid on meat colour, pH, composition, and water-holding characteristic in broilers under cyclic heat stress. Br. Poult. Sci. 53, 471–481.

Decuypere, E and Buyse, J. 2004. New approach of testing the effect of heat stress on eggshell quality: Mechanical and material properties of eggshell and membrane. Br. Poult. Sci. 45, 476–482.

Deeb, N and Cahaner, A. 2002. Genotype-by-environment interaction with broiler genotypes differing in growth rate. 3. Growth rate and water consumption of broiler progeny from weight-selected versus nonselected parents under normal and high ambient temperatures. Poult. Sci. 81, 293–301.

De-Fariara, D.E., Junqueira, O.M., Souza, P.A and Titto, E.A. I. 2001. Performance, body temperature and egg quality of laying hens fed vitamins D and C under three environmental temperatures. Brasilian Journal of Poultry Science. 3, 49–56.

Demeke, S. 2004. Egg Production and Performance of local white leghorn hens under intensive and rural household conditions in Ethiopia. LRRD 16: 2.

Dunnington, E.A. and Siegel, P.B. 1984: Thermoregulation in newly hatched chicks. Poult. Sci. 63, 1303-1106.

Ebeid, T.A., Suzuki, T and Sugiyama, T. 2012. High temperature influences eggshell quality and calbindin-D28k localization of eggshell gland and all intestinal segments of laying hens. Poult. Sci. 91, 2282–2287.

Edens, F.W and Siegel, H.S. 1975. Adrenal responses in high and low acth response lines of chickens during acute heat stress. Gen. Comp. Endocrinol. 25, 64-73.

Edens, F.W. 2009. Effect of environmental stressors on male reproduction. Poultry Science, 62(8),1676–1689,1983.

Etches, R. J., John, T. M and Verrinder Gibbins, A.M. 1995. Behavioural, physiological, neuroendocrine and molecular responses to heat stress. Ed. Daghir, N.J. CAB International, 31–65.

FAO, 2010a. Poultry Meat and Eggs: Agribusiness Handbook. Director of Investment Centre Division, FAO., Rome, Italy, pp: 77.

FAO, 2010b. The State of Food and Agriculture 2009. Live Stock in the Balance. Bernan Assoc., USA., ISBN: 9789251062159, Pages: 166.

Fedde, M.R. 1998. Relationship of structure and function of the avian respiratory system to disease susceptibility. Poult. Sci. 77, 1130–1138.

Felver-Gant, J.N., Mack, L.A., Dennis, R.L and Eicher, S.D and Cheng, H.W. 2012. Genetic variations alter physiological responses following heat stress in 2 strains of laying hens. Poult. Sci. 91, 1542–1551.

Freeman, B.A and Crapo, J.D. 1982. Biology of disease: Free radicals and tissue injury. Lab. Invest. 47,412-426.

Ghazi, S.H., Habibian, M., Moeini, M.M and Abdolmohammadi, A.R. 2012. Effects of different levels of organic and inorganic chromium on growth performance and immunocompetence of broilers under heat stress. Biol. Trace Elem. Res. 146, 309–317.

Gilbert, M., Slingenbergh, J and Xiao, X. 2008.Climate change and avian influenza, Revue Scientifiqueet Technique. 27(2), 459-466.

Gregory, N.G. 2010. Food Research International. 43 (7),1866-1873.

Grimes, J and Daghir, N.J. 2009. ed. poultry production in hot climates. J. Applied Poult. Res. 18, 131-134.

Guis, H., Caminade, C., Calvete, C., Morse, A.P., Tran, A and Baylis, M. 2011. Modelling The effects of past and future climate on the risk of bluetounge emergence in Europe. Journal of Rural Sociology Interface. 10. 1098/rsif.2011.0255.

Horst, P. 1988. Native fowl for a reservoir of genomes and major genes with direct and indirect effects on productive adaptability. Proceedings of the 18th World's Poultry Congress, Nagoya, Japan, pp. 99–105.

Horst, P. 1989. Native fowl as a reservoir for genomes and major genes with direct and indirect effects on the inadaptability and their potential for tropically oriented breeding plans. Archiv fur Geflugelkunde. 53, 93–101.

ILRI. 2006. Functional gene discovery for disease resistance in chicken. International Livestock Research Institute. http : // www.ilri.org / Functiona lGene Discovery.

Imik, H., Atasever, M.A., Urgar, S., Ozlu, H., Gumus, R and Atasever, M. 2012. Meat quality of heat stress exposed broilers and effect of protein and vitamin E. Br. Poult. Sci. 53, 689–698.

Imik, H., Ozlu, H., Gumus, R., Atasever, M.A., Urgar, S and Atasever, M. 2012. Effects of ascorbic acid and alpha-lipoic acid on performance and meat quality of broilers subjected to heat stress. Br. Poult. Sci. 53, 800–808.

Ivo, A.M. 2009. Why village poultry is a necessary route for cameroonflAfrican Centre for Community and Development, Bradford, UK.

Khan, S.H. and Sarda, K. 2003. Effect of vitamin C supplementation on the performance of Desi, Fayoumi and commercial White Leghorn chickens exposed to heat stress. Pakistan Veterinary Journal. 25(4), 116–119.

Kutlu, H.R and Forbes, J.M. 1993. Changes in growth and blood parameters in heat-stressed broiler chicks in response to dietary ascorbic acid. Livestock Prod. Sci. 36, 335-350.

Lacy, M.P and Czarick, M. 1992. Tunnel-ventilated broiler houses: broiler performance and operating costs. Journal of Applied Poultry Research 1, 104–109.

Lin, H., Mertens, K., Kemps, B., Govaerts, T., De Ketelaere, B., De Baerdemaeker, J., Decuypere, E and Buyse, J. 2004. New approach of testing the effect of heat stress on eggshell quality: Mechanical and material properties of eggshell and membrane. Br. Poult. Sci. 45,476–482.

Lourens, H., Van den Brand, M.J.W. Heetkamp, R. Meijerhof and Kemp, B. 2007. Effects of eggshell temperature and oxygen concentration on embryo growth and metabolism during incubation," Poultry Science. 86(10), 2194–2199.

Lourens. 2001. The importance of air velocity in incubation. World Poultry, 17(3)29–30.

Lu, Q., Wen, J and Zhang, H. 2007. Effect of chronic heat exposure on fat deposition and meat quality in two genetic types of chicken. Poult. Sci. 86, 1059–1064.

Mack, L.A., Felver-Gant, J.N., Dennis, R.L and Cheng, H.W. 2013. Genetic variation alter production and behavioral responses following heat stress in 2 strains of laying hens. Poult. Sci. 92, 285–294.

Mazzi, C.M., Ferro, M.I.T., Coelho, A.A.D., Savino, V.J.M., Macari, M.., Ferro, J.A., Givisiez, P.E.N., Giachetto, P.F., Silva, M.M., and Dionello, N.J.L. 2002. Effect of heat exposure on the thermoregulatory responses of selected naked neck chickens. Braz. J. Vet. Res. Anim. Sci., 54 (1): 35-44.

McDaniel, C.D., Bramwell R.K and Howarth, Jr B. 1996. The male's contribution to broiler breeder heat-induced infertility as determined by sperm-egg penetration and sperm storage within the hen's oviduct. Poult. Sci. 75(12),1546–1554.

McDaniel, C.D., Bramwell, R.K., Wilson, J.L and Howarth, B. 1995. Fertility of male and female broiler breeders following exposure to elevated ambient temperatures. Poult. Sci. 74(6), 1029–1038.

Merat, P. 1990. Pleiotropic and associated effects of major genes. In:Crawford, R.D.(ed.) Poultry Breeding and Genetics. Elsevier, Amsterdam. 429–467.

Mitchell, M.A. 1985. Effects of air velocity and convective and radiant heat transfer from domestic fowls at environmental temperatures of 20 and 30°C. British Poultry Science. 26, 413–423.

Morsy. 1998. Study of haematological parameters in the Nigerian local chicken. Nigerian Journal of Animal Production. 23, 94–97.

Mukherjee, T.K. 1992. Usefulness of indigenous breeds and imported stocks for poultry production in hot climates. Proceedings of the 19th World's Poultry Congress,Amsterdam, the Netherlands. 2, 31–37.

Mustaf, S., Kahraman, N.S and Firat, M.Z. 2009. Intermittent partial surface wetting and its effect on body-surface temperatures and egg production of white brown domestic laying hens in Antalya (Turkey). Br. Poult. Sci. 50, 33–38.

Niu, Z.Y., Liu, F.Z., Yan, Q.L and Li, W.C. 2009. Effects of different levels of vitamin E on growth performance and immune responses of broilers under heat stress. Poult.Sci. 88, 2101–2107.

Niu, Z.Y., Liu, F.Z., Yan, Q.L and Li, W.C. 2009. Effects of different levels of vitamin E on growth performance and immune responses of broilers under heat stress. Poult. Sci. 88, 2101–2107.

Njoku, P.C. 1986. Effect of dietary ascorbic acid (vitamin C) supplementation on the performance of broiler chickens in a tropical environment. Anim. Feed Sci. Technol. 16,17-24.

Njoku, P.C. 1989. Effects of dietary inclusion of ascorbic acid and palm oil on the performance of laying hens in a hot tropical environment. British Poultry Science. 30(4), 831–840.

Pant, K.P. 2011. Economics of climate change for small holder farmers in Nepal: A review. J. Agric. Environ. 12, 113-126.

Richards, M.P. 1997. Trace mineral metabolism in the avian embryo. Poult. Sci. 76,152-164.

Sahin, N., Sahin, K and Kucuk, O. 2001. Effects of vitamin E and vitamin A supplementation on performance, thyroid status and serum concentrations of some metabolites and minerals in broilers reared under heat stress (32fC). Veter inarni Medicina. 46(11-12),286–292.

Seo, S.N and R.O. Mendelsohn, 2006. The Impact of Climate Change on Livestock Management in Africa: A Structural Ricardian Analysis. World Bank Publications, USA., Pages: 48.

Settar, P., Yalcin, S., Turkmut, L., Ozkan, S and Cahanar, A. 1999. Season by genotype interaction related to broiler growth rate and heat tolerance. Poult. Sci. 78, 1353–1358.

Siegel, H. S. 1995. Stress, Strains & Resistance. Br. Poult. Sci. 36: 3-22.

Simmons, J.D., Lott, B.D and May, J.D. 1997. Heat loss from broiler chickens subjected to various wind speeds and ambient temperatures. Applied Engineering in Agriculture 13, 665–669.

Sohail, M.U., Hume, M.E., Byrd, J.A., Nisbet, D.J., Ijaz, A., Sohail, A., Shabbir, M.Z and Rehman, H. 2012. Effect of supplementation of prebiotic mannan-oligosaccharides and probiotic mixture on growth performance of broilers subjected to chronic heat stress. Poult.Sci. 91, 2235–2240.

Wang, S and Edens, F.W. 1993. Stress-induced heat-shock protein synthesis in peripheral leukocytes of turkeys (Meleagrisgallopavo). Comp. Biochem. Physiol. 106B, 621–628.

Wilson, H.R. 2001. Physiological requirements of the developing embryo: temperature and turning in Avian Incubation, S.G. Tullet, Ed., Poultry Science Symposium, 22, pp. 145–156,Butterworths-Heinnemann, London, UK, 1991. 12, p. 188.

Yahav, S and Hurwitz, S. 1996. Induction of thermotolerance in male broiler chickens by temperature conditioning at an early age. Poultry Sci. 75, 402–406.

Yahav, S and McMurtry, J. 2001. Thermotolerance acquisition in broiler chickens by temperature conditioning early in life–the effect of timing and ambient temperature. Poult. Sci. 80, 1662-1666.

Yalcin S and Siegel, P.B. 2003. Exposure to cold or heat during incubation on developmental stability of broiler embryos . Poult. Sci. 82 (9), 1388–1392.

Yalcin, S., Ozkan, S., Çabuk, M., Buyse, J., Decuypere, E and Siegel, P.B. 2005. Pre- and postnatal conditioning induced thermotolerance on body weight, physiological responses and relative asymmetry of broilers originating from young and old breeder flocks. Poult. Sci., 84, 967-976.

Yalcin, S., Settar, P., Ozkan, S and Cahaner, A. 1997. Comparative evaluation of three commercial broiler stocks in hot versus temperate climates. Poult. Sci. 76 (7), 921-9.

Zhang, Z.Y., Jia, G.Q., Zuo, J.J., Zhang, Y., Lei, J., Ren, L and Feng, D.Y. 2012. Effects of constant and cyclic heat stress on muscle metabolism and meat quality of broiler breast fillet and thigh meat. Poult. Sci. 91, 2931–2937.

Zhou, W.T., Fijita, M., Yamamoto, S., Iwasaki, K., Ikawa, R., Oyama, H and Horikawa, H. 1998. Effects of glucose in drinking water on the changes in whole blood viscosity and plasma osmolality of broiler chickens during high temperature exposure. Poult. Sci. 77, 644–647.