International Journal of Engineering Applied Sciences and Technology, 2019
Vol. 4, Issue 8, ISSN No. 2455-2143, Pages 72-83
Published Online December 2019 in IJEAST (http://www.ijeast.com)

STATE-OF-THE-ART TECHNOLOGIES FOR ASSESSING THERMAL COMFORT OF BROILER CHICKENS

Ayoola Olawole Jongbo
*Department of Agricultural and Environmental Engineering, Federal University of Technology, P.M.B. 704, Akure, Ondo State, Nigeria

Adekunle Temidayo Atta
Institute of Agricultural Research and Training, Obafemi Awolowo University, Moor Plantation, Ibadan, Oyo State, Nigeria

Abstract- **The thermal assessment of the environment where poultry birds are raised is very important to prevent them from poor welfare, poor health and poor performance. Contain evaluation of poultry environment would enable the poultry growers to understand the conditions of their flocks and also to know when there is a change in the behaviours of the birds. In order to assess the thermal comfort of broiler chickens without disturbing them, there is a need for the state-of-the-art technologies. There are different technologies adopted by various researchers to evaluate the thermal comfort of broiler chicken subjected to different environmental conditions. However, there is no comprehensive report on the techniques for assessing the thermal comfort of broiler chicken. Therefore, this study intended to comprehensively compile all the available technologies which have been used by the researchers to evaluate the thermal comfort of broiler chickens. This study has found out that, apart from thermal indices, precision livestock farming (PLF) equipment are very important tools which could be adopted by all broiler chicken growers to assess the thermal comfort of broiler chickens during hot conditions in order to prevent them from heat stress. Furthermore, it has also been reported that most farmers may not be able to afford the tools due to their high initial investment, unavailability of technical-know-how and high maintenance cost most especially in the developing countries.**

Keywords: **Thermal comfort; Broiler chickens; Precision livestock farming; Heat stress; hot condition.**

I. THERMAL COMFORT OF BROILER CHICKENS

The thermal condition inside the animal sheds is very important if good welfare and health of animals are to be ensured. The survival of animals strongly depends on their environment (Gaughan *et al*., 2009) during hot periods if animal building configuration and ventilation system are improperly designed (Lima *et al*., 2011; Gaughan *et al*., 2009). It could affect livestock homeostasis, production efficiency and growth (Purswell *et al*., 2012; Cangar *et al*., 2008). For broilers to survive during hot periods, they usually change their behaviour and physiology by reducing their feed consumption in order to minimise their core body temperature (DeShazer *et al*., 2009). These behavioural and physiological changes have been shown to cause a reduction in body growth and meat yield and quality (Arias *et al*., 2008). According to Tao and Xin (2003a), the body temperature between 41.0 and 42.0 °C of broilers is expected to be maintained as the ambient temperature is within the thermal neutral zone (18.0 ºC – 24.0 ºC). However, broiler chickens could find it difficult to maintain homeothermy if there is an increase in the ambient temperature. This may inevitably result in high mortality and economic losses (Tao and Xin, 2003a).

Broilers are homeotherms and they rely mainly on the thermal conditions of their environment for thermal comfort, body growth and performance. As the environment becomes hot, broilers require adequate cooling (Welker *et al*., 2008)and minimise feed consumption to survive heat stress (Cassuce *et al*., 2013; Welker *et al*., 2008; Dozier III *et al*., 2011). For broilers at different stages perform optimally, the optimum temperatures within their confined environment is shown in Table 1.

Table - 1 The ambient temperature required for broiler optimal performance (Cassuce *et al*., 2013)

Growth stages (Days)	Ambient temperature (°C)
1 to 7	32.0 - 34.0
8 to 14	28.0 - 32.0
15 to 21	26.0 - 28.0
22 to 28	24.0 – 26.0
29 to 35	18.0 – 24.0
36 to 42	18.0 - 24.0

The factor influencing the heat transfer between broiler and the environment are; their heat and moisture demands, nature of feather and their thermoregulation as broiler chickens dispel heat and moisture during thermoregulation (Blanco and Gous, 2006). The microclimate conditions of the broiler building are usually affected (altered) as the birds dissipate heat and moisture. This alteration would also result in a new thermal response of birds and their thermal response would cause additional environmental changes and the process continues (Gous *et al.*, 2006). Exposure of broiler chickens to the environmental changes could be detrimental as it could affect their welfare, performance and the economy of the farmers (Lara and Rostagno, 2013).

The microclimate of broiler chickens is very important when monitoring the thermal conditions on the building where the birds are kept. It replicates the environmental parameters (temperature, relative humidity and air velocity) felt by the birds either during hot or cold conditions (Reiter and Bessei, 2000). Against the believe of some farmers that the thermal conditions above the birds could represent the microclimate at the broiler level (0.2 m above the floor), a report by Purswell *et al.* (2008) had shown that temperature above 0.2 m differed by about 4.0 ˚C from that obtained at the broilers' microclimate which was found to be higher than that ambient temperature above the broiler chicks. The results of the study were obtained by fitting an integral temperature sensor to the back feather of the broiler chicks to evaluate the temperature in the animal occupied zone. At the same time, some thermocouples were positioned above the floor to assess the ambient temperature inside the building.

II. HEAT TOLERANCE OF BROILERS

Heat tolerance is the ability of livestock to maintain core body temperature when subjected to hot condition. The quantity of metabolic heat production and heat dissipation by animals determine the extent of heat stress they are subjected to (Berman, 2012). The productivity and welfare of animals are influenced by the heat from their immediate environment. As a result, consideration of potential heat-tolerant strains and heat stress relief for optimal production of livestock is unavoidable. Poultry production has recently witnessed progress in the genetic modification of fast-growing and high meat yield broiler chickens. But the genetically selected birds lack complete visceral organs development which makes them susceptible to heat stress during acute environmental conditions (Piestun *et al.*, 2008a, 2008b). Hot environmental conditions are detrimental to broiler chickens they could increase the metabolic heat production, economic losses, mortality rate, poor meat quality and meat production of broiler chickens (St-Pierre *et al.*, 2003).

The high body temperature and high metabolic heat production of broilers during hot periods could occur as a result of non-functional nervous thermoregulatory mechanisms and thermoregulatory control system (Janke *et al.*, 2002). Thus, body temperature regulation and the control of metabolic heat production of broilers could be attained by using an environmental control system and through the thermal modification of broiler chicks during embryogenesis (Tzschentke, 2008). Some research works have indicated that the exposure of broiler chicks to high temperature during embryogenesis could enable broiler chicks to survive hot conditions up to about 10 days after hatching (Yahav *et al.*, 2004b), 28 days after hatching (Loyau *et al.*, 2013) and adult broiler chickens (Piestun *et al.*, 2011). However, Collin *et al.*, (2007) showed that thermal manipulation of broiler chicks during embryogenesis could not improve heat tolerance of broiler for a long time but could influence the breast muscle yield of broilers at 42 days.

III. METHODS OF EVALUATING THE THERMAL COMFORT OF BROILER CHICKENS

Different methods could be used to assess the thermal comfort of broiler chickens under any climatic condition. Various research works have been carried out globally to assess the thermal comfort of broilers at different growing stages in order to measure the effect of hot conditions on broiler chickens' health, production and welfare. However, there is no comprehensive report concentrated on the methods that could be used for assessing the thermal comfort broiler chickens. This paper intended to fill the gap by providing in details the different ways that the thermal comfort of broiler could be assessed.

A. The level of vocalisation of broiler chickens -

Vocalisation is an important aspect of livestock production. In poultry production, broiler chickens have the capacity to produce about thirty different sounds (Moura *et al*., 2008) based on their conditions at that moment. The sounds of broilers vary from aggression due to separation from other birds (Marx *et al.*, 2001), pain due to thermal environments (Moura *et al*., 2008), hunger and need (Weary and Fraser, 1995), to inability to eat properly due to stress exposition (Zimmerman and Koene, 1998). In order to use the sound of broiler chickens as a thermal comfort indicator, it must predict exactly the condition of the birds and must be constant (Zimmerman and Koene, 1998). For broiler chicks, it is possible to assess their thermal comfort by their sound's amplitude and frequency (Moura *et al.*, 2008; Fontana *et al.*, 2014). Moura *et al.* (2008) carried out a study to assess the thermal comfort of broiler chicks that were subjected to different thermal conditions. In their research work, broiler chicks were subjected to warm condition (24.0 ºC – 29.0 ºC) and cold condition (15.0 ºC – 23.0 ºC). The amplitude and frequency of the sound of the broiler chicks were monitored with microphones and the behaviour of the chick to environmental conditions were observed with the real-time video camera. It was observed that thermal conditions to which the birds were subjected to affected their migration within the shed and their level of vocalisation. It was found out that as the air temperature increased, there was an increase in the chick migration from one region to another within the shed and an apparent increase in the vocalisation of the chicks. As the air temperature reduced below the thermal comfort zone, there was a decrease in the chicks' vocalisation compared with that of the period when the air temperature was over the thermal comfort zone. It was concluded that when broilers chickens are subjected to heat stress, their stress level could be assessed whenever there is an increase in their sound's amplitude and frequency (Moura *et al*., 2008).

B. Behavioural and productive responses -

The way the microclimate affects different strains of broiler chickens differs. Broiler chickens, bred for fast growth tend to adapt to hot conditions by changing their behaviours (distribution) while those with slow growth genes survive cold climatic conditions by altering their rate of feed consumption (Nielsen, 2012). Ferraz *et al.* (2014) evaluated the behavioural and productive responses of broilers chicks that were subjected to various air temperature. The chicks were at day one of age introduced an air temperature of 33.0 ˚C in a wind tunnel ventilated building. The behavioural response such as clustering, rates of drinking and feeding and distribution of the chicks subjected to different air temperatures were observed with the real-time video camera mounted above the chicks. Similarly, the feed consumption, water intake and body weight gain which were tagged as the productive response of the chicks were appraised. They found out that the chicks expended about 68 % and 12 % of the time huddling together and spreading apart respectively at a temperature of 27.0 ˚C. When the air temperature was increased to 36.0 ˚C, there was a reduction of about 51 % and 16 % in the time spent huddling and spreading respectively. In addition, the broiler chicks, subjected to 36 ˚C were found spending about 28 % and 5 % of the time feeding and drinking respectively. The authors added that a high correlation of about 96 % was found between the behavioural and productive responses of the broiler chicks and their thermal comfort. From this result, it could be concluded that behavioural and productive responses of broiler chickens could be used as indicators for evaluating their thermal comfort.

The thermal comfort zone of broiler breeders was assessed by Pereira and Nääs (2008) using their behavioural response. They implanted electronic identification transponders in the female broiler breeders while radio frequency identity (RFID) transponder-reader was positioned in the drinker area to monitor breeders' drinking behaviour. They discovered that the female broiler breeders were found spending their time drinking from the drinkers at about 67 % when the air environmental temperature was between 20.0 ˚C and 29.0 ˚C and relative humidity between 70.0 % and 80.0 %. The conclusion from the study was that behavioural pattern such as the time spent drinking water could be used to determine when the birds are experiencing heat stress or not and that the pattern could be adopted by poultry growers to control the climatic conditions inside the commercial broiler sheds.

C. Surface temperature -

A crucial parameter in the birds' thermal biology, which could contribute significantly to the thermal comfort of broiler chickens is the surface temperature (Cangar *et al*., 2008). With the latest technological development, the surface temperature of broiler chickens could easily be estimated using non-invasive technology called infrared thermography (IR). The technique of thermography involves the collection of emission (radiation) from the object's (for example broiler chickens) surface and then converts it to an electrical signal. The signal then creates an image of the exposed surface using various colours to express temperature distributions of the surface measured (Naas *et al*., 2014). Generally, the physiological response of the object such as broilers subjected to heat stress usually results in the skin temperature's fluctuation (Shinder *et al*., 2007). The rate of blood flow rate in birds could be influenced by the thermal stress to which they are subjected. According to Altan *et al*. (2003), broilers subjected to dehydration could reduce the rate of blood flow to its skin in order to control thermal exchange between their core body and the skin surface.

The heat production of broiler chickens could be used as a mechanism for assessing their thermal comfort (Nascimento *et al*., 2011). The surface temperatures of broiler chickens at different ages (7 days to 35 days old) exposed to different air temperatures were assessed by Nascimento *et al.* (2011) using an infrared thermal camera. The authors discovered that the surface temperature of broiler chickens was found increasing with an increase in air temperature from 18.0 ˚C to 32.0 ˚C. They also found that the age of broilers only had little or no impact on their surface temperatures. They added that broilers' surface temperature was found to be at its peak when the birds were 14 days old but dropped as the broilers approached table size (35 days old). Similarly, Nääs *et al.* (2010) assessed the thermal comfort of 42-day old broilers before the birds were taken to the abattoir. They found out that the body regions of the birds without feathers responded quickly to changes in the thermal environment compared to the feathered areas of the broilers' body. The temperature of the surfaces with feathers was found to be similar to the thermal temperature of the environment to which the birds were subjected to. It could be concluded from these studies that surface temperature of broiler chickens if regularly assessed could be used to determine their thermal comfort and at the same time used as a control measure for monitoring the environmental conditions inside the broiler buildings.

The spatial surface temperature distributions of broilers using infrared thermography were quantified by Cangar *et al.* (2008). They reported that the surface temperatures of broiler at different body parts such as shanks, feet, wattle, comb, back, and head differed by more than 10 ˚C when the birds were subjected to a fixed environmental condition. However, they recorded that the rate of blood flow in body parts without feathers was higher than the areas with feathers. This is an indication broiler could easily thermoregulate with their featherless body parts, where the blood flow rate is higher than the feathered parts during hot conditions. As reported by Tessier *et al.* (2003) contrary to that of Nascimento *et al.* (2011), the surface temperature gradient of birds increased with age showing that there is an interaction between broiler's age and their surface temperature distributions. From the report of Tessier *et al.* (2003), the surface temperatures of the younger birds were higher than the mature broilers due to their body-surface area ratio and the thickness of their feathers. This indicates that mature broilers would find it hard to lose body heat as the environmental conditions exceed their thermal comfort zone.

D. Thermal indices -

Thermal indices are mathematical expressions, that contain some environmental parameters such as temperature, humidity and air velocity, which could be used for estimating the thermal comfort of livestock and for determining the level of heat stress in livestock production (Sejian *et al.*, 2012). The losses related to heat stress could be monitored and prevented by weather safety indices (Hahn *et al.*, 2009). In addition, they could serve as a standard for categorising the environmental conditions in all livestock productions including animal transportations (Samal *et al.*, 2017). They could also be used as a "basis for the strategic management practices" in livestock productions (Samal *et al.*, 2017). They are also useful in the prediction of the effects of thermal conditions on animal productivity (Purswell *et al.*, 2012). The level of sensitivity of different animals to heat stress differs (Bohmanova *et al.*, 2007). Ruminants (cows, sheep and goats) could survive warm conditions longer than other animals such as broilers and pigs due to their lack of sweating glands. Broiler chickens could not lose heat by sweating but could do so by panting when subjected to a warm environment.

Some studies, as shown in Table 2, have shown that the thermal comfort of fast-growing birds (broiler chickens) could be assessed by using thermal indices based on their physiological and productive responses (Chepete *et al.*, 2005; Tao and Xin, 2003b). Environmental factors such as air velocity, air temperature and relative humidity have been indicated as the main factors affecting the physiological and productive responses livestock. Tao and Xin (2003) established an index called temperature-humidity-velocity index (THVI) which was based on the body temperature response of adult broilers exposed to different combinations of environmental conditions for evaluating the thermal comfort of the adult broiler. The homeostasis of the birds was determined using the index. They reported that homeostasis state of broilers could be considered normal if the body temperature rise threshold is 1.0 °C. As the body temperature rise threshold reached 2.5 °C, it could be considered as an alert. Danger and demand for an emergency could occur as the body temperature threshold reached 4.0 °C and above.

Authors and years	Indices	Animals	Remarks
Tao and Xin (2003)	$THVI = (0.85T_a + 0.15T_w)V^{-0.058}$	Ross male broiler chickens	The model was developed based on the core body temperature rise of adult broiler chickens subjected to severe thermal conditions in a controlled environment.
Chepete *et al.* (2005)	$THI = 0.62T_a + 0.38T_w$ for 3-4 weeks old broiler chickens $THI = 0.71T_a + 0.29T_w$ for 5-6 weeks old broiler chickens	Cobb 500 Broiler chickens	The indices indicated that broiler chickens kept in a non-controlled semi-arid environmental condition were mostly affected by the air temperature compared to another environmental factor such as relative humidity.
where THI = temperature-humidity index, THVI = temperature-humidity-velocity index, T_w = wet-bulb temperature (°C), T_a = dry bulb temperature (°C).			

Table - 2 Summary of the environmental indices for assessing the thermal comfort of farm animals

IV. TECHNOLOGY FOR ASSESSING THE THERMAL COMFORT OF BROILER CHICKENS

Precision Livestock Farming (PLF) is a newly designed scientific discipline where data obtained from animal behaviour and their surroundings, using sensors, could be unified with the real-time monitoring of animal welfare, health and productions (Ismayilova, 2013). PLF could afford the animal growers the opportunity to monitor their livestock in order to provide better care and environment for the animals (Ismayilova, 2013). An important aspect of PLF is the use of non-invasive and non-destructive sensors for the monitoring of behaviours of farm animals. The detained of the available techniques or instrumentations used in PLF and their applications can be found in Table 3. In this section, the uses of PLF technologies for assessing animal thermal comfort were discussed.

International Journal of Engineering Applied Sciences and Technology, 2019
Vol. 4, Issue 8, ISSN No. 2455-2143, Pages 72-83
Published Online December 2019 in IJEAST (http://www.ijeast.com)

Table - 3 Techniques for evaluating the thermal comfort of broiler chickens

Authors	Indicators	Instrumentation	Research findings
Moura *et al.* (2008)	**Distributions of broiler chicks; vocalisation amplitude and frequency**	**Real-time video camera, microphone**	**The hot environment had a significant impact on the broiler chicks' distribution and noise level.**
Pereira and Nääs (2008)	**Drinking behaviour**	**Real-time video camera**	**As the air temperature increased, birds were found visiting drinkers more often.**
Nielsen (2012)	**Migration and feed consumption**	**Real-time video camera**	**Non-uniformity of the environmental condition within the broiler building caused the birds to migrate to the cooler region within the broiler building.**
Nascimento *et al*. (2011)	**Surface temperature**	**Infrared thermography (IRT)**	**The surface temperature of broiler chickens was directly proportional to the air temperature changes in the broiler building.**
Baracho *et al*. (2011)	**Surface temperature**	**Infrared thermography**	**Skin temperature of birds at different locations within the poultry building differed.**
Pereira *et al*. (2005)	**Aggressive behaviour**	**Real-time video camera**	**Low air temperature triggered the aggressive behaviour of broiler breeders when offered food.**
Nääs *et al*. (2012)	**Broiler distribution**	**Real-time video camera and algorithm**	**Birds clustered around feeders when the air temperature was low. Separation from one other in order to increase heat loss increased as the air temperature increased. Similarly, the time spent on drinking water increased as the air temperature increased.**
Cangar *et al*. (2008)	**Skin temperature**	**Infrared thermography**	**The maximum difference between the broilers' skin temperature and their immediate environment occurred when the birds were14 days old. This could indicate that optimal air movement could be needed at age 14 days old compared to their other growth stages.**
Pereira *et al*. (2012)	**Cluster index**	**Real-time video camera**	**The rate of clustering among the broiler breeders was reported to be affected by the air temperature in the broiler building. Clustering rate reduced as the air temperature increased and vice versa.**

A. Real-time monitoring of broiler chickens with the time-lapse video camera -

Real-time monitoring of animals using time-lapse video cameras is an important PLF tool which has been widely adopted in livestock production (Ismayilova, 2013). In order to capture all relevant data when monitoring livestock behaviours, sophisticated image processing systems have been developed and reported many studies and tested in the laboratories and animal buildings. Systems for tracking the movement of livestock was developed by Kashiha *et al*. (2014b). A sensor for monitoring the behaviours and health conditions of broiler chickens was developed by Kashiha *et al*. (2013). The assessment of hen behaviour in response to ammonia concentration was determined using a real-time video camera (Kashiha *et al*., 2014a). The hen growth and activity in the poultry building was monitored with a video camera by Leroy *et al*., (2006). For commercial purpose, an innovative software called "eYeNamic" for automatic and continual monitoring of the activity of broiler chickens has been developed. The sophisticated tool was manufactured and supplied by Fancom BV, The Netherlands. The software directly works with video cameras to assist in distant monitoring and analyses of broiler chickens' behaviour (Montis *et al*., 2013). The software has the capacity to monitor the effect of the animals' microclimate on their activity such as eating and drinking, and distributions (Costa *et al*., 2014; Montis *et al*., 2013). The software could also detect automatically any abnormal activity in broiler chickens (Kristensen and Cornou, 2011).

B. Infrared thermography (IRT) -

Thermal imaging is another PLF tool used for monitoring the welfare and state of health of livestock. The tool used for thermal imaging is infrared thermography (IRT), a multifunctional equipment, which is a non-invasive and contactless thermal detection kit (Knizkova *et al*., 2007) which could be used for detecting inflammatory diseases in humans (Ring and Ammer, 2012), for diagnosing orthopaedic diseases in livestock (Knizkova *et al*., 2007), for assessing the state of pain, health and hoof lesions in cows (Theurer *et al*., 2013), evaluating the heat tolerance of livestock (Brown-Brandl *et al*, 2013). It could be used for measuring the surface temperature and body heat production of poultry birds (Nääs *et al*., 2010), for evaluating the hyperthermia induced by stress in birds (Edgar *et al*., 2013), and for appraising the response of livestock to management approaches (Yarnell *et al*., 2013). The metabolic heat production of birds could be evaluated using infrared thermography (Ferreira *et al*., 2011). In addition, the sensible heat exchange between confined livestock and their immediate environment could easily be quantified with IRT (Yahav *et al*., 2001). Furthermore, the feed consumed of livestock when experiencing heat stress could be monitored and estimated with IRT (Zhou and Yamamoto, 1997).

C. Bioacoustics -

Bioacoustics technique plays an important role in the survival of all living things. It could convey information, indicate emotional state, stress and welfare conditions of all animals (Jahns, 2008). Bioacoustics is a non-contact and non-destructive PLF tool, which could be used for evaluating the thermal comfort of animals, for effective management of animals and for monitoring animals' welfare, health and efficiency (Jahns, 2008). Animals in stress, due to changes in the environment, could respond with high sound intensity and frequency and longer duration of sound signals (Richards and Wiley, 1980) compared to animals in with the better environment. Recognising the sounds of animals in stress is nowadays possible with the advent of call recognisers also known as microphones to identify the emotional state, the needs and welfare conditions of the animals (Jahns, 2008). Adequate knowledge of the sound of heat-stressed broiler chickens could afford the poultry meat farmers to provide a conducive environment for the birds. Some research works had indicated that sound intensity, frequency and sound signal's duration could be adopted for predicting the emotional state and welfare conditions of different animals. It had been used for distinguishing between excitement, pain and fear in livestock such as cows and sheep (Weeks, 2008), for monitoring respiratory problems such as coughs and sneezes in dairy calves and pigs (Hemeryck and Berckmans, 2015). However, as regards its application in broiler production, a few works had been reported. The available works had shown its application in determining the welfare state of broiler chicks (Fontana *et al*., 2015) eggs' pipping stage in the incubator (Exadaktylos *et al*., 2011), determining the feed intake of broiler chickens (Aydin *et al*., 2015), and the assessment of broilers' activity (Aydin *et al*., 2010). It has also been used for assessing an average age and body weight gain of broiler chickens (Fontana *et al*., 2015) including the assessment of the sound level of broiler chicks (Moura *et al*., 2008). Similar to other PLF tools such as IRT, bioacoustics is yet to be commercially employed in the broiler production. This could be due to the interference of other sounds such as feeder's motors, feeder's auger, extraction fans or ventilators, and other equipment the poultry buildings.

V. LIMITATIONS OF THE PLF TECHNOLOGIES

Frequent assessment of the thermal comfort of broiler chicken is a vital aspect of poultry meat production. The impact of heat stress on animal welfare, health and production could be minimised if the thermal comfort of livestock could be constantly monitored so as to improve their performance all year round. However, not all tools are commercially applicable in commercial broiler buildings. Some of the tools are infrared thermography and bioacoustics. For infrared thermography, it has minimal coverage as the camera could not cover a large area at a time compared with that of a real-time video camera which has larger coverage. Another problem with the use of IRT in commercial broiler production is the effect of the background on the quality of thermal imaging and surface temperature of the object monitored. For instance, in deep litter broiler buildings, litters (dry and wet) could affect the quality of the surface temperatures measured from the birds. Similar to IRT, bioacoustics is yet to be commercially employed in broiler production. This could be due to the interference of other sounds such as feeder's motors, feeder's auger, extraction fans or ventilators, and other equipment the poultry buildings. Furthermore, another factor affecting their non-commercial application is their cost. All the sophisticated tools used for PLF are highly expensive and most farmers may not be able to afford more than one that will cover the whole poultry building. In addition, most farmers are not willing to invest in it due to their high cost of maintenance. For instance, a farmer in the developing countries would like to have the tools but may be discouraged due to non-availability of technological assistance in their immediate environment who could maintain the equipment. Furthermore, it will be too expensive for them to invite specialists from Europe and other developed countries to assist with the maintenance of the equipment. For small-scale farmers, investing in highly expensive equipment may not be possible due to their financial constraints.

VI. CONCLUSION

This report has shown different ways through which the thermal comfort of broiler chickens could be assessed without interfering with the broiler chickens using PLF tools. It has been confirmed in this study that it is very important to constantly evaluate the thermal comfort of broiler chickens in a confined environment either naturally ventilated or mechanically ventilated. It has also been identified that not all farmers at the moment could access the equipment most especially in the developing countries due to financial implications and non-availability of the PLF tools. Therefore, PLF tool manufacturers should intensify in their production of PLF tools with affordable price and minimal technical-know-how requirement so that all farmers could conveniently monitor their animals' welfare, health and performance. In addition, further studies could be conducted to investigate how the PLF equipment could be developed to suit all climatic condition as some are extremely warm all year round. Since thermal indices require computation due to many environmental parameters involved and may not be used to determine the stress state of animals.

VII. REFERENCE

Alsaaod, M., and Büscher, W. (2012). Detection of hoof lesions using digital infrared thermography in dairy cows. *Journal of Dairy Science*, *95*(2), 735–742. https://doi.org/10.3168/jds.2011-4762

Altan, O., Pabuçcuoğlu, A., Altan, A., Konyalioğlu, S., and Bayraktar, H. (2003). Effect of heat stress on oxidative stress, lipid peroxidation and some stress parameters in broilers. *British Poultry Science*, *44*(4), 545–550. https://doi.org/10.1080/00071660310001618334

Arias, R. A., Mader, T. L., and Escobar, P. C. (2008). Climatic factors affecting cattle performance in dairy and beef farms. *Archivos de Medicina Veterinaria*, *40*(1), 7–22. https://doi.org/10.4067/S0301-732X2008000100002

Aydin, A., Bahr, C., and Berckmans, D. (2015). A real-time monitoring tool to automatically measure the feed intakes of multiple broiler chickens by sound analysis. *Computers and Electronics in Agriculture*, *114*, 1–6. https://doi.org/10.1016/j.compag.2015.03.010

Aydin, A., Bahr, C., Viazzi, S., Exadaktylos, V., Buyse, J., and Berckmans, D. (2014). A novel method to automatically measure the feed intake of broiler chickens by sound technology. *Computers and Electronics in Agriculture*, *101*, 17–23. https://doi.org/10.1016/j.compag.2013.11.012

Aydin, A., Cangar, O., Ozcan, S. E., Bahr, C., and Berckmans, D. (2010). Application of a fully automatic analysis tool to assess the activity of broiler chickens with different gait scores. *Computers and Electronics in Agriculture*, *73*(2), 194–199. https://doi.org/10.1016/j.compag.2010.05.004

Baracho, M. S., Naas, I. . A., Nascimento, G. R., Cassiano, J. A., and Oliveira, K. R. (2011). Surface Temperature Distribution in Broiler Houses. *Brazilian Journal of Poultry Science*, *13*(3), 177–182.

Berman, A. (2012). From heat tolerance to heat stress relief: an evolution of notions in animal farming. In

R. J. Collier and J. L. Collier (Eds.), *Environmental physiology of livestock* (First, pp. 1–16). John Wiley and Sons, Inc.

Blanco, O. A., and Gous, R. M. (2006). Considerations for representing micro-environmental conditions in simulation models for broiler chickens. In R. Gous, T. Morris, and C. Fisher (Eds.), *Mechanistic Modelling in Pig and Poultry Production* (pp. 188–208). Trowbridge, UK: CAB International 2006. https://doi.org/10.1079/9781845930707.0000

Bligh, J. (2006). A theoretical consideration of the means whereby the mammalian core temperature is defended at a null zone. *Journal of Applied Physiology*, *100*, 1332–1337. https://doi.org/10.1152/japplphysiol.01068.2005.

Bohmanova, J., Misztal, I., and Cole, J. B. (2007). Temperature-humidity indices as indicators of milk production losses due to heat stress. *Journal of Dairy Science*, *90*(4), 1947–1956. https://doi.org/10.3168/jds.2006-513

Brown-Brandl, T. M., Eigenberg, R. A., and Purswell, J. L. (2013). Using thermal imaging as a method of investigating thermal thresholds in finishing pigs. *Biosystems Engineering*, *114*(3), 327–333. https://doi.org/10.1016/j.biosystemseng.2012.11.015

Cangar, Ö., Aerts, J. M., Buyse, J., and Berckmans, D. (2008). Quantification of the spatial distribution of surface temperatures of broilers. *Poultry Science*, *87*(12), 2493–2499. https://doi.org/10.3382/ps.2007-00326

Cassuce, D. C., Tinôco, I. F. F., Baêta, F. C., Zolnier, S., Cecon, P. R., and Vieira, M. F. A. (2013). Thermal comfort temperature update for broiler chickens up to 21 days of age. *Eng. Agríc., Jaboticabal*, *33*(1), 28–36.

Chepete, H. J., Chimbombi, E., and Tsheko, R. (2005). Production performance and temperature-humidity index of Cobb 500 broilers reared in open-sided naturally ventilated houses in Botswana. In T. Brown-Brandl (Ed.), *In Livestock Environment VII, 18-20 May 2005, Beijing, China (p. 524). American Society of Agricultural and Biological Engineers.* (pp. 524–535).

Collin, A., Berri, C., Tesseraud, S., Requena Rodó, F. E., Skiba-Cassy, S., Crochet, S., Yahav, S. (2007). Effects of thermal manipulation during early and late embryogenesis on thermotolerance and breast muscle characteristics in broiler chickens. *Poultry Science*, *86*, 795–800. https://doi.org/10.1093/ps/86.5.795

De Montis, A., Pinna, A., Barra, M., and Vranken, E. (2013). Analysis of poultry eating and drinking behaviour by software eYeNamic. *Journal of Agricultural Engineering*, *44*(s2), 166–172. https://doi.org/10.4081/jae.2013.s2.e33

De Moura, D. J., Nääs, I. D. A., Alves, E. C. D. S., Carvalho, T. M. R. De, Vale, M. M. Do, and Lima, K. A. O. De. (2008). Noise analysis to evaluate chick thermal comfort. *Scientia Agricola*, *65*(4), 438–443. https://doi.org/10.1590/S0103-90162008000400018

DeShazer, a. J., Hahn, L. G., and Xin, H. (2009). Chapter 1: Basic principles of the thermal environment and livestock energetics. *Livestock Energetics and Thermal Environmental Management*, 1–22. https://doi.org/801M0309

Edgar, J. L., Nicol, C. J., Pugh, C. A., and Paul, E. S. (2013). Surface temperature changes in response to handling in domestic chickens. *Physiology and Behavior*, *119*, 195–200. https://doi.org/10.1016/j.physbeh.2013.06.020

Eigenberg, R. A., Brown-Brandl, T. M., and Nienaber, J. A. (2007). Development of a livestock weather safety monitor for feedlot cattle. *Applied Engineering in Agriculture*, *23*(5), 657–660. https://doi.org/10.13031/2013.23666

Exadaktylos, V., Silva, M., and Berckmans, D. (2011). Real-time analysis of chicken embryo sounds to monitor different incubation stages. *Computers and Electronics in Agriculture*, *75*(2), 321–326. https://doi.org/10.1016/j.compag.2010.12.008

Ferrari, S., Piccinini, R., Silva, M., Exadaktylos, V., Berckmans, D., and Guarino, M. (2010). Cough sound description in relation to respiratory diseases in dairy calves. *Preventive Veterinary Medicine*, *96*(3–4), 276–280. https://doi.org/10.1016/j.prevetmed.2010.06.013

Ferraz, P. F. P., Yanagi Jr, T., Alvarenga, T. A. C., Reis, G. M., and Campos, A. T. (2014). Behaviour of chicks subjected to thermal challenge. *Eng. Agríc., Jaboticabal*, *34*(6), 1039–1049.

Ferreira, V., Francisco, N., Belloni, M., Aguirre, G., Caldara, F., Nääs, I., Polycarpo, G. (2011). Infrared thermography applied to the evaluation of metabolic heat loss of chicks fed with different energy densities. *Revista Brasileira de Ciência Avícola*, *13*(2), 113–118. https://doi.org/10.1590/S1516-635X2011000200005

Fontana, I., Tullo, E., and Butterworth, A. (2015). The use of vocalisation sounds to assess responses of broiler chicken to environmental variables. In I. Halachmi (Ed.), *Precision livestock farming applications* (First, pp. 187–198). Wageningen, The Netherlands: Wageningen Academic Publishers.

Fontana, I., Tullo, E., Butterworth, A., and Guarino, M. (2014). Broiler Vocalisation to Predict the Growth. In *Proceedings of Measuring Behaviour, Wageningen, The Netherlands, August 27-29*. Retrieved from http://www.measuringbehavior.org/files/2014/Proceedings/Fontana, I. - MB2014.pdf

Gaughan, J., Lacetera, N., Valtorta, S. E., Khalifa, H. H., Hahn, L., and Mader, T. (2009). Response of Domestic Animals to Climate Challenges. In K. L. Ebi, I. Burton, and G. R. McGregor (Eds.), *Biometeorology for Adaptation to Climate Variability and Change* (pp. 131–170). Heidelberg, Germany: Springer Science + Business Media, LLC. https://doi.org/10.1007/978-1-4020-8921-3_7

Gous, R., Morris, T., and Fisher, C. (2006). Mechanistic modelling in pig and poultry production. In R. Gous, T. Morris, and C. Fisher (Eds.), *Mechanistic Modelling in Pig and Poultry Production* (p. 331). Trowbridge, UK: CAB International 2006. https://doi.org/10.1079/9781845930707.0000

Hahn, G. L., Gaughan, J. B., Mader, T. L., and Eigenberg, R. A. (2009). Thermal indices and their applications for livestock environments. In J. A. DeShazer (Ed.), *Livestock Energetics and Thermal Environmental Management* (pp. 113–130). St. Joseph, Mich.: American Society of Agricultural and Biological Engineers. https://doi.org/ASABE # 801M0309

Havenstein, G. B., Ferket, P. R., and Qureshi, M. A. (2003). Carcass composition and yield of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. *Poultry Science*, *82*, 1509–1518. https://doi.org/10.3382/ps.0731795

Hemeryck, M., and Berckmans, D. (2015). Pig cough monitoring in the EU-PLF project: first results. In I. Halachmi (Ed.), *Precision livestock farming applications* (First, pp. 199–207). Wageningen, The Netherlands: Wageningen Academic Publishers.

Ismayilova, G. (2013). *The use of image labelling to identify pig behaviours for the development of a real-time monitoring and control tool*. The University of Milan. https://doi.org/10.1017/CBO9781107415324.004

Jahns, G. (2008). Call recognition to identify cow conditions-A call-recogniser translating calls to text. *Computers and Electronics in Agriculture*, *62*(1), 54–58. https://doi.org/10.1016/j.compag.2007.09.005

Janke, O., Tzschentke, B., Höchel, J., and Nichelmann, M. (2002). Metabolic responses of chicken and muscovy duck embryos to high incubation temperatures. *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology*, *131*(4), 741–750. https://doi.org/10.1016/S1095-6433(02)00012-0

Kashiha, M. A., Bahr, C., Ott, S., Moons, C. P. H., Niewold, T. A., Tuyttens, F., and Berckmans, D. (2014a). Automatic monitoring of pig locomotion using image analysis. *Livestock Science*, *159*(1), 141–148. https://doi.org/10.1016/j.livsci.2013.11.007

Kashiha, M. A., Green, A. R., Sales, T. G., Bahr, C., Berckmans, D., and Gates, R. S. (2014b). Performance of an image analysis processing system for hen tracking in an environmental preference chamber. *Poultry Science*, *93*(10), 2439–2448. https://doi.org/10.3382/ps.2014-04078

Kashiha, M. A., Pluk, A., Bahr, C., Vranken, E., and Berckmans, D. (2013). Development of an early warning system for a broiler house using computer vision. *Biosystems Engineering*, *116*(1), 36–45. https://doi.org/10.1016/j.biosystemseng.2013.06.004

Knizkova, I., Kunc, P., Gürdil, K. A. G., Pınar, Y., and Selvi, Ç. K. (2007). Applications of Infrared Thermography in Animal Productions. *Journal of Agricultural Sciences*, *22*(3), 329–336.

Kristensen, H. H., and Cornou, C. (2011). Automatic detection of deviations in activity levels in groups of broiler chickens - A pilot study. *Biosystems Engineering*, *109*(4), 369–376. https://doi.org/10.1016/j.biosystemseng.2011.05.002

Lara, L. J., and Rostagno, M. H. (2013). Impact of heat stress on poultry production. *Animals*, *3*(2), 356–369. https://doi.org/10.3390/ani3020356

Leroy, T., Vranken, E., Brecht, a Van, Struelens, E., Sonck, B., and Berckmans, D. (2006). A computer vision method for on-line behavioural quantification of individually caged poultry. *Transactions of the ASABE*, *49*(3), 795–802.

Lima, K. A. O., Moura, D. J., Carvalho, T. M. R., Bueno, L. G. F., and Vercellino, R. A. (2011). Ammonia emissions in tunnel-ventilated broiler houses. *Brazilian Journal of Poultry Science*, *13*(4), 265–270. https://doi.org/10.1590/S1516-635X2011000400008

Loh, B., Maier, I., Winar, A., Janke, O., and Tzschentke, B. (2004). Prenatal development of epigenetic adaptation processes in poultry: changes in metabolic and neuronal thermoregulatory mechanisms. *Avian and Poultry Biology Reviews*, *15*(3–4), 119–128. https://doi.org/10.3184/147020604783637976

Loyau, T., Berri, C., Bedrani, L., Métayer-Coustard, S., Praud, C., Duclos, M. J., Collin, A. (2013). Thermal manipulation of the embryo modifies the physiology and body composition of broiler chickens reared in floor pens without affecting breast meat processing quality. *Journal of Animal Science*, *91*(8), 3674–3685. https://doi.org/10.2527/jas.2013-6445

Malheiros, R. D., Moraes, V. M. B., Bruno, L. D. G., Malheiros, E. B., Furlan, R. L., and Macari, M. (2000). Environmental temperature and surface temperatures of broiler chicks in first-week post-hatch. *Journal of Applied Poultry Research*, *9*(1), 111–117.

Manteuffel, G., Puppe, B., and Schön, P. C. (2004). Vocalisation of farm animals as a measure of welfare. *Applied Animal Behaviour Science*, *88*(1–2), 163–182. https://doi.org/10.1016/j.applanim.2004.02.012

Marx, G., Leppelt, J., and Ellendorff, F. (2001). Vocalisation in chicks (Gallus gallus dom.) during stepwise social isolation. *Applied Animal Behaviour Science*, *75*(1), 61–74. https://doi.org/10.1016/S0168-1591(01)00180-0

McCafferty, D. J. (2007). The value of infrared thermography for research on mammals: previous applications and future directions. *Mammal Review*, *37*(3), 207–223. https://doi.org/10.1111/j.1365-2907.2007.00111.x

Naas, I. A., Garcia, R. G., and Caldara, F. R. (2014). Infrared thermal image for assessing animal health and welfare. *Biometeorol, J Anim Behav*, *2*(3), 66–72.

Nääs, I. A., Laganá, M., Neto, M. M., Canuto, S., and Pereira, D. F. (2012). Image analysis for assessing broiler breeder behaviour response to thermal environment. *Eng. Agríc., Jaboticabal*, *32*(4), 624–632. https://doi.org/10.1590/S0100-69162012000400001

Nääs, I. A., Romanini, C. E. B., Neves, D. P., Nascimento, G. R., and Vercellino, R. A. (2010). Broiler surface temperature distribution of 42 day old chickens. *Scientia Agricola*, *67*(5), 497–502. https://doi.org/10.1590/S0103-90162010000500001

Nascimento, G. R., Nääs, I. A., Pereira, D. F., Baracho, M. S., and Garcia, R. (2011). Assessment of broiler surface temperature variation when exposed to different air temperatures. *Brazilian Journal of Poultry Science*, *13*(4), 259–263.

Nielsen, B. L. (2012). Effects of ambient temperature and early open-field response on the behaviour, feed intake and growth of fast- and slow-growing broiler strains. *Animal*, *6*(09), 1460–1468. https://doi.org/10.1017/S1751731112000353

Pereira, D. F., and Nääs, I. A. (2008). Estimating the thermoneutral zone for broiler breeders using behavioural analysis. *Computers and Electronics in Agriculture*, *62*(1), 2–7. https://doi.org/10.1016/j.compag.2007.09.001

Pereira, D. F., Nääs, I. A., Filho, L. R. A. G., and Neto, M. M. (2012). Cluster index for accessing thermal comfort for broiler breeders. In *International Conference of Agricultural Engineering, CIGR-AgEng2012. Valencia, Spain. (July 29 – August 1)* (p. Paper Number: ILES12-0748). Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84878283813andpartnerID=40andmd5=6043bf721024ddd870bed69d5fdaf113

Pereira, D. F., Nääs, I. A., Romanini, C. E. B., Salgado, D. D., and Pereira, G. O. T. (2005). Welfare pointers in function of behaviour reactions of broiler breeders. *Eng. Agríc., Jaboticabal*, *25*(5), 308–314.

Piestun, Y., Halevy, O., Shinder, D., Ruzal, M., Druyan, S., and Yahav, S. (2011). Thermal manipulations during broiler embryogenesis improve post-hatch performance under hot conditions. *Journal of Thermal Biology*, *36*(7), 469–474. https://doi.org/10.1016/j.jtherbio.2011.08.003

Piestun, Y., Halevy, O., and Yahav, S. (2009). Thermal manipulations of broiler embryos—the effect on thermoregulation and development during embryogenesis. *Poultry Science*, *88*, 2677–2688. https://doi.org/10.3382/ps.2009-00231

Piestun, Y., Shinder, D., Ruzal, M., Halevy, O., Brake, J., and Yahav, S. (2008). Thermal manipulations during broiler embryogenesis: effect on the acquisition of thermotolerance. *Poultry Science*, *87*(8), 1516–1525. https://doi.org/10.3382/ps.2008-00030

Piestun, Y., Shinder, D., Ruzal, M., Halevy, O., and Yahav, S. (2008). The effect of thermal manipulations during the development of the thyroid and adrenal axes on in-hatch and post-hatch thermoregulation. *Journal of Thermal Biology*, *33*(7), 413–418. https://doi.org/10.1016/j.jtherbio.2008.06.007

Purswell, J. L., Dozier, W. A., Olanrewaju, H. A., Davis, J. D., Xin, H., and Gates, R. S. (2012). Effect of Temperature-Humidity Index on Live Performance in Broiler Chickens Grown From 49 To 63 Days of Age. In the *IX International Livestock Environment Symposium (ILES IX). An ASABE Conference Presentation Paper Number: ILES12-0265, Valencia, Spain (July 8-12 2012).* https://doi.org/10.13031/2013.41619

Purswell, J. L., Lott, B. D., Dozier, W. a., Roush, W. B., and Branton, S. L. (2008). Assessing the thermal comfort of broiler chicks. *International Journal of Poultry Science*, *7*(3), 202–206. https://doi.org/10.3923/ijps.2008.202.206

Reiter, K., and Bessei, W. (2000). Effect of stocking density of broilers on temperature in the litter and at bird level. *Archiv Für Geflügelkunde*, *64*(5), 204–206. Retrieved from http://www.cabdirect.org/

Richards, D. G., and Wiley, R. H. (1980). Reverberations and Amplitude Fluctuations in the Propagation of Sound in a Forest: Implications for Animal Communication. *The American Naturalist*, *115*(3), 381–399. https://doi.org/10.1086/283568

Ring, E. F. J., and Ammer, K. (2012). Infrared thermal imaging in medicine. *Physiological Measurement*, *33*(3), 33–46. https://doi.org/10.1088/0967-3334/33/3/R33

Samal, L., Sejian, V., Bagath, M., Krishnan, G., Manimaran, A., and Bhatta, R. (2017). Different heat stress indices to quantify stress response in livestock and poultry. In P. Rao (Ed.), *Livestock Meteorology* (pp. 165–180). New Delhi, India: New India Publishing Agency.

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

Sejian, V., Valtorta, S., Gallardo, M., and Singh, A. K. (2012). Ameliorative measures to counteract environmental stress. In V. Sejian, S. M. K. Naqvi, T. Ezeji, J. Lakritz, and R. Lal (Eds.), *Environmental Stress and Amelioration in Livestock Production* (pp. 153–180). Springer-Verlag Berlin Heidelberg. https://doi.org/10.1007/978-3-642-29205-7_7

Shinder, D., Rusal, M., Tanny, J., Druyan, S., and Yahav, S. (2007). Thermoregulatory responses of chicks (Gallus domesticus) to low ambient temperatures at an early age. *Poultry Science*, *86*(10), 2200–2209.

St-Pierre, N. R., Cobanov, B., and Schnitkey, G. (2003). Economic losses from heat stress by US livestock industries. *Journal of Dairy Science*, *86*(31), E52–E77. https://doi.org/10.3168/jds.S0022-0302(03)74040-5

Tao, X., and Xin, H. (2003a). Acute Synergistic Effects of Air Temperature, Humidity, and Velocity on Homeostasis of Market- Size Broilers. *Transactions of the ASABE*, *46*(2), 491–497.

Tao, X., and Xin, H. (2003b). Temperature-humidity-velocity index for market-size broilers. In *ASAE Annual International Meeting. Las Vegas, Nevada, USA (July 27-30)* (p. Paper Number: 034037). https://doi.org/10.13031/2013.14094

Tessier, M., Du Tremblay, D., Klopfenstein, C., Beauchamp, G., and Boulianne, M. (2003). Abdominal skin temperature variation in healthy broiler chickens as determined by thermography. *Poultry Science*, *82*(5), 846–849.

Theurer, M. E., Amrine, D. E., and White, B. J. (2013).

Remote Noninvasive Assessment of Pain and Health Status in Cattle. *Veterinary Clinics of North America - Food Animal Practice*, *29*(1), 59–74. https://doi.org/10.1016/j.cvfa.2012.11.011

Tzschentke, B. (2008). Monitoring the development of thermoregulation in poultry embryos and its influence by incubation temperature. *Computers and Electronics in Agriculture*, *64*(1), 61–71. https://doi.org/10.1016/j.compag.2008.05.003

Von Borell, E., Bünger, B., Schmidt, T., and Horn, T. (2009). Vocal-type classification as a tool to identify stress in piglets under on-farm conditions. *Animal Welfare*, *18*(4), 407–416.

Weary, D. M., and Fraser, D. (1995). Calling by domestic piglets: reliable signals of need? *Animal Behaviour*, *50*(4), 1047–1055. https://doi.org/10.1016/0003-3472(95)80105-7

Weeks, C. A. (2008). A review of welfare in cattle, sheep and pig lairages, with emphasis on stocking rates, ventilation and noise. *Animal Welfare*, *17*(3), 275–284.

Welker, J. S., Rosa, A. P., De Moura, D. J., Machado, L. P., Catelan, F., and Uttpatel, R. (2008). Broiler body temperature as a function of different thermal control systems in broiler housing. *Revista Brasileira de Zootecnia*, *37*(8), 1463–1467. https://doi.org/10.1590/S1516-35982008000800018

Xin, H., and Shao, B. (2005). Real-time Behavior-based Assessment and Control of Swine Thermal Comfort. In *Livestock Environment VII, Proceedings of the Seventh International Symposium, 18-20 May (Beijing, China). American Society of Agricultural Engineers, St. Joseph, Michigan USA.* (pp. 694–702).

Yahav, S., Collin, A., Shinder, D., and Picard, M. (2004). Thermal manipulations during broiler chick embryogenesis: effects of timing and temperature. *Poultry Science*, *83*, 1959–1963. https://doi.org/10.1093/ps/83.12.1959

Yahav, S., Rath, R. S., and Shinder, D. (2004). The effect of thermal manipulations during embryogenesis of broiler chicks (Gallus domesticus) on hatchability, body weight and thermoregulation after hatch. *Journal of Thermal Biology*, *29*(4–5), 245–250. https://doi.org/10.1016/j.jtherbio.2004.03.002

Yahav, S., Straschnow, A., Vax, E., Razpakovski, V., and Shinder, D. (2001). Air velocity alters broiler performance under harsh environmental conditions. *Poultry Science*, *80*(6), 724–726.

Yarnell, K., Hall, C., and Billett, E. (2013). An assessment of the aversive nature of an animal management procedure (clipping) using behavioural and physiological measures. *Physiology and Behavior*, *118*(October 2016), 32–39. https://doi.org/10.1016/j.physbeh.2013.05.013

Zhou, W. T., and Yamamoto, S. (1997). Effects of environmental temperature and heat production due to food intake on abdominal temperature, shank skin temperature and respiration rate of broilers. *British Poultry Science*, *38*(1), 107–114. https://doi.org/10.1080/00071669708417949

Zimmerman, P. H., and Koene, P. (1998). The effect of frustrative non-reward on vocalisations and behaviour in the laying hen, Gallus gallus domesticus. *Behavioural Processes*, *44*(1), 73–79. https://doi.org/10.1016/S0376-6357(98)00035-7