

EFFECT OF AIR MOVEMENT ON CHICK BODY TEMPERATURE DURING BROODING

by

TSUNG-LIN LU

(Under the Direction of Brian Fairchild)

ABSTRACT

Research was conducted to compare subcutaneous flank temperature (T_F) to rectal temperature (T_R) in broiler chicks and evaluate the effect of air movement on chick body temperature under different brooding temperatures (29.4, 32.2, and 35.0°C) during the first week of age. RFID sensors were surgically implanted into the subcutaneous layer of the flank to record T_F . The result showed T_F was a reliable indirect measurement of the rectal temperature ($T_R = 0.97 * T_F + 1.35$, $R^2 = 0.96$) with an accuracy of $\pm 0.1^\circ\text{C}$. The effect of air movement on chick body temperature was independent of age. At room temperature of 29.4°C, 0.5 m/s air caused body temperature of the first week to drop less than 0.3°C while body temperature was not affected at 32.2 and 35.0°C. At room temperature of 29.4 and 32.2°C, 1 m/s air caused body temperature of the first week to drop less than 0.3°C.

INDEX WORDS: Rectal Temperature, Flank Temperature, Air Movement, Probe Insertion
Depth

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TSUNG-LIN LU

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TSUNG-LIN LU

Major Professor:	Brian Fairchild
Committee:	Adam Davis
	Charles Roney
	Michael Czarick

Electronic Version Approved:

Ron Walcott
Interim Dean of the Graduate School
The University of Georgia
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CHAPTER 1
LITERATURE REVIEW
THERMOREGULATION

Broilers are homeotherms, which are capable of maintaining a relatively constant core body temperature regardless of the status of their physical activity or external environmental conditions. They achieve thermal balance by closely adjusting the heat produced as well as the heat dissipated from the body (Genç and Portier, 2005; Maiorka et al., 2006)

Thermogenesis

Thermogenesis can be divided into two categories: obligatory thermogenesis and facultative thermogenesis. Obligatory thermogenesis, involved in non-shivering thermogenesis, is the heat produced by basal metabolism related to maintenance of the body in a living state. This thermogenic mechanism involves processing of food in the gastrointestinal tract (thermic effect of food), which is the heat production that a bird can control to some extent through behavior, such as increasing or reducing feed consumption at lower or higher environmental temperature respectively. Facultative thermogenesis, consisting of both shivering and non-shivering thermogenesis, is superimposed on obligatory thermogenesis, where heat production is specifically increased in an attempt to maintain homeothermy during increased heat loss (Himms-Hagen, 1989; Hohtola, 2002; Lin and Sun, 2012). The primary mechanism of thermogenesis in birds is considered to be the shivering of the skeletal muscle due to its high capacity for metabolism and oxygen consumption (Barre et al., 1985; Barré et al., 1986; Mujahid and Furuse, 2008). Marjoniemi and Hohtola (1999) investigated the onset of shivering thermogenesis in Galliform

chicks, where domestic fowl (*Gallus Domesticus*) were able to increase oxygen consumption as early as 1-2 days of age. The results also showed that in comparison to pectorals, leg muscles (gastrocnemius) were mainly used in shivering thermogenesis during the first week of age due to more muscle mass and more mature muscles in legs. Barre et al. (1985) demonstrated that the electromyographic (EMG) activity of the gastrocnemius muscle increased markedly in 7-day-old muscovy ducklings exposed to cold ambient temperature. This increase in shivering response exhibited a linear correlation with the metabolic rate which indicated elevated heat production. However, the author also observed that in cold-acclimated muscovy ducklings the shivering thermogenesis did not occur until the ambient temperature reached 8.1°C, which was 14.2°C below the lower critical temperature (LCT). A study by Duchamp and Barre (1993) also discovered similar results, where increased blood was found in gastrocnemius muscle of cold-exposed muscovy duckling in absence of any shivering activity. The author suggested that the increased metabolic rate between the LCT and activation of shivering thermogenesis was related to non-shivering thermogenesis (NST). Brown adipose tissue has been shown to be involve in the NST in mammals (Cannon and Nedergaard, 1985). However, researchers have yet successfully identified such brown adipose tissue in avian species (Johnston, 1971; Saarela et al., 1991) and the skeletal muscle has been considered to be involved in such thermogenesis (Barre et al., 1985; Duchamp and Barre, 1993; Mujahid and Furuse, 2008).

Misson (1982) observed that in starved-1-week-old Light Sussex chickens, the body temperature was 2°C lower than those fed under thermoneutral temperature. Fasted Japanese quail chicks were also found to maintain higher shivering activity than fed birds in low ambient temperature, which indicated that shivering was used to partially compensate the decreased obligatory thermogenesis (Marjoniemi, 2000). Hirabayashi et al. (2005) examined the effect of

cold exposure on the morphological change of skeletal muscle in Rhode Island Red chickens, the result indicated birds that acquired cold tolerance increased the number of slow-twitch muscles by two-fold, thereby increasing thermogenic capacity.

Hormonal control of thermogenesis

Several studies have been conducted to determine the hormone response behind the thermogenic mechanism. Mujahid and Furuse (2008b) reported that when subjected to cold temperature conditions, layer-type chicks centrally administered with corticotropin releasing factor (CRF) had higher body temperature for a short duration, suggesting the short-term thermogenic effect of CRF and the involvement of the hypothalamic-pituitary-adrenal (HPA) axis. Similar thermogenic responses of CRF were also found in other studies with layer-type chicks (Mujahid and Furuse, 2008a; Tachibana et al., 2004)

Freeman (1970) investigated the effect of thyroxine (T_4) and triiodothyronine (T_3) on thermogenesis on one-day-old Rhode Island Red chicks. The result showed a significant rise in rectal temperature after 30 minutes of intraperitoneal injection of T_3 or T_4 when the birds are kept at 35°C , while the temperature maintained significantly higher than untreated chicks when the chicks are exposed to a 20°C environment. The role of thyroid hormone on thermogenesis on young Leghorn chicks was also investigated by Hwang-Bo et al. (1990). Heat production was increased after injection of T_3 , where the thermogenic effect was more prominent at 2 weeks of age compare to 1-week-old chicks. The author suggested this may be attributed to the immature thermogenesis of younger birds. Previous research reported intracerebroventricular injection of thyrotropin releasing hormone (TRH) increased body temperature in a dose-dependent manner. While the plasma thyroxine (T_4) and triiodothyronine (T_3) level was not affected in neonatal layer chicks, the plasma corticosterone (CORT) increased. The absence of increase in body temperature

after co-injection of TRH and CORT antagonist led the author to suggest that the thermogenic effect of TRH did not involve the release of thyroid hormones but TRH may be involved in stimulation of the HPA axis for thermogenesis as evidenced by increase in plasma corticosterone level after TRH injection (Takahashi et al., 2005).

Heat loss

Heat loss of a broiler can be divided into two categories – sensible heat loss and latent heat loss (Simmons et al., 1997). Latent heat loss, also known as evaporative heat loss is associated with the phase change of water (Simmons et al., 1997). As birds lack sweat glands and insulation is provided by feathers over the vast majority of the body (Dawson, 1982; Lin et al., 2005a), only a small proportion of water vapor through the skin by passive diffusion can occur therefore latent heat is primarily lost via the respiratory pathway (Richards, 1976; Simmons et al., 1997). Sensible heat loss occurs in three forms: radiation, conduction and convection. Radiation is the transfer of heat in the form of electromagnetic wave from warm to cooler objects. When two objects are in contact, the heat is transferred from the one with higher temperature to the other through conduction. These two types of sensible heat loss are negligible in birds raised in poultry houses as the temperature gradient between the birds and the surface within the house is small and bedding materials are good insulators. Sensible heat loss from birds occur mainly in the form of convection, where heat is transferred from the surface of the bird to the air when there is air movement (Czarick and Fairchild, 2008, Drury and Seigel, 1966). When the core body temperature of the bird rises, the heat is redistributed to the body surface through blood. While most blood flows from arterioles to venules through capillaries, an alternative pathway, arteriovenous anastomoses (a.v.a.), also exists. These a.v.a. connect the arterioles and venules, bypassing the capillaries, providing a larger diameter for movement of blood. The a.v.a. found in the skin has been shown to play a role in

thermoregulation, especially those without feather coverage (Grant, 1963; Wolfenson, 1983). The work of Wolfenson (1983) showed that when the ambient temperature rose from 23.4 ± 1.4 to $25.4 \pm 1.1^\circ\text{C}$, the metatarsal skin temperature increased from 31.1 ± 0.1 to $38.2 \pm 0.3^\circ\text{C}$. The blood flow to the leg increased from 14% to 30% while 83% of the total blood flow to the unfeathered skin occurred through a.v.a. The distribution of the blood flow in the feathered skin did not change significantly due to increased ambient temperature.

Sensible heat loss occurs when there is a temperature gradient between the surface of the bird and ambient temperature (Yahav et al., 2005). When the ambient temperature increases, the temperature gradient is reduced, causing a decrease in sensible heat loss. In response, the bird increases latent heat loss by increasing respiration rate (Lin et al., 2005a; Lin et al., 2005b; Simmons et al., 1997). Even at thermoneutral temperature, approximately 60% of total heat loss in a bird depends on latent heat loss (Czarick and Fairchild, 2008, Yahav et al, 2005). Thus, at higher ambient temperatures evaporative heat loss becomes increasingly crucial and it represents the only method for heat loss when the ambient temperature is equivalent to body temperature (Richards, 1971). This shift of heat loss was shown in increased water consumption during high ambient temperature, which reflected the utilization of water in the process of dissipating excess heat (Dawson, 1982; Farrell and Swain, 1977). Latent heat loss is achieved by evaporation of water to produce a cooling effect and is adversely affected by relative humidity. A study conducted using 5.5-6 week-old broilers showed that latent heat loss decreased as relative humidity increased and when the relative humidity was 90%, there was no latent heat loss observed at room temperatures of 30°C and 35°C (Genç and Portier, 2005).

Broiler chicks

Newly hatched chicks respond to low temperature environments more drastically compared to adult chickens due to their immature thermoregulatory system. Mujahid and Furuse (2008b) pointed out that the failure of young chicks to generate a metabolic response to low ambient temperature may be due to inability to enhance mitochondrial fatty acid transportation and oxidation and the enzymes involved in the oxidation process. Moreover, higher surface area to body mass ratio and lack of feathers also contributes to the inability of the young chick to maintain homeothermy in low temperature conditions (Wekstein and Zolman, 1971).

The chick body temperature increased in an age-dependent manner regardless of the environmental temperature. The rectal temperature of broiler chicks (Cobb) has been reported to increase from 39.0 - 39.7°C on Day 1 to 40.5 - 41.2°C on Day 7 (Maiorka et al., 2006; Malheiros et al., 2000). Wekstein and Zolman (1971) pointed out that younger broiler chicks (Vantress x Arbor Acre) subjected to cold environment had a more drastic drop in body temperature compared to older birds indicating they were able to maintain a constant body temperature. Freeman (1965a) suggested that chick body temperature increases with age and becomes constant at 6 days of age as a result of yolk material being progressively replaced by actively metabolizing tissue, while Nichelmann and Tzschentke (2002) stated that precocial birds (domestic fowl, turkeys and Muscovy ducks) reach homeothermy at approximately 10 days of age.

Thermoneutral zone

Thermoneutral zone is described as the range of ambient temperature where a bird produces minimum heat, requiring neither facultative thermogenesis nor shifting of energy for heat loss (Dawson and Whittow, 2000; Maiorka et al., 2006). Newly hatched chicks have relatively narrow zone of thermal neutrality (Christensen, 2009). The zone increases in an age-dependent manner as

the thermoregulatory system develops (Nichelmann and Tzachentke, 2002). Maiorka et al. (2006) reported that the thermoneutral zone for broiler chicks during the first week is between 33°C and 35°C. A study was carried out to investigate the effect of brooding temperature on broiler performance. The result of the study indicated that there were no significant difference in body weight and mortality between the broilers raised under (1) 35°C the first week, 32.2°C the second week, and 29.4°C the third week and (2) 29.4°C the first week, 26.7°C the second week, and 24.4°C the third week. However, a higher feed conversion was observed in the group of broilers raised at the lower temperature. Cassuce et al. (2013) studied the effect of different ambient temperatures on broiler performance during the first three weeks of life. The author suggested that the highest weight gain and lowest feed conversion of the birds was observed at 31.3°C in the first week, 26.3-27.1°C in the second week and 22.5-23.2°C in the third week. A similar study was conducted by Cândido et al. (2016) and the authors concluded that the optimum temperature range for the first three weeks of age were between 27-30°C, 24-27°C and 21-24°C respectively where better weight gain and feed conversion were observed. The results also suggested that under severe cold conditions, birds increased feed intake to raise heat production with no significant increase in weight gain, which supports the fact that birds require more energy to maintain body temperature when exposed to temperatures out of their thermoneutral zone.

Environmental and management factors affecting thermoregulation

Ambient temperature

Newly hatched chicks, when compared to adult chickens, are more sensitive to cold environment and are not able to maintain homeothermy in such conditions until thermogenesis is fully developed (Hirabayashi et al., 2005; Mujahid and Furuse, 2009). This is supported by several studies where the body temperature of young chicks dropped when they were subjected to cold

ambient temperature, where the increase in heat production was insufficient to compensate the increased heat loss (Malheiros et al., 2000; Mujahid and Furuse, 2008a; Mujahid and Furuse, 2009; Nichelmann and Tzschentke, 2002; Tzschentke, 1999). This hypothermic effect of low ambient temperature on chicks was age dependent (Marjoniemi and Hohtola, 1999; Mujahid, 2010; Nichelmann and Tzschentke, 2002). A study conducted by Wekstein and Zolman (1971) exposed young broiler chicks (Vantress x Arbor Acre) to cold conditions in ages from 8 hours post-hatch up to 500 hours post-hatch to 20°C and 10°C environment. Chicks 46 hours old were able to maintain their body temperature relatively constant at 20°C. However, when exposed to 10°C environment, chicks must be at least 128 hours post-hatch to be able to maintain their body temperature constant. The result indicated that as chicks grew older, they were able to maintain their body temperature relatively constant at lower environmental temperature conditions and the effect of low ambient temperature on chick body temperature diminished with age and would eventually be able to maintain homeothermy.

Relative humidity

It is generally recommended to maintain relative humidity (Rh) between 40-60% in poultry housing (Czarick and Fairchild, 2012). High Rh increases the difficulty to remove moisture from the litter, subsequently increasing ammonia level and footpad dermatitis. Keeping the Rh too low could increase the presence of dust in the house, which may increase disease transmission. Yahav et al. (1995) showed that when 5-8 week-old broilers were exposed to ambient temperature of 35°C, the rectal temperature was the lowest and bird performance was the best under Rh of 60-65% comparing to those raised in 40-45%, 50-55% and 70-75%. Another study conducted by Lin et al. (2005a) examine the effect of Rh on broiler (Arbor Acres) body temperature, the result pointed out that Rh had a significant effect on rectal temperature at 35°C where birds exposed to

35% Rh had a lower rectal temperature compared to those kept under 60% and 80% Rh. Another study by Lin et al. (2005b) investigated the effect of Rh on the body temperature of 1 week-old broiler chicks (Arbor Acres). The result showed that at 35°C, the rectal temperature was significantly lower at 60% Rh comparing to chicks in 35% and 85% Rh.

Stocking density

Stocking density has been shown to have an effect on broiler body temperature. At higher stocking density, heat dissipation in birds became more difficult as the air flow between birds was restricted due to reduced available floor space (McLean et al., 2002). Teo (2018) indicated that the effect of stocking density on market age broilers were air temperature dependent. When the stocking density increased from 4.9 to 33.4 kg/m², bird body temperature rose 0.4°C at room temperature of 22°C while body temperature increased by 0.7°C under 26°C. Another study showed that birds kept at 40 kg/m² had on average 0.3°C higher body temperature compared to those kept under 28 kg/m² (Abudabos et al. 2013).

Since stocking density in commercial broiler production was calculated based on the final body weight of a flock (NCC, 2017), it was unlikely to be much of a concern on chick body temperature during brooding period. Instead, chicks were often seen clustering into groups in the first few days which has been suggested as a behavior to maintain body temperature possibly in response to low ambient temperature and/or Rh as their thermoregulation was still under development (Deaton et al. 1996; Purswell et al. 2008).

BROODING BROILER CHICKS

The primary objective of brooding chicks is to efficiently and economically provide an optimal environment for the birds to develop. Given that the short time commercial broilers take to reach market weight in the modern production system, improper management during the post-hatching period can lead to significant losses in broiler production chain. Therefore, care should be taken in bird management from the first day of age (Fairchild, 2009; Leksrisompong et al., 2009; Maiorka et al., 2006).

As mentioned previously, newly hatched chicks have an immature thermoregulatory system and thus narrow thermoneutral zone. Providing an environment with ideal temperature is therefore crucial in brooding chicks to enable the birds to achieve their maximum growth potential. During the initial growth period, birds are prone to heat loss. As a result, supplemental heat is provided to ensure the birds maintain optimal body temperature preventing hypothermia which increases energy cost of thermal homeostasis (Malheiros et al., 2000). The effect of different brooding temperature was shown in a study conducted by Deaton et al. (1996), where poor feed conversion and mortality were observed in birds raised in lower ambient temperatures to 3 weeks of age. Bruzual et al. (2000) also concluded that brooding temperature of 26°C the first five days and 24°C from the sixth to twelfth day compared to 32°C the first five days and 29°C from the sixth to twelfth day had a significantly lower body weight gain and a numerically higher feed conversion ratio.

Poultry houses are equipped with heating systems such as forced air furnaces, conventional pancake brooders or radiant brooders to maintain the brooding temperature inside the house. However, heated air rises to the ceiling of the house instead of moving to the floor to keep the birds warm, generating temperature stratification within the house (Bottcher et al., 1988; Czarick

and Lacy, 2000; Ghoname et al., 2012). As a result, the target brooding temperature is never reached at bird level. This phenomenon could be compounded by what is commonly known as thermocline, where cold air leaks through the cracks of the house and moves along the floor, causing a drastic drop in temperature at bird level (Czarick and Fairchild, 2005). Temperature stratification is observed in all houses regardless of the type of heating system equipped. However, the temperature stratification problem is minimized in houses with brooders compared to those with furnaces as radiant brooders direct a large part of their heat to the floor rather than the air (Czarick and Fairchild, 2005; Ghoname et al. 2012).

Management practices can be adopted to ameliorate the effect of temperature stratification on the birds. By placing the thermostats near bird level, although it does not eliminate the stratification problem, it would at least provide a more representative temperature at bird level (Nienaber and Hahn, 1983; Czarick and Fairchild, 2005). However, in order to reach the target brooding temperature, the set temperature would have to be raised, which reduces the brooding efficiency and increases energy cost. Another method is the use of circulation fans to create uniform distribution of the heat throughout the house by generating air movement (Czarick and Lacy, 2000). The stratification can be significantly reduced by as much as 15.2°C from floor to ceiling in the poultry house and increase floor temperature by 2.2°C when the circulation fan speed was raised from 90 to 200 rpm. The amount of stratification reduction was similar in fans operating at a higher speed (135 and 200 rpm), while no reduction was observed when the fan was operating at 90 rpm. This led to the suggestion that a reduction in temperature stratification can be achieved when the fan speed is over a certain threshold (Bottcher et al., 1988). The benefit of operating circulation fans during brooding is not limited to eliminating temperature stratification. It is also known to reduce the amount of caked litter. The combination of increased air temperature and air

movement at floor level facilitates the removal of moisture from the litter (Czarick et al., 2001; Czarick and Fairchild, 2012).

Despite the beneficial effect provided by the use of circulation fans, air movement suggested by broiler management guidelines are considered conservative compared to that studied in research. According to some guidelines, the air velocity at bird level should not exceed 0.15-0.3 meters per second (30-60 feet per minute) during the brooding period to avoid wind chill effect on chicks (Aviagen, 2018; Cobb, 2018). However, the air speed in research at bird level was as high as 1.5 meters per second (300 feet per minute) (Bottcher et al., 1988).

EFFECT OF AIR MOVEMENT ON BODY TEMPERATURE

When the ambient temperature increased, not only do the birds rely more on latent heat loss but it eventually becomes the only method of dissipating heat (Genç and Portier, 2005; Richards, 1971). However, these studies were conducted in environmental conditions without air movement. Siegel and Drury (1968) suggested that although evaporative cooling from body surface is minimal, heat loss by convection can be increased by increasing air movement over the body surface. This suggestion was supported by several studies, where broiler body temperature decreased as air velocity over the bird increased (Furlan et al., 2000; Hamrita and Conway, 2017). In a study comparing the effect of multiple air speeds on the heat loss of 5-6 weeks old broilers, the results showed that sensible heat loss increased as air velocity increased. In addition, when the air speed was increased, some characteristics of increased latent heat loss such as increased respiratory rate and apparent discomfort were alleviated in birds exposed to high ambient temperature (Simmons et al., 1997). Furlan et al. (2000) further pointed out that the heat loss was more significant in unfeathered areas such as the legs. However, a combination of increased air velocity and air temperature could be detrimental to the birds. The result by Siegel and Drury

(1968) demonstrated that when the air temperature exceeded 40°C, significantly higher body temperature was observed in birds exposed to 150 meters per minute (m.p.m.) compared to 30 m.p.m. and 6 m.p.m. This indicated that the temperature gradient between the bird and air temperature resulted in a heat transfer from the environment to the bird and increasing air velocity made the situation worse by accelerating the heat transfer. Nevertheless, the results mentioned above demonstrated that air movement reduces broiler body temperature and is especially important in high ambient temperature conditions where evaporative heat loss is also compromised by high relative humidity.

The studies mentioned above regarding the effect of air movement on body temperature were conducted on broiler chickens between three and nine weeks of age. On the other hand, although concerns related to the wind chill effect on chicks has always existed, research on newly hatched chicks was scarce. Bottcher et al. (1988) observed that while the air speed at bird level was enhanced to 1.5 m/s (300 fpm), the birds made no significant attempt to move away from the fans. The author suggested that the reason that the wind chill effect normally observed at such high velocity was suppressed as the air temperature was sufficiently high enough for the birds.

MEASURING BODY TEMPERATURE

Older birds

Measuring body temperatures with thermometers or thermistors have been widely adopted by research in birds. In large birds, the thermometer or thermistor is typically used to measure rectal temperature by inserting the probe about 25 – 50 mm into the cloaca to monitor core temperature (Christensen et al., 2012; Donkoh, 1989; Lin et al., 2005b; May et al., 1987; Yahav et al, 1995). Yahav et al. (1995) also used a thermometer to monitor subcutaneous temperature by inserting it subcutaneously under the wing. Richards (1971) surgically inserted a thermistor into

the anterior hypothalamus of birds to measure brain temperature. However, the data acquired via rectal measurements were usually discontinuous unless the probe was fixed inside the cloaca. In addition, research has shown that handling birds could affect their body temperature. Elevation in rectal temperature was observed after repetitive handling of the bird (Cabanac and Guillemette, 2001; Cabanac and Aizawa, 2000). Therefore, different methods in measuring body temperature have been used to avoid this effect.

Although rectal temperature is often used as an indicator of the thermal status, from a commercial production stand point however, the use of thermometer is not the optimal tool in measuring bird body temperature. Thermal images captured by infrared thermography shows the surface temperature of the bird and has been used as an alternative method to monitor bird body temperature without handling the bird (Lin et al., 2005a; Lin et al., 2005b; Nascimento et al., 2011). Although surface body temperatures are generally lower than rectal temperature, locations such as facial surface temperature has been shown to have a good correlation to the rectal temperature ($R^2 = 0.83$) (Giloh et al., 2012).

Aside from rectal temperature, several studies have attempted to record core body temperature in contrast to surface temperature without handling the birds. Hicks (2016) surgically implanted temperature data loggers into the abdominal cavity from the right side of the lower abdomen. The author mentioned that as the loggers were not fixed inside the abdominal cavity, the loggers could migrate to other locations during the study. The advantage of the data loggers is that the temperature data collected is continuous and the recording interval can often be set based on the requirement of the study. However, in order to access the data, the data loggers have to be retrieved to download the information from the loggers.

Telemetry systems have also been used to record body temperature by inserting the temperature transmitter into the gizzard through the bird's mouth, which took about 4 - 6 hours to reach the designated location. Yet, the data loggers would sometimes be compromised as a result of the grinding action of the gizzard, therefore additional protection may be required (Brown–Brandl et al., 2003; Genç and Portier, 2005). Once these transmitters are connected to receiving systems, they are able to transmit the temperature data providing instant physiological information. The limitation for the telemetry system is that data can only be collected by the receiver when the transmitter is within a specific the range. There is also the possibility of interference in signal transmission when multiple sensors are within the signal range.

Chicks

The body temperatures of broiler chicks were typically measured by inserting the thermometers or thermistor probes about 15 – 30 mm into the cloaca (Dunnington and Siegel, 1984; Hirabayashi et al., 2005; Lin et al., 2005b; Malheiros et al., 2000; Misson, 1977; Mujahid and Furuse, 2009; Tachibana et al., 2004; Takahashi et al., 2005). Infrared thermography has also been used in monitoring chick surface body temperature (Lin et al., 2005b; Malheiros et al., 2000). However, implanting temperature data loggers in newly hatched chicks is generally more difficult than older chickens due to their size and the delicate tissue.

CHAPTER 2

STATEMENT OF PURPOSE

The use of circulation fans during the brooding period not only reduces the temperature stratification in the house, the air movement also reduces litter moisture and increase overall foot pad health of the birds. However, there are usually concerns toward generating air movement over chicks and air velocity at bird level has been recommended not to exceed 0.15 – 0.3 m/s during the brooding period. While air movement has been shown to reduce body temperature in broilers by increasing convective heat loss through the body surface, these studies were conducted on market age broilers between 3 and 9 weeks of age. Little research has been done to show the effect of air movement on young chicks. The first objective of this study was to evaluate the effect of air movement on chick body temperature during the brooding period.

While rectal temperature has been the most predominant representation of deep body temperature in chicks, the measuring process of rectal temperature is often time consuming, laborious and requires holding the chicks. Since holding the chick may result in chick temperature changes, temperature loggers have been widely and successfully used as a temperature monitoring tool in larger broilers as it provides an accurate and continuous measurement of body temperature without the need to hold the bird. However, the size of the temperature loggers limits their use in smaller chicks. Therefore, an alternative chick body temperature measuring method with the advantage of collecting quality temperature data is needed for the current research. The second objective of this study was to evaluate temperature measured via sensors from various locations as an indirect measurement of the rectal temperature.

CHAPTER 3
MATERIALS AND METHODS
EXPERIMENTAL DESIGNS

Chick temperature measurement

In this study, the LifeChip® with Bio-Thermo technology (Destron Fearing™, Dallas, TX, United States) was selected for abdominal cavity (T_{AC}), subcutaneous layer of the back (T_B) and Subcutaneous layer of the flank (T_F) temperature measurements. This Radio Frequency Identification (RFID) temperature sensor was chosen for its small size. It provides real time temperature measurements, allowing immediate knowledge of chick temperature changes and proper adjustments can be made accordingly. The sensor measured 2 mm by 14 mm and was able to record temperatures between 33°C and 43°C with an accuracy of $\pm 0.1^\circ\text{C}$ and a resolution of 0.1°C. It had a relatively low cost (\$10) compared to temperature data loggers (\$300) and telemetry sensors (\$425). Each RFID sensor was provided with a 12-gauge needle to facilitate the insertion process. The sensor does not have a battery and did not possess the ability to record temperature continuously nor automatically. A Global Pocket Reader™ Plus was used to scan and activate the sensors for temperature measurements and it had a maximum scanning distance of 10 cm. The rectal temperature (T_R) was taken to provide comparison. It was used as a reference temperature to other studies and for comparison with the T_{AC} , T_B , and T_F . T_R was measured by inserting the Thermistor Temperature Instrument TM99A (Cooper-Atkins®, Middlefield, CT, United States) approximately 2.5 cm into the cloaca of the chick. This thermistor had an accuracy of $\pm 0.2^\circ\text{C}$ and a resolution of 0.1°C.

RFID sensor and Thermistor temperature standardization

Standardization of the RFID sensors and the thermistor was carried out to offset the discrepancy of temperature readings between the different sensors. The Fluke Calibration 1551a Stik Thermometer (Fluke®, Everett, WA, United States) was used as a standard thermometer with an accuracy of $\pm 0.05^\circ\text{C}$. The standardization process was performed in a water bath at 38, 40, and 42°C . The temperature readings of the sensor and the thermistor were recorded every minute for 20 minutes in each water temperature. A corresponding Fluke thermometer temperature was also recorded as a reference temperature for measurement standardization. Regression analyses were performed for the RFID sensor and the thermistor to create correction factors (Table 1). These correction factors were applied to the data in this study for body temperature analysis.

Table 1. Correction factors for each RFID sensor and thermistor. Twenty samples were collected for each sensor at each temperature for regression analysis.

Sensor ID	Regression equation	Coefficient of determination (R^2)*
304136	$Y = 1.0153x - 0.389$	0.99
304137	$Y = 0.9985x + 0.2793$	0.99
304138	$Y = 0.9744x + 1.2343$	0.99
304139	$Y = 0.9874x + 0.4822$	0.99
304140	$Y = 1.0036x - 0.0232$	0.99
304141	$Y = 0.9824x + 0.6119$	0.99
304142	$Y = 1.0013x + 0.152$	0.99
304143	$Y = 0.9832x + 0.7201$	0.99
304144	$Y = 0.9854x + 0.543$	0.99
304145	$Y = 0.972x + 1.0608$	0.99
304054	$Y = 0.9854x + 0.6512$	0.99

304055	$Y = 0.9716x + 1.1523$	0.99
304056	$Y = 1.0086x - 0.3034$	0.99
304057	$Y = 1.0026x - 0.0163$	0.99
304058	$Y = 0.9999x + 0.0529$	0.99
304059	$Y = 1.0199x - 0.6451$	0.99
304060	$Y = 0.9801x + 1.0833$	0.99
304061	$Y = 0.9745x + 1.2429$	0.99
304062	$Y = 1.0067x - 0.176$	0.99
304063	$Y = 1.013x - 0.3952$	0.99
304044	$Y = 0.9739x + 1.2793$	0.99
304045	$Y = 0.9737x + 1.2916$	0.99
304046	$Y = 0.9806x + 0.7552$	0.99
304047	$Y = 0.9872 + 0.4645$	0.99
304048	$Y = 0.9852x + 0.5911$	0.99
304049	$Y = 0.976x + 0.8613$	0.99
304050	$Y = 1.0015x - 0.0152$	0.99
304051	$Y = 1.0129x - 0.4611$	0.99
304052	$Y = 0.985x + 0.4912$	0.99
304053	$Y = 0.9899x + 0.5674$	0.99
Thermistor	$Y = 1.0005x - 0.06$	0.99

* The proportion of the variance in the dependent variable that is predictable from the independent variable

RFID implantation location evaluation and temperature measurement

A series of trials were conducted to assess sensor implantation location and procedure. Adjustments were made to optimize the implantation and temperature measuring process prior to the temperature and air velocity study. The abdominal cavity, subcutaneous layer of the back, and subcutaneous layer of the flank were selected as locations for sensor implantation. Five newly hatched chicks were selected for assessment for each location. All the trials were conducted in the University of Georgia Poultry Research Center. All animal related procedures and management were performed following the animal use protocol approved by the University of Georgia IACUC.

Abdominal cavity

The sensor was surgically implanted into the abdominal cavity to represent T_{AC} . The chick was held in a ventral position to access the abdominal incision site. Disinfection of the site was performed with 70% ethanol and a local anesthetic, Lidocaine (Hospira, Lake Forest, IL, United States), was administered at 2 mg/kg dosage prior to incision. An incision was made on the left side of the lower abdomen, approximately at the location of the gizzard to avoid the unabsorbed yolk sac. The sensor was inserted into the abdominal cavity with a 12-gauge needle. The incision was closed with a nonabsorbable monofilament suture (Ethilon 6-0, Ethicon, Somerville, NJ, United States, LLC) followed by topical application of Bacitracin ointment, USP (Kroger Co., Cincinnati, OH, United States) to prevent infection.

Subcutaneous layer

The sensors were implanted into the subcutaneous layer of the back and the flank to represent T_B and T_F respectively. The chick was held in a dorsal position to approach the back. The flank was approached by holding the chick in a lateral position and exposing the flank under the wing. The disinfection and local anesthetic application procedure was the same as those for

abdominal cavity sensor implantation. The sensor was inserted with the needle approximately 5 mm to the left of the spinal cord between the right and left scapula subcutaneously to prevent injury to the nervous system. The flank position was investigated by inserting the sensor subcutaneously under the right wing. The subcutaneous implantation site was closed by 3M™ Vebond™ Tissue Adhesive (3M™, Maplewood, MN, United States) followed by topical application of Bacitracin ointment, USP.

The chicks were kept in a 1.2 m by 1.5 m pen for 3 days for evaluation. The chicks' behavior were evaluated for any alterations in motility, eating or drinking. The ability of the reader to scan the sensors for temperature measurements was tested. However, no temperature measurements were recorded during the 3-day period. The locations of the sensors were examined at the end of the evaluation period to check for signs of migration and the incision sites were also checked for signs of infection.

Rectal measurement depth analysis

The insertion depth of the rectal thermometer affected the results of T_R and a study for optimal insertion depth was required. Thirty-two Ross 708 broiler chicks, each serving as a replica, were randomly selected to investigate the effect of three different insertion depths, 15, 22, and 30 mm, of the thermistor probe on T_R readings. The chicks were kept in a 1.2 m by 1.5 m pen under 29.4°C room brooding temperature. The T_R was measured from day of hatch to day three of age where the next day after hatch was considered day one of age. The T_R was taken twice on day of hatch and three times per day from day one to day three of age. In each measurement period, three temperatures from different insertion depths were taken where the order of the measuring depth for each chick was randomly assigned. Each temperature reading was recorded 20 seconds after insertion of the thermistor probe.

Control of room relative humidity with humidification system

Maintaining room relative humidity (Rh) at a certain level was difficult during the study period as different room temperatures and outdoor RH conditions affected room Rh. A humidification system was built in attempt to regulate the room Rh. The system regulated the room Rh by introducing moisture into the room but it did not have the ability to decrease room Rh. PVC pipes were formed into a square shape with four spraying nozzles. The system was connected to water source with a hose which was controlled by an electric shut-off valve. The electric shut-off valve was powered by a Eos® 2 Digital Humidity Controller (Titan Controls®, Vancouver, WA, United States). The controller activated the system once the room Rh dropped below the set target Rh and shut down the system once the room Rh reached 5% above the target Rh. A dumping valve was connected to the hose to remove the remaining water after the system was shut down. The humidification system was positioned in front of the circulation fan parallel to the ceiling to create a more uniform moisture level inside the room. The room Rh was able to be maintained at the set Rh with an $\pm 5\%$ margin of error.

TRIALS

Sensor location study

Sensors were implanted into the abdominal cavity, subcutaneous layer of the back and the flank of the chicks to evaluate the use of T_{AC} , T_B , and T_F as an indicator of the rectal temperature. Experiment 1 was carried out with three trials to examine the relationship between T_R and T_{AC} or T_B . Experiment 2 was conducted with three trials to investigate the relationship between T_R and T_B or T_F . During each trial, 30 eggs were obtained from a local commercial hatchery at 18 days of incubation prior to in-ovo vaccination. The incubation of the eggs was continued at the hatchery of the University of Georgia Poultry Research Farm. Fifteen newly hatched Ross 708 broiler chicks

were randomly selected for sensor implantation with each chick serving as a replica. All trials were carried out from hatch to day seven of age. Each chick was surgically implanted with one sensor in the abdominal cavity to represent T_{AC} and one sensor in the subcutaneous layer of the back to represent T_B . The implantation procedures were those described previously in the implantation location evaluation section. Prior to surgery, each chick was weighed using a Scout® Pro SPE2001 scale (Ohaus Corporation, Pine Brook, NJ, United States) with a 0.1 gram accuracy and T_R was measured. The chicks were sprayed with neon paint partially on the back for identification after the surgery. During the trial period, the chicks were placed in a 1.2 m by 1.5 m pen with fresh pine shavings. Feed and water were provided ad libitum. The lighting schedule was set as 20L:4D and the room temperature was set at 35°C for the entire trial period. The room temperature and RH were recorded every minute with two UX100-23 External Temp/RH Data Loggers (Onset Computer Corporation, Bourne, MA, United States) with a temperature accuracy of $\pm 0.38^\circ\text{F}$ and Rh accuracy of $\pm 2.5\%$. The data loggers were secured to the drinker line and the Temp/RH sensors were placed at chick level.

Temperature measurement

Experiment (T_R vs T_{AC} or T_B)

T_R , T_{AC} , and T_B were measured four times daily in Trials one and two. The temperature was measured every four hours from 6 am to 6 pm. At each time point, two sets of body temperature were measured in the order of T_B , T_{AC} , and T_R for each chick with a 30-minute interval between the sets. The temperature was measured five times daily in Trial three from 6 am to 6 pm with 3 hours between each measurement period. One set of T_B , T_{AC} , and T_R was measured at each period.

Experiment (T_R vs T_B or T_F)

T_R , T_B , and T_F were measured five times daily from 6 am to 6 pm with a 3-hour interval. One set of body temperatures in the order of T_B , T_F , and T_R was measured in each measurement period. All other procedures were the same as described in the previous section.

Effect of low room temperature

The room temperature was reduced to examine the effect of low ambient temperature on chick body temperature and on the relationship between T_R and T_{AC} , T_B , or T_{SF} . The room temperature was lowered to 23.9°C on days three and six of age at the third measurement period of the day in Trials 1 and 2 of Experiment (T_R vs T_{AC} or T_B) and at the fourth measurement period in Trial three of Experiment (T_R vs T_{AC} or T_B). In Experiment (T_R vs T_B or T_F), the room temperature was dropped on days three and six of age at the fourth measurement period of the day.

The chick body weight was measured individually daily from hatch to the end of the trial. At the end of the trials, chicks implanted with sensors were euthanized by cervical dislocation and the sensors were removed from the chicks. The final locations of the sensors were documented.

Effect of air movement and brooding temperature on chick body temperature and on the relationship between T_R and T_F

A study (1 m/s Study) was conducted to determine if air movement and/or room temperature would change the relationship between T_R and T_F body temperature. The validation of the relationship between the T_R and T_F was conducted under brooding temperatures of 29.4, 32.2 and 35.0°C and under 0 and 1 m/s of air movement. The study consisted of three experiments (29.4, 32.2 and 35.0°C). Each experiment was carried out with two trials. A second study (0.5 m/s Study) was conducted with three experiments (29.4, 32.2 and 35.0°C) to investigate the effect of low velocity air movement (0.5 m/s) on chick body temperature under brooding temperatures of 29.4°C, 32.2°C and 35.0°C. The 0.5 m/s Study was not conducted to investigate the relationship

between T_R and T_F therefore T_R was not measured. Each experiment was conducted with one trial. Sixteen newly hatched Ross 708 broiler chicks, each serving as a replica, were randomly selected for sensor implantation. The chick source was the same to those described in the sensor location study. All trials were carried out from hatch to day seven of age. Each chick was surgically implanted with a sensor in the subcutaneous layer of the flank as described previously to represent T_F . Neon paint was sprayed partially on the back of the chicks for identification purposes after the surgery. The chicks were randomly assigned to control or treatment to investigate the effect of air movement with different air velocities on chick body temperature and, in the high air velocity trials, on the relationship between T_R and T_F . The chicks in both groups were kept in the same 1.2 m by 1.5 m pen. Lighting schedule was set up as 24 hours of light and the brooding temperature was set constant for the entire trial period. A circulation fan was equipped and set up to be operating throughout the entire trial period to reduce the temperature stratification in the room. Two UX100-23 External Temp/RH Data Loggers were used to monitor and record room conditions as previously described. A humidification system was setup during the study in attempt to regulate the room Rh. In the 1 m/s Study, one trial in the 35.0°C and 29.4°C Experiments was conducted after the humidification was installed. All trials in the 0.5 m/s Study were conducted with control over the room Rh. The Rh during these two trials were targeted to be maintained at $45\% \pm 5\%$.

Air movement treatment setup

The effect of air movement on chick body temperature and the relationship between T_R and T_F was investigated by exposing the chicks in treatment group under air movement. A 18" fan was attached to a 100 x 60 x 90 cm wooden box with a 90 x 30 cm opening at the bottom where a 45x15 6" cooling pad was inserted. Eight individual cell cages made with wire measuring 10 x 18

x 18 cm with pine shavings inside were placed 30 cm in front of the pad opening serving as the treatment cells (Figure 1). This generated an average velocity of 1 m/s air movement over the individual cells. An average velocity of 0.5 m/s air movement was generated by placing the individual cells approximately 60 cm away from the pad opening. Another eight identical individual cell cages in the same room but with no air movement over the cells served as the control cells. A data logger was placed in one of the cells in each group to record the temperature and RH.

Temperature measurement

Chick body temperature was measured at 6 am and 3 pm daily from day one to seven of age. At each time point, body temperature was measured at two periods, the pen period and the air movement period. The pen period measurements were taken while the chicks of both treatment groups were in the pen. Two sets of T_F and T_R were measured during the pen period in 1 m/s Study and two sets of T_F were measured in the 0.5 m/s Study. Each set of bird temperature measurements was done in 20 minutes. After the measurements in the pen period, the chicks were immediately placed into the individual cells of their corresponding treatment group. A 30-minute accommodation period was provided followed by three sets of T_F and T_R measurements or T_F measurements for 1 m/s or 0.5 m/s group respectively. Each set was done in 20 minutes. After the measurement, the chicks were placed back in the pen. The whole measurement process in each period lasted approximately two hours. The chick body weight was measured individually daily from hatch to the end of the trial. At the end of the trials, chicks implanted with sensors were euthanized by cervical dislocation and the sensors were removed from the chicks. The final locations of the sensors were documented.



Figure 1. Air movement treatment setup. Eight individual cells served as the control group (left) with no air movement where eight individual cells served as treatment group (right). The fan generated 0.5 or 1 m/s air movement over the treatment cells.

STATISTICAL ANALYSIS

JMP pro 13 was used to analyze data from the rectal measurement depth trial. One-way Analysis of variance (ANOVA) was used to compare the rectal temperature measured from the three different cloacal depths. Tukey HSD test was used to separate means for comparison.

All other statistical analyses were conducted via SAS. The 10 per day rectal and flank temperatures were recorded into Microsoft Excel for each chick. The final location of the RFID sensors was recorded. The flank, back and abdominal temperatures measured from sensors that migrated from the original implant location were not included in the analysis. Mixed effect model was used to evaluate the relationship between rectal temperature and temperature measured from

the flank, back or abdominal cavity. Body temperature served as a response variable while location (rectal, abdominal cavity, back, flank), age of day, and sample time served as explanatory variables in Experiment 1 and 2. Akaike's information criterion (AIC) value, a value used to determine the amount of parameters in a statistical model for a set of experimental data (Akaike, 1973), was used to determine the fitness of the model and a correlation analysis was conducted between rectal (T_R), abdominal cavity (T_{AC}) and back (T_B) temperature. Temperature data measured from different locations (T_R , T_F , T_{AC} , and T_B) were also analyzed with ANOVA and Tukey HSD test was used to separate means for comparison.

The relationship between rectal and flank temperature at various temperatures and levels of air movement was evaluated by mixed effect model for each room temperature. Chick and day of age was considered as random effects while time of day and air movement as fixed effects. Interaction terms of day of age, time of day, air movement and location were added. Two models were generated for each room temperature where the first model was fitted with $\rho_1 \neq \rho_2$ (ρ_1 = correlation coefficient of control group and ρ_2 = correlation coefficient of treatment group) assuming the correlation was effected by air movement, and a reduced second model with $\rho_1 = \rho_2 = \rho$, assuming the correlation was not affect by air movement. The two models were compared based on AIC values for the correlation evaluation.

A linear regression model with mixed effects was conducted to formulate an equation to convert flank temperature into calculated rectal temperature. Temperature data collected from the treatment group of all trials in 1 m/s air movement experiment was included in the analysis. The flank temperature of the 0.5 and 1 m/s trials were all converted into calculated rectal temperature with the equation for further comparison. The effect of air movement on chick body temperature

was investigated using mixed model with calculated rectal temperature as response, air movement, room temperature, day of age and trial as fixed effects while chick as random effects.

Hatch weight, weight gain and weight gain ratio were compared using One-way ANOVA between control and treatment group of each trial. All statistical results were determined significantly different if $P < 0.05$.

CHAPTER 4

RESULTS AND DISCUSSION

RFID IMPLANTATION LOCATION EVALUATION AND TEMPERATURE

MEASUREMENT TEST

An evaluation study was conducted to assess RFID sensor implantation location and procedure. A preliminary study was conducted to validate the procedures to be utilized prior to beginning the chick body temperature trials. Using the experience from that trial some adjustments were made accordingly to optimize the implantation and temperature measuring process prior to the RFID sensor location study.

After the implantation surgery, the chicks were immediately returned to their holding pen. All chicks that underwent the implantation procedure were eating and drinking within an hour of surgery. During the three-day evaluation period, no issues in mobility were observed.

The RFID reader was able to quickly scan all the sensors implanted in the three implant locations. However, the reader would only receive the temperature reading from the sensor with the strongest signal. The reader was able to receive temperature readings from a single implanted sensor within 2 seconds, but measurement time increased to 15 to 20 seconds because the scanning angle had to be adjusted multiple times to obtain readings from all three sensors

The sensors were recovered on the last day of the evaluation period from the original inserted location and no signs of infection was observed in any of the chicks.

RECTAL MEASUREMENT DEPTH ANALYSIS

Rectal temperature (T_R) varied significantly ($P < 0.01$) between the three insertion depths (Figure 2). The deeper the insertion depth, the higher the temperature recorded. The four-day average T_R was 40.4, 40.3, and 39.8°C for the 30 mm, 22 mm, and 15 mm depths respectively. The 22 mm insertion depth was only slightly, yet significantly, lower than the 30 mm (0.1°C), while the 15 mm depth was 0.6°C lower than the 30 mm depth.

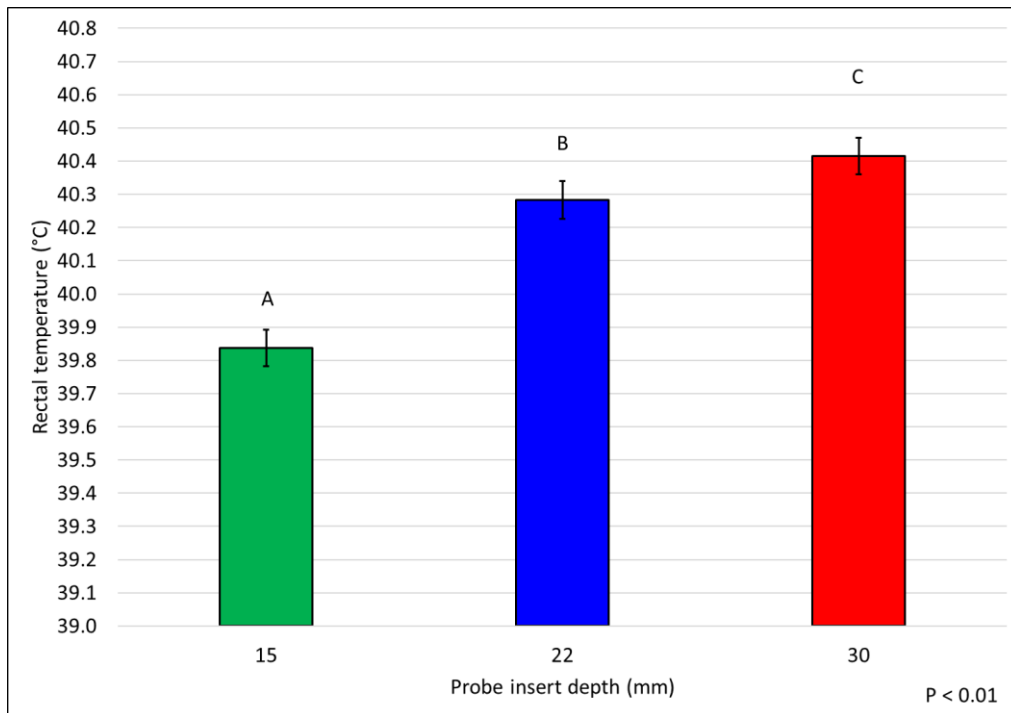


Figure 2. Average four-day rectal temperature measured from different insertion depth¹.

^{A-C} Means within the chart with no common superscript are significantly different ($P < 0.01$).

¹ Values are means \pm SEM ($n = 32$)

Average rectal temperature was significantly lower ($P < 0.01$) on day of hatch compared to 1-3 days of age (39.6, 40.3, 40.3, and 40.3°C) (Figure 3). However, there was no significant interaction between insertion depth and chick age, indicating that the relationship between the insertion depth and temperature reading was not age dependent (Figure 4).

The results in this study coincided with previous research performed by Lamoreux and Hutt (1938), where insertion of a thermometer 25 mm into the cloaca of White Leghorn and Rhode

Island Red chicks resulted in higher body temperature readings than that at 12 mm. Insertion depth of 37 mm, however, yielded slightly lower temperature readings comparing to that of 25 mm. The author pointed out that as the depth of insertion followed the order of 12, 25, and 37 mm, the gradual reduction in rectal temperature may be due to the cooling effect of adjacent tissue from repeated insertion of the thermometer.

Insufficient insertion depth of the thermometer probe can lead to lower body temperature readings. While there was no significant difference in temperature between 22 and 30 mm, chicks exhibited signs of discomfort when inserting the probe 30 mm into their cloaca indicated by increased vocalization and movement. As a result, in order to make sure an adequate insertion depth of at least 22 mm was achieved, an insertion depth of approximately 25 mm into the cloaca was used in subsequent testing.

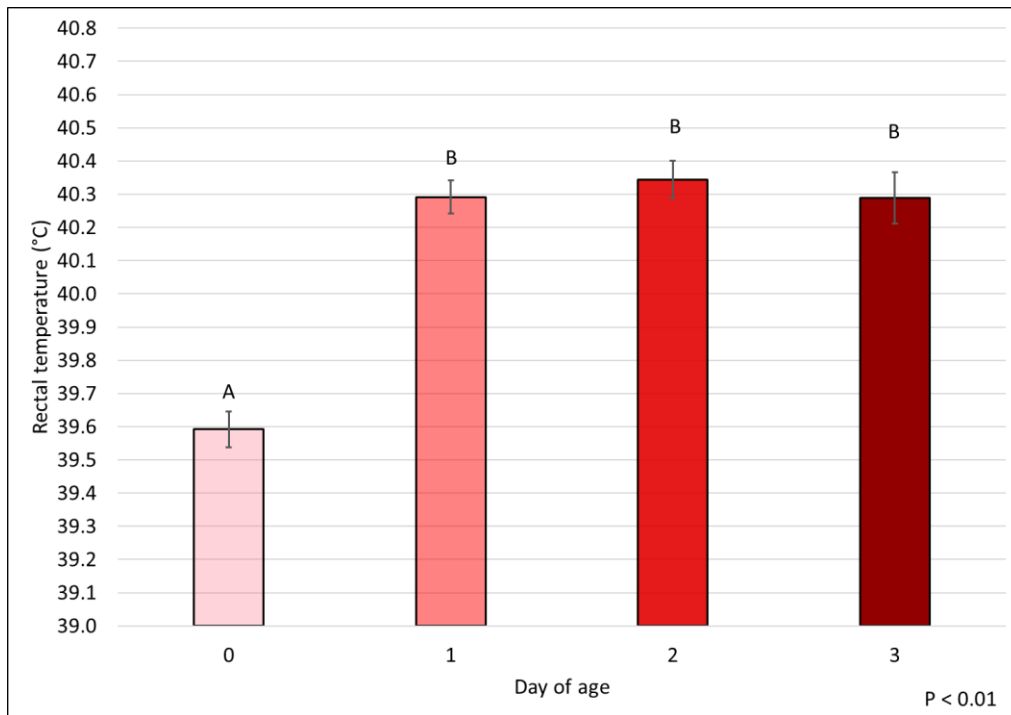


Figure 3. Daily average rectal temperature of all depths¹.

^{A-C} Means within the chart with no common superscript are significantly different (P<0.01).

¹ Values are means ± SEM (n = 32)

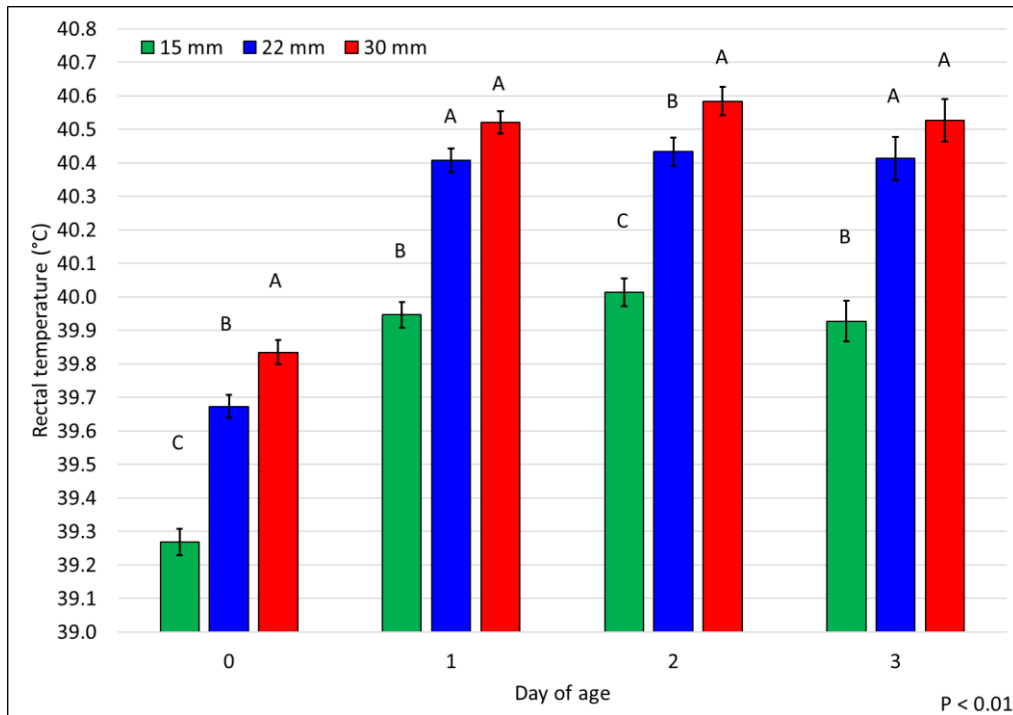


Figure 4. Daily average rectal temperature by different thermistor probe insertion depth (n = 32).

^{A-C} Daily means with no common superscript are significantly different (P<0.01).

¹ Values are means ± SEM (n = 32)

STUDIES

RFID SENSOR LOCATION STUDY EXPERIMENT 1 – RECTAL, ABDOMINAL CAVITY AND BACK

A location study was conducted to evaluate the correlation between the rectal temperature and temperature measured from different RFID sensor implantation locations (abdominal cavity and subcutaneous layer of the back) to determine the optimal RFID location.

The average room temperature for Trials 1, 2, and 3 were 33.3, 33.5, and 33.5°C respectively (Table 2). The average room Rh for Trials 1, 2, and 3 were 26, 27, and 26% respectively (Table 2). The moisture level of the room was not controlled during the study period and the Rh of the room was highly dependent of the outdoor condition. Although the average Rh between the three reps were similar, the larger variation observed in Trial 2 was likely due to the change in weather conditions.

Table 2. Average room temperature and relative humidity of Experiment 1¹.

Trial	Average Temperature (°C)	Average Relative Humidity (%)
1	33.3 ± 1.4	26 ± 5
2	33.5 ± 1.2	27 ± 8
3	33.5 ± 1.1	26 ± 5

^{A-C} Means within each column with no common superscript are significantly different (P<0.01).

¹ Values are means ± SD

The location of the sensors and mortality are summarized in Table 3. 96% of the sensors inserted into the back of the chicks remained in their original location while the remaining four were discovered in the muscular layer beneath the original location. 48% of the sensors inserted into the abdominal cavity remained in their original location. 32% of the sensors were discovered lodged in the muscular layer between the abdominal cavity and subcutaneous layer while 14% were found in the subcutaneous layer. 6% of the sensors dropped out of the chicks and were discovered in the litter.

Table 3. Location of the sensors at the end of the trial and mortality of Experiment 1.

	Back			Abdominal Cavity			Mortality
	Remained	Migrated	Lost*	Remained	Migrated	Lost*	
Trial 1	12	2	0	6	7	1	1
Trial 2	15	0	0	8	7	0	0
Trial 3	15	0	0	7	6	2	0
Total	42 (96%)	2 (4%)	0	21 (48%)	20 (46%)	3 (6%)	1

* sensor dropped out of the chick during the trial.

The sensors found in the muscular layer of the back were likely due to the sensors being inserted too deep into the muscular layer. The migration of the sensors observed in the abdominal cavity could be contributed to several reasons. First, the operation windows in chicks were small, which limited the surgical view and contributed to insertion error. Moreover, young chicks had a thinner and more delicate cutaneous and muscular tissue compared to older broilers. Tissue tear at the incision site by the suture could result from sudden large movement or chick resisting during T_R measurements, increasing the chance of sensors dropping out of the abdominal cavity.

There were significant interactions for “location*day of age” and “sample time*day of age” ($P < 0.001$) while “location*sample time*day of age” and “location*sample time” were not significant. AIC values reduced from -97.3 to -532.34 after removing the insignificant terms. A smaller AIC value indicated the model with interactions “location*day of age” and “sample time*day of age” had a better fit of the observed data and this model was used for further correlation analysis.

Figure 5 shows the average chick body temperature measured from rectal, abdominal cavity and back. T_R , T_{AC} and T_B increased from 40.5, 40.3, and 40.2°C on Day 1 to 41.5, 41.4, and 41.2°C on Day 7 of age. T_R was on average 0.1 and 0.3°C significantly higher than T_{AC} and T_B (Figure 6). The mean differences between T_R/T_{AC} and T_R/T_B were significantly and consistently small across all days of age ($P < 0.05$) (Table 4), suggesting the readings of both T_{AC} and T_B were similar to those of T_R .

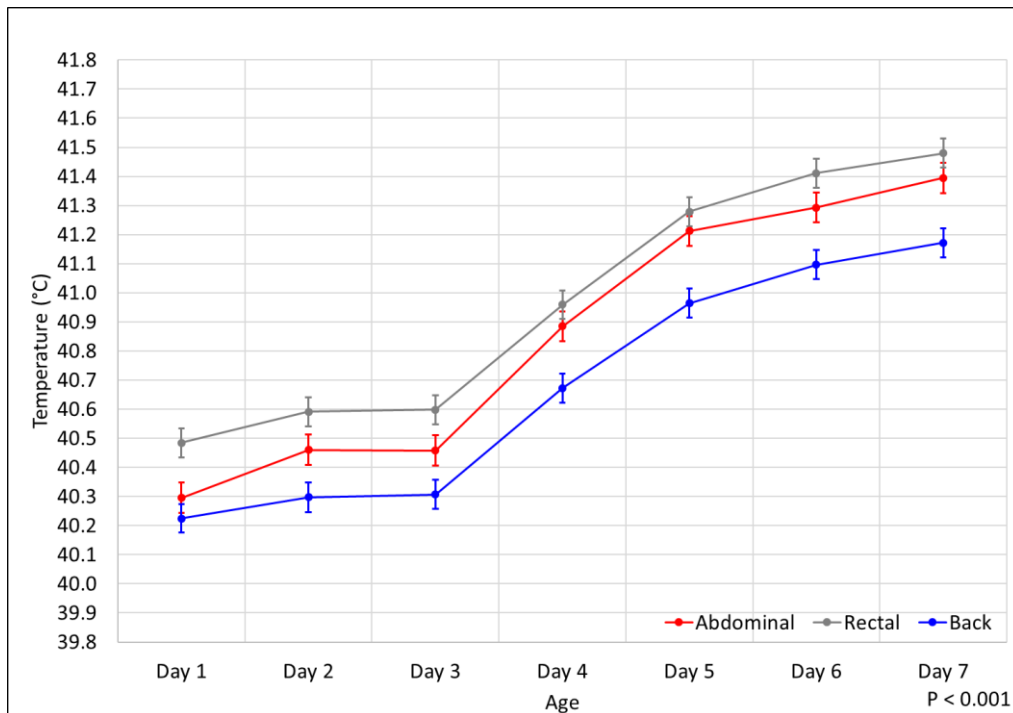


Figure 5. Averaged chick body temperature measured from different locations of Experiment 1.

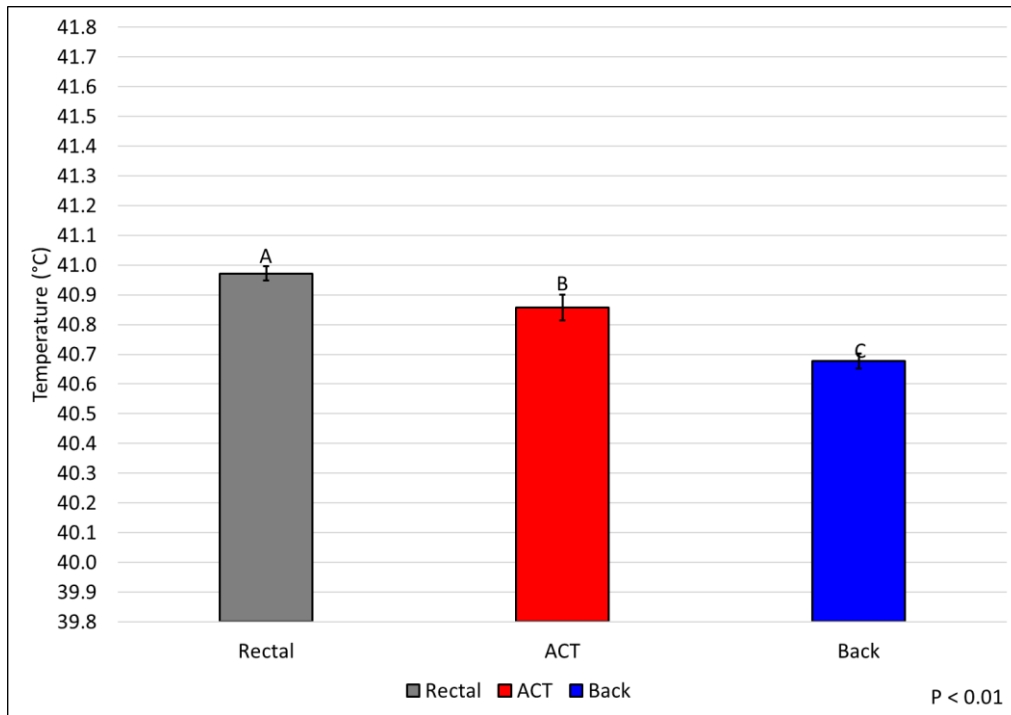


Figure 6. Comparison of temperature from three different locations of Experiment 1.

^{A-C} Means within the chart with no common superscript are significantly different ($P < 0.01$).

Table 4. Mean difference of rectal and abdominal cavity ($T_R - T_{AC}$)/back ($T_R - T_B$) by day of age of Experiment 1¹.

Day of age	Difference (°C)	
	$T_R - T_{AC}$	$T_R - T_B$
1	0.19 ± 0.02	0.26 ± 0.01
2	0.13 ± 0.02	0.29 ± 0.01
3	0.14 ± 0.02	0.29 ± 0.01
4	0.07 ± 0.02	0.28 ± 0.01
5	0.06 ± 0.02	0.31 ± 0.01
6	0.11 ± 0.02	0.31 ± 0.01
7	0.09 ± 0.02	0.31 ± 0.01
Average	0.11 ± 0.01	0.30 ± 0.01

¹ Values are means ± SEM (n = 45)

Table 5. Correlation matrix of temperatures measured from three locations of Experiment 1.

	Rectal	Abdominal cavity	Back
Rectal	1.0000	0.8298	0.8080
Abdominal cavity	0.8298	1.0000	0.7193
Back	0.8080	0.7193	1.0000

Hicks (2016) compared body temperatures measured from different locations in the body of 40-day-old broilers where the average T_{AC} and T_B were 41.5 and 40.8°C. The larger temperature difference observed between the T_{AC} and T_B temperature in this study was likely attributed to the larger size of the broilers compared to the chicks utilized in this study. A 40-day-old broiler was larger in size thus having a larger temperature gradient between the abdominal cavity temperature and the surface temperature (Tessier et al. 2003). Furthermore, baby chicks had limited space in the abdominal cavity for sensor implantation. Larger broilers, on the other hand, had more space that allow sensors to be implanted deeper, which was a better representation of the abdominal cavity temperature.

A correlation analysis was conducted and the result demonstrates rectal had a significant stronger correlation with the abdominal cavity (0.8298) where T_B has a correlation of (0.7193) to the rectal temperature. However, there was a higher possibility of losing abdominal sensors or sensor migration during the trial. Surgical implantation of the sensors into abdominal cavity also required more surgical skill and was a more invasive procedure. Hence, implanting RFID sensors into the subcutaneous layer of the back of chicks was the better choice of the two locations.

RFID SENSOR LOCATION STUDY EXPERIMENT 2 – RECTAL, BACK, AND FLANK

A second location study was conducted after the first (rectal vs. abdominal cavity and subcutaneous back) to investigate the correlation between rectal temperature and temperature measured from different subcutaneous locations (subcutaneous back and flank) to determine which of these two locations provided the closest correlation to rectal temperature.

The average room temperature for the three trials were 33.8, 33.9, and 34.3°C. The largest difference was observed between Trials 1 and 3 (0.5°C). This difference was small and was negligible when compared to the $\pm 1^\circ\text{C}$ variations within each trial. The average room Rh for Trials

1, 2, and 3 were 26, 28, and 44% respectively (Table 6). There were differences in Rh between the trials as the moisture level was not controlled during the trial periods and was highly dependent on the outdoor condition.

The location of the sensors and mortality are summarized in Table 7. 98% (42) of the sensors implanted in the back and the flank remained in their original location. One sensor was lost (slipped out of the incision site do tears from the suture tearing the cutaneous layer) from each of the implantation locations during the trial period. No migration of the sensors was observed. One mortality occurred in Trial 2 due to physical injury suffered at four days of age.

Table 6. Room temperature and relative humidity of Experiment 2.

Trial	Average Temperature (°C)	Average Relative Humidity (%)
1	33.8 ± 1.0	26 ± 4
2	33.9 ± 1.0	28 ± 7
3	34.3 ± 1.0	44 ± 5

^{A-C} Means within each column with no common superscript are significantly different (P<0.01).

Table 7. Location of the sensors at the end of the Experiment 2 and chick mortality.

Trial	Back			Flank			Mortality
	Remained	Migrated	Lost*	Remained	Migrated	Lost*	
1	14	0	1	14	0	1	0
2	14	0	0	14	0	0	1
3	14	0	0	14	0	0	0
Total	42 (98%)	0	1 (2%)	42 (98%)	0	1 (2%)	1

* sensor dropped out of the chick during the trial.

Mixed effect model was used to evaluate the correlation between the rectal (T_R) and abdominal cavity (T_{AC}) or rectal and back (T_B). The result were similar to those observed in Experiment 1 where significant interactions for “location*day of age”, “sample time*day of age” (P < 0.001) were observed while “location*sample time*day of age” and “location*sample time” were not significant. This was evident by the reduction of AIC values from -4244 to -4944 after removing the insignificant terms. The better fitted model was used for further correlation analysis.

Average chick body temperature measured from rectal, abdominal cavity and back increased from 40.7, 40.6, and 40.4°C on Day 1 to 41.4, 41.3, and 41.1°C on Day 7 of age under 35.0°C room temperature (Figure 7). This result was similar to a study previously done by Malheiros et al (2000) where the broiler rectal temperature increased from 40.2°C to 41.2°C after one week post-hatch. Han et al (2017) also reported an increase in broiler chick body temperature from 40.1°C to 41.0 °C during the first five days post hatch under 30°C brooding temperature.

T_R was on average 0.1 and 0.3°C significantly higher than T_F and T_B (Figure 8). The mean differences between T_R/T_F and T_R/T_B were significantly and consistently small across all days of age ($P < 0.05$) (Table 8), suggesting the readings of both T_F and T_B were close to those of T_R . Although both T_B , and T_F represented subcutaneous body temperature, a slightly higher average T_F was likely due to the additional layer of insulation against the surrounding environment provided by the wing.

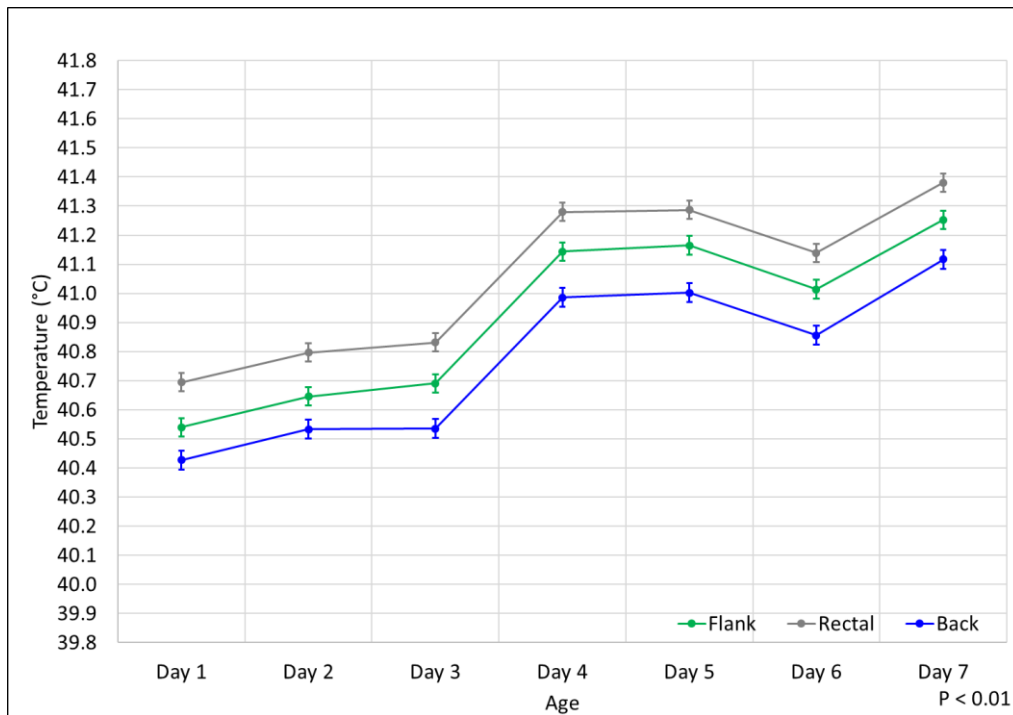


Figure 7. Average chick body temperature of different locations of Experiment 2.

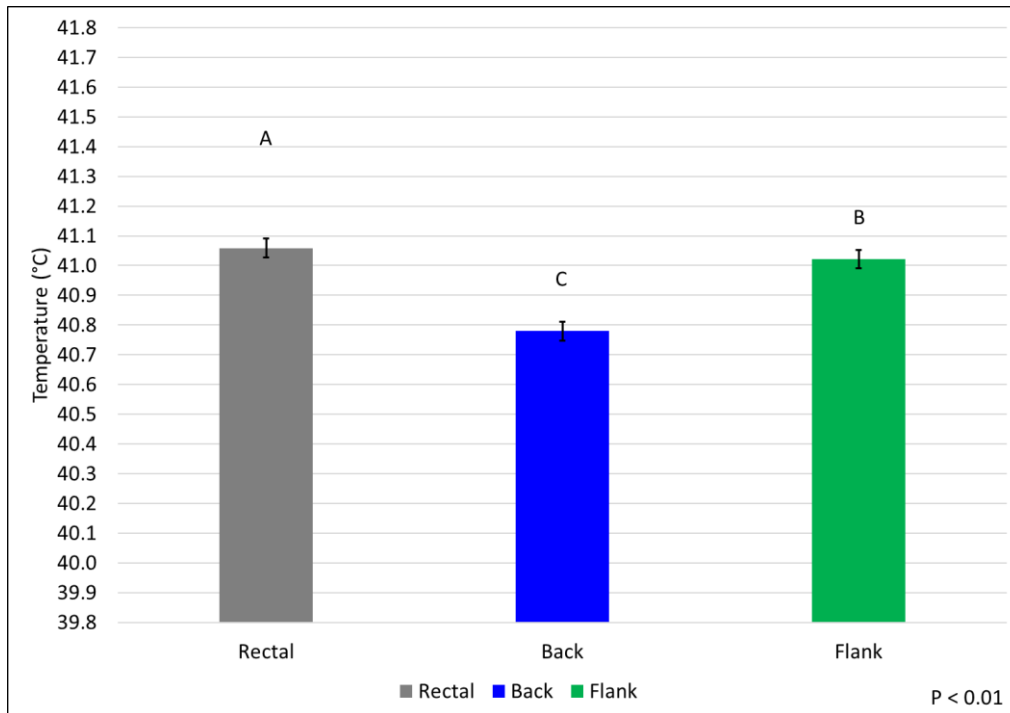


Figure 8. Comparison of temperature from rectal, subcutaneous back (Back) and flank (Flank). A – C Means within the chart with no common superscript are significantly different (P<0.01).

Table 8. Mean difference of rectal and back ($T_R - T_B$)/flank ($T_R - T_F$) by day of age in Experiment 2¹.

Day of age	Difference (°C)	
	$T_R - T_B$	$T_R - T_F$
1	0.28 ± 0.01	0.16 ± 0.01
2	0.26 ± 0.01	0.14 ± 0.01
3	0.30 ± 0.01	0.14 ± 0.01
4	0.29 ± 0.01	0.14 ± 0.01
5	0.30 ± 0.01	0.12 ± 0.01
6	0.28 ± 0.01	0.13 ± 0.01
7	0.26 ± 0.01	0.13 ± 0.01
Average	0.28 ± 0.004	0.14 ± 0.02

¹ Values are means ± SEM (n = 45)

Table 9. Correlation matrix of temperatures measured from three locations in Experiment 2.

	Rectal	Back	Flank
Rectal	1.0000	0.7855	0.8909
Back	0.7855	1.0000	0.7623
Flank	0.8909	0.7623	1.0000

A correlation analysis was conducted and the results show rectal had a significantly stronger correlation with the flank (0.8909) where T_B has a correlation of (0.7855) to the rectal temperature. The result of location trials indicated that subcutaneous layer sites were more reliable implantation locations compared to the abdominal cavity due to less sensor migration or loss of sensors. In addition, the surgery procedure was simpler and less invasive for subcutaneous implantation. The flank temperature site was shown to be a more consistent indirect measure of the rectal temperature of all three locations evaluated (T_F , T_B , and T_{AC}).

EFFECT OF AIR MOVEMENT AND ROOM TEMPERATURE ON THE CORRELATION BETWEEN RECTAL AND FLANK TEMPERATURE

The relationship between rectal and subcutaneous flank temperature was further investigated to determine whether the correlation would be affected by common variations in brooding temperature and air movement. This study was arranged into a 3 X 2 factorial design with three brooding temperatures (35.0, 32.2, and 29.4°C) and two air velocities (0 and 1 m/s).

During the three experiments the average air temperatures at three chick temperature measurement locations (pen, control and treatment cells) averaged within 0.5°C of the trials' target temperatures (Table 10). During the experiment there were slight, differences in air temperature (0.9°C or less) between all three chick temperature measurement locations for all trials. Although previous research has shown that room temperature differences of 10°C can reduce broiler chick body temperature by as much as 0.7°C (Malheiros et al. 2000) and a 5°C difference in room temperature caused broiler chick body temperature to drop 0.6°C (Lin et al. 2005b), in this study the differences in air temperature between the three chick temperature measurement locations were relatively small in comparison (0.9°C) and as a result were unlikely to have a significant impact on chick body temperature.

Table 10. Room temperature recorded from different locations during 1 m/s study.

Experiment	Trial	Average	Pen	Control Cell	Treatment Cell
32.2°C	1	32.0 ± 0.2	31.9 ± 0.2 ^C	32.0 ± 0.2 ^B	32.2 ± 0.3 ^A
	2	32.2 ± 0.6	32.2 ± 0.6 ^B	32.0 ± 0.6 ^C	32.3 ± 0.7 ^A
35.0°C	1	34.8 ± 0.4	35.0 ± 0.5 ^A	34.5 ± 0.3 ^B	35.0 ± 0.3 ^A
	2	34.3 ± 0.3	33.8 ± 0.3 ^C	34.3 ± 0.3 ^B	34.7 ± 0.4 ^A
29.4°C	1	29.0 ± 0.2	28.9 ± 0.2 ^C	29.0 ± 0.1 ^B	29.2 ± 0.3 ^A
	2	29.2 ± 0.5	29.1 ± 0.4 ^C	29.2 ± 0.4 ^B	29.4 ± 0.6 ^A

^{A-C} Means within each row with no common superscript are significantly different (P<0.01).

During the 32.2°C experiment the only method of controlling Rh levels within the study room was by adjusting the minimum ventilation rate of the room. Even at extremely low air exchange rates (350 cfm) the Rh was approximately 30% which is well below that typically recommended (40 to 60%) (Czarick and Fairchild, 2012) (Table 11). During the first trial at 35.0°C a humidification system was added to the room which had a negligible effect on room Rh. For the second 35.0°C trial a humidification system with higher capacity was installed in the room. The target Rh level was set at 45% and the average room Rh of all the three sensors were 43, 45 and 44% for the three trials respectively. A smaller and consistent variation in Rh was also observed after the installation of the humidification system (3% vs 7, 4 and 2%). There were slight yet significant differences in Rh between the control and treatment cell (less than 2%). Although research has shown Rh could affect body temperature and a difference of 25% can increase broiler body temperature by 0.5°C (Yahav et al. 1995; Lin et al. 2005a; Lin et al. 2005b), the Rh differences were relatively smaller in the current study (6% or less) and were unlikely to have a physiological effect on the chicks.

No sensors were lost at any point of the trial period. Two mortalities unrelated to sensor implantation were found out of 96 chicks during the 29.4, 32.2, and 35.0°C experiments.

Table 11. Relative humidity recorded from different locations during 1 m/s study.

Experiment	Trial	Average	Pen	Control Cell	Treatment Cell
32.2°C	1	33 ± 7	35 ± 7 ^A	33 ± 7 ^B	32 ± 7 ^C

	2	28 ± 4	30 ± 4 ^A	27 ± 4 ^B	26 ± 4 ^C
35.0°C	1	28 ± 2	27 ± 2 ^B	27 ± 2 ^B	29 ± 3 ^A
	2*	43 ± 3	46 ± 3 ^A	42 ± 2 ^B	41 ± 3 ^C
29.4°C	1*	45 ± 3	47 ± 3 ^A	44 ± 3 ^A	43 ± 3 ^B
	2*	44 ± 3	48 ± 4 ^A	43 ± 3 ^B	42 ± 3 ^C

^{A-C} Means within each row with no common superscript are significantly different (P<0.01).

* humidification system was installed in the room to control room RH

The effect of air movement (0, 1 m/s) and room temperature (29.4, 32.2, 35.0°C) on the correlation between rectal and flank temperature was investigated with mixed effect model. AIC values were compared between Models 1 and 2 for each room temperature (Table 12), where Model 1 assumed the correlation coefficient between T_R and T_F was different between control (0 m/s air) and treatment group (1 m/s air) while Model 2, a reduced model with one less parameter (group), assumed the correlation coefficient between T_R and T_F was not significantly different between the two groups. The result shows that there were no significant differences between Model 1 and Model 2. This suggested that the correlation coefficient between T_R and T_F was not affected by air movement and a reduced Model 2 without separating the groups was sufficient to fit the data.

Table 12. Correlation coefficient between rectal and flank temperature of control and treatment group of Experiment 3¹.

Experiment		Model 1 ($\rho_1 \neq \rho_2$)	Model 2 ($\rho_1 = \rho_2$)
29.4°C	-2 Res Log Likelihood	-1301.0	-1298.4
	AIC	-1289.0	-1288.4
32.2°C	-2 Res Log Likelihood	-366.2	-343.1
	AIC	-354.2	-331.1
35.0°C	-2 Res Log Likelihood	-1467.3	-1496.91
	AIC	-1485.3	-1486.91

¹ n = 32

A similar research project was done to examine the correlation between rectal temperature (T_R) and facial surface temperature (T_{FS}) measured by thermal-imaging camera in broilers (Giloh et al. 2012). A strong linear correlation was observed between T_R and T_{FS} ($R^2 = 0.83$) independent of age and room temperature. T_{FS} was consistently on average 2°C lower than T_R regardless of the

room temperature studied. The author indicated that the air movement generated from the ventilation system (0.9 – 1.5 m/s) did not affect the correlation between the two temperatures.

All trial data from the treatment groups were combined to generate a single regression model. This regression model was used to convert the flank temperature into calculated rectal temperature (T_{CR}). The result of the analysis generated a predicting equation: Calculated T_R (T_{CR}) = $0.97 * T_F + 1.39$ ($R^2 = 0.99$) with an accuracy of $\pm 0.1^\circ\text{C}$. As most studies used rectal temperature as a reference temperature, the equation was used to convert flank temperature into calculated rectal temperature for further analysis of the effect of different air velocities on chick body temperature. By calculating the rectal temperature, these data could be compared to the rectal temperature results of previous research.

EFFECT OF AIR MOVEMENT ON CHICK BODY TEMPERATURE

In addition to the 1 m/s study, a 0.5 m/s study was added to investigate the effect of air movement on chick body temperature. The study was conducted under 35.0, 32.2 and 29.4°C brooding temperatures. Rectal temperatures were not measured during the 0.5 m/s study as the results from 1 m/s study indicated flank temperatures was an acceptable indirect measurement of the rectal temperatures. All flank temperature data recorded from the 0.5 and 1 m/s study were converted into calculated rectal temperature (T_{CR}) with the predicting equation produced from the 1 m/s air movement experiment ($T_{CR} = 0.97 * T_F + 1.39$). No sensors were lost during the 0.5 m/s study period and no mortality occurred.

The air temperature at three chick temperature measurement locations within the room (pen, control and treatment cells) during the three trials averaged within 0.5°C of the trials' target temperatures. There were slight differences in air temperature recorded between all three chick temperature measurement locations within the room for all trials (Table 13). Pen temperatures for

all trials were on average 0.6°C lower than the cell temperatures possibly due to treatment/control cells being located 70 cm higher above the ground where the air temperature tended to be warmer due to stratification. Since the fan box moving air over the treatment cells was drawing air from 90 cm above the table where the treatment cells were located, the air moving over the treatment cells averaged 0.3°C higher than the control cells. The air temperature difference between the three chick temperature measurement locations were similar to those in 1 m/s trials (Table 7) and were also unlikely to have a significant impact on broiler chick body temperature compared to previous research mentioned above (Malheiros et al. 2000; Lin et al. 2005b).

The humidification system installed after 35.0°C Trial 2 of the 1 m/s study was also used in the 0.5 m/s study to control the room Rh. A target Rh of 45% was set to minimize the effect of Rh on body temperature. During the three trials the average Rh at the three chick measurement locations (pen, control and treatment cells) averaged within 2% of the target Rh (44, 44, and 46%) and were similar to those in the 1 m/s study (Table 14). Although slight differences in Rh was observed between the three chick temperature measurement locations, the differences were similar to those in the 1 m/s study (0.5 m/s: 9% or less vs 1 m/s: 6% or less) and were unlikely to cause a physiological effect on the chicks.

Table 13. Room temperature recorded from different locations during 0.5 m/s study.

Experiment	Average	Pen	Control Cell	Treatment Cell
35.0°C	34.7 ± 0.3	34.2 ± 0.3 ^C	34.8 ± 0.3 ^B	35.1 ± 0.4 ^A
32.2°C	32.2 ± 0.3	31.8 ± 0.2 ^C	32.2 ± 0.2 ^B	32.5 ± 0.4 ^A
29.4°C	29.0 ± 0.3	28.7 ± 0.3 ^C	29.0 ± 0.2 ^B	29.4 ± 0.3 ^A

^{A-C} Means within each row with no common superscript are significantly different (P<0.01).

Table 14. Room relative humidity recorded from different locations during 0.5 m/s study.

Trial	Average	Pen	Control Cell	Treatment Cell
35.0°C	44 ± 2	48 ± 2 ^A	42 ± 2 ^B	41 ± 2 ^C
32.2°C	44 ± 3	48 ± 3 ^A	42 ± 3 ^B	41 ± 3 ^C
29.4°C	46 ± 3	51 ± 4 ^A	44 ± 3 ^B	42 ± 3 ^C

^{A-C} Means within each row with no common superscript are significantly different (P<0.01).

Hatch weight, weight gain and weight gain ratio

Individual chick body weight was measured daily. Body weight gain and weight gain ratio was calculated for the control and treatment group of each trial (Table 15). Although there were no significant differences in hatch weight between the control and treatment groups within each trial, there was a significantly higher weight gain in the control group of the 32.2°C Trial 1. Overall, body weight gain of the chick was not significantly affected by room temperature or air movement.

Previous research has shown that while feed consumption of the first week was similar in the chicks raised between 26.7 and 35.0°C room temperature, a better feed efficiency and weight gain were observed in those brooded under 30.0 to 35.0°C (Harris et al. 1975). A similar result was seen in the current study where body weight gain was not significantly affected by room temperatures of 29.4, 32.2 or 35.0°C. However, since the feed consumption was not recorded in the current study, no feed efficiency data was presented.

Although air velocity at bird level has been recommended not to exceed 0.15-0.3 m/s during the brooding period (Aviagen, 2018; Cobb, 2018) because of possible adverse impact on chick performance. Chick performance did not appear to be affected in this study by the air movement. This could be due to the chicks in the treatment groups only being exposed to air movement for a short period of time (three hours per day) or the temperatures were warm enough that the convective heat loss caused by the air movement was not sufficient to affect chick performance. Furthermore, feed consumption was not recorded in the current study which could have been different. Therefore, these results suggested that further body temperature along with performance studies may be required to investigate the physiological effect of air movement on chicks.

Table 15. Chick hatch weight, end weight, weight gain and weight gain ratio during the trial period.

Experiment	Air velocity (m/s)	Flock age (wk)	Trial	Group	Hatch weight (g)	Weight gain (g)	Weight gain ratio
29.4°C	-	46	1	Ctrl	45.9 ± 3.5	87.1 ± 17.9	1.92 ± 0.46
	1		1	Trt	44.7 ± 3.8	92.7 ± 27.6	2.05 ± 0.45
	-	37	2	Ctrl	40.1 ± 2.0	61.2 ± 11.1	1.53 ± 0.32
	1		2	Trt	41.7 ± 2.9	66.3 ± 24.1	1.59 ± 0.58
	-	40	1	Ctrl	44.1 ± 1.4	65.7 ± 9.9	1.49 ± 0.24
	0.5		1	Trt	45.3 ± 0.7	73.3 ± 8.6	1.62 ± 0.20
32.2°C	-	47	1	Ctrl	48.6 ± 1.8	107.6 ± 18.1 ^A	2.21 ± 0.37 ^A
	1		1	Trt	47.9 ± 1.5	81.8 ± 16.0 ^B	1.70 ± 0.30 ^B
	-	40	2	Ctrl	46.0 ± 1.1	65.7 ± 7.2	1.43 ± 0.15
	1		2	Trt	47.0 ± 1.4	62.2 ± 12.3	1.32 ± 0.24
	-	46	1	Ctrl	40.7 ± 2.9	60.9 ± 15.1	1.49 ± 0.34
	0.5		1	Trt	40.5 ± 1.7	72.6 ± 16.4	1.79 ± 0.38
35°C	-	60	1	Ctrl	47.2±2.6	78.8 ± 15.8	1.67 ± 0.32
	1		1	Trt	45.7±3.1	80.6 ± 23.1	1.79 ± 0.60
	-	44	2	Ctrl	44.8±2.7	78.0 ± 18.5	1.76 ± 0.44
	1		2	Trt	44.7±2.9	78.6 ± 21.3	1.75 ± 0.42
	-	35	1	Ctrl	44.1±2.6	61.5 ± 6.0	1.40 ± 0.16
	0.5		1	Trt	44.0±2.3	58.8 ± 5.1	1.34 ± 0.12

A – B means within each column of each trial with no common superscript are significantly different (P < 0.01)

¹ n = 8 for treatment and control group of each trial

Chick behavior during the pen period

A time lapse camera was set up to record chick behavior during all the trials except the 1 m/s 35.0°C Trial 1 and 0.5 m/s 29.4°C Trial. Figures 9 to 11 represent some behavioral examples observed during the trials. A preliminary project using a wire frame box with four 6” circular antennas to automatically record flank temperature measured by the RFID sensor was conducted simultaneously except for 1 m/s 35.0°C Trial 1 (data not presented). The RFID sensor recording system was set up surrounding the feed tray with four antennas serving as entrance, allowing chicks to access feed (shown in Figure 9 to 11). All pens in the trials were set up identically.

During the pen period, chicks were observed occasionally clustering together at all three room temperatures. At 29.4°C, the time lapse camera recorded chicks coalescing after placement and low activity was observed in the first day (Figure 9A). While a few chicks (approximately 15%) may appeared to be more active and broke free from the group, most chicks remained as a cluster. Even when all the chicks were active, they tended to move around in the pen as a group (Figure 9B). At day four of age, chicks were observed forming a single but looser cluster when resting (Figure 9C). By day seven of age, chicks were resting in similar group pattern as in day four (Figure 9D).

In the 32.2°C trials, chicks were also seen often coalescing tightly in the pen on day one of age and few chicks were occasionally seen separated from the larger group when resting (Figure 10A). By day four of age, instead of forming a large group similar to that in 29.4°C trials, smaller groups were seen formed when the chicks were resting (Figure 10B). Toward the end of the week, instead of forming smaller groups when resting, chicks were spread out in the pen (Figure 10C).

In the 35.0°C trials, chicks rested as a single cluster group like those observed in the 29.4 and 32.2°C trials. However, chicks had higher activity level on day one of 35.0°C trials evident by higher feeding and drinking frequency where chicks spent more time coalescing in 32.2 and 29.4°C trials. (Figure 11A). On day two of age, chicks were already seen resting in smaller groups in contrast to large single groups in 32.2 and 29.4°C trials. (Figure 11B). By day three, chicks were seen spread out in the pen when resting (Figure 11C). On day six and seven of age in the 35.0°C trials, in addition to disappearance of grouping activity, chicks were also seen panting in the holding pen and in the air movement period, indicating signs of heat stress due to high brooding temperature.

Coalescing with conspecifics have been suggested to serve as a behavioral mechanism to maintain a higher rectal temperature in chicks as their thermoregulatory function was still under development (Rovee-Collier et al. 1996). Misson (1976) showed grouped chicks brooded throughout the room temperature range of 20-35°C had significantly higher rectal temperature (approximately 1°C) as they were able to coalesce for warmth compared to isolated chicks. The thermoneutral zone of the grouped chicks was, as a result, larger (31-37°C) compared to the isolated chicks (34-37°C). As the temperature reached the thermoneutral zone, the huddling activity disappeared in grouped chicks according to the author.

While huddling can be a response to unsatisfactory temperature conditions, it has been known as a defensive mechanism in other avian species (Adelie Penguin) against disturbance by predators or adverse conditions (Spurr, 1975). This may explain the field observations where chicks instinctively grouped together occasionally for security even if the air temperature would be considered acceptable.

Chicks clustered into groups for warmth when their thermoregulation system was still under development and the higher the room temperature the sooner the behavior disappeared. However, coalescing could also serve as a defensive mechanism against adverse conditions or an instinctive behavior for security. Therefore, care should be taken while interpreting such behavior.

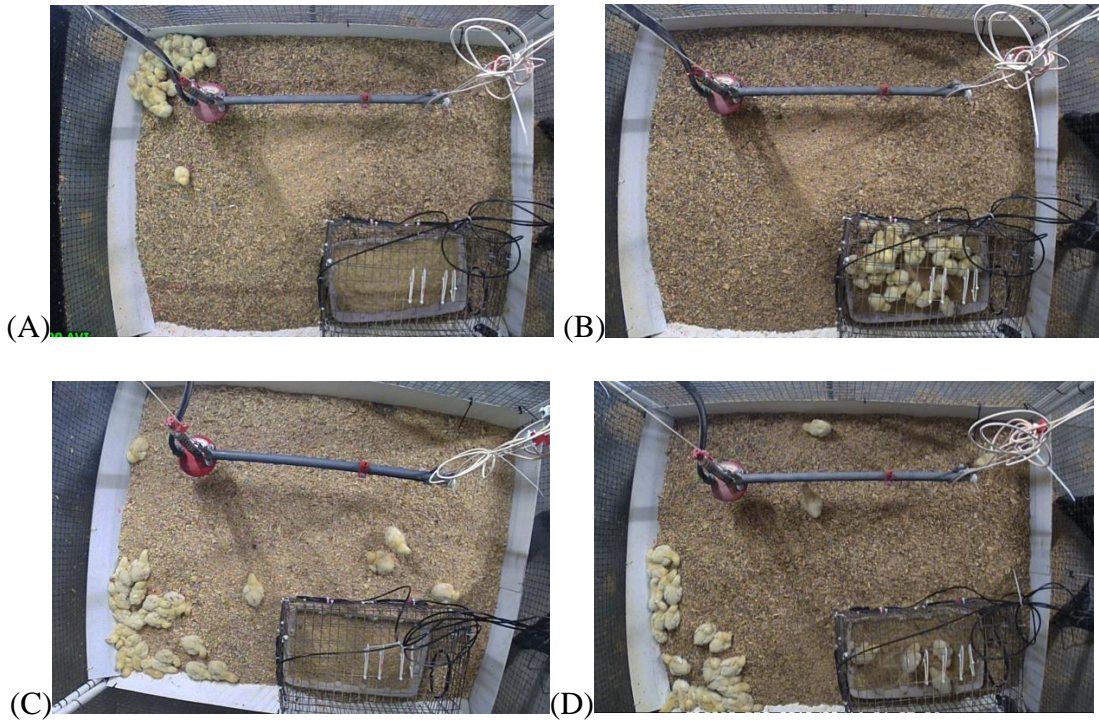


Figure 9. Chick behavior in 29.4°C trials. (A) Chicks coalescing on day one of age. (B) Chicks stayed closed to each other during feeding at day one of age. (C) Chicks formed a looser cluster when resting at day four of age. (D) Chicks resting in smaller groups.

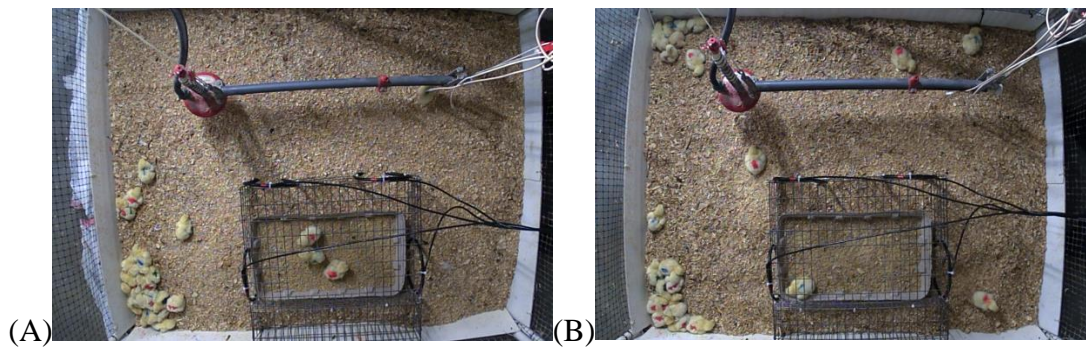




Figure 10. Chick behavior in 32.2°C trials. (A) Chicks coalescing on day two of age. (B) Chicks formed small clusters when resting on day four of age. (C) Chicks spread out when resting on day seven of age

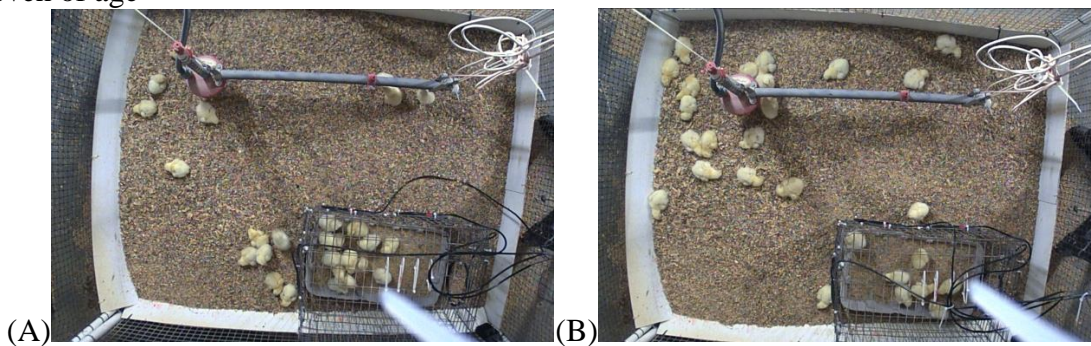


Figure 11. Chick behavior in 35.0°C trials. (A) Chicks exhibited higher frequency of feeding and drinking activity on day one (B) Chicks resting in smaller groups on day two of age (C) Chicks spread out when resting on day three of age.

Chick body temperature measured in the pen during the first week of age

Figure 12 shows the chick average calculated rectal temperature (T_{CR}) over the first week of age measured during the pen period. The calculated chick rectal temperature increased over time regardless of room temperature during the trial period. The average T_{CR} measured under 29.4, 32.2 and 35.0°C room temperatures significantly increased from 40.5, 40.4, and 40.5°C on day

one of age to 41.1, 41.1, and 41.2°C on day seven of age respectively. The results of the current study agreed with previous research results where chick body temperature was also observed to increase during the first week of age. Tzschentke and Nichelmann (1999) reported chick body temperature (species not specified) increased from 40.0°C to 41.2°C from day one to seven of age where Melheiros et al. (2000) observed broiler chick body temperature changed from 39.7°C on day one to 41.2°C on day seven of age. Freeman (1965b) suggested that the increase in body temperature observed in newly hatched chicks was due to replacement of yolk materials with active mass, thus increasing metabolic rate which was evident by increased oxygen consumption during the study.

A three-way interaction between room temperature, age of chick and trial ($P < 0.01$) was observed, indicating that the effect of room temperature on T_{CR} changed over time and between trials. Although room temperature had a slight yet significant effect on chick body temperature ($P = 0.0460$), the differences in T_{CR} among the three room temperatures at each day of age were all within 0.1°C. Melheiros et al. (2000) reported significantly lower rectal temperature in broiler chicks reared at lower room temperatures during the first week of age. However, both the room temperature range (20, 25, 35°C vs. 29.4, 32.2, 35.0°C) and temperature differences (5 and 10°C vs 2.8°C) were larger than those of the current study. It was likely that the magnitude of the room temperature differences and the range of the room temperature were not large enough to cause a significant change in chick body temperature in current study.

The effect of trial on body temperature could possibly be due to breeder flock age. The chicks originated from breeders of different flock ages between each trial. Weytjens (1999) suggested breeder flock age had an effect on thermoregulation of the broiler chicks. While the rectal temperatures were similar between the chicks originating from old and young breeder flocks

(25 vs 60-week of age) under 33°C room temperature, T_R of the chicks from young breeder flock was approximately 2°C lower than those from old breeder flock when the room temperature was 20°C.

Although the author (Weytjens, 1999) also saw a significant higher body weight in the chicks from older breeder flocks, no analysis was performed between the body weight and body temperature. Another study performed by Lamoreux and Hutt (1939) indicated that there were no correlations between body temperature and body weight of the White Leghorn and Rhode Island Red chicks at four days of age. Berman (1973) found that while there was a low correlation between the rate of growth and body temperature, a high negative correlation was seen between the growth rate and increments in body temperature. Although this result suggested that maintaining a constant body temperature was essential for maintenance of growth, the effect of growth rate on thermoregulatory ability of broilers was not investigated. Therefore, further studies may be required to evaluate the effect of growth rate on thermoregulatory ability of the chicks.

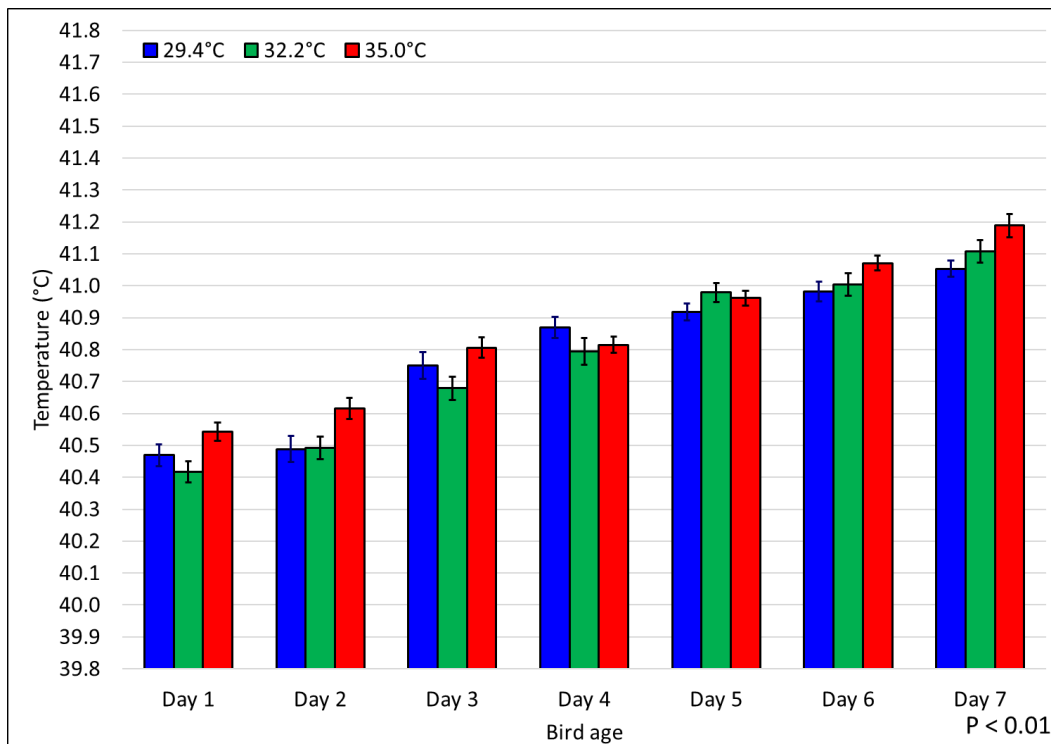


Figure 12. Chick average calculated rectal temperature of the first week during the pen period¹.
¹ n = 144

Moving chicks from the pen to individual cells caused changes in body temperature

The results showed chick body temperature in the control group changed when being moved from the pen to individual control cells (Figure 13). While average calculated rectal temperature (T_{CR}) of the 7-day period had a 0.2°C dropped under 29.4°C after being moved, T_{CR} did not change under 32.2°C and a 0.2°C increase in T_{CR} was observed under 35.0°C . Further analysis showed that the change of body temperature between the two measurement periods was age and room temperature dependent. In the 29.4°C trials, there was a significant drop of 0.3°C in body temperature on day one and 0.2°C on day two through day four of age ($P < 0.01$) where the drop diminished after day five (Figure 14). An interaction between measurement period and age was also observed in the 32.2°C trials ($P < 0.01$) (Figure 15). Body temperature dropped 0.3°C on day one of age, however temperature increased 0.1°C when moved to the individual cells on day seven. In 35.0°C trials, while body temperature dropped 0.1°C on day one, temperature increased between $0.2 - 0.3^{\circ}\text{C}$ after day five of age (Figure 16).

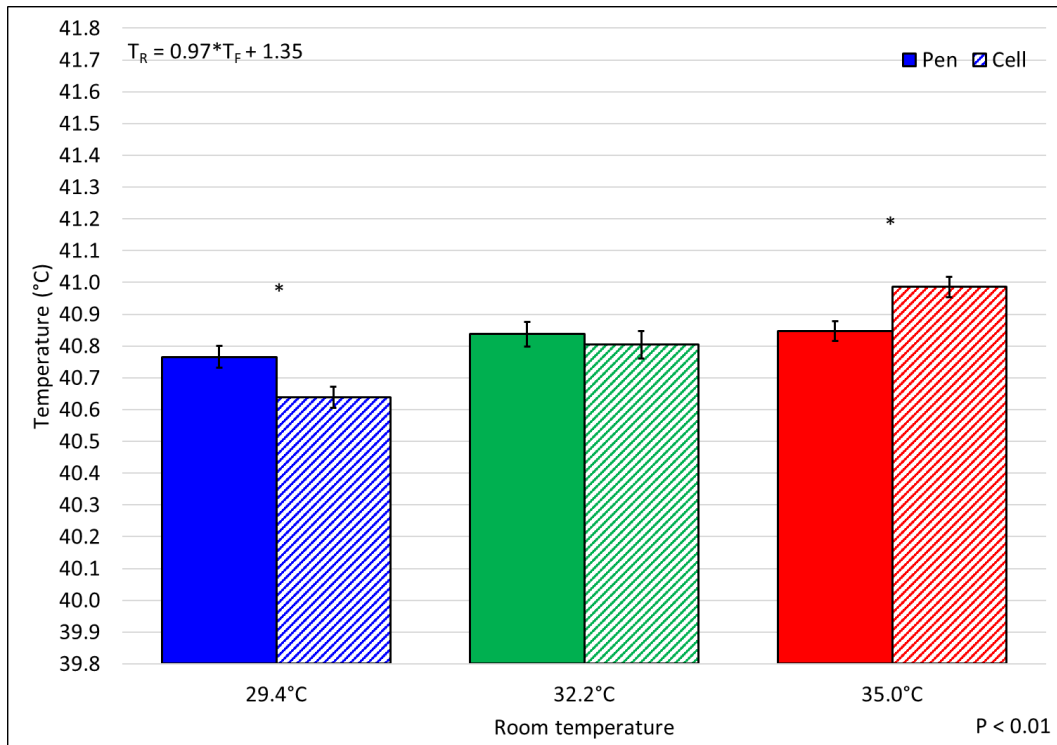


Figure 13. Comparison of calculated rectal temperature between pen and air movement periods from different room temperatures of control group chicks during the 7-day period¹.

¹ n = 72

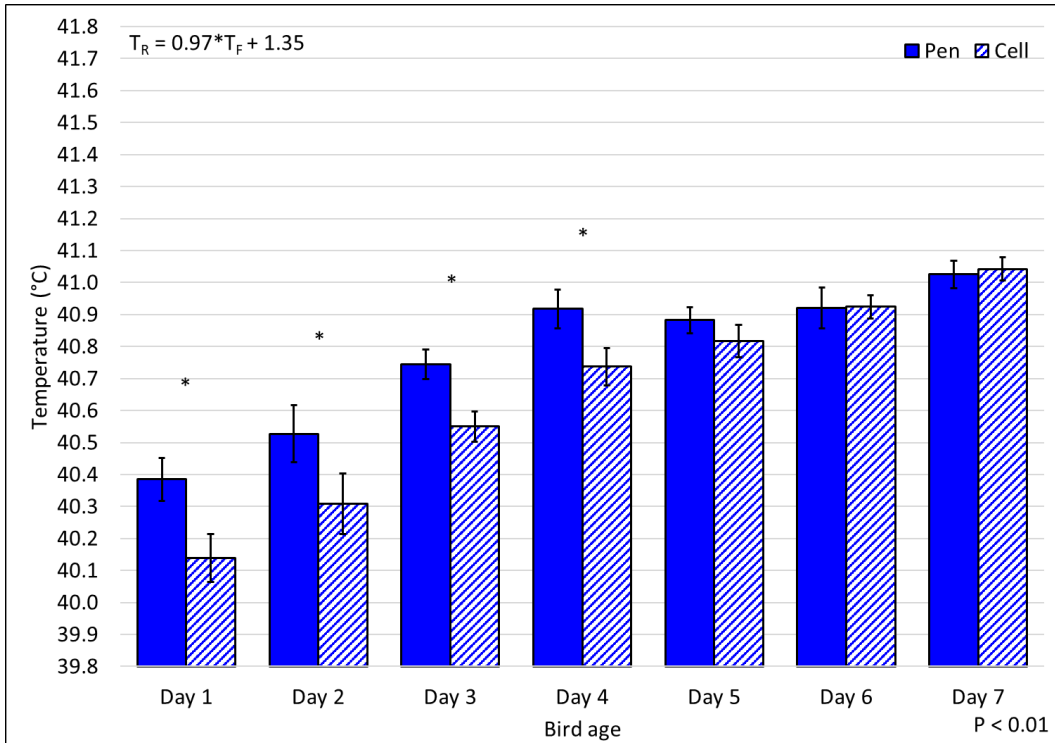


Figure 14. Comparison of calculated rectal temperature between pen and air movement periods of control group chicks in 29.4°C trials¹.

¹ n = 24

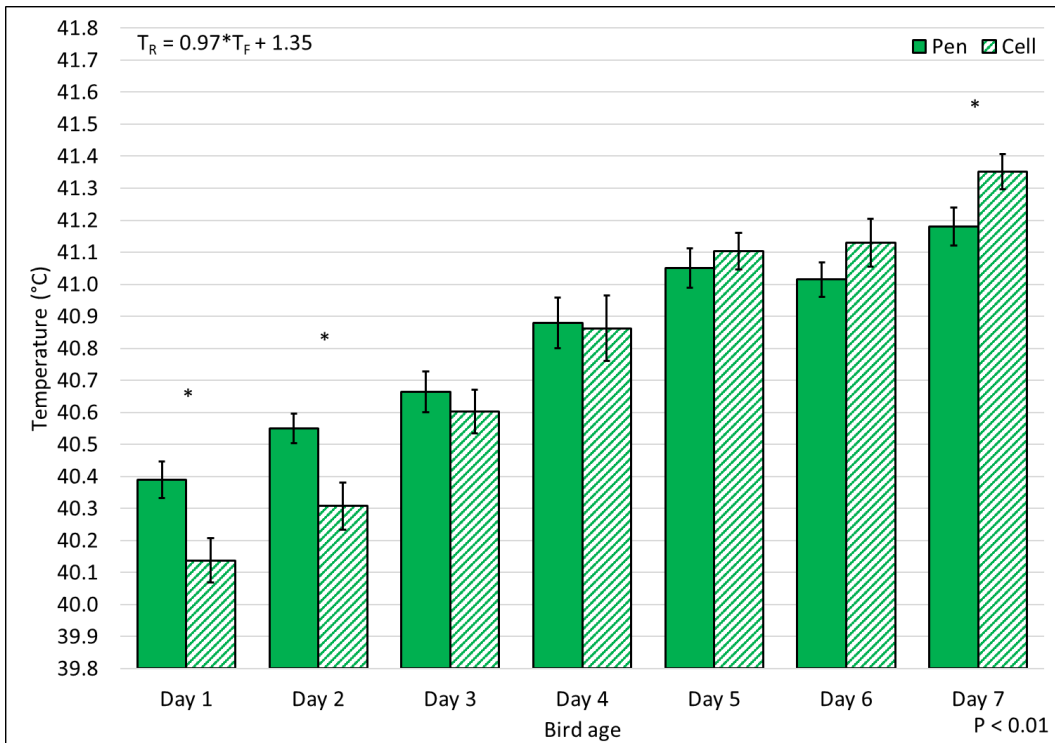


Figure 15. Comparison of calculated rectal temperature between pen and air movement periods of control group chicks in 32.2°C trials¹.

¹ n = 24

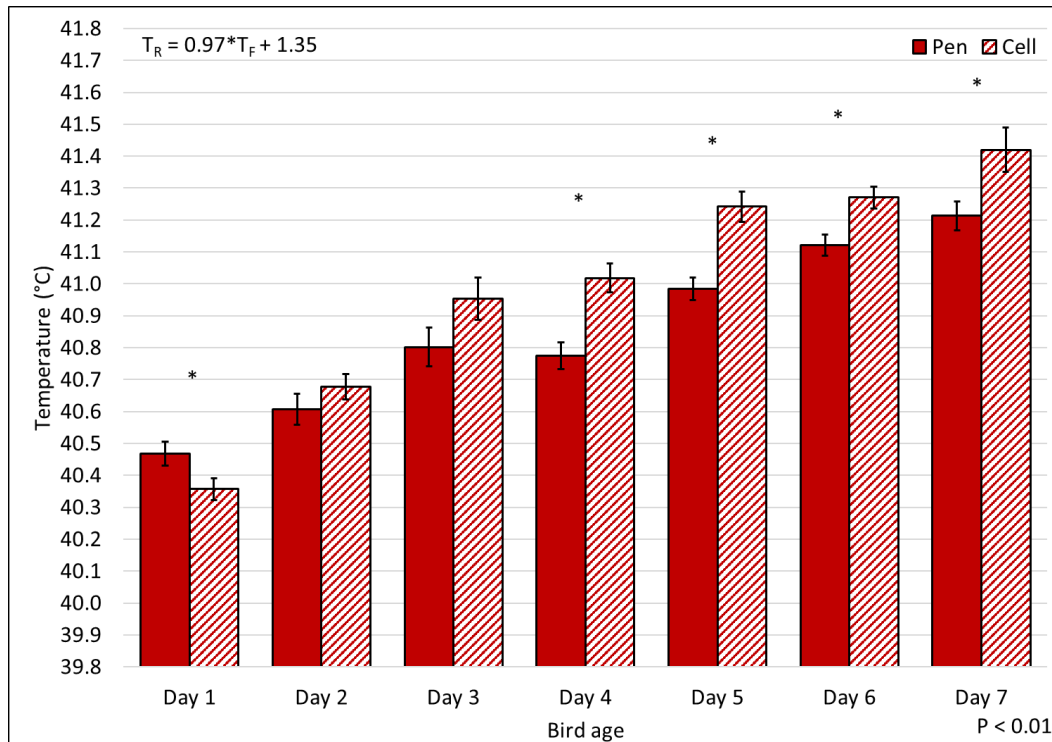


Figure 16. Comparison of calculated rectal temperature between pen and air movement periods of control group chicks in 35.0°C trials¹.

¹ n = 24

Wekstein and Zolman (1970) suggested that the effect of low air temperature on broiler chick body temperature response was age dependent. When the chicks were moved from a higher (35°C) to a lower (20°C) brooding temperature environment, younger chicks (8 hours post hatch) had a drop of 6°C in body temperature after one-hour exposure while body temperature of older chicks (34 hours post hatch) only dropped 2°C. This may likely explain the different chick body temperature responses at different ages observed in the current study.

Chicks were observed clustering into a group in the holding pen after placement during the trials. The chicks had a tendency to coalesce for warmth as their thermoregulation was not fully developed (Deaton et al. 1996; Purswell et al. 2008) and length of such behavior was room temperature dependent. However, in this study, chicks no longer had physical contact with one

another after being moved to the individual cells. This transition from coalescing for warmth to being isolated could be the reason for the decrease in T_{CR} in the first few days.

Chicks were being handled during relocation from the holding pen to the individual cells and during rectal temperature measurement. Sufka and Hughes (1991) showed layer chicks being handled and isolated from other chicks had a 0.6°C increase in rectal temperature at seven days of age compared to the control group. Research has shown the involvement of endogenous opioid system on isolation induced distress, where separation of the chicks from their conspecifics led to a state of opioid withdrawal. Body temperature was used as a stress indicator in that study and the result shown isolation distress caused a 0.5°C increase in rectal temperature (Frohm and Wallnau, 1983). This could likely explain the significant increase in body temperature observed in Day 7 of the 32.2°C trial and between Days 5 and 7 of the 35.0°C trial. Isolation also resulted in increased vocalization, which was also observed in the current study, indicating possible social separation induced distress.

Chick body temperature responded differently to handling and isolation when being moved to the control cells under different room temperatures and over time. As similar procedure were performed to the chicks in the treatment group, the effect of air movement on chick body temperature was analyzed between the control and treatment cells during the air movement period to offset the temperature changes between the pen and air movement periods.

Effect of 0.5 and 1 m/s air movement on chick body temperature

The temperatures measured from the control and treatment cells of the air movement period were analyzed to evaluate the effect of air movement on calculated rectal temperature. A mixed model was used to conduct the analysis. The analysis found that there were no significant difference in the effect of air movement on chick body temperature between the two trials of each

temperature in 1 m/s air movement experiment. There was no interaction between chick age and air movement, indicating that the effect of air movement on T_{CR} did not change over time. At 29.4, 32.2 and 35.0°C, 0.5 m/s air movement caused T_{CR} to drop on average 0.2, 0 and 0.1°C while 1 m/s moving air caused T_{CR} to drop 0.2, 0.3, and 0.1°C (Figure 17). Although these results were reported significant, the magnitude of the T_{CR} drops in all ages of all the trials were all less than 0.3°C. Research has shown diurnal variation of body temperature ranging from 0.9 to 2.6°C in different breeds of adult chickens (Fronza, 1921). Lamoreux and Hutt (1939) also showed White Leghorn and Rhode Island Red chick body temperature measurements taken an hour apart were significantly different due to diurnal variation (temperature not stated). The body temperature drops observed in the current study may still be within the natural diurnal variation that occurs in thermoneutral zone.

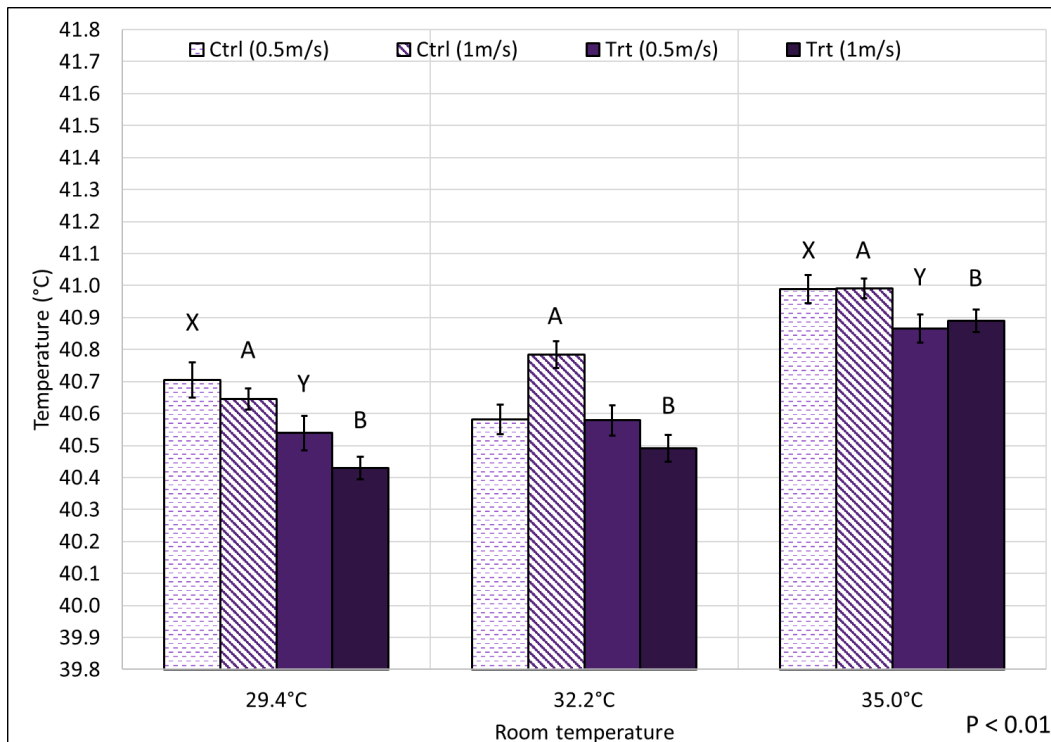


Figure 17. The effect of air movement on the calculated rectal temperature (Day 1-7)¹.

^{A-B} and ^{X-Y} means within each room temperature of 1 m/s and 0.5 m/s trials with no common superscript are significantly different.

¹ n = 144

Since there was a positive correlation between thermoregulation development and age in newly hatched chicks in the current study and was supported by previous research (Wekstein and Zolman, 1967), the effect of air movement on T_{CR} was further analyzed and compared between days one, four and seven of age.

Day one of age

Chicks brooded under 29.4 and 32.2°C had an average of 40.2 and 40.1°C calculated rectal temperature in the control group of the air movement period, where that of the chicks brooded under 35.0°C were significantly higher (40.4°C) ($P < 0.01$) (Figure 18). As the thermoregulation system was still under development, broiler chicks were more susceptible to heat loss under lower brooding temperatures and have a narrow thermoneutral zone (Wekstein and Zolman, 1967; Misson, 1976).

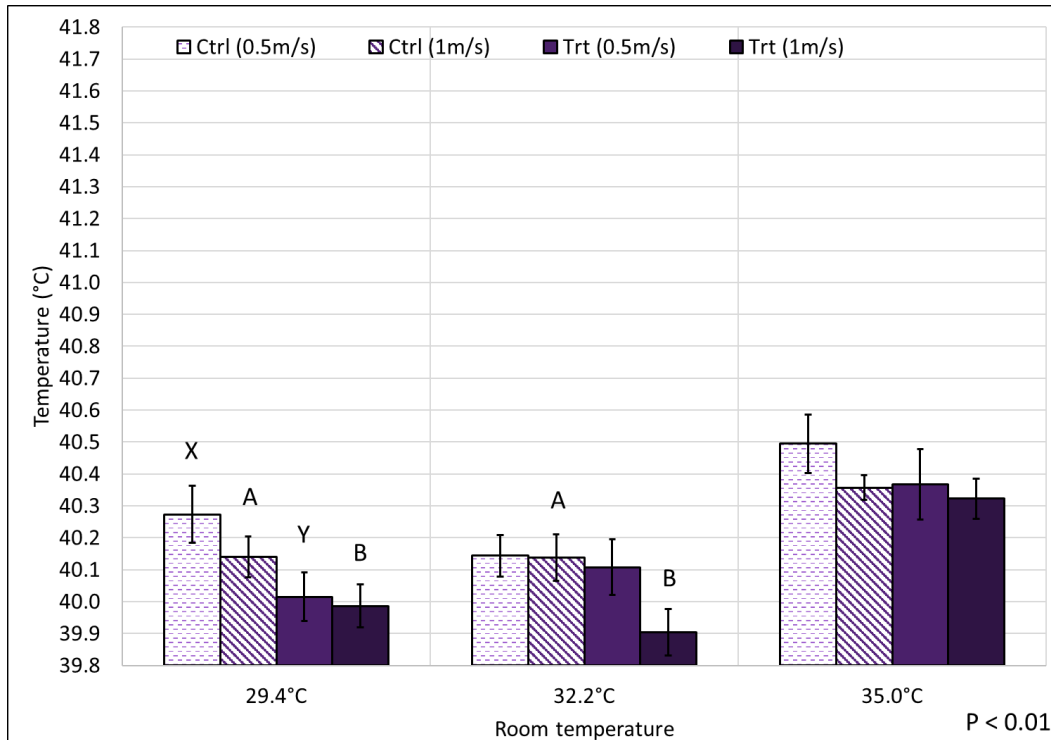


Figure 18. Effect of air movement on calculated rectal temperature of the chick at Day 1¹.

^{A-B} and ^{X-Y} means within each room temperature of 1 m/s and 0.5 m/s trials with no common superscript are significantly different.

¹ n = 144

While lower brooding temperature (29.4 and 32.2°C) resulted in a lower body temperature at day one of age, exposure to air movement caused an additional drop in calculated rectal temperature. At 29.4°C room temperature, both 0.5 and 1 m/s moving air caused significant drops in T_{CR} (0.3 and 0.2°C) ($P < 0.01$). At 32.2°C room temperature, while air movement of 1 m/s still caused a significant drop in T_{CR} (0.2°C) ($P < 0.01$), there was no change in T_{CR} when the chicks were exposed to 0.5 m/s moving air. The effect of 0.5 and 1 m/s moving air were insignificant when the chicks were brooded under 35.0°C.

Day four of age

Chick calculated rectal temperature of the control group measured in the air movement period was on average 40.7°C for both 29.4 and 32.2°C trials, while that of the 35.0°C was on average 0.3°C significantly higher (41.0°C) ($P < 0.01$) (Figure 19). A higher average T_{CR} of the control group observed in 1 m/s at 32.2°C was likely due to a 30% higher weight gain in 32.2°C trial 1 compared to the treatment group (Table 12), which was not repeated in the second trial. This may indicate an effect of different growth rates on thermoregulatory ability of the chicks, however, this requires further study to investigate the hypothesis.

In the 29.4°C trial, while the effect of 1 m/s air movement caused a similar significant T_{CR} drop on day four of age (0.3°C) compared to day one (0.2°C), T_{CR} was not significantly affected by 0.5 m/s. Results in 32.2 and 35.0°C trials on day four were found similar to those on day one of age. In the 32.2°C trials, T_{CR} was not significantly affected by 0.5 m/s air movement at day four of age, however, T_{CR} had a significant 0.3°C drop under 1 m/s. In the 35.0°C trials, T_{CR} was not significantly affected by both 0.5 and 1 m/s air movement.

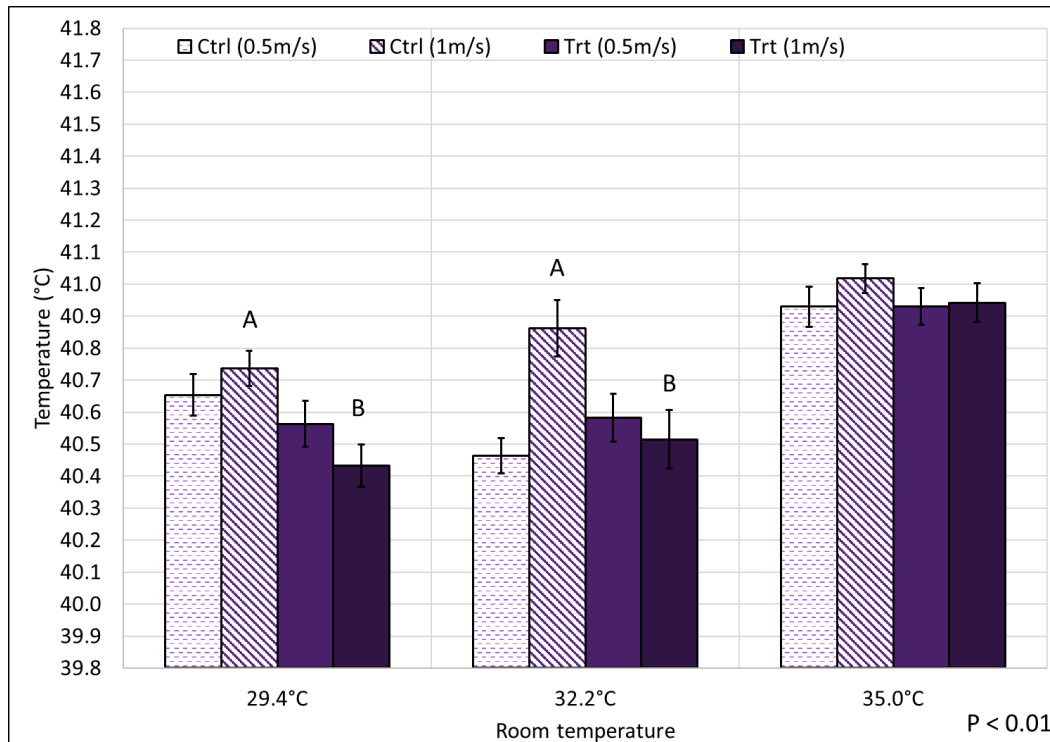


Figure 19. Effect of air movement on calculated rectal temperature of the chick at Day 4¹.
^{A-B} means within each room temperature of 1 m/s trials with no common superscript are significantly different.
¹ n = 144

Day seven of age

The average calculated rectal temperatures measured during the air movement periods are shown in Figure 20. The control group T_{CR} of 29.4 and 32.2°C trials were both on average 41.2°C, where that of 35.0°C was 0.2°C significantly higher (41.4°C) ($P < 0.01$). During day six and seven of the 35.0°C trials, chicks were observed panting in the control cells, suggesting that the room temperature was too warm for the chicks at this age.

At 29.4°C brooding temperature, a significant drop in T_{CR} was observed in the treatment group (0.2°C) under 0.5 and 1 m/s air movement ($P < 0.01$). Although 0.5 m/s air did not significantly affect T_{CR} of the treatment group in the 32.2°C trial, 1 m/s moving air caused a 0.2°C drop in T_{CR} in the treatment group ($P < 0.01$). While T_{CR} was not significantly affected at day one and four of the 35.0°C trials, T_{CR} significantly dropped under 0.5 m/s moving air (0.2°C) ($P <$

0.01). no significant change in body temperature was observed under 1 m/s moving air at 35.0°C room temperature.

While a brooding temperature of 35.0°C was likely acceptable for chicks during placement, these data showed that it was too hot for seven-day-old chicks as they were seen panting in the pen period and in the air movement period and it's above recommended temperature from primary breeders. Research has shown air movement facilitated heat loss through increasing sensible heat loss (Siegel and Drury, 1967; Simmons et al. 1997). However, chicks in the treatment group were also seen panting during the air movement period, as sensible heat loss was driven by the temperature difference between the surface of the chick and ambient temperature, it was possibly that the temperature difference was too small to cause significant change in body temperature (Yahav, 2007).

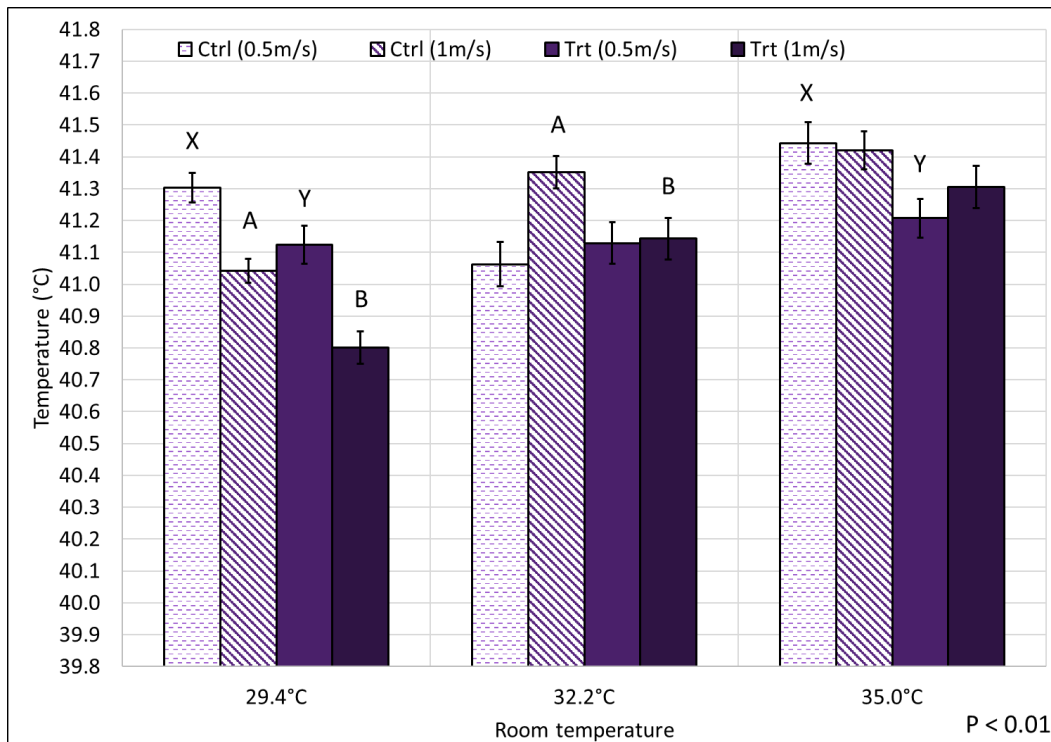


Figure 20. Effect of air movement on calculated rectal temperature of the chick at Day 7¹.
^{A-B} and ^{X-Y} means within each room temperature of 1 m/s and 0.5 m/s trials with no common superscript are significantly different.
¹ n = 144

Chick body temperature was on average significantly lower under 29.4 and 32.2°C in the air movement period of all trials compared to those in 35.0°C. Although 0.5 and 1 m/s air movement caused body temperature to further drop as much as 0.3°C in the three room temperature trials, the temperature changes observed in the current study were similar to those observed in the diurnal temperature variation reported by Lamoreux and Hutt (1939) in White Leghorn and Rhode Island Red chicks. Therefore, further body temperature along with performance studies are necessary to better understand the physiological effect of air movement on chicks.

CHAPTER 5

CONCLUSION

The objectives of this study were to develop an alternative to using rectal temperature measurements and to evaluate the effect of air movement during the brooding period on chick body temperature.

The conclusions were:

1. When measuring the rectal temperature, thermistor/thermometer probe should be inserted at least 22 mm to obtain an accurate temperature reading but not more than 30 mm.
2. Implantation of RFID sensors into the subcutaneous layer of the flank was shown to be a reliable indirect measurement of the chick rectal temperature in the first week of age.
3. The general equation ($T_R = 0.97 * T_F + 1.39$, $R^2 = 0.99$) can be used to calculate the rectal temperature from the flank temperature under different air temperatures (29.4 to 35.0°C) and air velocities (0 to 1 m/s) from hatch to Day 7 of age.
4. Chick body temperature increased on average 0.7°C during the first week of age regardless of the air temperature.
5. At room temperature of 29.4°C, 0.5 m/s air movement caused body temperature to drop on average less than 0.3°C. 0.5 m/s air movement had minimal effect at 32.2 and 35.0°C.
6. At 29.4 and 32.2°C room temperature, 1 m/s air movement caused body temperature to drop on average less than 0.3°C. Body temperature was not affected at 35.0°C.

Reference:

- Abudabos, A. M., E. M. Samara, E. O. S. Husssein, M. Q. Al-Ghadi, and R. M. Al-Atiyat. 2013. Impacts of stocking density on the performance and welfare of boiler chickens. *Ital. J. Anim. Sci.* 12: e11.
- Akaike, H. 1973. A new look at the statistical model identification. *IEEE Trans Automat Contr.* 19:716–723.
- Aviagen Ross Broiler Management Handbook. 2018. Accessed Jun. 2019. http://en.aviagen.com/assets/Tech_Center/Ross_Broiler/Ross-BroilerHandbook2018-EN.pdf
- Barre, H., A. Geloën, J. Chatonnet, A. Dittmar, and J.-L. Rouanet. 1985. Potentiated muscular thermogenesis in cold-acclimated muscovy duckling. *Am. J. Physiol. Regul. Integr. Comp. Physiol.* 249:R533–R538.
- Barré, H., J. Nedergaard, and B. Cannon. 1986. Increased respiration in skeletal muscle mitochondria from cold-acclimated ducklings: uncoupling effects of free fatty acids. *Comp. Biochem. Physiol., B.* 85:343–348.
- Berman, A. 1973. Homeothermy and growth rate in the fowl. *Br. Poult. Sci.* 14:319–328.
- Botcher, R. W., G. R. Baughman, and L. B. Driggers. 1988. Temperature stratification in broiler houses and the effects of ceiling fans. *Appl Eng Agric.* 4:66–71.
- Brown–Brandl, T. M., M. M. Beck, D. D. Schulte, A. M. Parkhurst, and J. A. Deshazer. 1997. Physiological responses of tom turkeys to temperature and humidity change with age. *J. Therm. Biol.* 22:43–52.
- Brown–Brandl, T. M., T. Yanagi, Jr., H. Xin, R. S. Gates, R. A. Bucklin, and G. S. Ross. 2013. A new telemetry system for measuring core body temperature in livestock and poultry. *Appl Eng Agric.* 19:583–589.
- Bruzual, J. J., S. D. Peak, J. Brake, and E. D. Peebles. 2000. Effects of relative humidity during the last five days of incubation and brooding temperature on performance of broiler chicks from young broiler breeders. *Poult. Sci.* 79: 1385–1391.
- Cabanac, M., and S. Aizawa. 2000. Fever and tachycardia in a bird (*Gallus domesticus*) after simple handling. *Physiol. Behav.* 69:541–545.
- Cabanac, A. J., and M. Guillemette. 2001. Temperature and heart rate as stress indicators of handled common eider. *Physiol. Behav.* 74:475–479.
- Cândido, M. G., I. D. F. Tinôco, F. D. A. D. C. Pinto, N. T. Santos, and R. P. Roberti. 2016. Determination of thermal comfort zone for early-stage broilers. *Eng. agríc.* 36:760–767.
- Cannon, B., and J. Nedergaard. 1985. *Essays Biochem.* 20: 110–164.
- Cassuce, D. C., I. D. F. Tinôco, F. C. Baêta, S. Zolnier, R. R. Cecon, and M. D. F. Vieira. 2013. Thermal comfort temperature update for broiler chickens up to 21 days of age. *Eng. agríc.* 33:28–36.
- Christensen, V. L. 2009. Development during the first seven days post-hatching. *Avian Biol Res.* 2:27.

- Christensen, K., Y. V. Thaxton, J. P. Thaxton, and C. G. Scanes. 2012. Changes in body temperature during growth and in response to fasting in growing modern meat type chickens. *Br. Poult. Sci.* 53:531–537.
- Cobb Broiler Management Guide. 2018. Accessed Jun. 2019. <https://cobbstorage.blob.core.windows.net/guides/5fc96620-0aba-11e9-9c88-c51e407c53ab>.
- Czarick, M., and B. D. Fairchild. 2005. Temperature stratification during brooding. Accessed Jan. 2019. <https://www.poultryventilation.com/system/tdf/vol17n2.pdf?file=1&type=node&id=4624&force=>
- Czarick, M., and B. D. Fairchild. 2008. Poultry housing for hot climates. Pages 81–131 in *Poultry production in hot climates*. ed. N.J. Dagher, Massachusetts, USA.
- Czarick, M., and B. D. Fairchild. 2012. The three keys to litter moisture control...fresh air, heat, and air movement. Accessed Jan. 2019. <https://www.poultryventilation.com/system/tdf/vol24n11.pdf?file=1&type=node&id=4935&force=>
- Czarick, M., and M. P. Lacy. 2000. Reducing temperature stratification in houses with forced air furnaces. Accessed Sep. 2018. <https://www.poultryventilation.com/system/tdf/vol12n4.pdf?file=1&type=node&id=4685&force=>
- Czarick, M., G. N. Tony, and T. F. Sanger. 2001. Circulation fans in houses with radiant brooders. Accessed Sep. 2018. <https://www.poultryventilation.com/system/tdf/vol13n1.pdf?file=1&type=node&id=4669&force=>
- Dawson, W. R. 1982. Evaporative losses of water by birds. *Comp. Biochem. Physiol. A Physiol.* 71:495–509.
- Dawson, W. R., and G. C. Whittow. 2000. Regulation of Body Temperature. Pages 343–390 in *Sturkie's Avian Physiology*.
- Deaton, J. W., S. L. Branton, J. D. Simmons, and B. D. Lott. 1996. The effect of brooding temperature on broiler performance. *Poult. Sci.* 75:1217–1220.
- Donkoh, A. 1989. Ambient temperature: a factor affecting performance and physiological response of broiler chickens. *Int J Biometeorol.* 33:259–265.
- Drury, L. N., and H. S. Siegel. 1966. Air velocity and heat tolerance of young chickens. *Trans ASABE.* 9: 0583–0585.
- Duchamp, C., and H. Barre. 1993. Skeletal muscle as the major site of nonshivering thermogenesis in cold-acclimated ducklings. *Am. J. Physiol. Regul. Integr. Comp. Physiol.* 265:R1076–R1083.
- Dunnington, E. A., and P. B. Siegel. 1984. Thermoregulation in newly hatched chicks. *Poult. Sci.* 63:1303–1313.
- Farrell, D. J., and S. Swain. 1977. Effects of temperature treatments on the heat production of starving chickens. *Br. Poult. Sci.* 18:725–734.
- Freeman, B. M. 1965a. The emergence of the homeothermic-metabolic response in the fowl (*Gallus domesticus*). *Comp. Biochem. Physiol.* 13:413–422.
- Freeman B. M. 1965b. The relationship between oxygen consumption, body temperature and surface area in the hatching and young chick. *Br. Poult. Sci.* 6:67–72

- Freeman B. M. 1970. Thermoregulatory mechanisms of the noenate fowl. *Comp. Biochem. Physiol.* 33:219–230.
- Frohman, K. D., and L.B. Wallnau. 1983. Opiate effects on isolation-induced hyperthermia. *Pharmacol. Biochem. Behav.* 19:163–167.
- Fronza, F. M. 1921. A Comparative study of the body temperature of the different species and some representative breeds of poultry—a preliminary report. *Poult. Sci.* 1:16–22.
- Furlan, R. L., M. Macari, E. R. Secato, J. R. Guerreiro, and E. B. Malheiros. 2000. Air velocity and exposure time to ventilation affect body surface and rectal temperature of broiler chickens. *J Appl Poult Res.* 9:1–5.
- Genç, L., and K. M. Portier. 2005. Sensible and latent heat productions from broilers in laboratory conditions. *Turk J Vet Anim Sci.* 29:635–643.
- Ghoname, M. S., A. A. Derbala, T. Z. Fouda, and S. M. Abdellatif. 2012. Effect of heating system on temperature stratification inside the broiler housing. *Miser J. Eng.* 29:1197–1212
- Giloh M., D. Shinder, and S. Yahav. 2012. Skin surface temperature of broiler chickens is correlated to body core temperature and is indicative of their thermoregulatory status. *Poult. Sci.* 91:175–188.
- Grant, R. T. 1963. Vasodilation and body warming in the rat. *J. Physiol.* 167:311–317.
- Hamrita, T. K., and R. H. Conway. 2017. Effect of air velocity on deep body temperature and weight gain in the broiler chicken. *J Appl Poult Res.* 26:111-121.
- Han, G., H. Yang, M. A. Bahry, T. V. Phuong, D. H. Phong, H. Ikeda, M. Furuse, and V. S. Chowdhury. 2017. L-Leucine acts as a potential agent in reducing body temperature at hatching and affords thermotolerance Q2 in broiler chicks. *Comp. Biochem. Physiol., Part A Mol. Integr. Physiol.* 204:48–56.
- Harris, G. C., Jr., G. S. Nelson, W. H. Dodgen, and R. L. Seay. 1975. The influence of air temperature during brooding on broiler performance. *Poult. Sci.* 54:571–577.
- Hicks, M. R. 2016. Comparing subcutaneous sites to deep body temperature in broiler chickens. MSc Thesis. Univ. Georgia, Athens.
- Himms-Hagen, J. 1989. Role of thermogenesis in the regulation of energy balance in relation to obesity. *Can. J. Physiol. Pharmacol.* 67:394–401.
- Hirabayashi, M., D. Ijiri, Y. Kamei, A. Tajima, and Y. Kanai. 2005. Transformation of skeletal muscle from fast-to slow-twitch during acquisition of cold tolerance in the chick. *Endocrinology.* 146:399–405.
- Hohtola, E. 2002. Facultative and obligatory thermogenesis in young birds: a cautionary note. *Comp. Biochem. Physiol., Part A Mol. Integr. Physiol.* 131:731–739.
- Hwang-Bo, J., T. Muramatsu, and J. Okumura. 1990. Research note: age dependency of triiodothyronine-induced thermogenesis in young chicks: inhibition by propylthiouracil. *Poult. Sci.* 69:1599–1601.
- Johnston, D. W. 1971. The absence of brown adipose tissue in birds. *Comp Biochem Physiol A Comp Physiol.* 40:1107–1108.
- Lamoreux, W. F., and F. B. Hutt. 1939. Variability of body temperature in the normal chick. *Poult. Sci.* 18:70–75.
- Leksrisompong, N., H. Romero-Sanchez, P.W. Plumstead, K. E. Brannan, S. Yahav, and J. Brake. 2009. *Poult. Sci.* 88:1321–1329.
- Lin, L., and Y. Sun. 2012. Thermogenic characterization of ghrelin receptor null mice. *Meth. Enzymol.* 514:355–370.

- Lin, H., H. F. Zhang, H. C. Jiao, T. Zhao, S. J. Sui, X. H. Gu, Z. Y. Zhang, J. Buyse, and E. Decuyper. 2005a. Thermoregulation responses of broiler chickens to humidity at different ambient temperatures. I. One week of age. *Poult. Sci.* 84:1166–1172.
- Lin, H., H. F. Zhang, R. Du, X. H. Gu, Z. Y. Zhang, J. Buyse, and E. Decuyper. 2005b. Thermoregulation responses of broiler chickens to humidity at different ambient temperatures. II. Four weeks of age. *Poult. Sci.* 84:1173–1178.
- Maiorka, A., F. Dahlke, and M. S. F. d. A. Morgulis. 2006. Broiler adaptation to post-hatching period. *Cienc Rural.* 36: 701–708.
- Malheiros, B. D., V. M. B. Moraes, L. D. G. Bruno, E. B. Malheiros, R. L. Furlan, and M. Macari. 2000. Environmental temperature and cloacal and surface temperatures of broiler chicks in first week post-hatch. *J Appl Poult Res.* 9:111–117.
- Marjoniemi, K. 2000. The effect of short-term fasting on shivering thermogenesis in Japanese quail chicks (*Coturnix coturnix japonica*): indications for a significant role of diet-induced/growth related thermogenesis. *J. Therm. Biol.* 25:459–465.
- Marjoniemi, K., and E. Hohtola. 1999. Shivering thermogenesis in leg and breast muscles of galliform chicks and nestlings of the domestic pigeon. *Physiol. Biochem. Zool.* 72:484–492.
- May, J. D., J. W. Deaton, S. L. Branton. 1987. Body temperature of acclimated broilers during exposure to high temperature. *Poult. Sci.* 66:378–380.
- McLean, J. A., C. J. Savory, and N. H. C. Sparks. 2002. Welfare of male and female broiler chickens in relation to stocking density, as indicated by performance, health and behavior. *Anim. Welf.* 11:55-73.
- Misson, B. H. 1976. The effects of temperature and relative humidity on the thermoregulatory responses of grouped and isolated neonate chicks. *J Agric Sci.* 86:35–43.
- Misson, B. H. 1977. The relationships between age, mass, body temperature and metabolic rate in the neonatal fowl (*Gallus domesticus*). *J. Therm. Biol.* 2:107–110.
- Misson, B. H. 1982. The thermoregulatory responses of fed and starved 1-week-old chickens (*Gallus domesticus*). *J. Therm. Biol.* 7:189–192.
- Mujahid, A. 2010. Acute cold-induced thermogenesis in neonatal chicks (*Gallus gallus*). *Comp. Biochem. Physiol., Part A Mol. Integr. Physiol.* 156:34–41.
- Mujahid, A., and M. Furuse. 2008a. Central administration of corticotropin-releasing factor induces thermogenesis by changes in mitochondrial bioenergetics in neonatal chicks. *Neuroscience.* 155:845–851.
- Mujahid, A., and M. Furuse. 2008b. Homeothermy in neonatal chicks exposed to low environmental temperature with or without intracerebroventricular administration of corticotropin-releasing factor. *FEBS Lett.* 582:3052–3060.
- Mujahid, A. and M. Furuse. 2009. Behavioral responses of neonatal chicks exposed to low environmental temperature. *Poult. Sci.* 88:917–922.
- Nascimento, G. R., I. A. Nääs, D. F. Pereira, M. S. Baracho, and R. Garcia. 2011. Assessment of broiler surface temperature variation when exposed to different air temperatures. *Rev. Bras. Cienc. Avic.* 13:259–263.
- National Chicken Council Animal Welfare Guidelines and Audit Checklist for Broilers, 2017. National Chicken Council. Accessed Sep. 2018. <http://www.nationalchickencouncil.org/wp-content/uploads/2017/07/NCC-Welfare-Guidelines-Broilers.pdf>

- Nichelmann, M., and B. Tzschentke. 2002. Ontogeny of thermoregulation in precocial birds. *Comp. Biochem. Physiol., Part A Mol. Integr. Physiol.* 131:751–763.
- Nienaber, J. A., and G. L. Hahn. 1983. Temperature distribution within controlled environment animal rooms. *Trans ASAE.* 26:895–896.
- Purswell, J. L., B. D. Lott, W. A. Dozier, W. B. Roush, S. L. Branton. 2008. Assessing thermal comfort of broiler chicks during brooding. *Int J Poult Sci.* 7:202–206.
- Richards, S. A. 1971. The significance of changes in the temperature of the skin and body core of the chicken in the regulation of heat loss. *J. Physiol.* 216:1–10.
- Richards, S. A. 1976. Evaporative water loss in domestic fowls and its partition in relation to ambient temperature. *J Agric Sci.* 87:527–532.
- Rovee-Collier, C., H. Hayne, and G. Collier. 1997. Behavioral thermoregulation in chicks: the best nest. *Dev Psychobiol.* 31:231–244.
- Saarela, S., J. S. Keith, E. Hohtola, and P. Trayhurn. 1991. Is the "mammalian" brown fat-specific mitochondrial uncoupling protein present in adipose tissues of birds? *Comp. Biochem. Physiol., B.* 100:45–49.
- Siegel, H. S., and L. N. Drury. 1968. Physiological responses to high lethal temperature and air velocity in young fowl. *Poult Sci.* 47:1230–1235.
- Simmons, J. D., B. D. Lott, and J. D. May. 1997. Heat loss from broiler chickens subjected to various air speeds and ambient temperatures. *Appl Eng Agric.* 13:665–669.
- Spurr, E. B., 1975. Behavior of the Adélie Penguin Chick. *Condor.* 77:272–280.
- Sufka, K. J., and R. A. Hughes. 1991. Differential effects of handling on isolation-induced vocalizations, hypoalgesia and hyperthermia in domestic fowl. *Physiol. Behav.* 50:129–133.
- Tachibana, T., E.-S. Saito, S. Saito, S. Tomonaga, D. M. Denbow, and M. Furuse. 2004. Comparison of brain arginine-vasotocin and corticotrophin-releasing factor for physiological responses in chicks. *Neurosci. Lett.* 360:165–169.
- Takahashi, H., M. Ligo, K. Ando, T. Tachibana, D. M. Denbow, and M. Furuse. 2005. Regulation of body temperature by thyrotropin-releasing hormone in neonatal chicks. *Brain Res. Dev. Brain Res.* 157:58–64.
- Teo, M. L. 2018. The effect of different stocking densities on body temperature of broiler chickens. MSc Thesis. Univ. Georgia, Athens.
- Tessier, M., D. Du Tremblay, C. Klopfenstein, G. Beauchamp, and M. Boulianne. 2003. *Poult Sci.* 82:846–849.
- Tzschentke, B., and M. Nichelmann. 1999. Development of avian thermoregulatory system during the early postnatal period: development of the thermoregulatory set-point. *Ornis Fenn.* 76:189–198.
- Wekstein, D. R., and J. F. Zolman. 1971. Cold stress regulation in young chickens. *Poult. Sci.* 50:56–61.
- Weytjens, S. 1999. Thermoregulation in chicks originating from breeder flocks of two different ages. *J Appl Poult Res.* 8:139–145.
- Wolfenson, D. 1983. Blood flow through arteriovenous anastomoses and its thermal function in the laying hen. *J. Physiol.* 334:395–407.
- Yahav, S., S. Goldfeld, I. Plavnik, and S. Hurwitz. 1995. Physiological responses of chickens and turkeys to relative humidity during exposure to high ambient temperature. *J. Therm. Biol.* 3:245–253.

Yahav, S., D. Shinder, J. Tanny, and S. Cohen. 2005. Sensible heat loss: the broiler's paradox. *Worlds Poult Sci J.* 61:419–434.