Broiler surface temperature distribution of 42 day old chickens

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ABSTRACT: Broiler chickens in Brazil are generally reared from 1 to 42 days when they are exposed to procedures such as fasting, harvesting, crating and transport to slaughter. Maintaining homeostasis is of great importance for broiler survival under harsh environment especially prior to slaughter. Heat loss varies in the distinct parts of the body during the growth period, and it is related to the air temperature of the environment and to the amount of feather covering. This research aimed to study the surface temperature distribution using infrared thermographic image processing to characterize 42 day old broiler chicken surface temperature prior to slaughter. Broilers were reared for 42 days and prior to harvest and transport to slaughter the infrared surface temperature was recorded along the day. Data from the thermograms taken in feather and featherless regions were compared during the 42nd day of growth. High correlation between featherless regions and air temperature was found showing that these areas respond fast to changes in the rearing environment. Two functions were developed for predicting both surface temperature for featherless and feather covered areas of the broiler body parts.
Key words: thermal comfort, heat loss, thermoregulation, infrared thermography

Distribuição da temperatura superficial de frangos de corte com 42 dias de idade

RESUMO: No Brasil frangos de corte são normalmente alojados de 1 até 42 dias, quando são expostos a procedimentos como: jejum, apanha, colocação em caixas e transporte até o abate. Manter a homeostase do corpo é de grande importância para a sobrevivência de frangos de corte sob ambiente quente, especialmente na 7ª semana de crescimento. A perda de calor varia nas partes do corpo e está relacionada à temperatura do ar e à cobertura de penas. Avaliou-se a distribuição da temperatura superficial usando o processamento de imagens de câmera termográfica infravermelho, para caracterizar a temperatura superficial de frangos de corte de 42 dias de idade, no período anterior à apanha para o abate. Os frangos foram alojados de 1 a 42 dias e, antes de serem apanhados e transportados para o abate, foram registradas temperaturas superficiais infravermelho durante o dia.. Os resultados dos termogramas das regiões com penas e sem penas foram comparados, durante o 42º dia. Alta correlação entre regiões sem penas e a temperatura ambiente foi encontrada, mostrando que estas áreas respondem rapidamente a alterações no ambiente do alojamento. Duas funções foram desenvolvidas para predizer a temperatura superficial das regiões com e sem penas, do corpo de frangos com 42 dias, sendo conhecida a temperatura do ar do ambiente.
Palavras-chave: conforto térmico, perda de calor, termorregulação, termografia infravermelha

Introduction

Nearly 60% of Brazilian broiler chicken production is generally subjected to harsh environmental conditions especially in regions where high ambient temperatures are prevalent during most of the year and where climate control is not used in the housing. Thermal comfort and eventual environmental thermal challenges are important for broilers to maintain constant body temperature during their growth period (Yahav et al., 2001; Yahav et al., 2004; Cangar et al., 2008). Physiological response to heat stress in birds results in a fluctuation in skin temperature (Richards, 1971; Tessier et al., 2003; Shinder et al., 2007). This variation, however, depends on the part of the body where it occurs, and usually it remains within 5°C, even when the room temperature exceeds the thermal comfort zone (Zhou and Yamamoto, 1997).

Due to the thick insulation coat of feathers on most of the body surface, the sensible heat loss from broilers becomes more efficient on body areas that are featherless such as shanks, feet, wattle and comb; and those are the body parts where the blood flow increases when the bird is exposed to heat stress (Cangar et al., 2008). Zhou and Yamamoto (1997) suggested that broilers exposed to dehydration due to heat stress significantly decreased the blood flow to exchange heat from internal organs and the skin surface. This induces to lower sensible heat loss from extremities and featherless areas, lower evaporative heat loss and higher sensible heat loss from the trunk, increasing the metabolic expenditure of regulat-

ing their body temperature (Richards, 1971). Yahav et al. (1998) proved the ability of the naked neck chickens to both cope with the need of thermo regulating at low ambient temperatures and to maintain their body temperature at high level, in order to optimizing their sensible heat exchange.

The use of infrared thermography allows the identification spots of distinct values of radiant temperature and it has been valuable to recognize physiological peak incidents in humans and animals. Surface temperature measurements can be made without disturbance and with better precision, especially on animal coats that have low heat capacities (McCafferty et al., 1998; Tessier et al., 2003; Montanholi et al., 2008; Bouzida et al., 2009).

Most broiler chickens in Brazil are caught, caged and transported within the 6th week of growth and the simultaneous exposure to harsh temperatures during this management may lead to extra loss in the final results at slaughter, including the incidence of pale meat, representing important economical drawback to producers (Mendes, 2001; Bianchi et al., 2005).

This research aimed to study the diurnal variation of body surface temperature of 42 day old broiler chickens prior to slaughter.

Material and Methods

Three hundred male Cobb® 500 broilers were reared from 1 day old in six small scale houses (3.2 m length, 1.4 m width, and 1.4 m height), being 50 in each house in a constant flock density up to 30 kg m^{-2}. Commercial feedstuff was given *ad libitum* since the first week. Five birds were randomly selected to be weighed every day, and the mean body weight at 42 day was 2981.5 ± 86.7 g. Tap potable water was available for the birds at all times.

Air dry bulb temperature (Ta) was recorded continuously (every 30 min) using a data logger placed in the geometrical center of each house. The data used for cal-

culating diurnal rearing ambient temperature fluctuation were selected within an interval in the morning (7h00 – 12h00) and one in the afternoon (12h30 – 18h00).

For surface temperature recording, one broiler per house was randomly chosen at the 42nd day of rearing to collected infrared thermal images, in both morning (9h00 and 11h00) and afternoon (12h30, 14h00, 15h30, and 17h00), using an infrared thermography camera with precision of ± 0.1°C and a spectrum range of 7.5 - 13 μm. Thermograms were taken at ambient air temperatures (Tair) ranging from 25.4 to 31.9°C. For all images a blue/red color scheme was used and the chosen temperature scale was between 30°C and 40°C. For a better visualization of the images a cardboard was placed behind each bird during the process to avoid visual interference from the surrounding area. The thermal camera was placed approximately 1 m from the broiler in order to have a complete image filling within the entire angle of sight (Figure 1). Since electromagnetic radiation travels in straight lines, errors due to angle distortion can occur. To minimize the error which is nearly negligible for objects with a rough surface, such as animals, the image was registered using an angle of 90° from the bird surface. The emissivity coefficient (ε) used was 0.94 for the regions with feathers and 0.95 for the featherless regions, which are within the range of emissivity values for biological material. There are several suggestions for this matter in the literature. McCafferty et al. (1998) assumed the emissivity value of 0.98 for plumage, when calculating the radiant heat loss of a barn owl (*Tyto alba*). Dawson et al. (1999) adopted the emissivity value of keratin (0.8) to construct a model of radiant heat transfer through the penguin coat. Ward et al. (1999) and Cangar et al. (2008) suggested the overall emissivity value of 0.95 for the bird. Malheiros et al. (2000) used ε = 0.94 to determine the variation of the surface temperature in post hatch pullets. The images of the broiler surface were divided in 14 regions to allow assessment of regional Ts
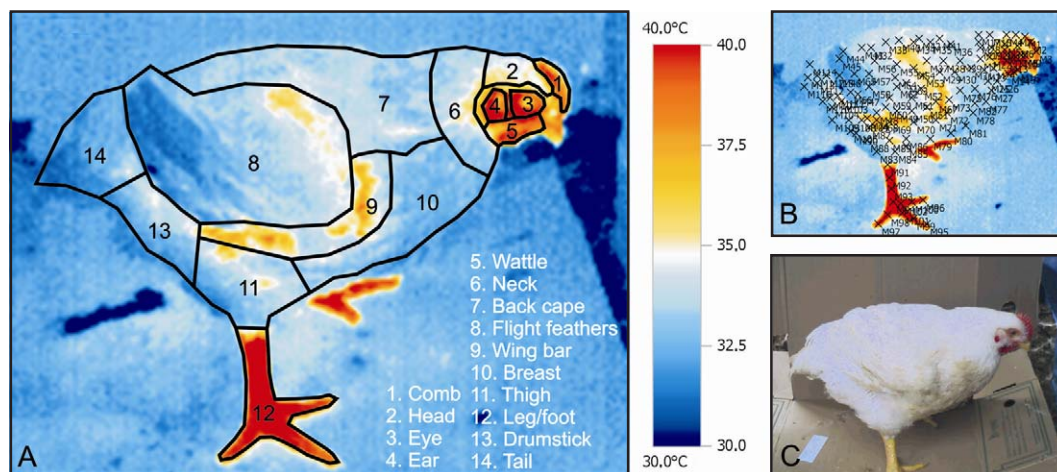

Figure 1 – View of the regions on a broiler thermography image where the surface temperature values were extracted using the software (A), the points where Ts was registered (B), and actual picture of the broiler (C).

distribution, as suggested by Ward et al. (1999). Mean surface temperature (Ts) and standard deviation of a given body area were calculated using the temperature measured at several randomly chosen points located within the chosen body parts (Figure 1). The number of points selected in each body part is shown in parenthesis as follows: comb (3), head (4), eye (3), ear (3), wattle (3), neck (12), back cape (15), flight feathers (24), wing bar (7), breast (8), thigh (8), leg/foot (12), drumstick (9), and tail (6). Each thermogram was analyzed using a processing and data converting software provided by the camera manufacturing company.

One-way ANOVA was undertaken to find out Ts difference between the selected regions of the body. In a second step a two-way ANOVA was applied to test the difference of the feather covering parts and the time of the day. The Tukey test was applied using the temperature gradient (Eq. 1) in the parts with feather and featherless as function of the time and period of the day. Individual data were organized in two groups A = body parts with feathers; and B = featherless body parts, and the multiple Tukey test was applied to verify the differences between Ts in both groups and during the time of the day. The statistical software Minitab® v. 1.5 was used to process the data. Statements of significance are based on $p < 0.05$. Regression analysis was applied to the body parts surface temperature for both periods of the day in order to find a function that estimates the body parts surface temperature for both areas (with feather and featherless), as function of the rearing air temperature.

Results and Discussion

Mean Tair in the morning was 27.5 ± 1.9°C increasing towards the afternoon to 31.2 ± 0.6°C. Air temperature varied from the thermoneutral value of 25.4 ± 0.9°C in the beginning of the experiment (9h30) to the upper temperature of 31.9 ± 0.8°C at 15h30. Relative humidity remained constant along the day and the air velocity within the houses due to natural ventilation was low, varying from 0.5 to 0.7 m s^{-1}. The majority of Ts registered for the bird body parts varied along the day ($p < 0.05$) with the exception of the comb, the wattle and the wing bar (Table 1).

Yahav et al, 2001; 2004) observed that high AV (> 2.5 m s^{-1}) increases performance and alleviates heat stress in broiler chickens when compared to birds exposed to low AV (0.5 to 1.0 m s^{-1}) under same harsh conditions. In this specific experiment the rearing condition had low air velocity and consequently low heat exchange by convection. Heat loss by radiation and convection as function of the temperature gradient (ΔT) between Ts (ºC) and Tair (ºC) were the driving force for broiler sensible heat loss, and the featherless regions of the body are the parts that provided the highest mean temperature gradient, both in the morning and in the afternoon (Table 2).

Table 1 – Surface temperature in body regions (Ts), air temperature (Tair), relative humidity (RH) and wind velocity (AV) in the morning and the afternoon, and summarized mean values in the morning, the afternoon and daily.

Body region	Surface condition	n	Morning 9h30	Morning 11h00	Morning 12h30	Mean	Afternoon 14h00	Afternoon 15h30	Afternoon 17h00	Mean	Daily mean	P-value
								Surface temperature (°C)				
1	B	3	38.4 ± 0.9	38.1 ± 1.4	39.5 ± 0.8	38.7 ± 1.2	38.8 ± 0.6	39.0 ± 0.7	38.7 ± 0.7	38.9 ± 0.6	38.8 ± 1.0	0.1334*
2	A	4	32.3 ± 0.7 b	34.4 ± 1.4 a	34.0 ± 1.2 a	33.6 ± 1.3	34.1 ± 1.0 a	35.3 ± 0.8 a	34.0 ± 1.0 a	34.5 ± 1.0	34.0 ± 1.3	0.0005
3	B	3	38.4 ± 0.4 b	38.4 ± 0.7 b	38.5 ± 0.7 ab	38.4 ± 0.6	38.8 ± 0.8 ab	39.6 ± 0.5 a	38.5 ± 0.8 ab	38.9 ± 0.8	38.7 ± 0.8	0.0424
4	B	3	37.8 ± 0.7 b	38.8 ± 0.9 ab	38.9 ± 0.5 ab	38.5 ± 0.9	39.2 ± 0.8 a	39.4 ± 0.9 a	38.9 ± 0.8 ab	39.2 ± 0.8	38.9 ± 0.9	0.0258
5	B	3	39.1 ± 0.8	39.1 ± 1.0	39.4 ± 0.5	39.2 ± 0.8	39.2 ± 0.4	39.2 ± 0.3	38.6 ± 1.2	39.0 ± 0.7	39.1 ± 0.7	> 0.050*
6	A	12	31.3 ± 0.4 b	33.6 ± 0.8 a	33.6 ± 0.8 a	32.8 ± 1.3	32.9 ± 1.0 a	33.9 ± 0.9 a	33.2 ± 0.8 a	33.3 ± 1.0	33.1 ± 1.2	0.0001
7	A	15	30.9 ± 0.9 b	33.2 ± 0.9 a	33.4 ± 0.9 a	32.5 ± 1.4	33.2 ± 1.1 a	33.6 ± 0.7 a	32.4 ± 1.0 ab	33.0 ± 1.1	32.8 ± 1.3	0.0003
8	A	24	30.5 ± 0.9 b	33.2 ± 0.5 a	32.9 ± 0.6 a	32.2 ± 1.4	32.6 ± 1.1 a	33.0 ± 0.6 a	32.4 ± 1.0 a	32.7 ± 0.9	32.5 ± 1.2	0.0000
9	B	7	35.1 ± 1.7	34.7 ± 1.2	35.5 ± 1.1	35.1 ± 1.3	35.0 ± 0.8	36.8 ± 2.0	34.1 ± 1.5	35.3 ± 1.8	35.2 ± 1.6	0.0633*
10	A	8	30.5 ± 0.8 b	32.5 ± 1.1 a	32.5 ± 0.7 a	31.8 ± 1.3	31.8 ± 1.0 ab	32.4 ± 1.3 a	31.6 ± 0.9 ab	31.9 ± 1.1	31.8 ± 1.2	0.0138
11	A	8	30.9 ± 0.5 b	33.0 ± 0.8 a	33.0 ± 0.8 a	32.3 ± 1.2	32.3 ± 0.8 a	32.6 ± 0.5 a	32.3 ± 0.5 a	32.4 ± 0.6	32.3 ± 0.9	0.0001
12	B	12	38.6 ± 0.6 b	39.4 ± 0.5 ab	39.1 ± 0.4 ab	39.0 ± 0.6	39.8 ± 0.9 a	40.0 ± 0.4 a	39.4 ± 1.0 ab	39.7 ± 0.8	39.4 ± 0.8	0.0157
13	A	9	30.5 ± 0.4 b	30.6 ± 0.4 b	32.5 ± 0.7 a	31.9 ± 1.1	32.0 ± 1.0 a	32.5 ± 0.8 a	31.5 ± 0.6 ab	32.0 ± 0.9	31.9 ± 1.0	0.0001
14	A	6	29.5 ± 0.4 b	31.7 ± 0.8 a	31.8 ± 0.7 a	31.0 ± 1.2	31.8 ± 1.0 a	31.9 ± 0.8 a	31.1 ± 0.7 a	31.6 ± 0.9	31.3 ± 1.1	0.0500
Ave Ta			25.4 ± 0.9	27.7 ± 0.8	29.5 ± 0.5	27.5 ± 1.9	31.2 ± 0.4	31.7 ± 0.5	30.6 ± 0.5	31.2 ± 0.6	29.3 ± 2.0	-
Ave RH			69.9 ± 15.6	58.7 ± 10.0	51.0 ± 4.8	60.0 ± 12.7	42.5 ± 4.3	41.6 ± 4.8	42.0 ± 5.0	42.0 ± 5.0	50.9 ± 13.2	-
AV			0.5 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.5 ± 0.3	0.7 ± 0.1	0.7 ± 0.2	0.7 ± 0.1	0.7 ± 0.2	0.6 ± 0.3	-

A = with feather; B = featherless. N = number of points in the thermogram. *non significant at 95%. Tair = air temperature (°C); RH = air relative humidity (%); AV = air velocity (m s^{-1}). Means within the same row with different letters differ ($p > 0.05$).

The overall diurnal temperature fluctuation (from 7h00 to 18h00) was 9.0°C whereas the lowest registered air temperature occurred at 7h00 (23.2°C) and the highest at 15h30 (32.2°C). Surface temperature of the body parts and the rearing air temperature were different ($p < 0.05$) in the morning and in the afternoon (Table 1 and 2). High correlation between featherless regions and T_{air} was found (0.8) showing that these areas respond fast to changes in the air temperature, probably due to high blood flow to these areas. The coefficient of correlation for the body parts with feathers was 0.6, and the probable reason of the small correlation is the air layer that increases the thermal inertia between the skin and the feathers. Malheiros et al. (2000) reported an increase in skin thermal conductance when the air temperature rose from 20 to 40°C, implying in an increase in peripheral blood flow, which might be the determinant factor to change the surface temperature during exposure to differ-ent environmental temperatures. Cangar et al. (2008) found that the comb had the highest temperature gradient while the wing had the lowest. The head and neck regions and perhaps some areas around the abdomen are poorly feathered, hence insulation is quite poor in these areas, and consequently the sensible heat flow is improved (Li and Yamamoto, 1991; Choi et al., 1997).

The body featherless areas (comb, eye, ear, wattle, wing bar and leg/foot) presented higher temperatures than the areas of the body covered by feathers (head, neck, back cape, flight feathers, breast, thigh, drumstick, and tail) (Figure 1). Peripheral blood circulation increase is directly related to high room temperatures in hot weather, but it is less efficient for broiler to benefit from the heat loss in the surface covered with feathers (Cangar et al., 2008). This was also found in this experiment where T in the body areas with feathers remained lower than in the featherless areas (Table 3).

Table 2 – Results of two-way ANOVA and Tukey test for the temperature gradient (ΔT) between surface temperature (Ts) and air temperature (Tair).

Surface condition	Body region	ΔT (°C)		
		Morning	Afternoon	Daily
With feather	head	6.1	3.3	4.7
	neck	5.3	2.1	3.8
	back cape	5.0	1.8	3.5
	flight feathers	4.7	1.5	3.2
	breast	4.3	0.7	2.5
	thigh	4.8	1.2	3.0
	drumstick	4.4	0.8	2.6
	tail	3.5	0.4	2.0
Featherles	comb	11.2	7.7	9.5
	eye	10.9	7.7	9.4
	ear	11.0	8.0	9.6
	wattle	11.7	7.8	9.8
	wing bar	7.6	4.1	5.9
	leg/foot	11.5	8.5	10.1
Tukey Test	ΔT (morning vs afternoon)	p - value = 0.00605		
	Body region (with feather vs featherless)	p - value = 0.00017		

Table 3 – Variation of mean temperature gradient (ΔT) at studied times and the body parts.

Time	ΔT (°C)		
	Body parts with feather	Body parts featherless	
9h30	6.2 a (head)	8.4 a (wattle)	
11h00	5.9 a (neck)	7.2 b (leg/foot)	
12h30	4.1 b (back cape)	5.8 c (comb)	p - value < 0.001
14h00	2.0 c (thigh; tail)	4.3 d (wing bar)	
15h30	2.1 c (drumstick; breast)	4.3 d (eye)	
17h00	2.3 c (flight feathers)	4.4 d (ear)	

Means within the same column with different letters differ (Tukey, $p < 0.05$).

Broiler acute physiological responses to high environmental temperatures are directly related to the maintenance of homeothermy, but small increases in body temperature may be tolerated, not necessarily resulting in thermal shock (Donkoh, 1989). The author states that birds require a cool environment for at least in part of the day recover from mild heat stress. In this experiment broilers were exposed to heat stress in the afternoon, and the weather data in the previous week was very similar, indicating that birds were exposed to the same weather profile for nearly seven days. The process of acclimatization (IUPS Thermal Commission, 2001) requires from four to seven days to be completed in domestic fowls (Yahav et al., 2005). Therefore, the alterations related to the threshold response to physiological changes which are involved in heat dissipation are not likely to have yet taken place in the studied birds when data were collected.

Cooper and Washburn (1998) studied the economic importance of broiler production under heat stress exposure and found that when the room temperature is near 30°C, there is an increase in body temperature; however, 42 days old broilers are within the limit of coping with heat stress. Cooper and Washburn (1998) showed that the birds benefited from the sensible heat loss in the morning, due to the high value of ΔT and increased the latent heat loss when the rearing ambient temperature increased towards the afternoon. Apparently, 42 day old broilers remain within the limit of thermal tolerance for the diurnal temperature fluctuation within the range found in this experiment.

Latent heat loss prevails over sensible heat in older birds during exposure to heat stress, although the surface temperature increases in the naked areas are an attempt of maximizing sensible heat loss as well (Yahav et al., 2004; Cangar et al., 2008). Zhou and Yamamoto (1997) measured the response of surface temperature in broilers and found the largest values in featherless skin temperature when increasing air temperature to 28°C, indicating that those areas are probably considered to be specialized for temperature regulation, since they can adjust heat exchange (Yahav et al., 2004). Although the input to heat exchange of feathered areas is small but as it corresponds to a large area it has to be included in all sensible heat loss calculations (Yahav et al., 2005).

Two clusters were found in the Ts results (Figure 2): the body parts covered by feathers (A) and the featherless body parts (B). Linear regression analysis was applied using Tair data and both A and B surface temperatures. Results confirmed two linear functions that allow the prediction of A Ts (R^2 = 99.1%) and B Ts (R^2 = 94.7%) from the value of Tair (Eq. 1 and 2).

A = 36.32 + 0.12 Tair   Eq.1

B = 8.53 + 0.61 A   Eq.2

If the models are applied for both featherless and feathered body parts, Ts can be predicted by knowing Tair. From calculated values of A and B sensible heat exchange can be estimated in the pre-slaughter period under the
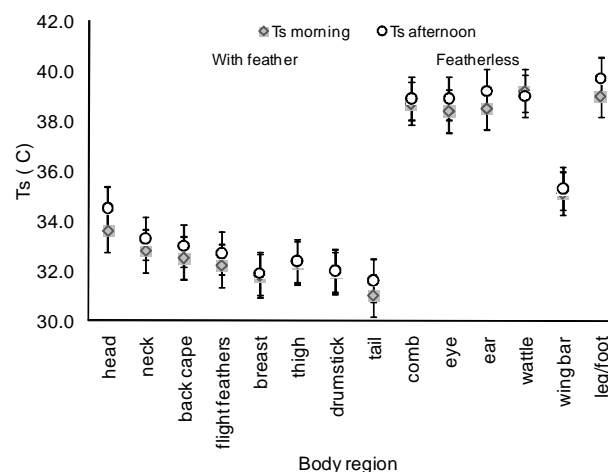

Figure 2 – Body region surface temperature organized by clusters (with feathers and featherless) during the morning and afternoon.

studied conditions. Ts will differ when birds have different age and were exposed to acute heat stress. Cook et al. (2006) confirmed a highly significant relationship between radiated temperature and body feather cover, and proposed a real-time assessment of feather cover from the mean image temperature. Similar results were found in the present (Table 3 and Figure 2) study as featherless body regions presented higher surface temperature.

Broiler chicken pre-slaughter management (fasting, catching, caging, and transportation) during hot weather conditions increases blood uric acid, albumin, and glucose levels, which are reliable indicators of stress in broilers (Aksit et al., 2006). Pre-slaughter handling and transport of broiler chickens as assessed by dead-on-arrivals, physical injury, carcass characteristics, physiological stress responses, fearfulness and aversion are also reported to be enhanced by the exposition to high temperatures as well as to a decrease in bird welfare (Nicol and Scott, 1990). Brossi et al. (2009) stated that the heat stress, chronic or acute, suffered by broilers at the pre-slaughter handling, generates negative consequences on the functional properties of the meat. Pale poultry meat has been of interest in recent years due to several reports estimating that its incidence is dependent on flock, season, and factors affecting pre-slaughter management and transportation (Bianchi et al., 2005).

Conclusion

Infrared thermography provided a detailed description of the radiative temperature of broilers previous to catching which would have been difficult to achieve using solid sensors. The relationship between radiated temperature and feather cover was significant, and a real-time assessment of feather cover can be obtained from the mean image temperature subsidizing flock management decision during pre-slaughter handling. Equations were developed to predict broiler surface temperature as function of air temperature.

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